SEDAR

Southeast Data, Assessment, and Review

SEDAR 71

South Atlantic Gag

Stock Assessment Report

April 2021

SEDAR
4055 Faber Place Drive, Suite 201 North Charleston, SC 29405

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Southeast Data, Assessment, and Review

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South Atlantic Gag

Section I: Introduction

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I. Introduction

1. SEDAR Process Description

SouthEast Data, Assessment, and Review (SEDAR) is a cooperative Fishery Management Council process initiated in 2002 to improve the quality and reliability of fishery stock assessments in the South Atlantic, Gulf of Mexico, and US Caribbean. The improved stock assessments from the SEDAR process provide higher quality information to address fishery management issues. SEDAR emphasizes constituent and stakeholder participation in assessment development, transparency in the assessment process, and a rigorous and independent scientific review of completed stock assessments.

SEDAR is managed by the Caribbean, Gulf of Mexico, and South Atlantic Regional Fishery Management Councils in coordination with NOAA Fisheries and the Atlantic and Gulf States Marine Fisheries Commissions. Oversight is provided by a Steering Committee composed of NOAA Fisheries representatives: Southeast Fisheries Science Center Director and the Southeast Regional Administrator; Regional Council representatives: Executive Directors and Chairs of the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils; a representative from the Highly Migratory Species Division of NOAA Fisheries; and Interstate Commission representatives: Executive Directors of the Atlantic States and Gulf States Marine Fisheries Commissions.

SEDAR 71 addressed the stock assessment for South Atlantic Gag. The assessment process consisted of a series of webinars held from May 2020 – March 2021. The Stock Assessment Report is organized into 2 sections. Section I –Introduction contains a brief description of the SEDAR Process, Assessment and Management Histories for the species of interest, and the management specifications requested by the Cooperator. Section II is the Assessment Process report. This section details the assessment model, as well as documents any data recommendations that arise for new data sets presented during this assessment process, or changes to data sets used previously.

The final Stock Assessment Reports (SAR) for South Atlantic Gag was disseminated to the public in April 2021. The Council's Scientific and Statistical Committee (SSC) will review the SAR for its stock. The SSCs are tasked with recommending whether the assessments represent Best Available Science, whether the results presented in the SARs are useful for providing management advice and developing fishing level recommendations for the Council. An SSC may request additional analyses be conducted or may use the information provided in the SAR as the basis for their Fishing Level Recommendations (e.g., Overfishing Limit and Acceptable Biological Catch). The South Atlantic Fishery Management Council's SSC will review the assessment at its April 2021 meeting, followed by the Council receiving that information at its June 2021 meeting. Documentation on SSC recommendations is not part of the SEDAR process and is handled through each Council.

2. Gag Grouper Management Overview

2.1 Fishery Management Plan and Amendments

The following summary describes only those management actions that likely affect gag fisheries and harvest.

Original SAMFC FMP
The Fishery Management Plan (FMP), Regulatory Impact Review, and Final Environmental Impact Statement for the Snapper-Grouper Fishery of the South Atlantic Region, was approved in 1983 and implemented in August of 1983. The FMP establishes a management regime for the fishery for snappers, groupers and related demersal species of the continental shelf of the southeastern United States in the fishery conservation zone under the area of authority of the South Atlantic Fishery Management Council and the territorial seas of the states, extending from the North Carolina/Virginia border through the Atlantic side of the Florida Keys to 83° W longitude. In the case of the sea basses, the management regime applies only to south of Cape Hatteras, North Carolina. Regulations apply only to Federal waters.

Measures in the original FMP that would have affected gag include gear limitations (i.e., poisons, explosives, fish traps, trawls), and establishment of modified habitats or artificial reefs as Special Management Zones (SMZs).

SAFMC FMP Amendments affecting gag

Description of Action(s)	FMP/Amendment	Effective Date
• Prohibited trawl gear to harvest fish south of Cape Hatteras, NC and north of Cape Canaveral, FL. • Directed fishery defined as vessel with trawl gear and ≥200 pounds (lbs) snapper grouper on board. • Established rebuttable assumption that vessel with snapper grouper on board had harvested such fish in the exclusive economic zone (EEZ).	Amendment #1	01/12/89
• Prohibited gear: fish traps except black sea bass traps north of Cape Canaveral, FL; entanglement nets; longline gear inside 50 fathoms; bottom longlines to harvest wreckfish; powerheads and bangsticks in designated SMZs off S. Carolina. • Defined overfishing/overfished and established rebuilding timeframe: red snapper and groupers (including gag) ≤ 15 years (year 1 = 1991). • No retention of snapper grouper species caught in other fisheries with gear prohibited in snapper grouper fishery if captured snapper grouper had no bag limit or harvest was prohibited. • 20" total length (TL) size limit for gag. • Aggregate grouper bag limit – 5/person/day, excluding Nassau grouper and goliath grouper.	Amendment #4	01/01/92
• Established program to limit initial eligibility for snapper grouper fishery: Must demonstrate landings of any species in the snapper grouper fishery management unit in 1993, 1994, 1995 or 1996; and have held valid snapper grouper permit between 02/11/96 and 02/11/97. • Granted transferable permit with unlimited landings if vessel landed ≥ 1,000 lbs of snapper grouper species in any of the years. • Granted non-transferable permit with 225 lb trip limit to all other vessels. • Modified optimum yield (OY), and overfishing definitions. • Allowed permitted vessels to possess filleted fish harvested in the Bahamas under certain conditions.	Amendment #8	12/14/98

• Gag: 24" TL; no commercial harvest or possession > bag limit, and no purchase or sale, during March and April. • Gag and Black grouper: within 5 fish aggregate grouper bag limit, no more than 2 fish may be gag or black grouper (individually or in combination).	Amendment #9	2/24/99
• Maximum sustainable yield (MSY) proxy = 30% static spawning potential ratio (SPR) (except for Goliath and Nassau). • OY: hermaphroditic groupers = 45% static SPR. • Overfished/overfishing evaluation for gag: overfished (static SPR = 27%). • Overfishing level = F>F30% static SPR. • MSST = [(1-M) or 0.5 whichever is greater]*B_{MSY}. • MFMT = F_{MSY}.	Amendment #11	12/02/99
• Prohibit the sale of bag-limit caught snapper grouper species.	Amendment #15B	12/16/09
• Specified interim allocations for gag: 51% commercial & 49% recreational. • Rec & commercial shallow water grouper spawning closure January through April. • Directed gag comm quota= 352,940 lbs gutted weight (gw). • Specified that harvest of all shallow water groupers close when the gag quota is met. • Reduced 5-fish aggregate grouper bag limit, including tilefish species, to a 3-fish aggregate. • Captain and crew on for-hire trips cannot retain the bag limit of vermilion snapper and species within the 3-fish grouper aggregate.	Amendment #16	7/29/09
• Required use of non-stainless steel circle hooks when fishing for snapper grouper species with hook-and-line gear and natural baits north of 28 deg. N latitude in the South Atlantic EEZ. • Implemented an area closure for snapper-grouper species that extends from southern Georgia to northern Florida where harvest and possession of all snapper-grouper species is prohibited.	Amendment #17A	3/3/11

• Established commercial and recreational quotas as annual catch limits (ACLs) for gag (comm = 352,940 lbs gw); rec = 340,060 lbs gw). • Established aggregate ACL for gag, red grouper & black grouper = 662,403 lbs gw. • Established commercial & recreational AMs for gag, red grouper & black grouper aggregate.	Amendment #17B	1/31/11
• Removed aggregate (red, black, and gag) ACLs and established fishing levels and AMs for red grouper.	Amendment #24	7/11/12
• Modified AMs for snapper grouper species, including gag	Amendment #34	2/22/16

2.2 Regulatory Amendments

Regulatory Amendment #9: Effective 7/15/11. Established 1,000 lbs gw commercial trip limit for gag.

Regulatory Amendment #15: Effective 9/12/13. Removed measure that prohibits harvest of all shallow water groupers when the gag commercial quota is met. Reduced the gag commercial quota from 353,940 to 326,722 lbs gw.

Regulatory Amendment #21: Effective 11/6/14. Modified the definition of the overfished threshold (MSST) for red snapper, blueline tilefish, gag, black grouper, yellowtail snapper, vermilion snapper, red porgy, and greater amberjack to MSST =75%(SSB_{MSY}).

Regulatory Amendment #14: Effective 12/8/14. Added trip-limit reduction to 500 lbs gw when 75% of the commercial quota for gag was reached.

Regulatory Amendment #22: Effective 9/11/15 – Adjusted catch levels for gag as follows:

Year	ABC	Total ACL	Commercial ACL (51%)	Directed Commercial Quota*	Recreational ACL (49%)
2015	666,000	632,700	322,677	295,459	310,023
2016	671,000	637,450	325,100	297,882	312,351
2017	713,000	677,350	345,449	318,231	331,902
2018	748,000	710,600	362,406	335,188	348,194
2019	773,000	734,350	374,519	347,301	359,832

All values in lbs gw
*Directed commercial quota = Commercial ACL – 27,218 lbs gw. This reduction accounts for discard mortality after commercial harvest for gag closes but commercial harvest for shallow water groupers remains open.

2.3 Emergency and Interim Rules (if any)

None for gag

2.4 Secretarial Amendments

None for gag

2.5 Control Date Notices

1. Notice of Control Date (07/30/91 56 FR 36052) - Anyone entering federal snapper grouper fishery (other than for wreckfish) in the EEZ off S. Atlantic states after 07/30/91 was not assured of future access if limited entry program developed.
2. Notice of Control Date (10/14/05 70 FR 60058) - Anyone entering federal snapper grouper fishery off S. Atlantic states after 10/14/05 was not assured of future access if limited entry program developed.
3. Notice of Control Date (01/31/11 76 FR 5325) - Anyone entering federal snapper grouper fishery off S. Atlantic states after 09/17/10 was not assured of future access if limited entry program developed.
4. Notice of Control Date (6/15/16 76 FR 66244) - Fishermen entering the federal for-hire recreational sector for the snapper grouper fishery after June 15, 2016, will not be assured of future access should a management regime that limits participation in the sector be prepared and implemented.

2.6 Management Program Specifications

Table 2.6.1. General Management Information

South Atlantic

Species	Gag (*Mycteroperca microlepis*)
Management Unit	Southeastern US
Management Unit Definition	All waters within South Atlantic Fishery Management Council Boundaries
Management Entity	South Atlantic Fishery Management Council
Management Contacts SERO / Council	SERO: Rick DeVictor SAFMC: Myra Brouwer
Current stock exploitation status	Not overfishing
Current stock biomass status	Not overfished

Table 2.6.2. Specific Management Criteria

Criteria	South Atlantic – from SEDAR 10 2014 Update			
	Units	Definition	Base Run Value	Median of Base Run MCBs
MSST[1]	1,000 lbs ww	MSST = 75% SSB_{MSY}	3,028.7	3,409.0
MFMT	y^{-1}	F_{MSY}	.29	.27
MSY	1,000 lbs gw	Yield at F_{MSY}	938.2	900.4
F_{MSY}	y^{-1}	F rate resulting in B_{MSY}	.29	.27
OY	1,000 lbs gw	Yield at 75% F_{MSY}	921.1	883.6
R_{MSY}	1,000 age-1 fish	Recruits at MSY	243	232
F Target	y^{-1}	75% F_{MSY}	.21	.20
Yield at F_{TARGET} (equilibrium)	1,000 lbs gw	Yield at F_{OY}	921.1	883.6
M	y^{-1}	Point estimate used to scale Lorenzen M	.14	
Terminal F	y^{-1}	Exploitation	.232	
Terminal Biomass[1]	1,000 lbs ww	Biomass	3,915.4	
Exploitation Status		$F_{current}/F_{MSY}$	1.23	1.37
Biomass Status[1]		SSB/MSST	1.29	1.38
		SSB/SSB_{MSY}	.97	1.04
$T_{REBUILD}$ (if appropriate)				

1. Biomass values report for management parameters and status determinations should be based on biomass metrics recommended through the Assessment process and SSC. This may be total, spawning stock or some measure thereof, and should be applied consistently in this table.

Table 2.6.3. Stock Rebuilding Information

N/A

Table 2.6.4. Stock projection information.

(This provides the basic information necessary to bridge the gap between the terminal year of the assessment and the year in which any changes may take place or specific alternative exploitation rates should be evaluated)

South Atlantic

Requested Information	Value
First Year of Management	2021
Projection Criteria during interim years should be based on (e.g., exploitation or harvest)	ACL if ACL met; average exploitation, if ACL not met
Projection Outputs	
Landings	Pounds and numbers
Discards	Pounds and numbers
Exploitation	F & Probability F>MFMT
Biomass (total or SSB, as appropriate)	SSB & Probability SSB>MSST (and Prob. SSB>SSBmsy if under rebuilding plan
Recruits	Number

Table 2.6.5 Base Run Projections Specifications. Long Term and Equilibrium conditions.

Criteria	Definition	If overfished	If overfishing	Neither overfished nor overfishing
Projection Span	Years	$T_{REBUILD}$	10	10
Projection Values	$F_{CURRENT}$	X	X	X
	F_{MSY}	X	X	X
	75% F_{MSY}	X	X	X
	$F_{REBUILD}$	X		
	F=0	X		

Table 2.6.6. P-star projections. Short term specifications for OFL and ABC recommendations. Additional P-star projections may be requested by the SSC once the ABC control rule is applied.

Criteria		Overfished	Not overfished
Projection Span	Years	5	5
Probability Values	50%	Probability of stock rebuild	Probability of overfishing
	30%	Probability of stock rebuild	Probability of overfishing

Table 2.6.7. Quota Calculation Details
If the stock is managed by quota, please provide the following information

Commercial ACL (2019 and subsequent years)	374,519 lbs gw, (169,879 kg), 441,932 lbs ww (200,457 kg)
Commercial Quota (2019 and subsequent years)	347,301 lb gw, (157,533 kg); 409,816 lbs ww, (185,889 kg)
Recreational ACL (2019 and subsequent years)	359,832 lbs gw (171,807 kg), 424,602 pounds whole weight (lbs ww), (202,733 kg)
Next Scheduled Quota Change	n/a
Annual or averaged quota?	annual
If averaged, number of years to average	n/a
Does the quota include bycatch/discard?	Yes

How is the quota calculated - conditioned upon exploitation or average landings?

A stock assessment completed in 2006 indicated gag was experiencing overfishing and was approaching an overfished condition (SEDAR 10 2006). Snapper Grouper Amendment 16 (SAFMC 2009) established management measures to end overfishing of gag. These measures included a four-month (January through April) spawning season closure for recreational and commercial harvest of shallow water grouper species including gag, black grouper, red grouper, scamp, rock hind, red hind, coney, graysby, yellowfin grouper, yellowmouth grouper, and tiger grouper (the latter was removed from the FMP in 2011); a directed commercial ACL for gag; and a reduction in the recreational bag limits for shallow water grouper species. Also included was a provision to close all shallow water grouper species when the gag ACL was met or projected to be met. The intent of this action was to reduce incidental catch of gag. The gag commercial AM has only been triggered once since it was implemented in 2009, which resulted in a closure of shallow water groupers in 2012. The commercial ACL was also exceeded by 21% in 2011, but it did not trigger the AM as the overage was not realized until after the fishing year had ended.

Regulatory Amendment 15 to the Snapper Grouper FMP (SAFMC 2013a) reduced the gag commercial ACL by 27,218 lbs gw from 353,940 lbs gw to 326,722 lbs gw to account for discard mortality of gag that would result from targeting other shallow water groupers (i.e., red grouper and scamp) after harvest of gag is closed. The gag ACL was adjusted for post-quota bycatch mortality in accordance with analyses in Amendment 16 to the Snapper Grouper FMP (SAFMC 2009a), and the reduction in the gag ACL was calculated by determining the pounds of gag lost from discard mortality if eliminated target trips still occurred but instead of targeting gag they fished for the other co-occurring shallow water groupers. A discard mortality rate of 40% was applied to the pounds of gag caught to estimate dead discards in pounds. Additionally, during development of Amendment 16, the Snapper Grouper Advisory Panel (AP) and other fishermen reported that their trips would be reduced by 20% after a gag quota closure. To get an additional estimate of dead discards, target trips were decreased by 20% to estimate pounds of gag lost to discard mortality. Total dead discards in pounds were calculated by combining the pounds of gag lost to discard mortality from non-target trips with the pounds of gag lost to discard mortality from target trips switching to target other shallow water grouper. This analysis is described in detail in Appendix E of Regulatory Amendment 15 (SAFMC 2013a).

Does the quota include bycatch/discard estimates? If so, what is the source of the bycatch/discard values? What are the bycatch/discard allowances?

The commercial ACL for gag was specified originally in Amendment 16 (SAFMC 2009). However, the ACL was lowered by 1,000 lbs gw to account for Post Quota Bycatch Mortality (PQBM). This adjustment in the ACL was intended to account for dead discards of gag that might occur after the gag quota was met. Hence, the ACL (previously referred to as a total allowable catch) was decreased by that amount and constitutes the commercial ACL of 352,940 lbs gw that was in place through 2012.

Results of similar analyses to those conducted during development of Amendment 16 (SAFMC 2009) and submitted by the NMFS Southeast Regional Office in support of Regulatory Amendment 15 (SAFMC 2013) are summarized in the table below. The average lbs gw of gag discarded dead between the end of October and the end of December were calculated. These months were chosen because the 2012 closure went into effect on October 20. Note that the analyses in Amendment 16 defined a target gag trip as one where 75% or more of the landings constituted gag. Further, Amendment 16 assumed 20% of the trips would not be taken after a gag closure occurred based on information from the Snapper Grouper AP and other fishermen.

An analysis was conducted for Regulatory Amendment 15 to determine the pounds of gag lost from discard mortality if eliminated target trips still occurred but instead of targeting gag they fished for the other shallow water groupers. This required the average pounds of gag caught per trip to be calculated for non-target gag trips. The pounds of gag per trip displayed a log-normal distribution. Therefore, the geometric average was calculated instead of the commonly used arithmetic average because the geometric average is a better measure of central tendency with log-normally distributed data. The geometric average of the pounds of gag per trip was multiplied against the number of gag target trips to provide the pounds of gag that could be landed if gag target trips switched to fishing for other shallow water groupers. The discard mortality rate of 40% was applied to the pounds of gag caught to estimate dead discards in pounds. Additionally, during development of Amendment 16, the Snapper Grouper AP and other fishermen reported that their trips would be reduced by 20% after a gag quota closure. To get an additional estimate of dead discards, target trips were decreased by 20% to estimate pounds of gag lost to discard mortality. Total dead discards in pounds were calculated by combining the pounds of gag lost to discard mortality from non-target trips with the pounds of gag lost to discard mortality from target trips switching to target other shallow water grouper. Therefore, the adjusted gag ACL that accounts for PQBM when fishermen target other South Atlantic shallow-water grouper (SASWG) species would be 353,940 – 27,217 = 326,722 lbs gw. Regulatory Amendment 15 became effective on September 12, 2013.

The update assessment (SEDAR 10 Update 2014) included data through 2012, before regulations were changed in 2013 to remove the AM that prohibited harvest of all SASWG (red grouper, black grouper, scamp, yellowmouth grouper, yellowfin grouper, red hind, rock hind, graysby, and coney) once the commercial ACL for gag was met. When the next assessment is conducted, these discards will be included in the discard estimate from the assessment and an adjustment to the ACL will not be required. Regulatory Amendment 22 implemented the following adjustments to fishing levels:

Table 2.6.8. ABC and ACLs specified for gag where ACL = OY = 95%ABC

Year	ABC	Total ACL	Commercial ACL (51%)	Directed Commercial Quota*	Recreational ACL (49%)
2015	666,000	632,700	322,677	295,459	310,023
2016	671,000	637,450	325,100	297,882	312,351
2017	713,000	677,350	345,449	318,231	331,902
2018	748,000	710,600	362,406	335,188	348,194
2019	773,000	734,350	374,519	347,301	359,832

All values in lbs gw
*Directed commercial quota = Commercial ACL – 27,218 lbs gw.

Table 2.6.8 South Atlantic gag landings and estimated dead discards from October 21 to December 31, 2011, with gag target trips removed.
Gag target trips were defined as trips where >90%, >75%, >50%, and >25% of the shallow water grouper landings came from gag. All pounds are in lbs gw. Release mortality rate is 40%. SASWG = South Atlantic Shallow Water Groupers

Gag Target Trip Criteria	Trips Switching to Targeting SASWG*	Non-Target Trips Taken*	Pounds of Gag Caught from Switching Gag Target trips to other SASWG	Pounds of Gag caught from Non-Target Gag Trips	Total Pounds of Gag Lost to Discard Mortality
>90%	198	203	30,286	58,647	35,573
>75%	**232**	**160**	**29,260**	**38,785**	**27,218**
>50%	297	79	19,983	9,746	11,892
>25%	334	32	12,774	1,900	5,870

Source: NMFS SERO 2013
*73 trips catching 18,936 lbs gw of gag using spear were removed

Are there additional details of which the analysts should be aware to properly determine quotas for this stock?

2.7 Management and Regulatory Timeline

The following tables provide a timeline of Federal management actions by fishery.

Table 2.7.1. Annual Commercial Gag Regulatory Summary Prepared by Myra Brower

Year	Quota (units)	ACL (units)	Days Open	fishing season	reason for closure	season start date (first day implemented)	season end date (last day effective)	Size limit (units and length type, indicate maximum or natural length)	size limit start date	size limit end date	Retention Limit (units)	Retention Limit Start Date	Retention Limit End Date	Aggregate Retention Limit (units)	Aggregate Retention Limit Start Date	Aggregate Retention Limit End Date
1983	N/A	N/A	365	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1984	N/A	N/A	366	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1985	N/A	N/A	365	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1986	N/A	N/A	365	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1987	N/A	N/A	365	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1988	N/A	N/A	366	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1989	N/A	N/A	365	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1990	N/A	N/A	365	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1991	N/A	N/A	365	open	N/A	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1992	N/A	N/A	366	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
1993	N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
1994	N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
1995	N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
1996	N/A	N/A	366	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
1997	N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
1998	N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
1999	N/A	N/A	59	open	N/A	1-Jan	28-Feb	20 inches	1-Jan	23-Feb	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	24-Feb	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-May	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2000	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2001	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
2002	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
2003	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
2004	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2005	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2006	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	N/A	N/A
	N/A	N/A	610	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2007	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2008	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
	N/A	N/A	245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2009	N/A	N/A	59	open	N/A	1-Jan	28-Feb	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	61	closed	seasonal	1-Mar	30-Apr	24 inches	1-Jan	31-Dec	2 fish (gag or black)	1-Mar	30-Apr	5 fish (groupers)	1-Mar	30-Apr
	N/A	N/A	89	open	N/A	1-May	28-Jul	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
	352,940 (lbs gw)	N/A	156	open	N/A	29-Jul	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2010	352,940 (lbs gw)	N/A	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
2011	352,940 (lbs gw)	352,940 (lbs gw)	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			245	open	N/A	1-May	31-Dec	24 inches	1-Jan	31-Dec	1,000 lbs gw	15-Jul	31-Dec	N/A	N/A	N/A
2012	see ACL	352,940 (lbs gw)	121	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			172	open	N/A	1-May	19-Oct									
			24	closed	ACL met	20-Oct	12-Nov									
			8	open	gag reopened	13-Nov	20-Nov									
			41	closed	ACL met	21-Nov	31-Dec									
2013	see ACL	352,940 (lbs gw)	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			134	open	N/A	1-May	11-Sep				1,000 lbs gw	1-May	31-Dec			
	see ACL	326,722 (lbs gw)	62	open	N/A	12-Sep	12-Nov									
			49	closed	ACL met	13-Nov	31-Dec									
2014	see ACL	326,722 (lbs gw)	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			204	open	N/A	1-May	20-Nov				1,000 lbs gw	1-May	31-Dec			
			41	closed	ACL met	21-Nov	31-Dec									
2015	see ACL	326,722 (lbs gw)	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			133	open	N/A	1-May	10-Sep				1,000 lbs gw	1-May	31-Dec			
		295,459 lbs gw	37	open	N/A	11-Sep	17-Oct	24 inches			1,000 lbs gw					
			75			18-Oct	31-Dec		1-Jan	31-Dec	500 lbs gw					
2016	see ACL	297,882 lbs gw	121	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			245	open	N/A	1-May	31-Dec				1,000 lbs gw	1-May	31-Dec			
2017	see ACL	318,231 lbs gw	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			245	open	N/A	1-May	31-Dec				1,000 lbs gw	1-May	31-Dec			
2018	see ACL	335,188 lbs gw	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
			245	open	N/A	1-May	31-Dec				1,000 lbs gw	1-May	31-Dec			
2019	see ACL	347,301 lbs gw	120	closed	seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	N/A	N/A	N/A	N/A	N/A	N/A
											1,000 lbs gw	1-May	31-Dec			

Notes:

Regulatory Amendment 30 proposes extending the commercial seasonal closure ONLY OFF THE CAROLINAS AND FOR RED GROUPER ONLY. Regulations are expected to affect the 2020 fishing year.

Regulatory Amendment 14 implemented a trip limit reduction to 500 lbs gw upon 75% of commercial ACL being met. Effective 12/8/2014.

Table 2.7.2. Annual Recreational Gag Regulatory Summary Prepared by Myra Brower

.

Year	Amendment	Quota (# fish)	ACL (# fish)	Days Open	fishing season	reason for closure	season start date (first day implemented)	season end date (last day effective)	Size limit	size limit start date	size limit end date	Retention Limit (# fish)	Retention Limit Start Date	Retention Limit End Date	Aggregate Retention Limit[1] (# fish)	Aggregate Retention Limit Start Date	Aggregate Retention Limit End Date
1983	FMP	N/A	N/A	123	open	N/A	31-Aug	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1984		N/A	N/A	366	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1985		N/A	N/A	365	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1986		N/A	N/A	365	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1987		N/A	N/A	365	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1988		N/A	N/A	366	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1989		N/A	N/A	365	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1990		N/A	N/A	365	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1991		N/A	N/A	365	open	N/A	1-Jan	31-Dec	None	N/A	N/A	None	N/A	N/A	None	N/A	N/A
1992	4	N/A	N/A	366	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	None	1-Jan	31-Dec	5	1-Jan	31-Dec
1993		N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	None	1-Jan	31-Dec	5	1-Jan	31-Dec
1994		N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	None	1-Jan	31-Dec	5	1-Jan	31-Dec
1995		N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	None	1-Jan	31-Dec	5	1-Jan	31-Dec
1996		N/A	N/A	366	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	None	1-Jan	31-Dec	5	1-Jan	31-Dec
1997		N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	None	1-Jan	31-Dec	5	1-Jan	31-Dec
1998		N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	31-Dec	None	1-Jan	31-Dec	5	1-Jan	31-Dec
1999	9	N/A	N/A	365	open	N/A	1-Jan	31-Dec	20 inches	1-Jan	23-Feb	None	1-Jan	23-Feb	5	1-Jan	31-Dec
									24 inches	24-Feb	31-Dec	2 (gag or black)	24-Feb	31-Dec	5	1-Jan	31-Dec
2000		N/A	N/A	366	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2001		N/A	N/A	365	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2002		N/A	N/A	365	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2003		N/A	N/A	365	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2004		N/A	N/A	366	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2005		N/A	N/A	365	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2006		N/A	N/A	365	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2007		N/A	N/A	365	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2008		N/A	N/A	366	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	31-Dec	5	1-Jan	31-Dec
2009		N/A	N/A	365	open	N/A	1-Jan	31-Dec	24 inches	1-Jan	31-Dec	2 (gag or black)	1-Jan	28-Jul	5	1-Jan	28-Jul
	16											1 (gag or black)	29-Jul	31-Dec	3	29-Jul	31-Dec
2010		N/A	N/A	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2011	17b	see ACL	340,060 lbs gw	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2012		see ACL	340,060 lbs gw	121	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2013		see ACL	340,060 lbs gw	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2014		see ACL	340,060 lbs gw	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2015		see ACL	340,060 lbs gw	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				133	open	N/A	1-May	10-Sep									
	Reg 22		310,023 lbs gw	112	open	N/A	11-Sep	31-Dec									
2016		see ACL	312,351 lbs gw	121	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2017		see ACL	331,902 lbs gw	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2018		see ACL	348,194 lbs gw	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									
2019		see ACL	359,832 lbs gw	120	closed	Seasonal	1-Jan	30-Apr	24 inches	1-Jan	31-Dec	1 (gag or black)	1-May	31-Dec	3	1-May	31-Dec
				245	open	N/A	1-May	31-Dec									

Notes: Regulatory Amendment 30 proposes extending the recreational seasonal closure ONLY OFF THE CAROLINAS AND FOR RED GROUPER ONLY. Regulations are expected to affect the 2020 fishing year.

Closures due to Meeting Commercial Quota or Commercial/Recreational ACL

Commercial:

- October 20, 2012; reopened from Nov. 13-21, 2012
- November 13, 2013
- November 21, 2014

Recreational: none

2.8 State Regulatory History

2.8.1 North Carolina

There are currently no NC state-specific regulations for gag. NC has complemented federal regulations for all snapper grouper species via proclamation authority since 1991. Between 1992 and 2005, species-specific regulations were added to the proclamation authority contained in rule 15A NCAC 03M .0506. In 2002, North Carolina adopted its Inter-Jurisdictional Fishery Management Plan (IJ FMP), which incorporates all ASMFC and council-managed species by reference, and adopts all federal regulations as minimum standards for management. In completing the 2008 update to the IJ FMP, all species-specific regulations were removed from rule 15A NCAC 03M .0506, and proclamation authority to implement changes in management was moved to rule 15A NCAC 03M .0512. Since this time, all snapper grouper regulations are contained in a single proclamation, which gets updated anytime there is an opening/closing of a particular species in the complex, as well as any changes in allowable gear, etc. The most current Snapper Grouper proclamation (and all previous versions) can be found using this link: http://portal.ncdenr.org/web/mf/proclamations.

15A NCAC 03M .0506 SNAPPER-GROUPER COMPLEX
(a) In the Atlantic Ocean, it is unlawful for an individual fishing under a Recreational Commercial Gear License with seines, shrimp trawls, pots, trotlines or gill nets to take any species of the Snapper-Grouper complex.
(b) The species of the snapper-grouper complex listed in the South Atlantic Fishery Management Council Fishery Management Plan for the Snapper-Grouper Fishery of the South Atlantic Region are hereby incorporated by reference and copies are available via the Federal Register posted on the Internet at www.safmc.net and at the Division of Marine Fisheries, P.O. Box 769, Morehead City, North Carolina 28557 at no cost.
History Note: Authority G.S. 113-134; 113-182; 113-221; 143B-289.52;
Eff. January 1, 1991;
Amended Eff. April 1, 1997; March 1, 1996; September 1, 1991;
Temporary Amendment Eff. December 23, 1996;
Amended Eff. August 1, 1998; April 1, 1997;
Temporary Amendment Eff. January 1, 2002; August 29, 2000; January 1, 2000; May 24, 1999;
Amended Eff. October 1, 2008; May 1, 2004; July 1, 2003; April 1, 2003; August 1, 2002.

15A NCAC 03M .0512 COMPLIANCE WITH FISHERY MANAGEMENT PLANS
(a) In order to comply with management requirements incorporated in Federal Fishery Management Council Management Plans or Atlantic States Marine Fisheries Commission Management Plans or to

implement state management measures, the Fisheries Director may, by proclamation, take any or all of the following actions for species listed in the Interjurisdictional Fisheries Management Plan:
(1) Specify size;
(2) Specify seasons;
(3) Specify areas;
(4) Specify quantity;
(5) Specify means and methods; and
(6) Require submission of statistical and biological data.
(b) Proclamations issued under this Rule shall be subject to approval, cancellation, or modification by the Marine Fisheries Commission at its next regularly scheduled meeting or an emergency meeting held pursuant to G.S. 113-221.1.
History Note: Authority G.S. 113-134; 113-182; 113-221; 113-221.1; 143B-289.4;
Eff. March 1, 1996;
Amended Eff. October 1, 2008.

2.8.2 South Carolina

SECTION 50-5-2730 of the SC Code states:
"Unless otherwise provided by law, any regulations promulgated by the federal government under the Fishery Conservation and Management Act (PL94-265) or the Atlantic Tuna Conservation Act (PL 94-70) which establishes seasons, fishing periods, gear restrictions, sales restrictions, or bag, catch, size, or possession limits on fish are declared to be the law of this State and apply statewide including in state waters."
HISTORY: 2000 Act No. 245, § 14; 2002 Act No. 342, § 47.

As such, SC gag regulations are (and have been) pulled directly from the federal regulations as promulgated under Magnuson. I am not aware of any separate gag regulations that have been codified in the SC Code.

The only other state law that might involve limiting traditional fishing practices for gag in state waters would be SECTION 50-5-110 (bang stick prohibition; see below). Also recall that through one of the snapper grouper Management Plan amendments bangsticks were prohibited in federal waters off SC only for taking all snapper grouper species. Gag would be a primary target for this type of gear if it were allowed.

SECTION 50-5-110. Use of poison, explosive, or bang stick to take marine resources; penalty.
"It is unlawful to use poison, an explosive, or a bang stick or similar device in state waters to take marine resources. A person who violates this section by use of poison or an explosive other than a bang stick or similar device is guilty of a misdemeanor and, upon conviction, must be fined not less than one thousand dollars nor more than two thousand five hundred dollars or imprisoned for not more than thirty days and must have his saltwater privileges suspended for twelve months. A person who violates this section by use of a bang stick or similar device is guilty of a misdemeanor and, upon conviction, must be fined not less than twenty-five dollars nor more than five hundred dollars or imprisoned for not more than thirty days and must have his saltwater privileges suspended for twelve months. "

HISTORY: 1962 Code Section 28-174; 1952 Code Section 28-174; 1942 Code Section 3310; 1932 Code Section 3310; 1924 (33) 1016; 1952 (47) 2890; 1993 Act No. 181, Section 1259; 2000 Act No. 245, Section 1.

2.8.3 Georgia

Gag is currently identified as a managed species in Georgia code. Georgia enforces a 2 fish creel/possession limit and a 24 inch TL size limit.

2.8.4 Florida

Florida Atlantic and Monroe County Gag Grouper Regulation History

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
1980	None	None	None		
1981	None	None	None		
1982	None	None	None		
1983	None	None	None		
1984	None	None	None		
1985	18 inches	None	None	Established an 18-inch minimum size limit.	July 29, 1985

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
1986	18 inches	5 per person within the 5-fish grouper aggregate bag limit	None	Established a five-fish daily recreational bag limit for grouper (excluded Red Hind and Rock Hind). Prohibited commercial harvest of snapper and grouper by longline gear and established a bycatch allowance of 5% for harvesters using longline gear to target other species. Prohibited use of stab nets (or sink nets) to harvest snapper and grouper in Atlantic state waters of Monroe County. Allowed 5% of snapper and grouper in possession of harvester to be smaller than the minimum size limit. Required snapper and grouper to be landed in whole condition (head and tail intact).	Dec. 11, 1986
1987	18 inches	5 per person within the 5-fish grouper aggregate bag limit	None		
1988	18 inches	5 per person within the 5-fish grouper aggregate bag limit	None		

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
1989	18 inches	5 per person within the 5-fish grouper aggregate bag limit	None		
1990	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None	Designated all snapper and grouper "restricted species" and required commercial harvesters to possess a Restricted Species endorsement on their Saltwater Products License. Increased minimum size limit to 20 inches. Set allowable gear as hook and line, black sea bass trap, spear, gig, or lance (except powerheads, bangsticks, or explosive devices) for snapper and grouper. Prohibited commercial harvest in state waters when harvest is prohibited in adjacent federal waters. Required snapper and grouper to be landed in whole condition.	Feb. 1, 1990
1991	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None		
1992	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None		

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
1993	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None	Allowed persons with either a Gulf of Mexico or South Atlantic federal commercial reef fish permit to commercially harvest snappers and groupers (except red snapper) in all state waters, until July 1, 1995.	Oct. 18, 1993
1994	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None	Allowed a two-day possession limit for reef fish for persons aboard charter and headboats on trips exceeding 24 hours, provided the vessel is equipped with a permanent berth for each passenger, and each passenger has a receipt verifying the trip length. Modified rule language to provide the same state and federal definitions of Gulf of Mexico and Atlantic Ocean regions.	March 1, 1994
1995	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None	Continued allowing persons with either a South Atlantic or Gulf federal commercial reef fish permit to commercially harvest reef fish in all state waters through Dec. 31, 1995.	July 1, 1995

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
1996	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None	(1) Continued allowing persons with either a South Atlantic or Gulf federal commercial reef fish permit to commercially harvest reef fish in all state waters through Dec. 31, 1996. (2) Continued allowing persons with either a South Atlantic or Gulf federal commercial reef fish permit to commercially harvest reef fish in all state waters through Dec. 31, 1997.	(1) Jan. 1, 1996 (2) Nov. 27, 1996
1997	20 inches	5 per person within the 5-fish grouper aggregate bag limit	None		
1998	Monroe County: 20 inches Atlantic Ocean: 24 inches	Monroe County: 5 per person within the 5-fish grouper aggregate bag limit Atlantic Ocean: 2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Atlantic Ocean: Commercial harvest prohibited in March and April	Atlantic Ocean: Increased minimum size limit to 24 inches TL. Atlantic Ocean: Modified recreational bag limit to be two Gag Grouper or Black Grouper, combined, per person per day within the five-fish grouper aggregate bag limit. Atlantic Ocean: Prohibited harvest and possession in excess of the recreational bag limit, and purchase and sale of Gag Grouper and Black Grouper during March and April.	Dec. 31, 1998

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
1999	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April	Monroe County: Increased minimum size limit to 24 inches TL. Monroe County: Modified the recreational bag limit to be two Gag Grouper or Black Grouper, combined, per person per day within the five-fish grouper aggregate bag limit. Monroe County: Prohibited harvest and possession in excess of the recreational bag limit, and purchase and sale of Gag Grouper and Black Grouper during March and April.	March 1, 1999
2000	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April	Eliminated the five-day commercial season closure extension. Restored the documentation requirement for reef fish species possessed during a closure period.	Jan. 1, 2020
2001	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April		
2002	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April		

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
2003	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April		
2004	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April		
2005	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April		
2006	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Commercial harvest prohibited in March and April	Specified that "total length" means the straight line distance from the most forward point of the head with the mouth closed, to the farthest tip of the tail with the tail compressed or squeezed, while the fish is lying on its side.	July 1, 2006
2007	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Same as federal waters	Set commercial trip limits in the Atlantic to be the same as adjacent federal waters. Prohibited commercial fishermen from harvesting or possessing the recreational bag limit on commercial trips.	July 1, 2007

Year	**Minimum Size Limit**	**Recreational Daily Harvest Limits**	**Commercial Daily Harvest Limits**	**Regulation Changes**	**Rule Change Effective Date**
2008	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Same as federal waters		
2009	24 inches	2 Gag Grouper or Black Grouper per person within the 5-fish grouper aggregate bag limit	Same as federal waters		
2010	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters	Reduced the recreational grouper aggregate to three fish per day in Atlantic and Monroe County state waters, and allowed no more than one Gag Grouper or Black Grouper, combined, per day. Prohibited harvest of shallow-water groupers from January 1 – April 30 in Atlantic and Monroe County state waters. Prohibited the captain and crew of for-hire vessels from retaining any species in the aggregate grouper bag limit. Required dehooking tools be aboard commercial and recreational vessels for use as needed to remove hooks from Atlantic reef fish.	Jan. 19, 2010

Year	Minimum Size Limit	Recreational Daily Harvest Limits	Commercial Daily Harvest Limits	Regulation Changes	Rule Change Effective Date
2011	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters		
2012	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters		
2013	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters		
2014	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters	Removed prohibition on captain and crew of for-hire vessels from retaining recreational bag limits of Vermilion Snappers, groupers and Golden Tilefish on for-hire trips in state waters of the Atlantic (including Monroe County for grouper and Golden Tilefish).	March 13, 2014

Year	Minimum Size Limit	Recreational Daily Harvest Limits	Commercial Daily Harvest Limits	Regulation Changes	Rule Change Effective Date
2015	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters		
2016	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters	Created an exception allowing recreational anglers to land reef fish as fillets instead of as whole fish, provided the reef fish were recreationally harvested in The Bahamas and specific conditions are met.	Sept. 13, 2016
2017	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters		
2018	24 inches	1 Gag Grouper or Black Grouper per person within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters		

Year	Minimum Size Limit	Recreational Daily Harvest Limits	Commercial Daily Harvest Limits	Regulation Changes	Rule Change Effective Date
2019	24 inches	1 Gag Grouper or Black Grouper per person per day within the 3-fish grouper aggregate bag limit Harvest prohibited Jan. – April	Same as federal waters		

Florida Atlantic and Monroe County Gag Grouper Regulation Changes by Date

July 29, 1985
- Established an 18-inch minimum size limit for Gag Grouper.

December 31, 1986
- Established a daily recreational bag limit of five fish for any combination of groupers, excluding Red Hind and Rock Hind.
- Prohibited use of longline gear by commercial fishermen for harvest of snapper and groupers, and created a bycatch allowance of 5% for commercial harvesters using longline gear to legally target other species.
- Prohibited the use of stab nets (or sink nets) to take snapper or grouper in Atlantic waters of Monroe County.
- Allowed 5% of snapper or grouper in the possession of a harvester to be smaller than the minimum size limit.
- Required snappers and groupers to be landed in whole condition (head and tail intact).

February 1, 1990
- Designated all snapper and grouper as "restricted species."
- Increased the minimum size limit for Gag Grouper to 20 inches.
- Set the allowable gear as hook and line, black sea bass trap, spear, gig, or lance (except powerheads, bangsticks, or explosive devices).
- Prohibited commercial harvest of any species of snapper, grouper or sea bass in state waters whenever harvest of that species is prohibited in adjacent federal waters.

October 18, 1993
- Allowed persons who possess wither a Gulf of Mexico or South Atlantic federal reef fish permit to commercially harvest snappers and groupers (except red snapper) in all state waters, until July 1, 1995.

March 1, 1994
- Allowed a two-day possession limit for reef fish statewide for persons aboard charter and headboats on trips exceeding 24 hours, provided the vessel is equipped with a permanent berth for each passenger aboard, and each passenger has a receipt verifying the trip length.

- Modified rule language to provide the same state and federal definitions of Gulf of Mexico and Atlantic Ocean regions.

July 1, 1995
- Allowed persons who possess wither a Gulf of Mexico or South Atlantic federal reef fish permit to commercially harvest snappers and groupers (except red snapper) in all state waters, until December 31, 1995.

January 1, 1996
- Allowed persons who possess wither a Gulf of Mexico or South Atlantic federal reef fish permit to commercially harvest snappers and groupers (except red snapper) in all state waters, until December 31, 1996.

November 27, 1996
- Allowed persons who possess wither a Gulf of Mexico or South Atlantic federal reef fish permit to commercially harvest snappers and groupers (except red snapper) in all state waters, until December 31, 1997.

December 31, 1998
- Modified Black Grouper and Gag Grouper management in Atlantic Ocean state waters only:
  - Reduced the recreational bag limit to two Black Grouper or Gag Grouper, combined, per person within the five-fish grouper aggregate.
  - Increased the minimum size limit to 24 inches total length.
  - Prohibited harvest and possession in excess of the recreational bag limit, and purchase and sale during March and April.

March 1, 1999
- Modified Black Grouper and Gag Grouper management in Monroe County state waters only:
  - Reduced the recreational bag limit to two Black Grouper or Gag Grouper, combined, per person within the five-fish grouper aggregate.
  - Increased the minimum size limit to 24 inches total length.
  - Prohibited harvest and possession in excess of the recreational bag limit, and purchase and sale during March and April.

January 1, 2000
- Eliminated the five-day commercial season extension in the reef fish rule.
- Restored the documentation requirement for reef fish species possessed during a closure period.

July 1, 2006
- Specified that, for purposes of determining the legal size of reef fish species, "total length" means the straight line distance from the most forward point of the head with the mouth closed to the farthest tip of the tail with the tail compressed or squeezed while the fish is lying on its side.

July 1, 2007
- Set commercial trip limits in the Atlantic that are the same as trip limits in adjacent federal waters.
- Prohibited commercial fishermen from harvesting or possessing the recreational bag limit of reef fish species on commercial trips.

January 19, 2010

- Reduced recreational aggregate grouper bag limit to 3 fish per person per day in all Atlantic and Monroe County state waters.
- Reduced the recreational bag limit to one Black Grouper or Gag Grouper, combined, per person within the three-fish grouper aggregate.
- Prohibited all harvest of shallow water groupers (including Gag Grouper, Black Grouper, Red Grouper, Scamp, Red Hind, Rock Hind, Coney, Graysby, Yellowfin Grouper, Yellowmouth Grouper, and Tiger Grouper) from January 1 – April 30 in Atlantic and Monroe County state waters.
- Prohibited the captain and crew of for-hire vessels from retaining any species in the aggregate grouper bag limit.
- Required dehooking tools to be aboard commercial and recreational vessels for anglers to use as needed to remove hooks from Atlantic reef fish.

March 13, 2014

- Eliminated prohibition on captain and crew of for-hire vessels from retaining recreational bag limits of Vermilion Snappers, groupers and Golden Tilefish on for-hire trips in state waters of the Atlantic (including Monroe County for grouper and Golden Tilefish).

September 13, 2016

- Created an exception allowing recreational anglers to land reef fish as fillets instead of as whole fish, provided the reef fish were recreationally harvested in The Bahamas and specific conditions are met.
-

3. Assessment History

South Atlantic Gag grouper was first assessed using virtual population analysis with data from 1986 - 1997 (Potts and Manooch 1998). Spawning potential ratio (SPR) was estimated at 30% and fishing mortality on fully recruited ages ranged from 0.20 to 0.32. A benchmark assessment of Gag grouper in the South Atlantic was conducted under SEDAR-10 using a statistical catch-at-age model and an age-aggregated production model (SEDAR 2006). The assessment had a terminal year of 2004. Spawning stock biomass fell below values corresponding to MSY in the early 1980s and remained low until the end of the assessment period, when it increased to slightly above MSST. The assessment concluded the stock was not overfished but was experiencing overfishing, with estimated fishing mortality 31-46% above the Fmsy benchmark. An update of the SEDAR-10 benchmark assessment was conducted in 2014 using data through 2012 (SEDAR 2014). Stock and fishery status estimated by this assessment showed similar trends to those from the SEDAR-10 benchmark assessment. The stock declined until the mid-1980s and fluctuated around MSST until the 2010s. The estimated fishing mortality rate exceeded Fmsy for most of the 1980s through 2000s. The assessment concluded the stock was experiencing overfishing but was not overfished.

References

Potts, J. C. and C. S. Manooch, III. 1998. Population assessment of the gag (Mycteroperca microlepis) from the Southeastern United States.

SEDAR. 2006. SEDAR – South Atlantic Gag Grouper Stock Assessment Report. SEDAR, North Charleston SC. 485 pp. available online at: http://sedarweb.org/sedar-10

SEDAR. 2014. SEDAR – 2014 Update, SEDAR 10 South Atlantic Gag Grouper. SEDAR, North Charleston SC. 171 pp. available online at: http://sedarweb.org/sedar-10

4. Regional Maps

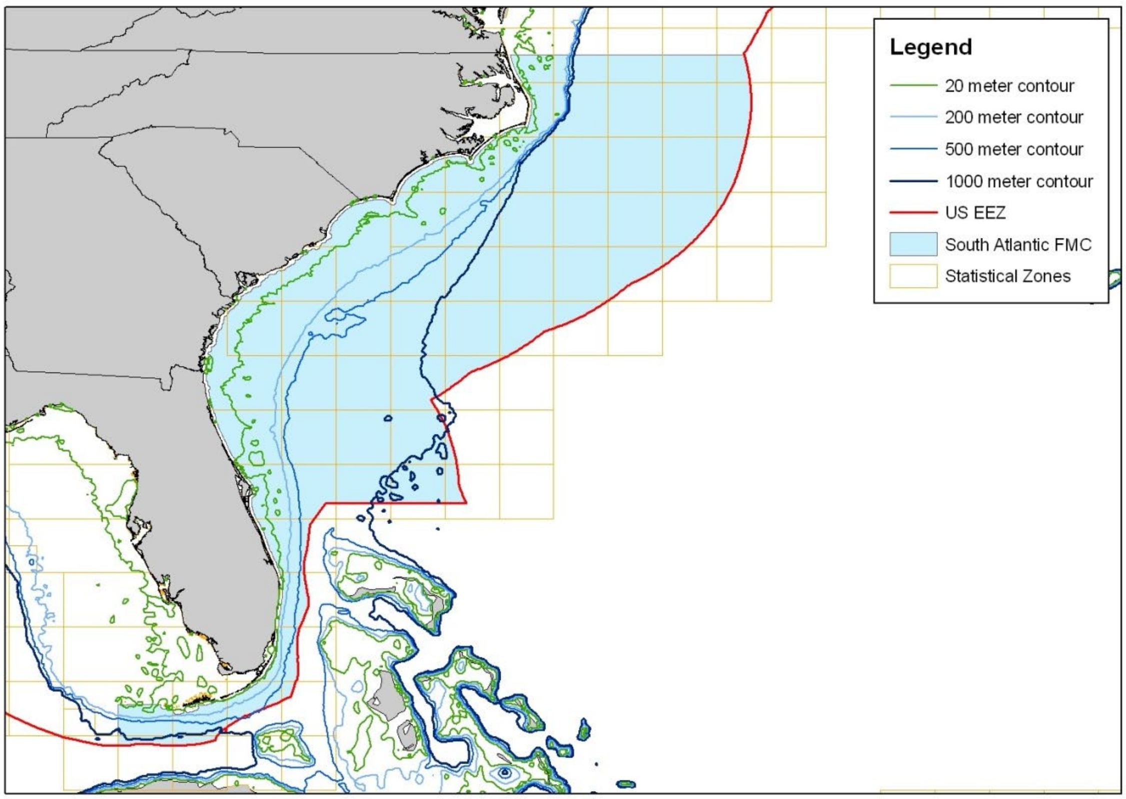

Figure 3.1: South Atlantic Fishery Management Council and EEZ boundaries.

5. Abbreviations

APAIS	Access Point Angler Intercept Survey
ABC	Allowable Biological Catch
ACCSP	Atlantic Coastal Cooperative Statistics Program
ADMB	AD Model Builder software program
ALS	Accumulated Landings System; SEFSC fisheries data collection program
AMRD	Alabama Marine Resources Division
ASMFC	Atlantic States Marine Fisheries Commission
ASPIC	a stock production model incorporating covariates
ASPM	age-structured production model
B	stock biomass level
BAM	Beaufort Assessment Model
BMSY	value of B capable of producing MSY on a continuing basis
CFMC	Caribbean Fishery Management Council
CIE	Center for Independent Experts
CPUE	catch per unit of effort
EEZ	exclusive economic zone
F	fishing mortality (instantaneous)
FMSY	fishing mortality to produce MSY under equilibrium conditions
FOY	fishing mortality rate to produce Optimum Yield under equilibrium
FXX% SPR	fishing mortality rate that will result in retaining XX% of the maximum spawning production under equilibrium conditions
FMAX	fishing mortality that maximizes the average weight yield per fish recruited to the fishery
F0	a fishing mortality close to, but slightly less than, Fmax
FL FWCC	Florida Fish and Wildlife Conservation Commission
FWRI	(State of) Florida Fish and Wildlife Research Institute
GA DNR	Georgia Department of Natural Resources
GLM	general linear model
GMFMC	Gulf of Mexico Fishery Management Council
GSMFC	Gulf States Marine Fisheries Commission

GULF FIN	GSMFC Fisheries Information Network
HMS	Highly Migratory Species
LDWF	Louisiana Department of Wildlife and Fisheries
M	natural mortality (instantaneous)
MAFMC	Mid-Atlantic Fishery Management Council
MARMAP	Marine Resources Monitoring, Assessment, and Prediction
MDMR	Mississippi Department of Marine Resources
MFMT	maximum fishing mortality threshold, a value of F above which overfishing is deemed to be occurring
MRFSS	Marine Recreational Fisheries Statistics Survey; combines a telephone survey of households to estimate number of trips with creel surveys to estimate catch and effort per trip
MRIP	Marine Recreational Information Program
MSST	minimum stock size threshold, a value of B below which the stock is deemed to be overfished
MSY	maximum sustainable yield
NC DMF	North Carolina Division of Marine Fisheries
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
OY	optimum yield
SAFMC	South Atlantic Fishery Management Council
SAS	Statistical Analysis Software, SAS Corporation
SC DNR	South Carolina Department of Natural Resources
SEAMAP	Southeast Area Monitoring and Assessment Program
SEDAR	Southeast Data, Assessment and Review
SEFIS	Southeast Fishery-Independent Survey
SEFSC	Fisheries Southeast Fisheries Science Center, National Marine Fisheries Service
SERO	Fisheries Southeast Regional Office, National Marine Fisheries Service
SPR	spawning potential ratio, stock biomass relative to an unfished state of the stock
SSB	Spawning Stock Biomass
SSC	Science and Statistics Committee
TIP	Trip Incident Program; biological data collection program of the SEFSC and Southeast States.
TPWD	Texas Parks and Wildlife Department
Z	total mortality, the sum of M and F

SEDAR

Southeast Data, Assessment, and Review

SEDAR 71

South Atlantic Gag

Section II: Assessment Report

April 2021

SEDAR
4055 Faber Place Drive, Suite 201 North Charleston, SC 29405

Document History

Report Release April 2021

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1. Introduction

1.1 Executive Summary

This operational assessment evaluated the stock of Gag Grouper (*Mycteroperca microlepis*) in the South Atlantic region of the southeastern United States. The primary objective was to improve the 2006 SEDAR-10 benchmark assessment of Gag Grouper, which was updated with additional data in 2014. Using data through 2012, the last update indicated that the stock was undergoing overfishing but was not overfished. For this assessment, data compilation and assessment methods were guided by methodology of SEDAR-10 and the 2014 update, as well as by current SEDAR practices. The assessment period was 1962–2019.

Available data included indices of abundance, landings, discards, and annual length and age compositions from fishery dependent and fishery independent sources. Two indices of abundance were included in the base run: a fishery dependent index from recreational headboat logbooks and a fishery independent video index from the SouthEast Reef Fish Survey (SERFS). Data on landings and discards were modeled from four fleets: commercial handline, commercial diving, recreational headboats, and general recreational (all modes except headboat).

The primary model used in the update to SEDAR-10 and the current assessment was the Beaufort Assessment Model (BAM), an integrated statistical catch-age formulation. A base run of BAM was configured to provide point estimates of key management quantities, such as stock and fishery status. Uncertainty in estimates from the base run was evaluated through a mixed Monte Carlo/Bootstrap Ensemble (MCBE) procedure and by sensitivity analysis.

The current assessment indicated that spawning stock declined in the 1970s and 1980s, was relatively stable near MSY levels from the mid-1980s to the early 2000s, and then declined further through the terminal year of the assessment (2019). The terminal (2019) base-run estimate of spawning stock was below the minimum stock size threshold (SSB_{2019}/MSST=0.20), indicating that the stock is overfished. With the exception of a few years in the late 1990s and early 2000s, the estimated fishing rate has exceeded the maximum fishing mortality threshold (MFMT) since the mid-1980s. The estimated terminal fishing rate based on a three-year geometric mean is above F_{msy} ($F_{F2017\text{-}2019}/F_{msy}$=2.15), indicating overfishing is occurring. All of the MCBE runs agreed with the base run that the stock is overfished and that overfishing is occurring.

The qualitative trends of this operational assessment were similar to those from the 2014 update of SEDAR10 but there were some differences in the estimated magnitude of stock size and of fishing mortality. This is not surprising given several modifications made to both the data and the model (described throughout the report), in particular the use of updated and re-calibrated MRIP (Marine Recreational Information Program) estimates of recreational landings and discards. Compared to the last update, this assessment suggested higher levels of past (1980s to 2000s) fishing mortality and lower levels of stock size (1960s to 1980s) relative to their benchmarks, though current estimates near the terminal year of the last assessment (2010-2012) were very similar to those from the update assessment. Since the last update (2012), the current assessment has estimated very poor recruitment (2010-2019), and despite declines in landings over the same period, spawning biomass has continued to decline and fishing mortality has increased. The low recruitment and declining spawning biomass are supported by the recreational headboat index and the SERFS video index, which have show 2-3 fold declines over the last 10 years.

1.2 Workshop Time and Place

The SEDAR 71 South Atlantic Gag assessment took place over a series of webinars held from May 2020 to March 2021.

1.3 Terms of Reference

1. Update the approved Update of SEDAR 10 Gag Grouper model with data through 2019. Provide a model consistent with the previous assessment configuration and revised models as necessary to incorporate and evaluate any changes allowed for this update. Apply the current BAM configuration incorporating approved improvements developed since the 2014 update. Evaluate whether the model is able to reliably estimate steepness at this time.

2. Evaluate and document the following specific changes in input data or deviations from the benchmark model.

- Consider including the SERFS video index to address the need for additional fishery independent information.
- Consider potential misidentification as Black Grouper in the estimate of Gag Grouper landings in the South Atlantic.
- Evaluate data uncertainty with respect to the recreational landings

3. Document any changes or corrections made to model and input datasets and provide updated input data tables. Provide commercial and recreational landings and discards in pounds and numbers.

4. Update model parameter estimates and their variances, model uncertainties, estimates of stock status and management benchmarks, and provide the probability of overfishing occurring at specified future harvest and exploitation levels.

5. Convene a panel including SSC representatives to meet via webinar, as needed to review model development and provide guidance.

6. Develop a stock assessment report to address these TORs and fully document the input data, methods, and results.

1.4 List of Participants

Appointee	Function	Affiliation
Panel		
Kevin Craig	Lead Analyst	Beaufort, NC
Rob Cheshire	Data Compiler	SEFSC Beaufort
Julie DeFilippi-Simpson	Panelists	ACCSP
Marcel Reichert	Panelists	SCDNR
Keilin Gamboa-Salazar	Panelists	SCDNR
Dawn Glasgow	Panelists	SCDNR
Alan Bianchi	Panelists	NCDMF
Dawn Franco	Panelists	GADNR
Wilson Laney	Panelists	SSC
Scott Crosson	Panelists	SSC
Anne Lange	Panelists	SSC
Kyle Shertzer	Assessment Team	Beaufort, NC
Erik Williams	Assessment Team	Beaufort, NC
Andy Ostrowski	Assessment Team	Beaufort, NC
Vivian Matter	Assessment Team	Miami, FL
Kelly Fitzpatrick	Assessment Team	Beaufort, NC
Ken Brennan	Assessment Team	Miami, FL
Beth Wrege	Assessment Team	Miami
Appointed Observers		
Jack Cox	Observer	SGAP
Randy McKinley	Observer	SGAP
Mark Marhefka	Observer	SGAP
STAFF		
Kathleen Howington	Coordinator	SEDAR
Mike Errigo	Staff	SAFMC
Jeff Pulver	Observer	SERO
Tim Griner	Council Representative	SAFMC
Chris Conklin	Council representative	SAFMC
Non-panel Data Providers		
Steve Brown	Data Provider	FLFWC
Andrew Cathey	Data Provider	NCDMF
Kayla Rudnay	Data Provider	SCDNR
Dominique Lazarre	Data Provider	FLFWC
Refik Orhun	Data Provider	SEFSC Miami, FL
Kevin McCarthy	Data Provider	SEFSC Miami, FL
Larry Beerkircher	Data Provider	SEFSC Miami, FL

Appointee	**Function**	**Affiliation**
Other		
Margaret Finch	Observer	SCDNR
Mike Rinaldi	Observer	ACCSP
Chip Collier	Observer	SAFMC
Michelle Willis	Observer	SCDNR
Alan Lowther	Observer	NOAA
Allie Iberle	Observer	SAFMC
David Wyanski	Observer	SCDNR
Eric Fitzpatrick	Observer	NOAA
Erika Burgess	Observer	FLFWC
Kevin Kolmos	Observer	SCDNR
Matthew Nuttall	Observer	NOAA
McLean Seward	Observer	NCDENR
Nicholas Fisch	Observer	UFL
Reid Wilson Laney	Observer	South Atlantic SSC
Stephen Long	Observer	SCDNR
Tracey Smart	Observer	SCDNR
Walter Bubley	Observer	SCDNR
Wiley Sinkus	Observer	SCDNR

1.5 Document List

Document #	Title	Authors	Date Received
Documents Prepared for SEDAR 71			
SEDAR71-WP01	An Update to Gag Grouper (*Mycteroperca microlepis*) Calendar Age Calculations	Andrew D. Ostrowski, C. Michelle Willis, Keilin Gamboa-Salazar, and Margaret W. Finch	10/22/2020
SEDAR71-WP02	Standardized video counts of Southeast U.S. Atlantic gag (*Mycteroperca microlepis*) from the Southeast Reef Fish Survey	Rob Cheshire and Nathan Bacheler	10/2/2020
SEDAR71-WP03	Gag Grouper (*Mycteroperca microlepis*) Reproductive Parameters in Support of the SEDAR 71 Assessment	Keilin R. Gamboa-Salazar, Dawn M. Glasgow, and David M. Wyanski	10/20/2020
SEDAR71-WP04	Gag Fishery-Independent Index of Abundance and Age/Length Compositions in US South Atlantic Waters Based on a Chevron Trap Survey (1990-2019)	Dawn M. Glasgow and C. Michelle Willis	10/9/2020
SEDAR71-WP05	General Recreational Survey Data for Gag in the South Atlantic	Vivian M. Matter and Matthew A. Nuttall	10/13/2020
Final Assessment Report			
SEDAR71-SAR1	SEDAR 71 South Atlantic Gag Stock Assessment Report	Prepared by SEDAR 71 Panel	April 2021
Reference Documents			
SEDAR71-RD01	Relative survival of gags Mycteroperca microlepis released within a recreational hook-and-line fishery: Application of the Cox Regression Model to control for heterogeneity in a large-scale mark-recapture study	Beverly Sauls	5/14/2020

Document #	Title	Authors	Date Received
Reference Documents Cont.			
SEDAR71-RD02	Effects of age and size on spawning and egg production in gag and scamp grouper off the southeastern United States	Keilin R. Gamboa-Salazar, David M. Wyanski, Walter J. Bubley, and Nikolai Klibansky	5/26/2020
SEDAR71-RD03	Life history of juvenile gag, mycteroperca microlepis, in north carolina estuaries	Steve W. Ross and Mary L. Moser	10/28/2020
SEDAR71-RD04	Snapper Grouper Advisory Panel Fishery Performance Report for Gag September 2020	SAFMV Snapper Grouper Advisory Panel	11/3/2020

1.6 Statements Addressing Each term of Reference

Note: Original ToRs are in normal font. Statements addressing ToRs are in italics and preceded by a dash (−).

1. Update the approved Update of SEDAR 10 Gag Grouper model with data through 2019. Provide a model consistent with the previous assessment configuration and revised models as necessary to incorporate and evaluate any changes allowed for this update. Apply the current BAM configuration incorporating approved improvements developed since the 2014 update. Evaluate whether the model is able to reliably estimate steepness at this time.

   SEDAR71 applied the current BAM configuration. The assessment model structure and data sources were similar to those used in the SEDAR 2014 update and the SEDAR 10 benchmark. Important modifications, such as natural mortality, composition likelihoods, selectivity blocking, and indices are documented in section 2 of the report and were investigated through sensitivity analysis (section 4.11).

2. Evaluate and document the following specific changes in input data or deviations from the benchmark model.
   - Consider including the SERFS video index to address the need for additional fishery independent information.
   - Consider potential misidentification as Black Grouper in the estimate of Gag Grouper landings in the South Atlantic.
   - Evaluate data uncertainty with respect to the recreational landings

   The SERFS video index was included in the BAM based run (SEDAR71-WP02). Selectivity of the video index was assumed flat-topped with the ascending limb informed by the selectivity of the chevron trap, as recommended by the Selectivity Working Group (SEDAR73-WP14). The potential for misidentification of Gag Grouper as Black Grouper was addressed (SEDAR 71-WP05). Revised MRIP estimates were included and their uncertainly evaluated in the ensemble modeling (section 3.7 of the report).

3. Document any changes or corrections made to model and input datasets and provide updated input data tables. Provide commercial and recreational landings and discards in pounds and numbers.

   Changes to data and the model are documented in the report and tables of updated data inputs and removals in both pounds and numbers provided.

4. Update model parameter estimates and their variances, model uncertainties, estimates of stock status and management benchmarks, and provide the probability of overfishing occurring at specified future harvest and exploitation levels.

   All of these key estimates and outputs are documented in the report.

5. Convene a panel of several SSC representatives to meet via webinar, as needed to review model development and provide guidance.
   The Assessment Panel met from May 2020 to March 2021.

6. Develop a stock assessment report to address these TORs and fully document the input data, methods, and results.

   See this report.

2 Data Review and Update

In this operational assessment of gag, the start year is 1962 (as in SEDAR-10) and the terminal year is 2019. An update to SEDAR-10 was completed in 2014 with a terminal year of 2012. The input data for this assessment are described below, with focus on modifications from SEDAR-10 that were recommended by the Assessment Panel.

2.1 Data Review

In this operational assessment, the Beaufort Assessment Model (BAM) was fitted to data sources similar to those used in the SEDAR-10 benchmark.

- Landings: Commercial Handline, Commercial Dive, General Recreational (all modes except headboat), Recreational Headboat
- Discards: Commercial Handline, General Recreational (all modes except headboat), Headboat
- Indices of abundance: Headboat, SERFS Video
- Length compositions: Headboat, Headboat-at-sea discards
- Age compositions of landings: Commercial Handline, Commercial Dive, Headboat, SERFS Chevron Trap

In addition to data fitted by the model, this assessment utilized life history information that was treated as input. Natural mortality, female maturity at age, and the population growth curve were updated from the last assessment while sex ratio, time of peak spawning, and discard mortality were the same as in SEDAR-10.

2.2 Data Update

The following is a summary of the data differences between this operational assessment and the SEDAR-10 benchmark assessment. Data available for this assessment are summarized in Tables 1–14.

- Fleet Structure: All commercial (handline, dive) and recreational (general recreation, headboat) landings were updated through 2019 and modeled as separate removal streams as in SEDAR-10. Similarly, commercial handline discards, general recreational discards, and headboat discards were updated through 2019 and modeled as separate removal streams as in SEDAR-10. The estimates for commercial and recreational discards are either model- or ratio-based, therefore the entire time series of estimates was updated.
- Indices of abundance: A fishery dependent index of abundance (headboat) and a fishery independent index of abundance (SERFS video) were used in this assessment. This differs from SEDAR-10 which did not include the video index but did include a commercial handline index. The Panel decided to remove the commercial handline index because it was in conflict with the headboat and video index in this assessment. Further, there were concerns about hyperstability in the commercial handline index, particularly since 2010, due to potential effects of spawning season closures and the red snapper moratorium. The effect of this decision was evaluated via sensitivity analysis. The SERFS Chevron trap index as well as a fishery dependent headboat-at-sea discard index were also considered in the current assessment, but were excluded due to small sample sizes. A MRFSS index was considered in SEDAR-10 but was removed during the assessment phase and also not included in the 2014 update, and so was not re-considered here.

- Size/age compositions of landings: Commercial handline, commercial dive, headboat, general recreational, and SERFS chevron trap age and length composition data were updated through 2019, the terminal year of the assessment. General recreational and commercial length compositions were not used in the current assessment due to conflicts with the age data. Headboat length compositions were used for seven years when age composition data were not available but were otherwise excluded from the assessment. SERFS length compositions were also not included because age compositions were available. Limited age compositions from the general recreational fleet were considered but were ultimately excluded because they were limited to the charter mode in South Florida and the Panel determined they were not representative of the general recreational fleet.
- Life History: The von Bertalannfy growth curve and the female maturity schedule were updated with additional samples collected since SEDAR-10. Lorenzen age-based natural mortality was used, similar to SEDAR-10, but was updated given the new von Bertalannfy growth parameters. In addition, SEDAR-10 scaled the Lorenzen curve over all ages (1+) while the current assessment scaled the curve over fully selected ages (5+). Gag is a protogynous hermaphrodite, with sex change to males occurring near 10 years of age. Time-varying sex ratio was considered as in SEDAR-10, but the Panel decided the information was limited, and so a constant sex ratio varying with age was assumed. Discard mortality was set to 0.4 for the commercial handline fleet and 0.25 for the general recreational and headboat fleets, as in SEDAR-10. Other life history inputs were the same as SEDAR-10.
- Similar to the SEDAR-10 update the indices were weighted using the iterative reweighting procedure recommended by Francis (2011). In contrast to SEDAR-10, the Dirichlet multinomial distribution, rather than the robust multinomial distribution, was used for composition data. The Dirichlet multinomial is a self-weighting distribution, thus removing the need for external weights on the composition data.

2.2.1 Life history

Life history information is summarized in Table 1. The von Bertalanffy growth curve was updated with additional samples collected since SEDAR-10. The curve was fit using a truncated (at the size limit) normal distribution and inverse-weighted by sample size. In this assessment the growth curve was estimated external to the assessment model. The von Bertalanffy growth parameters estimated for SEDAR-10 were ($\widehat{L_\infty} = 905$ mm, $\widehat{K} = 0.354$ yr^{-1}, and $\widehat{t_0} = -0.395$ yr) while those estimated here were ($\widehat{L_\infty} = 1161$ mm, $\widehat{K} = 0.168$ yr^{-1}, and $\widehat{t_0} = -1.11$ yr).

The female maturity schedule was also updated with additional samples since SEDAR-10. Data on female maturity were fit with several alternative models and compared using AIC. The best fit model yielded an age at 50% female maturity of 4.6, an increase over that used in SEDAR-10. The age at 50% female maturity in SEDAR-10 was ~ 3. As in SEDAR-10, all males were considered mature.

Similar to SEDAR-10, Lorenzen age-based natural mortality scaled to a point estimate of $M = 0.15$ was used in this assessment, but was updated given the new von Bertalanffy growth parameters. In addition, SEDAR-10 scaled the Lorenzen curve over all ages (1+) while the current assessment scaled the curve over fully selected ages (5+), consistent with most prior SEDAR assessments. This resulted in a higher natural mortality than was used in SEDAR-10.

In SEDAR-10, the proportion female at age varied across time blocks, with an increasing proportion of females in the later years. The Assessment Panel discussed these data extensively and found they were not sufficient to adequately estimate time-varying sex ratio and, therefore, recommended that sex ratio be time-invariant. Mature male and female biomass was used as the measure of reproductive potential, similar to SEDAR-10.

Other related inputs remained the same as in SEDAR-10 such as the length-weight relationship, the gutted weight to whole weight conversion (WW=1.059GW), and the release mortality rates (0.4 for the commercial handline fleet and 0.25 for the headboat and general recreational fleets).

2.2.2 Commercial landings and discards

Commercial landings were developed for 1962-2019. The two dominant commercial fleets for gag, handline and diving, were modeled in the assessment. Any landings from other commercial gears (e.g., longline or trawl) were combined with landings of the handline fleet; those other gears were relatively small contributors, typically much less than 1% of the total. Estimates of commercial dive landings were zero prior to 1976. Estimates of commercial handline discards were revised for their full time period 1999–2019. Commercial landings were modeled in units of 1000 lb gutted weight, and discards in units of 1000 fish (Table 2).

2.2.3 Recreational landings and discards

Recalibrated MRIP data were used for the landings and discards of all recreational modes with the exception of headboat, which were estimated from the South Atlantic Headboat Survey (SRHS). MRIP and headboat landings and discards were developed for 1981–2019. The FHWAR method was used to generate estimates of historical recreational landings from 1962–1980. General recreational and headboat landings and discards were maintained as separate fleets but shared the same selectivity, as in SEDAR-10. The Assessment Panel discussed pooling the two fleets but recommended they remain separate as gag have an estuarine phase where they may be exploited more by general recreational anglers than by headboats. Recreational landings and discards were fitted in units of 1000 fish, as these data are primarily recorded in numbers (Table 2).

2.2.4 Indices of abundance

The headboat index was updated with two modification since SEDAR-10. Due to recent spawning season closures that affect catch per effort in the fishery, November to April samples were filtered in order to extend the terminal year of the index to 2019. Second, the start year of the index was changed from 1973 in SEDAR-10 to 1980 in the current assessment due to reporting issues primarily in South Florida in the earlier years. A new fishery independent video index (2011–2019) was developed for this assessment from the SERFS program using a zero-inflated negative binomial model. The year 2010 was excluded due to limited spatial coverage. Chevron trap samples from SERFS and from earlier MARMAP trap sampling were also investigated to determine if a trap index could be developed as well. Trap sample sizes were very limited and so only a video index was developed. The commercial handline index was standardized and updated from 1993–2019 using a delta-GLM approach, similar to SEDAR-10, but was not used in the base run. A headboat-at-sea observer index was also investigated, but there were insufficient data to develop a discard-only index. As in past SEDAR assessments, CVs on fishery dependent indices were set to 0.2 to avoid the situation where fishery dependent indices were considered more certain than fishery independent indices due to the larger sample sizes of the former.

The two indices used in the base run of this assessment are tabulated in Table 3 and shown in Figure 1.

2.2.5 Length and age compositions

Commercial and recreational length and age compositions were updated through 2019. The Assessment Panel considered several possible applications of length composition data, such as including length composition data in years with no or limited age composition data, as well as pooling length compositions over years. Because the growth curve is not estimated internal to the model, length-at-age is highly variable for gag, and selectivity is modeled as a function of age, length compositions typically have low information content. Length composition data were also in conflict with age compositions as well as multiple indices. Therefore, the Panel recommended removing length compositions with two exceptions. First, headboat length compositions were retained for seven years (1988–1989, 1996–2000) when headboat age composition data were not available. Inclusion of these length composition improved the pooled fit to the headboat age compositions. Second, headboat-at-sea discard length compositions were available for nine years (2005–2013) and were retained to inform selectivity of recreational discards. Age and length composition data is not available for fish directly observed in the SERFS video data. Therefore, SERFS chevron trap age compositions were used to estimate selectivity of the SERFS video index (described in §3.3).

The annual sample sizes of fish and trips by fleet are shown in Tables 4 and 5.

3 Stock Assessment Methods

This operational assessment updates the primary model applied during SEDAR-10 to South Atlantic gag. SEDAR-10 had a terminal year of 2006 and an update was completed in 2014 with a terminal year of 2012. The methods are reviewed below and modifications since the 2014 update are indicated.

3.1 Overview

The primary model in this assessment was the Beaufort Assessment Model (BAM), which applies an integrated statistical catch-age formulation, implemented with the AD Model Builder software (Williams and Shertzer 2015). In essence, the model simulates a population forward in time while including fishing processes (Quinn and Deriso 1999; Shertzer et al. 2008). Parameters to be estimated are systematically varied until characteristics of the simulated population match available data on the real population. The model is similar in structure to Stock Synthesis (Methot 1989; 2009). Versions of BAM have been used in previous SEDAR assessments of reef fishes and other species in the U.S. South Atlantic, including gag, and is now the primary model used in stock assessments in the region.

3.2 Data Sources

The catch-age model included data from four fleets that caught gag in southeastern U.S. waters from the Florida Keys to the North Carolina-Virginia border: commercial handlines (hook-and-line), commercial diving, recreational headboats, and general recreational. The model was fitted to data on annual landings (in gutted weight for commercial fleets, in numbers for recreational fleets), annual dead discards (in numbers) from all fleets except for commercial diving, annual length compositions of landings and discards from the headboat fleet, annual age compositions of landings from the handline, dive, and headboat fleets, one fishery dependent index of abundance (headboat) and one fishery independent index of abundance (SERFS video). As in the SEDAR-10 update, ages $1 - 12^{+}$ were used to fit composition data, and discard mortality was set to 0.4 for commercial handlines and 0.25 for the headboat and general recreational fleets. Data used in the model are described further in §2 of this report.

3.3 Model Configuration and Equations

Model structure and equations of the BAM are detailed in Williams and Shertzer (2015). The assessment time period was 1962–2019. A general description of the assessment model follows.

Stock dynamics In the assessment model, new biomass was acquired through growth and recruitment, while abundance of existing cohorts experienced exponential decay from fishing and natural mortality. The population was assumed closed to immigration and emigration. The model included age classes $1 - 16^+$, where the oldest age class 16^+ allowed for the accumulation of fish (i.e., plus group).

Initialization Initial (1962) abundance at age was computed in the model as the equilibrium age structure for ages 1–16. This equilibrium was based on natural and fishing mortality (F_{init}), where F_{init} was estimated by the model ($F_{\text{init}} = 0.032$). This estimated value is similar to the assumed value in the SEDAR-10 update ($F_{\text{init}} = 0.03$) and is consistent with the low level of reported landings near the start of the assessment period. Deviations around the initial equilibrium age structure were not estimated, because information on age structure, as provided by composition data, did not become available until much later in the assessment period. The effect of other values of F_{init} were evaluated via sensitivity analysis.

Growth Mean total length (TL, in units of mm) at age of the population was modeled with the von Bertalanffy equation, and weight at age (whole weight, WW) was modeled as a function of total length (Table 1, Figure 2). The von Bertalanffy parameters were updated from those in SEDAR-10 and treated as input to the assessment model. The parameters estimates for the population were $\widehat{L_\infty} = 1161$ mm, $\widehat{K} = 0.168$ yr^{-1}, and $\widehat{t_0} = -1.11$ yr. A separate von Bertalanffy equation was estimated from only fishery dependent data in order to convert ages of landings to lengths in the assessment model. Early SEDAR assessments used the population growth curve for this purpose, but more recent assessment have used separate population and fishery growth curves. The parameter estimates for the fishery growth curve were also estimated external to the assessment model and were $\widehat{L_\infty} = 1155$ mm, $\widehat{K} = 0.154$, and $\widehat{t_0} = -2.16$ yr. For both growth curves the distribution of size at age was assumed normal with separate coefficients of variation (CVs) estimated by the assessment model.

Conversion equations (TL-WW, WW-GW) were unchanged from SEDAR-10. Landings were converted to gutted weight using the conversion GW=WW/1.059.

Natural mortality rate The natural mortality rate (M) was assumed constant over time, but decreasing with age. The form of M as a function of age was based on Lorenzen (1996). The Lorenzen (1996) approach inversely relates the natural mortality at age to mean weight at age W_a by the power function $\text{M}_a = \alpha W_a^\beta$, where α is a scale parameter and β is a shape parameter. Lorenzen (1996) provided point estimates of $\hat{\alpha} = 3.69$ and $\hat{\beta} = -0.305$ for oceanic fishes, which were used for this assessment. Other approaches to natural mortality were considered, but the Assessment Panel recommended the Lorenzen (1996) approach, consistent with SEDAR-10. As in the SEDAR-10 benchmark and the 2014 update, the age-dependent estimates of M_a were re-scaled to provide the same fraction of fish surviving to the oldest observed age (30 yr) as would occur with constant $M = 0.15$. This approach using cumulative mortality allows the fraction of the population surviving to the oldest age to be consistent with the findings of Hoenig (1983) and Hewitt and Hoenig (2005). In contrast to SEDAR-10 update, however, the Assessment Panel recommended scaling the age dependent natural mortality vector only over the fully selected ages (i.e., 5^+), as is common practice in recent SEDAR assessments, rather than all ages (i.e., 1^+). The updated von Bertalanffy growth curve also changed the mean weight at age used to estimate M. As a result, M was higher in this assessment compared to SEDAR-10. The effect of changes in the magnitude and scaling of M were evaluated via sensitivity analysis, and uncertainty in M was included in the ensemble modeling.

Maturity, sex ratio, and spawning stock Maturity and sex ratio were updated with new data since the SEDAR-10 update. Maturity at age of females was modeled as an increasing logistic function. The age at 50% female maturity was estimated to be 4.6 years and all males were considered mature.

Gag is a protogynous hermaphrodite (transitions from female to male with age). The proportion male at age was modeled with an increasing logistic function and was assumed constant across years. The estimated age at sexual transition was 10.5 years. SEDAR-10 assumed that sex ratio varied in time, but discussions with the Assessment Panel suggested these data were too limited to accurately quantify time varying sex ratio, and no updated sex ratio information was provided for this assessment. Further, time-varying sex ratio would likely influence other life history traits which were assumed constant for this assessment. Therefore, sex ratio was assumed constant in time.

As in past SEDAR assessments of protogynous species, total mature biomass of males and females was used as the measure of spawning potential. By including mature males, this approach considers the possibility of sperm limitation, which is reasonable given the low proportion of males in the population. However, total mature biomass may be a less accurate measure of spawning potential than mature female biomass or female egg production, particularly if sperm is not limiting. Female biomass or egg production requires accurate information on sex ratio and female fecundity, which is limited for gag. Therefore, the Assessment Panel recommended that sex ratio be considered constant in time and total mature biomass of males and females be used to represent the spawning stock. As in SEDAR-10, spawning biomass was computed each year from the number at age at the time of peak spawning (mid-April).

Recruitment Expected recruitment of age-1 fish was predicted from spawning stock using the Beverton–Holt spawner-recruit model. Annual variation in recruitment was assumed to occur with lognormal deviations starting in 1976, when composition data could provide information on year-class strength. Prior to 1976, recruitment was assumed to follow the spawner-recruit curve precisely. Recruitment deviations were estimated to the terminal year of the assessment (2019) because age compositions of the SERFS chevron trap survey (used to inform selectivity of the video index) had reasonably high selectivity for age–1 fish. Steepness was not estimable in the SEDAR-10 update assessment and was fixed at $h = 0.84$ based on meta-analysis (Shertzer and Conn 2012). In this assessment, steepness could be estimated ($h = 0.898$) and profiling indicated a range between $h = 0.85$ and $h = 0.95$. The effect of other values of steepness were evaluated via sensitivity analysis.

Landings Time series of landings from four fleets were modeled: commercial handline (1962–2019), commercial diving (1976–2019), recreational headboat (1962–2019), and general recreational (1962–2012). Landings were modeled with the Baranov catch equation (Baranov 1918) and were fitted in either weight or numbers (1000 lb gutted weight for commercial and 1000 of fish for recreational).

Discards Commercial handline discard mortalities were modeled starting in 1999, and headboat and general recreational discard mortalities starting in 1981. As with landings, discard mortalities (in units of 1000 fish) were modeled with the Baranov catch equation (Baranov 1918), which required estimates of discard selectivities (described below) and release mortality rates. Headboat and recreational release mortality rates were both 0.25, and the commercial release mortality rate was 0.4. Sensitivity runs and ensemble modeling (described below) considered other values of discard mortality.

Fishing For each time series of landings and discards, the assessment model estimated a separate full fishing mortality rate (F). Age-specific rates were then computed as the product of full F and selectivity at age. As in the 2014 update, apical F was computed as the maximum of F at age summed across fleets.

Selectivities Selectivities were estimated using either a two-parameter logistic model (flat-topped) or a four-parameter logistic-exponential model. This parametric approach reduces the number of estimated parameters and imposes theoretical structure on the estimates. Dome-shaped selectivity was modeled by 1) estimating logistic selectivity for ages prior to full selection (two estimated parameters, $\widehat{\eta}$ and $\widehat{\alpha}_{50}$), 2) assuming the age at full selection (fixed parameter, a_f), and 3) estimating the descending limb using a negative exponential model (one estimated parameter, $\widehat{\sigma}$):

$$\text{selex}_a = \begin{cases} \frac{1}{1+\exp[-\widehat{\eta}(a-\widehat{\alpha}_{50})]} & : \quad a < a_f \\ 1.0 & : \quad a = a_f \\ \exp\left(-\left(\frac{(a-a_f)}{\widehat{\sigma}}\right)^2\right) & : \quad a > a_f \end{cases} \tag{1}$$

The commercial diving fleet was assumed to have dome-shaped selectivity, which was considered time-invariant. The age at full selection was fixed at $a_f = 5$, the value most consistent with the data (as indicated by likelihood values of model runs using various values of a_f).

The commercial handline and recreational landings were assumed to have flat-topped selectivities. The two recreational fleets, headboat and general recreational, shared the same selectivity. In SEDAR-10, the flat-topped selectivities were blocked into three time periods to reflect changes in size limit regulations: 1962–1991 (no size limit), 1992–1998 (20-inch limit), and 1999–2012 (24-inch limit). Analysis of commercial handline length and age composition data indicated no effect of size limit changes on the composition of the landings. Further, only length composition data were available in the two early time blocks while age composition data were available for the third time block. Preliminary models with selectivity blocks indicated temporal shifts in selectivity that were inconsistent with expectations based on changes in size limits (e.g., shifts to smaller fish when size limits were imposed). This was the result of differences in the availability of length composition data and age composition data across time, with early selectivity periods informed primarily by length compositions while later selectivity periods were informed primarily by age compositions. As a result, the Assessment Panel recommended that selectivity of the commercial handline fishery be assumed constant in time. Similar analysis of headboat and general recreational length and age compositions indicated a relatively small shift in selectivity with the imposition of the 20-inch size limit in 1992 but no additional change in age or length composition of the landings associated with the increase to a 24-inch size limit in 1999. Therefore, selectivity in the recreational fleets was modeled with a pre- size limit block (1962–1991) and a post- size limit block (1992–2019). The effect of this change in selectivity blocks was assessed via sensitivity analysis.

Discard selectivities could not be freely estimated for the different fleets because only limited length composition data from the headboat fleet (2005–2013) were available to inform their estimation. Therefore, selectivity of discards for both commercial and recreational fleets was assumed to be 1.0 for age–1 fish (based on inspection of the headboat-at-sea discard data) and then assumed to be the probability that fish of a given age were below the size limit (either 20-inch or 24-inch) for ages $2 - 16^{+}$ based on the von Bertalannfy growth curve. This approach differs from that used in the SEDAR-10 update, where discard selectivities were assumed as the difference between the estimated logistic curve for landings and the same curve shifted two years younger, but is more consistent with the approach used in recent SEDAR assessments. The limited discard length composition data available (2005–2013) since the imposition of the 24–inch size limit in 1999 suggested a mix of age–1 and age–2 fish in the recent discards. Therefore, the selectivity of age–2 fish was estimated in the recent period (1999–2019). This approach reflects potential increases in discarding associated with the most recent regulatory period and makes use of the limited composition data, but also assumes some discarding, particularly of age–1 fish, occurred historically prior to size limit regulations. Further, the approach assumes the same discarding practices for the recreational and commercial fleets, which is reasonable given that both are primarily hook-and-line fisheries and have been subject to the same size limit regulations. In this assessment, normal prior distributions were applied to all estimated selectivity parameters. These priors were loose ($CV = 0.5$) and used primarily to avoid search space in the optimization with potentially no curvature in the likelihood surface.

Selectivity of the fishery independent video index followed recommendations of the Selectivity Workgroup (see SEDAR73-WP14 (2020)). In that workshop, it was recommended that the selectivity of the chevron trap gear be assumed dome-shaped due to the limits that the trap opening imposes on the size and age composition of captured fish, while the selectivity of the video should be assumed flat-topped. As recommended in (SEDAR73-WP14 2020)) the ascending limb of the video index selectivity mirrored that of the chevron trap gear until it reached a value of 1.0, after which it was fixed at 1.0. This approach is guided by the belief that the ascending limb of the trap selectivity is determined by availability to the gear (therefore also available to be seen on video), but that larger, older fish, when present, would be detectable by video but not necessarily enter the traps.

Indices of abundance The model was fitted to a fishery dependent index standardized from headboat logbooks (1980–2019) and a fishery independent video index (2011-2019). The predicted indices are conditional on selectivity and were computed from numbers (recreational) or weight (commercial) at age at the midpoint of the year. The SEDAR-10 benchmark and 2014 update included three fishery dependent indices of abundance: commercial handline (1993–2011), headboat (1973–2012), and general recreational (1981-2004). The general recreational index was not developed for this assessment. The Assessment Panel had concerns about hyperstability in the commercial handline index (1993–2019). In addition, there were concerns about the effects of the red snapper moratorium in 2010 on the behavior of the fleet. The commercial handline index was also in conflict with the other two indices. Therefore, the Assessment Panel recommended excluding the commercial handline index. The effect of removing the commercial handline index as well as truncating or assuming a different catchability for the fishery dependent indices was evaluated via sensitivity analysis.

Catchability In the BAM, catchability scales indices of relative abundance to the estimated population at large. Several options for time-varying catchability were implemented in the BAM following the recommendations of SEDAR Procedural Guidance (2009). In particular, the BAM allows for density dependence, linear trends, and random walk, as well as time-invariant catchability. For Gag, catchability of the indices and the fleets were assumed constant in time. The effect of assuming a random walk on catchability for the fishery dependent indices was assessed via sensitivity analysis.

Biological reference points Biological reference points (benchmarks) were calculated based on maximum sustainable yield (MSY) estimates from the Beverton–Holt spawner-recruit model with bias correction (expected values in arithmetic space). Computed benchmarks included MSY, fishing mortality rate at MSY (F_{MSY}), and spawning stock at MSY (SSB_{MSY}). In this assessment, spawning stock measures total biomass (mt) of mature males and females. These benchmarks are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. The selectivity pattern used here was the effort-weighted selectivities at age, with effort from each fleet estimated as the full F averaged over the last three years of the assessment.

Fitting criterion The fitting criterion was a penalized likelihood approach in which observed landings and discards were fit closely, and observed composition data and abundance indices were fit to the degree that they were compatible. Landings and discards were fit using lognormal likelihoods. The CVs of landings and discards (in arithmetic space) were assumed equal to 0.05 to achieve a close fit to these data while allowing for some imprecision. In practice, the small CVs are a matter of computational convenience, as they help achieve the desired result of close fits to the landings and discards, while avoiding having to solve the Baranov equation iteratively (which is complex with multiple fleets).

SEDAR-10 update fit age and length composition data using the robust multinomial distribution as recommended by Francis (2011). More recent work has questioned the use of the multinomial distribution in stock assessment models (Francis 2014), and recommended either the Dirichlet-multinomial or logistic-normal distribution as alternatives (Francis 2017; Thorson et al. 2017). Both are self-weighting and therefore iterative re-weighting (e.g., Francis (2011)) is unnecessary, and both better account for intra-haul correlations (i.e., fish caught in the same set are more alike in length or age than fish caught in different sets). The Dirichlet-multinomial allows for observed zeros (the logistic normal does not). This assessment used the Dirichlet-multinomial distribution, with sample sizes represented by the annual number of trips (Table 5) adjusted by an estimated variance inflation factor for each source of composition data.

The model includes the capability for each component of the likelihood to be weighted by user-supplied values. When applied to indices, these weights modified the effects of the CVs derived from index standardization. CVs from index standardization are often smaller for fishery dependent indices than for fishery independent indices due to the typically larger sample sizes. Therefore, initial CVs for the fishery dependent headboat index were set to 0.2, similar to past SEDAR assessments, to ensure that the fishery independent index was not considered less certain than the fishery dependent index. In the base run, weights on the two indices were adjusted iteratively from the initial values based on the index standardization (Table 3) until standard deviations of normalized residuals (SDNRs) were near 1.0, as recommended by Francis (2011). The effect of iterative re-weighting of the indices was evaluated via sensitivity analysis.

For parameters defining selectivities, CV of size at age, the Dirichlet-multinomial variance inflation factors, F_{init}, and σ_R, normal priors were applied to maintain parameter estimates near reasonable values, and to prevent the optimization routine from drifting into parameter space with negligible gradient in the likelihood. For σ_R, the prior mean (0.6) and standard deviation (0.15) were based on Beddington and Cooke (1983) and Mertz and Myers (1996).

Configuration of base run The base run was configured as described above. Uncertainty in parameter estimates and data used to fit the model were evaluated through sensitivity analyses and an ensemble modeling approach (described below).

Sensitivity analyses Sensitivity runs were chosen to investigate issues that arose specifically with this assessment. They are intended to demonstrate directionality of results with changes in inputs or simply to explore model behavior, and not all are considered equally plausible. These model runs vary from the base run as follows.

- S1: Steepness $h = 0.85$, lower than in the base run
- S2: Steepness $h = 0.95$, higher than in the base run
- S3: Steepness $h = 0.84$, based on meta analysis (Shertzer and Conn 2012)
- S4: Headboat index alone
- S5: SERFS video index alone
- S6: Base run indices (headboat and video) with no iterative reweighting (weights=1.0)
- S7: Base run indices with headboat index truncated after 2009
- S8: Base run indices plus commercial handline index
- S9: Base run indices plus catchability (q) block on handline index (pre-2010, 2010-2019)
- S10: Base run indices plus commercial handline with random walk on all fishery dependent q
- S11: $F_{\mathrm{init}} = 0.048$, 50% higher than in the base run
- S12: $F_{\mathrm{init}} = 0.016$, 50% lower than in the base run
- S13: Discard mortality equal to 0.35 for all fleets, near the upper bound of Sauls (2014)
- S14: Discard mortality equal to 0.15 for all fleets, near the lower bound of Sauls (2014)
- S15: Three selectivity blocks around size limits, as in SEDAR-10
- S16: Dome-shaped selectivity of the SERFS video index
- S17: Natural mortality from SEDAR-10 update, lower than base run and scaled over all ages
- S18: Natural mortality from current assessment but scaled over all ages, as in SEDAR-10 update
- S19: Low natural mortality ($M = 0.10$) used to scale the age-dependent vector of Lorenzen (1996)
- S20: High natural mortality ($M = 0.25$) used to scale the age-dependent vector of Lorenzen (1996)
- S21: Natural mortality constant with age at Hoenig (1983) estimate $M = 0.15$
- S22: Life history (growth, mortality and maturity) from the SEDAR-10 update
- S23: Female egg production as the measure of reproductive potential

Retrospective analyses were also conducted by incrementally dropping one year at a time for five iterations. In these runs, the terminal years were 2018, 2017, 2016, 2015, or 2014.

3.4 Parameters Estimated

The model estimated average fishing mortality rates for each fleet and annual F deviations, selectivity parameters, catchability coefficients associated with indices, parameters of the spawner-recruit model, annual recruitment deviations, CV of size at age, and Dirichlet-multinomial variance inflation factors for compositions. Not all of these parameters equate to statistical degrees of freedom, particularly the F parameters, which are constrained to match the landings and thus represent a computational convenience rather than freely estimated parameters.

3.5 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F, as were equilibrium landings and spawning biomass. Equilibrium landings and discards were also computed as functions of biomass B, which itself is a function of F. As in computation of MSY-related benchmarks (described in §3.6), per recruit and equilibrium analyses applied the most recent selectivity patterns averaged across fleets, weighted by each fleet's F from the last three years of the assessment (2017–2019).

3.6 Benchmark/Reference Point Methods

In this assessment of gag, the quantities F_{MSY}, $\mathrm{SSB}_{\mathrm{MSY}}$, B_{MSY}, and MSY were estimated by the method of Shepherd (1982). In that method, the point of maximum yield is identified from the spawner-recruit curve and parameters describing growth, natural mortality, maturity, and selectivity. The value of F_{MSY} is the F that maximizes equilibrium removals.

On average, expected recruitment is higher than that estimated directly from the spawner-recruit curve because of lognormal deviation in recruitment. Thus, in this assessment, the method of benchmark estimation accounted for lognormal deviation by including a bias correction in equilibrium recruitment. The bias correction (ς) was computed from the variance (σ_R^2) of recruitment deviations in log space: $\varsigma = \exp(\sigma_R^2/2)$. Then, equilibrium recruitment (R_{eq}) associated with any F is,

$$R_{eq} = \frac{R_0 \left[\varsigma 0.8h\Phi_F - 0.2(1-h)\right]}{(h-0.2)\Phi_F} \tag{2}$$

where R_0 is virgin recruitment, h is steepness, and $\Phi_F = \phi_F/\phi_0$ is spawning potential ratio given growth, maturity, and total mortality at age (including natural and fishing mortality rates). In this formulation, R_0 and h pertain to the median-unbiased Beverton-Holt curve. The R_{eq} and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of F_{MSY} is the F giving the highest ASY, and the estimate of MSY is that ASY. The estimate of $\mathrm{SSB}_{\mathrm{MSY}}$ follows from the corresponding equilibrium age structure, as does the estimate of discard mortalities (D_{MSY}), here separated from ASY (and consequently, MSY).

Estimates of MSY and related benchmarks are conditional on selectivity pattern. The selectivity pattern used here was an average of terminal-year selectivities from each fleet, where each fleet-specific selectivity was weighted in proportion to its corresponding estimate of F averaged over the last three years (2017–2019). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of MSY and related benchmarks.

The maximum fishing mortality threshold (MFMT) is set to F_{MSY}, and the minimum stock size threshold (MSST) is $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$. Overfishing is defined as $F > \mathrm{MFMT}$ and overfished as $\mathrm{SSB} < \mathrm{MSST}$. Current status of the stock is represented by SSB in the latest assessment year (2019), and current status of the fishery is represented by the geometric mean of F from the latest three years (2017–2019).

3.7 Uncertainty and Measures of Precision

For the base run of the catch-age model (BAM), uncertainty in results and precision of estimates was computed through an ensemble modeling approach (Scott et al. 2016; Jardim et al. 2021) using a mixed Monte Carlo and bootstrap framework (Efron and Tibshirani 1993; Manly 1997). Monte Carlo and bootstrap methods are often used to characterize uncertainty in ecological studies, and the mixed approach has been applied successfully in stock assessment (Restrepo et al. 1992; Legault et al. 2001; SEDAR4 2004; SEDAR19 2009; SEDAR24 2010). The approach is among those recommended for use in SEDAR assessments (SEDAR Procedural Guidance 2010).

The Monte Carlo/bootstrap ensemble (MCBE) approach translates uncertainty in model input into uncertainty in model output, by fitting the assessment model many times with different values of "observed" data and key input parameters. A chief advantage of the ensemble modeling approach is that the resulting ensemble model describes a range of possible outcomes, so that uncertainty is characterized more thoroughly than it could be by any single fit or handful of sensitivity runs. A minor disadvantage of the approach is that computational demands are relatively high, though parallel computing can somewhat mitigate those demands.

In this assessment, the BAM was successively re-fit in $n = 4370$ trials that differed from the original inputs by bootstrapping on data sources, and by Monte Carlo sampling of several key input parameters. The 4370 trials were based on a trim of the 5341 initial runs where only runs where $F_{\text{MSY}} < 3.0$, the maximum gradient < 0.1, and steepness < 0.99 were retained. The $n = 4370$ trials used to characterize uncertainty were sufficient for convergence of standard errors in management quantities.

The ensemble model should be interpreted as providing an approximation to the uncertainty associated with each output. The results are approximate as all runs are given equal weight in the results, yet some might fit the available data or represent stock characteristics better than others.

3.7.1 Bootstrap of observed data

To include uncertainty in time series of observed removals and indices of abundance, multiplicative lognormal errors were applied through a parametric bootstrap. To implement this approach in the MCBE trials, random variables ($x_{s,y}$) were drawn for each year y of time series s from a normal distribution with mean 0 and variance $\sigma^2_{s,y}$ [that is, $x_{s,y} \sim N(0, \sigma^2_{s,y})$]. Annual observations were then perturbed from their original values ($\hat{O}_{s,y}$),

$$O_{s,y} = \hat{O}_{s,y}[\exp(x_{s,y} - \sigma^2_{s,y}/2)] \tag{3}$$

The term $\sigma^2_{s,y}/2$ is a bias correction that centers the multiplicative error on the value of 1.0. Standard deviations in log space were computed from CVs in arithmetic space, $\sigma_{s,y} = \sqrt{\log(1.0 + CV^2_{s,y})}$. As used for fitting the base run, CVs of removals were assumed to be 0.05, and CVs of indices of abundance were those provided by, or modified from, the data providers (tabulated in Table 3 of this assessment report).

Uncertainty in age and length compositions were included by drawing new distributions for each year of each data source, following a multinomial sampling process. Ages (or lengths) of individual fish were drawn at random with replacement using the cell probabilities of the original data. For each year of each data source, the number of individuals sampled was the same as in the original data (number of fish) and the effective sample sizes used for fitting (number of trips) was unmodified.

3.7.2 Monte Carlo sampling

In each successive fit of the model, several parameters were fixed (i.e., not estimated) at values drawn at random from distributions described below.

Natural mortality A point estimate of natural mortality ($M = 0.15$) was given by the SEDAR-10 DW based on (Hoenig 1983), but with some uncertainty. To carry forward this source of uncertainty, Monte Carlo sampling was used to generate deviations from the point estimate. A new M value was drawn for each MCB trial from a uniform distribution [0.1, 0.2]. Each realized value of M was used to scale the age-specific Lorenzen curve, as in the base run.

Discard mortalities Uncertainty in discard mortality rates (δ) were included in the ensemble modeling based on the estimates and range of discard mortality reported in (Sauls 2014) and used in SEDAR-10. For the commercial fleet, values were drawn for each model run from a uniform distribution (range [0.3, 0.5]) with center equal to the point estimate ($\delta = 0.4$). For the recreational fleet, values were drawn from a uniform distribution (range [0.15, 0.35]) with center equal to the point estimate ($\delta = 0.25$).

Historical recreational landings In the current assessment, historical recreational landings (1962–1980) were estimated using the FHWAR method, an improvement over the method based on Saltwater Angler Surveys (SWAS) that was used in SEDAR-10. In the ensemble model runs, a scalar was applied to the historical (1962-1980) recreational time series, drawn from a uniform distribution spanning 75% to 125% of that used in the base run.

3.8 Projections

Projections were run to predict stock status in the 10 years after the assessment, 2020–2029.

The structure of the projection model was the same as that of the assessment model, and parameter estimates were those from the assessment. Any time-varying quantities, such as selectivities, were fixed to the most recent values of the assessment period. A single selectivity curve was applied to calculate landings, averaged across fleets using geometric mean Fs from the last three years of the assessment period, similar to computation of MSY benchmarks (§3.6).

Expected values of SSB (time of peak spawning), F, recruits, landings, and discards were represented by deterministic projections using parameter estimates from the base run. These projections were built on the estimated spawner-recruit relationship with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at F_{MSY} would yield MSY from a stock size at SSB_{MSY}. Uncertainty in future time series was quantified through stochastic projections that extended the ensemble model fits of the stock assessment model.

3.8.1 Initialization of projections

Although the terminal year of the assessment is 2019, the assessment model computes abundance at age (N_a) at the start of 2020. For projections, those estimates were used to initialize N_a. However, the assessment has no information to inform the strength of 2020 recruitment, and thus it computes 2020 recruits (N_1) as the expected value, that is, without deviation from the estimate of mean recruitment, and corrected to be unbiased in arithmetic space. In the stochastic projections, lognormal stochasticity was applied to these abundances after adjusting them to be unbiased in log space, with variability based on the estimate of σ_R. Thus, the initial abundance in year one (2020) of the projection period included this variability in N_1. The deterministic projections were not adjusted in this manner, because deterministic recruitment follows mean recruitment.

Fishing rates that define the projections were assumed to start in 2022, which is the earliest year management could react to this assessment. Because the assessment period ended in 2019, the projections required an interim period (2020–2021). Here, the interim period was modeled by applying L_{current}, the average landings over the last three years of the assessment (2017–2019).

3.8.2 Uncertainty of projections

To characterize uncertainty in future stock dynamics, stochasticity was included in replicate projections, each an extension of a single assessment fit from the ensemble modeling. Thus, projections carried forward uncertainties in natural mortality, discard mortality, and historical recreational removals, as well as in estimated quantities such as spawner-recruit parameters (h, R_0 and σ_R), selectivity curves, and in initial (start of 2020) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte Carlo procedure, in which the estimated recruitment of each model within the ensemble was used to compute mean annual recruitment values ($\bar{R}_y$). Variability was added to the mean values by choosing multiplicative deviations at random from a lognormal distribution,

$$R_y = \bar{R}_y \exp(\epsilon_y). \tag{4}$$

Here ϵ_y was drawn from a normal distribution with mean 0 and standard deviation σ_R, where σ_R is the standard deviation from the relevant ensemble model component.

The procedure generated 20,000 replicate projections of models within the ensemble drawn at random (with replacement). In cases where the same model run was drawn, projections would still differ as a result of stochasticity in projected recruitment streams. Central tendencies were represented by the deterministic projections of the base run, as well as by medians of the stochastic projections. Precision of projections was represented graphically by the 5^{th} and 95^{th} percentiles of the replicate projections.

Projection scenarios

For this assessment four projections scenarios were considered: $F = 0$ $F = F_{\text{current}}$, $F = F_{\text{MSY}}$, and $F = F_{\text{rebuild}}$. The landings in the interim period (2020–2021) were assumed to be $L_{\text{current}}$for all projections.

For the $F = F_{\text{rebuild}}$ projection, the rebuilding time frame was considered the generation time of gag plus 10 years. The generation time of gag was estimated as 11 years; therefore, the rebuilding time frame was set to 2040 (terminal year 2019 + 21 years). F_{rebuild} was defined as the maximum F that allows rebuilding by the end of the rebuilding time frame (2040), defined as 50% of replicate projections for which SSB has reached SSB_{MSY}.

- Scenario 1: $F = 0$
- Scenario 2: $F = F_{\text{current}}$, defined as the geometric mean F of 2017-2019
- Scenario 3: $F = F_{\text{MSY}}$
- Scenario 4: $F = F_{\text{rebuild}}$, defined as the maximum F that allows rebuilding by the recovery time horizon

4 Stock Assessment Results

4.1 Measures of Overall Model Fit

The Beaufort Assessment Model (BAM) fit well to the available data. Predicted age compositions from each fishery were reasonably close to observed data in most years, as were predicted length compositions (Figure 3). The model was configured to fit observed commercial and recreational landings closely (Figures 4–7), as well as observed discards (Figures 8–10). Fits to the headboat and SERFS video indices generally captured the observed trends but not annual fluctuations (Figure 11–12).

4.2 Parameter Estimates

Estimates of all parameters from the catch-age model are shown in Appendix B. Estimates of management quantities and some key parameters, such as those of the spawner-recruit model, are reported in sections below.

4.3 Stock Abundance and Recruitment

In general, estimated abundance at age showed truncation of the older ages mostly through the 1980s, a gradual decline in abundance through the 2000s, and a more precipitous decline beginning in the late 2000s (Figure 13; Table 6). Estimated abundance increased slightly toward the end of the time series, mostly due to higher estimated recruitment in 2016 and 2019 than has generally occurred over the last decade. Annual number of recruits is shown in Table 6 (age-1 column) and in Figure 14. The strongest estimated recruitment event (age-1 fish) occurred in 1982, with strong year classes occurring in 1996 and 2002. Recruitment was lower during the 2000s but near MSY levels, and then showed a strong decline beginning in 2010. Low recruitment in 2010 and 2011 was also noted in the 2014 update assessment (terminal year 2012). In the most recent decade, the strongest year classes were predicted to have occurred in 2016 and 2019 (the terminal year).

4.4 Total and Spawning Biomass

Estimated biomass at age followed a similar pattern as abundance at age (Figure 15; Table 7). Total biomass and spawning biomass showed similar trends—a general decline throughout the 1970s and 1980s, followed by a relatively stable period in the 1990s and early 2000s, and a more precipitous decline through the late 2000s to the end of the assessment period (Figure 16; Table 8). The decline in biomass since the mid-2000s is supported by the trends in abundance from the headboat index and the SERFS video index, which show a two- to three-fold decline in abundance over the last decade.

4.5 Selectivity

Selectivities of commercial and recreational landings are shown in Figures 17–18. Full selection occurred near age–6 for commercial fleets and near age–4 for recreational fleets. Selectivity of commercial and recreational discards are shown in Figures 19. Age-1 fish were the most prominent in the discards, with more age–2 occurring in the recent time period, though age classes up to age–6 were represented, as discards were assumed proportional to the probability that fish were below the size limit for a given age.

Average selectivities of landings and of discard mortalities were computed from F-weighted selectivities in the most recent period of regulations (Figure 20). These average selectivities were used to compute benchmarks and in projections.

Selectivity of the chevron trap and video survey are shown in Figure 21. All selectivities from the most recent period for each fleet and survey, including average selectivities, are tabulated in Table 9.

4.6 Fishing Mortality, Landings, and Discards

The estimated fishing mortality rates (F) generally increased through the 1970s, peaked in the 1980s, and then declined through the 1990s and early 2000s. (Figure 22). Since then fishing mortality rates have again increased and are similar to those in the 1980s, mostly due to the low abundance of gag at the end of the assessment period. In most years, the commercial handline fleet was the largest contributor to total F but the general recreational fleet has been an increasingly important contributor to fishing mortality, both from landings and from discards, particularly in the 2000s (Table 10).

Estimated landings have been dominated by the general recreational and commercial handline fisheries for most of the assessment period with relatively small contributions from the headboat and commercial dive fisheries (Figures 23, 24; Tables 11, 12). Over the last 20 years, nearly half or more of the landings have come from the general recreational sector. Estimated discard mortalities occurred on a smaller scale than landings, and the majority come from the general recreational fleet (Figures 25, 26; Tables 13, 14).

4.7 Spawner-Recruitment Parameters

The estimated Beverton–Holt spawner-recruit curve is shown in Figure 27, along with the effect of density dependence on recruitment, depicted graphically by recruits per spawner as a function of spawning stock (mt). Values of recruitment-related parameters were as follows: steepness $\widehat{h} = 0.898$ (estimated), unfished age-1 recruitment $\widehat{R_0} = 526309$, unfished spawners (mt) per recruit $\phi_0 = 0.0148$, and standard deviation of recruitment residuals in log space $\widehat{\sigma}_R = 0.44$ (which resulted in bias correction of $\varsigma = 1.10$). Uncertainty in these quantities was estimated through ensemble modeling (Figure 28).

4.8 Per Recruit and Equilibrium Analyses

Yield per recruit and spawning potential ratio were computed as functions of F (Figure 29). As in computation of MSY-related benchmarks, per recruit analyses applied the most recent selectivity patterns averaged across fisheries, weighted by F from the last three years (2017–2019).

As in per recruit analyses, equilibrium landings and spawning biomass were computed as functions of F (Figure 30). By definition, the F that maximizes equilibrium landings is F_{MSY}, and the corresponding landings and spawning biomass are MSY and SSB_{MSY}. Equilibrium landings and discards could also be viewed as functions of biomass B, which itself is a function of F (Figure 31).

4.9 Benchmarks / Reference Points

As described in §3.6, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics, corresponding to the expected spawner-recruit curve (Figure 27). Reference points estimated were F_{MSY}, MSY, B_{MSY} and SSB_{MSY}. Standard errors of benchmarks were approximated as those from ensemble modeling (§3.7).

Estimates (base run) of benchmarks and median values from ensemble modeling are summarized in Table 15. Point estimates of MSY-related quantities were $F_{\text{MSY}} = 0.37$ (y^{-1}), MSY = 1455.1 (1000 lb gutted), $B_{\text{MSY}} = 4278.4$ (mt), and $\text{SSB}_{\text{MSY}} = 1563.9$ (mt). Median estimates were $F_{\text{MSY}} = 0.35$ (y^{-1}), MSY = 1453.5 (1000 lb gutted), $B_{\text{MSY}} = 4368.7$ (mt), and $\text{SSB}_{\text{MSY}} = 1659.4$ (mt). Distributions of these benchmarks from the ensemble modeling are shown in Figure 32.

4.10 Status of the Stock and Fishery

Estimated time series of stock status (SSB/MSST) showed a general decline through the 1970s and 1980s, relatively stability near MSY levels from the mid-1980s to early 2000s, and then further decline to the end of the assessment period (Figure 33, Table 8). Base-run estimates of spawning biomass were generally above the threshold (MSST) during the 1990s and early 2000s and consistently below the threshold since 2008. Current stock status was estimated in the base run to be $\text{SSB}_{2019}/\text{MSST} = 0.20$ (Table 15), indicating that the stock is overfished in the terminal year. Median values from ensemble modeling indicated similar results ($\text{SSB}_{2019}/\text{MSST} = 0.19$). The uncertainty analysis suggested that the terminal estimate of stock status is robust (Figures 34, 35). Of the ensemble model runs, 100% indicated that the stock was below MSST in 2019. Age structure estimated by the base run indicated fewer older fish than the (equilibrium) age structure expected at MSY, a condition that has been persistent since the 1990s (Figure 36).

The estimated time series of F/F_{MSY} suggests that overfishing has occurred since the 1980s with the highest fishing mortality in the mid-1980s and in the most recent years (late 2010s) of the assessment period (Figure 33, Table 8). Current fishery status in the terminal year, with current F represented by the geometric mean from the period 2017–2019, was estimated by the base run to be $F_{2017-2019}/F_{\text{MSY}} = 2.15$, and the median value was $F_{2017-2019}/F_{\text{MSY}} = 2.27$ (Table 15). As with stock status, the estimate of fishery status was robust (Figures 34, 35). Of the ensemble model runs, 100% agreed with the base run that the stock is currently experiencing overfishing.

4.11 Comparison to previous assessment

Stock and fishery status estimated by the current assessment showed trends similar to those from the 2014 update but with some differences in magnitude (Figure 37). The current assessment estimated higher fishing mortality compared to SEDAR-10, especially during the 1980s to early 2000s. The current assessment also estimated higher spawning biomass in the earlier years (1980s), but similar spawning biomass in the 1990s and 2000s. In this assessment, updated and recalibrated MRIP estimates of general recreational landings and discards were used. Those estimates are several times higher per year than the estimates used in SEDAR-10, and are the result of an improvement in the estimation of recreational effort (for details of how the MRIP is an improvement of MRFSS, see https://www.fisheries.noaa.gov/recreational-fishing-data/how-marine-recreational-information-program-has-improved). Even so, the status benchmarks remain on similar scales (Figure 37). Natural mortality estimates and the maturity ogive also differ between SEDAR-10 and the current assessment, and likely contribute to the model estimating a more productive stock.

4.12 Sensitivity Analyses

Sensitivity runs, described in §3.3, were used for exploring data or model issues that arose during the assessment process, for evaluating implications of assumptions in the base assessment model, and for interpreting ensemble model results in terms of expected effects of input parameters. Sensitivity runs are simply a tool for better understanding model behavior, and therefore should not be used as the basis for management. All runs are not equally plausible and do not necessarily reflect alternative states of nature. Many of the sensitivity runs described in §3.3 were designed to evaluate the effects of changes made since the 2014 update.

None of the sensitivity runs investigated here altered the terminal biomass or fishery status (Figures 38–49). Time series of F/F_{MSY} and $\text{SSB}/\text{SSB}_{\text{MSY}}$ demonstrate the model was most sensitive to steepness (Figure 38), natural mortality (Figure 45, 46), and the life history parameters (growth, maturity, natural mortality; Figure 47). The model was relatively insensitive to the combination of indices included, truncation of the headboat index in 2009 (due to potential effects of the red snapper moratorium), index weighting, or whether index catchabilities were modeled in separate time blocks or as a random walk (Figures 39–41). Similarly, the initialization (Figure 42), alternative discard mortality rates (Figure 43), selectivity blocking (Figure 44), and the measure of reproductive potential (i.e., total mature biomass or female egg production; Figure 48) had little effect on the status indicators. All of the sensitivities agreed with the status indicated by the base run that the population is overfished and that overfishing is occurring (Figure 49, Table 16).

Retrospective analyses suggested some overestimation of F and of recruitment in some of the years (Figure 50). Steepness was estimated at increasingly higher values, but within a relatively narrow range ($h = 0.9 - 0.99$) for earlier terminal years. Terminal year status did not change across retrospective runs (Figure 51).

4.13 Projections

Projection results for gag are shown in Figures 52–59 and Tables 17–20. Gag, are not projected to rebuild (SSB > $\mathrm{SSB_{MSY}}$) by 2029 under any of the projection scenarios that were considered unless $F = 0$. Under $F = 0$, rebuilding is projected to occur by 2027. F_{rebuild} was estimated as $F = 0.33$, about 89% of F_{MSY}. F_{rebuild} is the fishing rate where the probability that SSB > $\mathrm{SSB_{MSY}}$ reaches 50% in 2040.

5 Discussion

5.1 Comments on the Assessment

Estimated benchmarks played a central role in this assessment. Values of $\mathrm{SSB_{MSY}}$ and F_{MSY} were used to gauge the status of the stock and fishery. Computation of benchmarks was conditional on selectivity, and if selectivity patterns change again in the future, for example as a result of new size limits or different relative catch allocations among sectors, estimates of benchmarks would likely change as well.

The base run of the BAM indicated that the stock is overfished ($\mathrm{SSB_{2019}/MSST} = 0.20$), and that overfishing is occurring ($F_{2017-2019}/F_{\mathrm{MSY}} = 2.15$). The ensemble model indicated that the stock status is most likely below MSST with 100% of the runs indicating the stock is overfished. Similarly, 100% of the ensemble model runs indicate that the stock is experiencing overfishing. The population abundance and spawning biomass have been at their lowest level since the 1980s, due in part to low estimated recruitment over the last decade. The decline in abundance over the last decade is supported by both the fishery dependent headboat index and the fishery independent SERFS video index, which have show two- to three-fold declines over this period. Likewise, landings have declined to their lowest observed levels in recent years.

In addition to including the more recent years of data, this operational assessment contained several modifications to the data of SEDAR-10, as well as to the BAM implementation. The main modifications, as described throughout this report, were the following:

- The recreational landings and discards were based on the MRIP re-calibrated data which increased the recreational removals relative to SEDAR-10.
- Length compositions were excluded except for those from headboat-at-sea discards and a few years of headboat landings.
- A SERFS video index was included.
- The commercial handline index was removed due to conflicts with other data sources.

- Steepness was estimated at $h = 0.898$ rather than fixed at $h = 0.84$.
- Selectivity blocks around size-limit regulations were removed for the commercial fleet and reduced for the recreational fleets.
- Age and length compositions were fitted using the Dirichlet-multinomial distribution.
- Reproductive parameters (growth, age at maturity, natural mortality) were updated with more recent data.

The fishery independent video index is a promising approach to track the abundance of gag. In general, fishery dependent indices may not track actual abundance well because of factors such as hyperstability and regulatory changes such as fishery closures. As such management measures become more common in the southeast U.S., the utility of fishery dependent indices for tracking population abundance may decline, highlighting the importance of fishery independent sampling. The utility of the SERFS video index for future assessment could be improved if length information of observed fish were available to inform the selectivity of the index. As in past SEDAR assessment, selectivity of the video index index was informed by the age compositions of fish captured in the chevron trap, which may differ from those observed on video.

This assessment highlighted the need for continued and increased age sampling. Sufficient age composition data is critical for characterizing year class strength and for informing selectivity patterns of various fishing fleets. Length composition data have less utility in this regard due to the typically large variation in length-at-age for many southeast U.S. species; this was particularly true for gag. The lack of long-term age composition data made estimating changes in selectivity due to size limit regulations difficult. The size limits for gag implemented in 1992 and 1999 appeared to have little or no effect on the length distributions of fish in the landings. However, sufficient data to estimate selectivity during the earliest years was not available, and so the composition of early removals and discards is uncertain.

The assessment accounted for the protogyny of gag implicitly by measuring spawning stock as the sum of male and female mature biomass, as recommended by Brooks et al. (2008). Accounting for protogynous sex change is important for stock assessments (Alonzo et al. 2008), and the approach taken here has the advantage of being tractable. However, it ignores possible dynamics of sexual transition, which may be quite complex (e.g., density dependent, mating-system dependent, occurring at local spatial scales). In addition, a protogynous life history accompanied by size- or age-selective harvest places disproportionate fishing pressure on males. This situation creates the possibility for population growth to become limited by the proportion of males. When this occurs, accounting for male (sperm) limitation may be important to the stock assessment (Alonzo and Mangel 2004; Brooks et al. 2008); however, in practice there is typically little or no information available to quantify sperm limitation.

5.2 Comments on the Projections

As usual, projections should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5–10 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.

- Fisheries were assumed to continue fishing at their estimated current proportions of total effort, using the estimated current selectivity patterns. New management regulations that alter those proportions or selectivities would likely affect projection results.
- The projections assumed that the estimated spawner-recruit relationship applies in the future and that past residuals represent future uncertainty in recruitment. If future recruitment is characterized by runs of large or small year classes, possibly due to environmental or ecological conditions, stock trajectories may be affected.
- Projections apply the Baranov catch equation to relate F and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures are in effect, introducing additional and unquantified uncertainty into the projection results.

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7 Tables

Table 1. Life-history characteristics, including average body length and whole weight (mid-year), proportion females mature (all males assumed mature), proportion female, and natural mortality at age. The CV of length at age was estimated by the assessment model; other values were treated as input.

Age	Total length (mm)	Total length (in)	CV length	Whole weight (kg)	Whole weight (lb)	Female maturity	Proportion female	Natural mortality
1	412.2	16.2	0.17	0.91	2.00	0.07	1.00	0.415
2	528.1	20.8	0.17	1.88	4.14	0.10	1.00	0.332
3	626.0	24.6	0.17	3.10	6.84	0.15	1.00	0.285
4	708.8	27.9	0.17	4.47	9.85	0.29	0.99	0.255
5	778.8	30.7	0.17	5.90	13.00	0.63	0.99	0.234
6	837.9	33.0	0.17	7.31	16.12	0.82	0.97	0.220
7	887.9	35.0	0.17	8.67	19.12	0.89	0.94	0.208
8	930.2	36.6	0.17	9.95	21.93	0.92	0.88	0.200
9	965.9	38.0	0.17	11.11	24.50	0.94	0.77	0.193
10	996.2	39.2	0.17	12.17	26.82	0.95	0.61	0.188
11	1021.7	40.2	0.17	13.11	28.90	0.96	0.41	0.184
12	1043.3	41.1	0.17	13.94	30.73	0.96	0.24	0.180
13	1061.5	41.8	0.17	14.67	32.34	0.97	0.13	0.178
14	1077.0	42.4	0.17	15.31	33.74	0.97	0.06	0.175
15	1090.0	42.9	0.17	15.86	34.96	0.97	0.03	0.173
16	1101.0	43.3	0.17	16.33	36.01	0.98	0.01	0.172

Table 2. Observed time series of landings (L) and dead discards (D) for commercial handlines (L.cH.ob), commercial diving (L.cD.ob), recreational headboat (L.HB.ob), and general recreational (L.GR.ob). Commercial landings are in units of 1000 lb gutted weight. Recreational landings and all dead discards are in units of 1000 fish.

Year	L.cH.ob	L.cD.ob	L.HB.ob	L.GR.ob	D.cH.ob	D.HB.ob	D.GR.ob
1962	150.34	.	8.41	6.32	.	.	.
1963	136.98	.	7.66	5.75	.	.	.
1964	128.39	.	7.18	5.40	.	.	.
1965	130.40	.	7.41	5.57	.	.	.
1966	99.11	.	5.58	4.19	.	.	.
1967	210.93	.	11.77	8.83	.	.	.
1968	309.92	.	17.72	13.29	.	.	.
1969	217.17	.	12.13	9.10	.	.	.
1970	299.03	.	16.66	12.49	.	.	.
1971	306.72	.	17.18	12.89	.	.	.
1972	204.48	.	13.44	8.57	.	.	.
1973	290.49	.	17.99	12.44	.	.	.
1974	372.77	.	13.92	16.05	.	.	.
1975	421.77	.	8.57	17.90	.	.	.
1976	565.04	3.75	7.56	24.34	.	.	.
1977	627.57	8.81	8.48	22.46	.	.	.
1978	967.40	13.87	6.01	38.43	.	.	.
1979	907.55	18.92	9.55	36.55	.	.	.
1980	846.15	16.40	6.96	36.23	.	.	.
1981	983.99	13.88	13.91	215.49	.	0.135	7.440
1982	1027.43	15.85	11.84	101.54	.	0.148	3.490
1983	1101.10	9.08	16.46	49.85	.	4.065	35.905
1984	1108.19	18.75	18.69	445.92	.	0.298	27.520
1985	865.72	11.62	16.13	78.36	.	0.150	4.765
1986	819.84	6.34	17.35	59.48	.	0.850	10.443
1987	857.78	21.93	24.09	123.52	.	1.522	27.465
1988	672.39	12.96	24.21	72.77	.	0.485	5.390
1989	967.01	22.26	22.42	178.14	.	0.838	29.690
1990	784.30	19.07	17.59	78.11	.	2.232	22.148
1991	656.43	85.01	13.55	76.66	.	1.600	19.503
1992	691.66	106.76	13.94	61.31	.	1.090	17.637
1993	756.63	78.15	11.80	81.05	.	0.628	15.800
1994	800.03	97.50	9.81	93.17	.	1.032	38.017
1995	840.43	83.77	10.54	55.52	.	2.872	60.750
1996	751.90	118.56	7.50	91.75	.	0.775	39.828
1997	608.22	98.71	6.85	47.89	.	3.147	69.590
1998	654.46	138.79	8.67	101.23	.	0.762	36.380
1999	538.08	113.49	5.34	82.42	2.980	1.238	64.275
2000	438.23	63.02	5.98	58.58	3.160	3.188	111.168
2001	450.08	82.30	5.12	105.76	5.456	0.725	53.517
2002	448.33	84.52	4.58	67.72	4.640	1.340	98.625
2003	443.90	117.41	3.27	89.24	2.056	1.317	157.137
2004	476.39	74.97	7.61	100.72	3.060	1.555	80.330
2005	573.44	53.60	8.05	55.90	3.264	1.670	89.945
2006	486.70	57.84	4.60	80.59	1.216	0.935	100.448
2007	560.80	73.02	6.70	77.72	1.236	0.882	145.955
2008	425.89	57.36	3.06	102.91	1.488	1.157	126.373
2009	396.19	64.64	3.00	72.46	1.396	2.085	98.132
2010	340.25	95.30	3.28	40.91	1.120	1.210	71.250
2011	361.84	70.68	2.63	34.32	1.356	0.965	50.462
2012	294.93	71.30	2.10	36.69	1.508	1.298	93.525
2013	349.01	51.55	1.38	19.54	2.016	0.495	38.983
2014	341.71	34.49	1.04	36.77	2.220	0.342	67.585
2015	270.25	50.63	0.87	19.85	1.316	0.282	42.000
2016	209.90	54.49	0.64	25.40	1.284	0.245	18.090
2017	190.89	46.06	0.64	28.63	0.956	0.172	9.738
2018	220.70	46.92	0.79	24.91	1.660	0.180	13.240
2019	275.30	37.06	0.46	21.72	1.792	0.120	6.027

Table 3. Observed indices of abundance and CVs from recreational headboat (U.HB.ob) and SERFS video (U.VID.ob).

Year	U.HB.ob	cv.U.HB	U.VID.ob	cv.U.VID
1980	1.63	0.22	.	.
1981	1.41	0.22	.	.
1982	1.70	0.22	.	.
1983	1.72	0.22	.	.
1984	1.54	0.22	.	.
1985	1.40	0.22	.	.
1986	1.38	0.22	.	.
1987	1.55	0.22	.	.
1988	1.75	0.22	.	.
1989	1.65	0.22	.	.
1990	1.52	0.22	.	.
1991	1.28	0.22	.	.
1992	1.27	0.22	.	.
1993	1.06	0.22	.	.
1994	1.14	0.22	.	.
1995	1.00	0.22	.	.
1996	1.03	0.22	.	.
1997	1.17	0.22	.	.
1998	1.35	0.22	.	.
1999	1.02	0.22	.	.
2000	0.84	0.22	.	.
2001	0.77	0.22	.	.
2002	0.72	0.22	.	.
2003	0.76	0.22	.	.
2004	1.01	0.22	.	.
2005	1.07	0.22	.	.
2006	0.71	0.22	.	.
2007	0.99	0.22	.	.
2008	0.68	0.22	.	.
2009	0.74	0.22	.	.
2010	0.99	0.22	.	.
2011	0.85	0.22	0.80	0.62
2012	0.59	0.22	1.61	0.40
2013	0.40	0.22	1.78	0.42
2014	0.31	0.22	1.25	0.33
2015	0.23	0.22	1.06	0.35
2016	0.20	0.22	0.45	0.38
2017	0.18	0.22	0.67	0.35
2018	0.20	0.22	0.71	0.40
2019	0.18	0.22	0.68	0.40

Table 4. Sample sizes (number fish) of length compositions (lcomp) or age compositions (acomp) by survey or fleet. Data sources are Headboat (HB), headboat discards (HB.D), commercial handlines (cH), and commercial diving (cD).

Year	lcomp.HB.nfish	lcomp.HB.D.nfish	acomp.cH.nfish	acomp.cD.nfish	acomp.HB.nfish
1980	.	.	.	.	71
1981	.	.	.	.	166
1982	.	.	.	.	69
1983	.	.	.	.	290
1984	.	.	.	.	340
1985	.	.	.	.	180
1986	.	.	.	.	135
1987	.	.	.	.	41
1988	541	.	.	.	.
1989	471	.	.	.	.
1990	.	.	.	.	22
1991	.	.	.	.	28
1992	.	.	.	.	32
1993	.	.	.	.	16
1994	.	.	.	.	71
1995	.	.	.	.	111
1996	222	.	.	.	.
1997	199	.	58	.	.
1998	367	.	.	.	.
1999	274	.	56	.	.
2000	197	.	36	.	.
2001	.	.	115	.	21
2002	.	.	53	.	47
2003	.	.	45	.	85
2004	.	.	310	.	41
2005	.	127	441	.	114
2006	.	49	867	.	82
2007	.	65	1381	.	99
2008	.	90	1090	.	25
2009	.	98	681	35	75
2010	.	43	967	143	106
2011	.	42	1014	106	38
2012	.	73	996	.	71
2013	.	44	729	62	100
2014	.	.	593	166	59
2015	.	.	489	66	43
2016	.	.	381	127	43
2017	.	.	287	66	38
2018	.	.	555	85	65
2019	.	.	327	38	20

Table 5. Sample sizes (number trips) of length compositions (lcomp) or age compositions (acomp) by fleet. Data sources are headboat (HB), headboat discards (HB.D) commercial handlines (cH), and commercial diving (cD).

Year	lcomp.HB.n	lcomp.HB.D.n	acomp.cH.n	acomp.cD.n	acomp.HB.n
1980	.	.	.	.	44
1981	.	.	.	.	99
1982	.	.	.	.	44
1983	.	.	.	.	145
1984	.	.	.	.	147
1985	.	.	.	.	106
1986	.	.	.	.	86
1987	.	.	.	.	25
1988	255	.	.	.	.
1989	202	.	.	.	.
1990	.	.	.	.	14
1991	.	.	.	.	23
1992	.	.	.	.	20
1993	.	.	.	.	13
1994	.	.	.	.	24
1995	.	.	.	.	29
1996	123	.	.	.	.
1997	138	.	11	.	.
1998	211	.	.	.	.
1999	149	.	18	.	.
2000	118	.	16	.	.
2001	.	.	20	.	11
2002	.	.	15	.	37
2003	.	.	13	.	52
2004	.	.	42	.	28
2005	.	61	101	.	75
2006	.	28	225	.	55
2007	.	39	343	.	56
2008	.	44	316	.	21
2009	.	40	244	16	53
2010	.	29	235	22	63
2011	.	35	262	25	31
2012	.	45	212	.	43
2013	.	35	169	20	68
2014	.	.	155	33	35
2015	.	.	120	18	32
2016	.	.	106	22	34
2017	.	.	88	18	33
2018	.	.	150	27	39
2019	.	.	96	13	18

Table 6. Estimated total abundance at age (1000 fish) at start of year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1962	576.58	379.67	269.76	199.64	151.53	116.73	90.86	71.51	56.72	45.30	36.36	29.31	23.71	19.23	15.64	69.11	2151.65
1963	576.58	380.00	270.56	200.61	152.48	117.68	91.70	72.19	57.27	45.74	36.72	29.59	23.94	19.41	15.79	69.78	2160.03
1964	576.80	380.07	270.96	201.42	153.44	118.64	92.64	73.02	57.94	46.28	37.15	29.94	24.23	19.64	15.97	70.60	2168.73
1965	577.00	380.26	271.13	201.86	154.20	119.52	93.52	73.87	58.68	46.89	37.64	30.33	24.55	19.90	16.18	71.53	2177.06
1966	577.19	380.37	271.23	201.94	154.49	120.08	94.19	74.55	59.35	47.47	38.12	30.73	24.86	20.16	16.39	72.46	2183.58
1967	577.38	380.66	271.71	202.50	155.03	120.80	95.06	75.43	60.17	48.24	38.78	31.27	25.30	20.52	16.68	73.74	2193.29
1968	577.52	380.26	270.59	201.25	153.87	119.61	94.19	74.95	59.94	48.15	38.79	31.31	25.35	20.55	16.71	73.88	2186.91
1969	577.39	379.83	269.00	198.85	151.39	117.19	91.92	73.16	58.66	47.24	38.14	30.85	25.00	20.28	16.49	72.90	2168.29
1970	577.14	380.21	269.88	199.10	150.95	116.64	91.24	72.36	58.04	46.87	37.93	30.75	24.97	20.28	16.50	72.92	2165.78
1971	577.00	379.65	269.14	198.53	149.94	115.11	89.77	70.97	56.72	45.81	37.18	30.21	24.58	20.01	16.29	72.06	2152.98
1972	576.71	379.49	268.60	197.82	149.34	114.17	88.44	69.69	55.53	44.69	36.27	29.56	24.11	19.66	16.05	71.07	2141.20
1973	576.50	379.71	269.50	198.64	150.04	114.99	88.85	69.58	55.27	44.34	35.86	29.23	23.91	19.54	15.99	71.03	2142.97
1974	576.39	379.14	268.57	198.01	149.39	114.26	88.37	69.00	54.46	43.56	35.12	28.52	23.34	19.13	15.68	70.02	2132.97
1975	576.12	379.07	268.17	197.26	148.65	113.28	87.30	68.21	53.67	42.65	34.28	27.75	22.63	18.55	15.25	68.53	2121.37
1976	550.03	379.05	268.51	197.35	148.27	112.67	86.43	67.28	52.96	41.96	33.52	27.05	21.98	17.96	14.77	66.89	2086.68
1977	272.99	361.58	267.70	196.57	147.09	110.89	84.59	65.49	51.36	40.72	32.43	26.00	21.07	17.16	14.06	64.11	1773.83
1978	554.89	179.44	255.25	195.76	146.08	109.38	82.66	63.61	49.62	39.19	31.24	24.98	20.11	16.33	13.34	60.95	1842.84
1979	684.42	363.79	125.51	183.70	141.94	104.65	77.97	59.33	45.99	36.14	28.70	22.97	18.44	14.88	12.12	55.29	1975.84
1980	549.64	448.48	254.01	90.07	132.71	101.24	74.25	55.70	42.69	33.34	26.34	21.01	16.89	13.59	11.00	49.97	1920.92
1981	517.61	360.36	313.72	182.79	65.25	94.89	71.98	53.15	40.17	31.02	24.36	19.33	15.48	12.47	10.07	45.29	1857.95
1982	1039.27	322.90	224.12	188.42	108.07	37.49	53.77	40.98	30.47	23.19	18.01	14.21	11.32	9.09	7.34	32.68	2161.34
1983	330.30	669.08	214.89	148.83	123.15	67.73	22.98	33.04	25.34	18.98	14.53	11.34	8.98	7.17	5.78	25.51	1727.64
1984	332.23	190.93	452.15	148.88	101.42	79.58	42.51	14.43	20.86	16.11	12.13	9.33	7.31	5.80	4.65	20.33	1458.64
1985	753.67	176.62	90.69	180.05	54.50	33.75	25.18	13.38	4.56	6.65	5.17	3.91	3.02	2.37	1.89	8.16	1363.58
1986	854.76	477.83	112.72	55.88	103.94	27.96	16.20	11.97	6.38	2.19	3.22	2.51	1.91	1.48	1.16	4.94	1685.05
1987	668.11	543.40	315.52	73.18	33.87	55.23	13.78	7.88	5.84	3.14	1.08	1.60	1.25	0.95	0.74	3.07	1728.64
1988	700.48	404.71	339.71	188.02	39.33	15.21	22.41	5.48	3.15	2.35	1.27	0.44	0.66	0.52	0.39	1.58	1725.71
1989	616.10	447.68	267.03	219.85	113.16	20.63	7.38	10.73	2.64	1.52	1.15	0.62	0.22	0.32	0.25	0.98	1710.28
1990	805.26	366.24	269.32	150.21	111.18	47.87	7.89	2.77	4.04	1.00	0.58	0.44	0.24	0.08	0.13	0.48	1767.72
1991	842.01	501.29	240.58	174.11	90.80	59.12	23.67	3.86	1.36	2.00	0.50	0.29	0.22	0.12	0.04	0.31	1940.25
1992	493.46	529.65	333.93	159.29	109.52	51.75	32.00	12.77	2.10	0.75	1.11	0.28	0.16	0.13	0.07	0.20	1727.17
1993	411.53	312.29	369.69	220.86	97.95	61.26	27.59	17.02	6.86	1.14	0.41	0.62	0.16	0.09	0.07	0.15	1527.71
1994	595.37	259.50	217.41	241.38	134.04	54.33	32.43	14.56	9.06	3.70	0.62	0.23	0.34	0.09	0.05	0.12	1563.22
1995	709.94	362.98	179.03	137.91	141.05	71.53	27.68	16.48	7.47	4.71	1.94	0.33	0.12	0.18	0.05	0.09	1661.49
1996	943.84	420.58	251.07	117.84	84.54	78.75	38.02	14.66	8.81	4.04	2.57	1.07	0.18	0.07	0.10	0.08	1966.21
1997	581.73	591.13	290.23	156.28	66.74	43.36	38.43	18.52	7.22	4.40	2.05	1.32	0.55	0.09	0.03	0.09	1802.18
1998	445.73	333.22	409.10	196.38	99.97	39.38	24.57	21.79	10.61	4.20	2.59	1.22	0.79	0.33	0.06	0.08	1590.02
1999	565.53	267.30	229.63	260.72	115.48	53.86	20.34	12.70	11.40	5.65	2.27	1.41	0.67	0.43	0.18	0.07	1547.66
2000	575.08	336.62	173.04	147.01	159.82	66.96	30.41	11.54	7.28	6.63	3.32	1.35	0.85	0.40	0.26	0.16	1520.73
2001	595.98	319.74	207.60	112.06	94.25	99.66	41.20	18.83	7.21	4.60	4.23	2.13	0.87	0.55	0.26	0.27	1509.45
2002	848.80	361.35	207.99	125.80	64.30	51.99	54.05	22.47	10.38	4.02	2.59	2.40	1.22	0.50	0.31	0.31	1758.49
2003	608.84	500.35	232.10	132.56	77.32	37.81	29.96	31.31	13.16	6.16	2.41	1.57	1.46	0.74	0.30	0.38	1676.46
2004	484.49	329.29	299.04	140.39	77.00	42.71	20.42	16.29	17.25	7.37	3.50	1.39	0.91	0.85	0.43	0.40	1441.72
2005	420.90	279.59	206.24	179.74	79.66	41.25	22.25	10.68	8.60	9.23	3.99	1.91	0.76	0.50	0.47	0.46	1266.24
2006	540.59	232.74	171.13	130.75	109.92	45.61	22.79	12.30	5.95	4.85	5.26	2.29	1.10	0.44	0.29	0.54	1286.55
2007	583.92	299.52	141.48	102.98	75.07	59.72	24.09	12.07	6.58	3.22	2.65	2.89	1.27	0.61	0.25	0.47	1316.80
2008	477.78	305.47	173.15	81.15	55.37	37.28	28.46	11.48	5.81	3.21	1.59	1.32	1.45	0.64	0.31	0.36	1184.83
2009	425.20	250.56	174.60	91.55	39.21	24.73	16.00	12.22	4.98	2.56	1.43	0.72	0.60	0.66	0.29	0.31	1045.61
2010	256.00	228.81	147.50	98.49	47.30	18.32	10.98	7.09	5.48	2.27	1.18	0.67	0.34	0.28	0.31	0.28	825.30
2011	254.95	137.74	136.48	90.31	56.50	24.53	9.05	5.43	3.56	2.82	1.19	0.63	0.36	0.18	0.15	0.32	724.21
2012	268.94	141.64	84.46	85.66	53.37	30.27	12.50	4.61	2.80	1.87	1.50	0.64	0.34	0.20	0.10	0.26	689.16
2013	221.58	127.52	76.55	50.03	49.09	28.48	15.58	6.46	2.41	1.49	1.01	0.82	0.35	0.19	0.11	0.20	581.90
2014	168.84	124.96	79.46	49.55	30.76	27.41	15.12	8.26	3.46	1.31	0.82	0.56	0.46	0.20	0.11	0.18	511.47
2015	157.49	79.30	66.50	44.73	26.23	14.71	12.39	6.81	3.75	1.59	0.61	0.39	0.27	0.22	0.10	0.14	415.23
2016	273.63	81.15	45.80	40.65	25.68	13.45	7.11	5.98	3.33	1.87	0.81	0.31	0.20	0.14	0.11	0.12	500.34
2017	102.14	167.94	53.15	27.40	21.81	12.21	6.03	3.19	2.72	1.55	0.89	0.39	0.15	0.10	0.07	0.12	399.85
2018	107.19	63.65	110.60	30.70	13.85	9.58	5.01	2.47	1.33	1.16	0.68	0.39	0.18	0.07	0.04	0.08	346.97
2019	283.49	63.57	40.58	65.59	15.70	5.81	3.63	1.88	0.94	0.52	0.47	0.28	0.16	0.07	0.03	0.05	482.78
2020	305.17	181.25	42.82	24.04	32.03	5.91	1.90	1.16	0.61	0.31	0.18	0.16	0.10	0.06	0.03	0.03	595.75

Table 7. Estimated biomass at age (1000 lb, whole weight) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1962	1152.58	1573.00	1843.95	1966.74	1969.39	1881.87	1737.24	1567.93	1389.57	1215.19	1050.72	900.59	766.99	648.82	546.53	2488.80	22699.90
1963	1152.58	1574.32	1849.24	1976.22	1981.74	1897.30	1753.34	1582.92	1403.02	1226.87	1060.87	909.41	774.26	654.99	551.82	2512.61	22861.94
1964	1153.02	1574.76	1852.10	1984.38	1994.08	1912.73	1771.41	1601.00	1419.34	1241.20	1073.43	919.99	783.52	662.71	558.43	2542.37	23044.48
1965	1153.46	1575.42	1853.21	1988.57	2004.00	1926.84	1788.17	1619.52	1437.63	1257.52	1087.76	932.34	793.88	671.53	565.71	2576.10	23231.66
1966	1153.90	1575.87	1853.87	1989.45	2007.97	1935.88	1800.96	1634.51	1453.95	1273.39	1101.65	944.24	804.03	680.13	573.20	2609.39	23392.15
1967	1154.12	1577.19	1857.17	1994.96	2015.03	1947.34	1817.71	1653.91	1474.23	1293.89	1120.83	961.00	818.36	692.25	583.34	2655.47	23616.58
1968	1154.56	1575.42	1849.46	1982.62	1999.81	1928.16	1800.96	1643.33	1468.50	1291.47	1121.05	962.32	819.68	693.57	584.23	2660.32	23535.45
1969	1154.12	1573.66	1838.66	1959.03	1967.63	1889.36	1757.53	1604.08	1437.19	1267.22	1102.09	948.21	808.66	684.32	576.51	2625.26	23193.29
1970	1153.68	1575.20	1844.61	1961.45	1961.89	1880.54	1744.74	1586.67	1421.98	1257.08	1096.14	944.90	807.55	684.32	576.73	2625.93	23123.41
1971	1153.46	1573.00	1839.76	1955.72	1948.67	1855.85	1716.30	1556.02	1389.57	1228.86	1074.31	928.37	794.99	675.06	569.67	2595.06	22854.89
1972	1152.80	1572.34	1836.01	1948.67	1940.95	1840.64	1690.95	1528.02	1360.25	1198.65	1048.30	908.30	779.77	663.37	561.08	2559.35	22589.67
1973	1152.36	1573.22	1841.96	1956.82	1949.99	1853.87	1698.88	1525.60	1353.86	1189.39	1036.39	898.16	773.16	659.40	558.87	2557.80	22580.19
1974	1152.14	1570.79	1835.79	1950.65	1941.61	1842.18	1689.62	1513.03	1334.24	1168.23	1014.79	876.34	754.64	645.51	548.29	2521.65	22359.95
1975	1151.69	1570.57	1832.92	1943.15	1931.91	1826.31	1669.12	1495.62	1314.84	1143.98	990.76	852.97	731.71	626.11	533.30	2468.07	22082.83
1976	1099.44	1570.35	1835.35	1944.26	1927.06	1816.39	1652.59	1475.11	1297.64	1125.68	968.49	831.14	710.99	606.05	516.32	2408.77	21785.64
1977	545.64	1498.04	1829.84	1936.54	1911.63	1787.73	1617.53	1436.09	1258.40	1092.17	936.97	799.18	681.45	579.15	491.63	2308.90	20710.67
1978	1109.15	743.40	1744.74	1928.38	1898.62	1763.48	1580.49	1394.87	1215.63	1051.38	902.57	767.65	650.58	551.16	466.50	2194.70	19963.08
1979	1368.19	1507.30	857.82	1809.56	1844.83	1687.20	1490.99	1300.73	1126.78	969.15	829.16	705.92	596.57	502.21	423.73	1990.99	19011.13
1980	1098.78	1858.06	1736.14	887.36	1724.68	1632.08	1419.56	1221.14	1045.87	894.42	761.26	645.73	546.31	458.56	384.49	1799.41	18114.28
1981	1034.63	1492.97	2144.44	1800.74	848.12	1529.79	1376.35	1165.36	983.92	832.02	703.94	594.15	500.67	420.86	351.86	1630.98	17410.79
1982	2077.64	1337.77	1531.99	1856.29	1404.57	604.29	1028.24	898.60	746.49	622.14	520.29	436.51	366.19	306.66	256.62	1176.83	15170.89
1983	660.28	2772.09	1468.94	1466.30	1600.56	1091.95	439.38	724.44	620.82	509.27	419.98	348.33	290.35	242.07	201.94	918.67	13775.15
1984	664.03	791.02	3090.44	1466.74	1318.14	1282.87	812.62	316.36	511.03	432.11	350.54	286.82	236.34	195.77	162.48	732.15	12649.69
1985	1506.64	731.71	619.94	1773.84	708.35	544.10	481.49	293.44	111.77	178.35	149.47	120.15	97.67	80.03	66.14	293.66	7756.75
1986	1708.58	1979.75	770.52	550.49	1350.77	450.62	309.75	262.35	156.31	58.86	93.03	77.16	61.73	49.82	40.79	177.91	8098.90
1987	1335.56	2251.36	2156.78	720.91	440.26	890.45	263.45	172.84	143.08	84.22	31.31	49.16	40.56	32.19	25.79	110.45	8748.39
1988	1400.38	1676.84	2321.91	1852.32	511.25	245.15	428.36	120.15	77.16	63.05	36.82	13.67	21.16	17.42	13.67	56.88	8856.19
1989	1231.50	1854.75	1825.21	2165.82	1470.70	332.68	141.10	235.23	64.59	41.01	33.07	19.18	7.05	10.80	8.82	35.27	9477.23
1990	1609.82	1517.44	1840.86	1479.74	1444.91	771.62	150.80	60.63	98.77	26.90	16.75	13.45	7.72	2.87	4.41	17.20	9064.09
1991	1683.23	2076.97	1644.43	1715.20	1180.13	953.06	452.61	84.66	33.29	53.57	14.33	9.04	7.05	4.19	1.54	11.02	9923.89
1992	986.35	2194.48	2282.45	1569.25	1423.53	834.23	611.78	279.99	51.37	20.06	32.19	8.60	5.29	4.19	2.42	7.28	10313.45
1993	822.54	1293.89	2526.94	2175.74	1272.95	987.67	527.57	373.24	168.21	30.64	11.90	19.18	5.07	3.09	2.42	5.51	10226.58
1994	1190.06	1075.19	1486.14	2377.91	1742.09	875.90	619.94	319.23	222.01	99.21	18.08	7.05	11.02	2.87	1.76	4.41	10052.64
1995	1419.12	1503.99	1223.79	1358.49	1833.14	1153.24	529.11	361.34	182.98	126.33	56.00	10.14	3.97	6.17	1.54	3.31	9772.87
1996	1886.72	1742.53	1716.08	1160.95	1098.78	1269.42	727.09	321.43	215.83	108.25	74.30	32.85	5.95	2.21	3.53	2.87	10368.78
1997	1162.94	2449.12	1983.72	1539.49	867.52	699.09	734.80	406.09	177.03	118.17	59.08	40.34	17.86	3.09	1.32	3.31	10262.96
1998	891.11	1380.54	2796.34	1934.56	1299.40	634.93	469.81	477.74	259.93	112.66	74.96	37.26	25.35	11.24	1.98	2.87	10410.67
1999	1130.53	1107.38	1569.47	2568.39	1500.91	868.40	388.89	278.44	279.33	151.46	65.48	43.43	21.61	14.55	6.39	2.65	9997.97
2000	1149.71	1394.64	1182.78	1448.22	2077.20	1079.38	581.58	252.87	178.35	177.91	96.12	41.45	27.34	13.45	9.04	5.51	9715.77
2001	1191.38	1324.76	1419.12	1103.86	1224.89	1606.73	787.71	412.93	176.59	123.46	122.14	65.48	28.00	18.52	9.04	9.70	9624.50
2002	1696.68	1497.16	1421.54	1239.22	835.77	838.20	1033.53	492.73	254.19	107.81	74.96	73.86	39.46	16.75	11.02	11.02	9644.12
2003	1217.17	2073.01	1586.45	1306.02	1004.87	609.58	572.98	686.52	322.54	165.13	69.67	48.28	47.18	25.13	10.58	13.67	9758.98
2004	968.49	1364.22	2043.91	1382.96	1000.68	688.50	390.44	357.15	422.63	197.75	101.19	42.55	29.32	28.66	15.21	14.55	9048.21
2005	841.28	1158.31	1409.64	1770.75	1035.29	664.91	425.49	234.13	210.76	247.80	115.30	58.64	24.69	16.98	16.31	16.75	8247.27
2006	1080.71	964.30	1169.77	1288.16	1428.60	735.24	435.85	269.62	145.95	130.07	151.90	70.33	35.72	14.77	10.14	19.62	7950.53
2007	1167.35	1240.98	966.95	1014.57	975.55	962.76	460.77	264.77	161.16	86.42	76.72	88.85	41.01	20.72	8.60	16.75	7553.70
2008	955.04	1265.67	1183.44	799.40	719.59	600.98	544.10	251.77	142.42	86.20	46.08	40.56	46.96	21.61	10.80	13.01	6727.41
2009	849.88	1038.16	1193.36	901.91	509.71	398.82	306.00	267.86	122.14	68.56	41.23	22.05	19.40	22.27	10.14	11.02	5782.28
2010	511.69	947.99	1008.17	970.25	614.65	295.42	209.88	155.43	134.26	60.85	34.17	20.50	10.80	9.48	11.02	10.14	5005.16
2011	509.71	570.78	933.00	889.57	734.36	395.51	173.06	119.05	87.30	75.62	34.39	19.40	11.69	6.17	5.29	11.69	4576.14
2012	537.71	586.87	577.39	843.93	693.57	488.10	238.98	100.97	68.56	50.27	43.43	19.84	11.02	6.61	3.53	9.48	4279.84
2013	442.91	528.45	523.16	492.95	638.02	459.22	298.06	141.54	59.08	40.12	29.32	25.35	11.46	6.39	3.75	7.28	3706.85
2014	337.53	517.64	543.22	488.10	399.70	442.03	289.03	181.00	84.66	35.27	23.81	17.42	14.99	6.83	3.75	6.39	3391.15
2015	314.82	328.49	454.59	440.70	341.06	237.00	236.78	149.25	91.93	42.77	17.64	11.90	8.60	7.50	3.31	4.85	2691.18
2016	546.97	336.20	313.06	400.36	333.78	216.71	136.03	130.96	81.57	50.27	23.37	9.70	6.39	4.63	3.97	4.41	2598.59
2017	204.15	695.78	363.32	269.85	283.29	196.87	115.30	69.89	66.80	41.67	25.79	12.12	5.07	3.31	2.42	4.19	2359.61
2018	214.29	263.67	755.97	302.47	179.90	154.32	95.90	54.23	32.41	31.09	19.62	12.12	5.73	2.42	1.54	3.09	2128.56
2019	566.81	263.45	277.34	646.17	204.15	93.70	69.45	41.23	23.15	13.89	13.45	8.60	5.29	2.42	1.10	1.98	2231.96
2020	610.02	750.89	292.77	236.78	416.23	95.24	36.38	25.57	14.99	8.38	5.07	4.85	3.09	1.98	0.88	1.10	2504.23

Table 8. Estimated time series of status indicators, fishing mortality, and biomass. Fishing mortality rate is apical F. Total biomass (B, mt) and spawning biomass (SSB, mt) are at the start of the year. The MSST *is defined as 75%*SSB_{MSY}. *Prop.fem is the estimated proportion of mature fish that are female.*

Year	F	F/F_{MSY}	B	$B/B_{unfished}$	SSB	SSB/SSB_{MSY}	SSB/MSST	Prop.fem
1962	0.0222	0.0603	10296	0.8314	6669	4.265	5.686	0.786
1963	0.0200	0.0544	10370	0.8373	6752	4.317	5.756	0.786
1964	0.0186	0.0506	10453	0.8440	6823	4.363	5.817	0.785
1965	0.0189	0.0514	10538	0.8508	6895	4.409	5.879	0.785
1966	0.0142	0.0386	10610	0.8567	6970	4.457	5.942	0.784
1967	0.0300	0.0815	10712	0.8649	7024	4.491	5.989	0.783
1968	0.0450	0.1224	10675	0.8620	6970	4.457	5.943	0.782
1969	0.0315	0.0856	10520	0.8494	6878	4.398	5.864	0.782
1970	0.0436	0.1186	10489	0.8469	6823	4.363	5.817	0.782
1971	0.0455	0.1236	10367	0.8370	6718	4.296	5.728	0.782
1972	0.0320	0.0870	10247	0.8273	6643	4.247	5.663	0.783
1973	0.0451	0.1225	10242	0.8270	6605	4.224	5.632	0.784
1974	0.0514	0.1398	10142	0.8189	6510	4.162	5.550	0.785
1975	0.0531	0.1442	10017	0.8088	6399	4.092	5.456	0.787
1976	0.0699	0.1901	9882	0.7979	6266	4.007	5.342	0.789
1977	0.0775	0.2107	9394	0.7585	6059	3.874	5.166	0.787
1978	0.1244	0.3382	9055	0.7311	5774	3.692	4.922	0.790
1979	0.1291	0.3508	8623	0.6963	5360	3.427	4.570	0.797
1980	0.1269	0.3450	8216	0.6634	4957	3.170	4.226	0.802
1981	0.3565	0.9691	7897	0.6376	4260	2.724	3.632	0.803
1982	0.2806	0.7626	6881	0.5556	3367	2.153	2.871	0.829
1983	0.2599	0.7065	6248	0.5045	2950	1.886	2.515	0.844
1984	0.9506	2.5839	5738	0.4633	2186	1.398	1.864	0.858
1985	0.5399	1.4675	3518	0.2841	1284	0.821	1.095	0.897
1986	0.5172	1.4059	3674	0.2966	1136	0.726	0.969	0.933
1987	0.7180	1.9516	3968	0.3204	990	0.633	0.844	0.949
1988	0.5324	1.4471	4017	0.3243	940	0.601	0.801	0.963
1989	0.7782	2.1152	4299	0.3471	1051	0.672	0.896	0.969
1990	0.5115	1.3902	4111	0.3320	1097	0.701	0.935	0.975
1991	0.4093	1.1127	4501	0.3634	1241	0.794	1.058	0.975
1992	0.4230	1.1497	4678	0.3777	1385	0.886	1.181	0.972
1993	0.4310	1.1714	4639	0.3745	1482	0.948	1.264	0.966
1994	0.4688	1.2742	4560	0.3682	1559	0.997	1.330	0.963
1995	0.4272	1.1613	4433	0.3579	1569	1.003	1.337	0.962
1996	0.5112	1.3894	4703	0.3797	1496	0.957	1.276	0.961
1997	0.3596	0.9774	4655	0.3759	1415	0.905	1.206	0.959
1998	0.4518	1.2281	4722	0.3813	1482	0.947	1.263	0.956
1999	0.3594	0.9770	4535	0.3662	1553	0.993	1.324	0.954
2000	0.2714	0.7376	4407	0.3558	1696	1.084	1.446	0.954
2001	0.3981	1.0822	4366	0.3525	1699	1.086	1.448	0.949
2002	0.3378	0.9183	4374	0.3532	1555	0.994	1.326	0.947
2003	0.4017	1.0917	4427	0.3574	1475	0.943	1.257	0.944
2004	0.4407	1.1978	4104	0.3314	1365	0.873	1.164	0.941
2005	0.3847	1.0456	3741	0.3020	1303	0.833	1.111	0.940
2006	0.4274	1.1617	3606	0.2912	1298	0.830	1.107	0.944
2007	0.5334	1.4498	3426	0.2766	1174	0.751	1.001	0.946
2008	0.6374	1.7326	3052	0.2464	951	0.608	0.811	0.948
2009	0.6060	1.6471	2623	0.2118	756	0.484	0.645	0.951
2010	0.4958	1.3477	2270	0.1833	679	0.434	0.579	0.953
2011	0.4670	1.2693	2076	0.1676	676	0.433	0.577	0.955
2012	0.4525	1.2301	1941	0.1567	670	0.428	0.571	0.955
2013	0.4271	1.1610	1681	0.1358	631	0.404	0.538	0.953
2014	0.5904	1.6048	1538	0.1242	552	0.353	0.471	0.948
2015	0.5211	1.4165	1221	0.0986	442	0.283	0.377	0.945
2016	0.5941	1.6148	1179	0.0952	381	0.244	0.325	0.949
2017	0.6855	1.8632	1070	0.0864	315	0.201	0.269	0.950
2018	0.7718	2.0978	965	0.0780	257	0.165	0.219	0.955
2019	0.9321	2.5336	1012	0.0817	235	0.150	0.200	0.966
2020	.	.	1136	0.0917	.	.	.	0.980

Table 9. Selectivity at age for commercial handlines (cH), commercial diving (cD), headboat (HB), commercial discard mortalities (D.cH), headboat discard mortalities (D.HB), SERFS Video index (VID), selectivity of landings averaged across fisheries (L.avg), and selectivity of discard mortalities averaged across fisheries (D.avg). The selectivity of landings from the headboat and general recreational fleets were assumed equal, as was the selectivity of discards from the headboat and general recreational fleets. TL is total length. For time-varying selectivities, values shown are from the terminal assessment year.

Age	TL(mm)	TL(in)	cH	cD	HB	D.cH	D.HB	SERFS VID	L.avg	D.avg	L.avg+D.avg
1	412.2	16.2	0.003	0.003	0.007	1.000	1.000	0.511	0.005	0.069	0.074
2	528.1	20.8	0.017	0.019	0.125	0.776	0.776	1.000	0.052	0.054	0.105
3	626.0	24.6	0.080	0.116	0.746	0.229	0.229	1.000	0.295	0.016	0.311
4	708.8	27.9	0.306	0.485	0.984	0.078	0.078	1.000	0.544	0.005	0.549
5	778.8	30.7	0.691	0.906	0.999	0.028	0.028	1.000	0.823	0.002	0.825
6	837.9	33.0	0.919	1.000	1.000	0.012	0.012	1.000	0.969	0.001	0.970
7	887.9	35.0	0.983	0.927	1.000	0.005	0.005	1.000	1.000	0.000	1.000
8	930.2	36.6	0.997	0.759	1.000	0.003	0.003	1.000	0.991	0.000	0.991
9	965.9	38.0	0.999	0.526	1.000	0.002	0.002	1.000	0.968	0.000	0.968
10	996.2	39.2	1.000	0.302	1.000	0.001	0.001	1.000	0.946	0.000	0.946
11	1021.7	40.2	1.000	0.149	1.000	0.001	0.001	1.000	0.930	0.000	0.930
12	1043.3	41.1	1.000	0.067	1.000	0.001	0.001	1.000	0.922	0.000	0.922
13	1061.5	41.8	1.000	0.029	1.000	0.000	0.000	1.000	0.918	0.000	0.918
14	1077.0	42.4	1.000	0.012	1.000	0.000	0.000	1.000	0.916	0.000	0.916
15	1090.0	42.9	1.000	0.005	1.000	0.000	0.000	1.000	0.915	0.000	0.915
16	1101.0	43.3	1.000	0.002	1.000	0.000	0.000	1.000	0.915	0.000	0.915

Table 10. Estimated time series of fully selected fishing mortality rates for commercial handlines (F.cH), commercial diving (F.cD), headboat (F.HB), general recreational (F.GR), commercial discard mortalities (F.cH.D), headboat discard mortalities (F.HB.D), and general recreational discard mortalities (F.GR.D). Also shown is apical F, the maximum F at age summed across fleets, which may not equal the sum of fully selected F's because of dome-shaped selectivities.

Year	F.cH	F.cD	F.HB	F.GR	F.cH.D	F.HB.D	F.GR.D	Apical F
1962	0.011	0.000	0.006	0.005	0.000	0.000	0.000	0.022
1963	0.010	0.000	0.006	0.004	0.000	0.000	0.000	0.020
1964	0.009	0.000	0.005	0.004	0.000	0.000	0.000	0.019
1965	0.009	0.000	0.006	0.004	0.000	0.000	0.000	0.019
1966	0.007	0.000	0.004	0.003	0.000	0.000	0.000	0.014
1967	0.015	0.000	0.009	0.007	0.000	0.000	0.000	0.030
1968	0.022	0.000	0.013	0.010	0.000	0.000	0.000	0.045
1969	0.015	0.000	0.009	0.007	0.000	0.000	0.000	0.031
1970	0.021	0.000	0.013	0.010	0.000	0.000	0.000	0.044
1971	0.022	0.000	0.013	0.010	0.000	0.000	0.000	0.045
1972	0.015	0.000	0.010	0.007	0.000	0.000	0.000	0.032
1973	0.021	0.000	0.014	0.010	0.000	0.000	0.000	0.045
1974	0.028	0.000	0.011	0.013	0.000	0.000	0.000	0.051
1975	0.032	0.000	0.007	0.014	0.000	0.000	0.000	0.053
1976	0.044	0.001	0.006	0.020	0.000	0.000	0.000	0.070
1977	0.051	0.001	0.007	0.019	0.000	0.000	0.000	0.077
1978	0.082	0.002	0.006	0.035	0.000	0.000	0.000	0.124
1979	0.083	0.003	0.009	0.035	0.000	0.000	0.000	0.129
1980	0.084	0.003	0.007	0.034	0.000	0.000	0.000	0.127
1981	0.119	0.003	0.014	0.222	0.000	0.000	0.016	0.357
1982	0.156	0.004	0.013	0.110	0.000	0.000	0.004	0.281
1983	0.189	0.002	0.017	0.053	0.000	0.012	0.108	0.260
1984	0.275	0.006	0.027	0.644	0.000	0.001	0.101	0.951
1985	0.350	0.005	0.032	0.155	0.000	0.000	0.008	0.540
1986	0.389	0.003	0.029	0.098	0.000	0.001	0.014	0.517
1987	0.501	0.013	0.034	0.175	0.000	0.003	0.047	0.718
1988	0.400	0.007	0.032	0.097	0.000	0.001	0.009	0.532
1989	0.500	0.009	0.031	0.242	0.000	0.002	0.056	0.778
1990	0.376	0.007	0.024	0.107	0.000	0.003	0.032	0.511
1991	0.275	0.030	0.017	0.094	0.000	0.002	0.027	0.409
1992	0.258	0.034	0.026	0.112	0.000	0.002	0.038	0.423
1993	0.257	0.023	0.020	0.137	0.000	0.002	0.042	0.431
1994	0.254	0.027	0.019	0.176	0.000	0.002	0.075	0.469
1995	0.267	0.024	0.023	0.120	0.000	0.005	0.102	0.427
1996	0.262	0.039	0.016	0.201	0.000	0.001	0.049	0.511
1997	0.224	0.034	0.013	0.094	0.000	0.006	0.135	0.360
1998	0.228	0.044	0.015	0.173	0.000	0.002	0.092	0.452
1999	0.171	0.032	0.010	0.151	0.004	0.002	0.096	0.359
2000	0.125	0.016	0.012	0.120	0.005	0.005	0.161	0.271
2001	0.132	0.023	0.011	0.235	0.008	0.001	0.075	0.398
2002	0.147	0.028	0.011	0.157	0.005	0.001	0.105	0.338
2003	0.156	0.042	0.007	0.201	0.003	0.002	0.193	0.402
2004	0.181	0.028	0.017	0.219	0.005	0.002	0.125	0.441
2005	0.221	0.020	0.019	0.130	0.006	0.003	0.167	0.385
2006	0.188	0.021	0.012	0.210	0.002	0.002	0.170	0.427
2007	0.246	0.031	0.021	0.241	0.002	0.001	0.227	0.533
2008	0.239	0.031	0.011	0.361	0.003	0.002	0.222	0.637
2009	0.282	0.044	0.011	0.275	0.003	0.004	0.195	0.606
2010	0.262	0.067	0.013	0.162	0.003	0.003	0.196	0.496
2011	0.273	0.047	0.011	0.143	0.004	0.003	0.163	0.467
2012	0.222	0.048	0.010	0.178	0.005	0.004	0.319	0.453
2013	0.278	0.038	0.008	0.110	0.008	0.002	0.146	0.427
2014	0.320	0.031	0.007	0.239	0.011	0.002	0.325	0.590
2015	0.313	0.056	0.007	0.154	0.007	0.002	0.237	0.521
2016	0.289	0.072	0.006	0.237	0.005	0.001	0.065	0.594
2017	0.330	0.077	0.006	0.283	0.005	0.001	0.049	0.685
2018	0.472	0.092	0.007	0.215	0.011	0.001	0.091	0.772
2019	0.646	0.071	0.005	0.226	0.006	0.000	0.021	0.932

Table 11. Estimated time series of landings in numbers (1000 fish) for commercial handlines (L.cH), commercial diving (L.cD), headboat (L.HB), and general recreational (L.GR).

Year	L.cH	L.cD	L.HB	L.GR	Total
1962	7.37	0.00	8.41	6.32	22.10
1963	6.71	0.00	7.66	5.75	20.12
1964	6.28	0.00	7.18	5.40	18.87
1965	6.37	0.00	7.41	5.57	19.36
1966	4.84	0.00	5.58	4.19	14.61
1967	10.28	0.00	11.77	8.83	30.89
1968	15.09	0.00	17.73	13.30	46.12
1969	10.57	0.00	12.14	9.10	31.81
1970	14.57	0.00	16.67	12.50	43.74
1971	14.96	0.00	17.20	12.90	45.06
1972	9.99	0.00	13.45	8.57	32.02
1973	14.23	0.00	18.01	12.45	44.69
1974	18.31	0.00	13.94	16.07	48.31
1975	20.79	0.00	8.58	17.92	47.29
1976	27.99	0.24	7.56	24.38	60.17
1977	31.22	0.58	8.48	22.49	62.76
1978	48.39	0.91	6.01	38.51	93.82
1979	45.45	1.23	9.55	36.61	92.84
1980	42.24	1.06	6.96	36.27	86.53
1981	49.71	0.92	13.91	215.87	280.41
1982	54.11	1.10	11.84	101.43	168.49
1983	60.60	0.65	16.45	49.78	127.48
1984	64.06	1.37	18.68	439.42	523.52
1985	54.01	0.88	16.13	78.33	149.35
1986	53.85	0.48	17.35	59.49	131.16
1987	60.50	1.75	24.09	123.47	209.81
1988	52.61	1.12	24.21	72.75	150.67
1989	76.87	1.88	22.41	177.82	278.98
1990	60.84	1.55	17.59	78.04	158.02
1991	49.61	6.74	13.55	76.54	146.43
1992	51.24	8.36	13.93	61.17	134.70
1993	55.45	6.12	11.79	80.74	154.11
1994	57.38	7.48	9.80	92.71	167.37
1995	58.25	6.19	10.54	55.39	130.37
1996	51.28	8.71	7.50	91.46	158.95
1997	42.45	7.54	6.85	47.84	104.67
1998	46.75	10.91	8.67	101.00	167.32
1999	38.38	8.83	5.34	82.28	134.83
2000	30.00	4.65	5.98	58.48	99.11
2001	29.42	5.82	5.12	105.25	145.61
2002	28.97	6.01	4.58	67.45	107.00
2003	29.07	8.60	3.27	88.62	129.55
2004	31.89	5.67	7.61	99.87	145.05
2005	39.03	4.11	8.05	55.70	106.89
2006	32.87	4.32	4.60	80.32	122.12
2007	37.37	5.34	6.70	77.70	127.10
2008	28.47	4.23	3.06	102.74	138.49
2009	27.45	4.98	3.00	72.52	107.94
2010	24.38	7.53	3.28	41.14	76.33
2011	26.09	5.53	2.63	34.60	68.85
2012	20.83	5.40	2.10	37.00	65.34
2013	23.83	3.76	1.38	19.64	48.61
2014	22.83	2.49	1.04	37.11	63.47
2015	18.00	3.70	0.87	19.92	42.49
2016	14.09	4.04	0.64	25.47	44.23
2017	13.10	3.50	0.64	28.61	45.85
2018	16.16	3.83	0.79	24.90	45.68
2019	21.62	3.13	0.46	21.73	46.95

Table 12. Estimated time series of landings in gutted weight (1000 lb) for commercial handlines (L.cH), commercial diving (L.cD), headboat (L.HB), and general recreational (L.GR).

Year	L.cH	L.cD	L.HB	L.GR	Total
1962	150.34	0.00	120.07	90.23	360.65
1963	136.98	0.00	109.59	82.26	328.83
1964	128.40	0.00	102.99	77.46	308.85
1965	130.42	0.00	106.60	80.12	317.14
1966	99.13	0.00	80.52	60.46	240.11
1967	211.01	0.00	170.29	127.74	509.04
1968	310.12	0.00	256.26	192.17	758.55
1969	217.29	0.00	175.01	131.28	523.58
1970	299.29	0.00	239.90	179.82	719.01
1971	307.04	0.00	246.49	184.89	738.42
1972	204.65	0.00	192.20	122.52	519.37
1973	290.88	0.00	256.76	177.48	725.13
1974	373.52	0.00	197.79	228.10	799.42
1975	422.86	0.00	121.07	253.05	796.98
1976	567.19	3.75	106.29	342.55	1019.78
1977	630.23	8.81	121.57	322.24	1082.86
1978	973.04	13.87	87.32	559.33	1633.56
1979	911.79	18.92	133.10	510.07	1573.89
1980	849.21	16.40	91.93	479.01	1436.55
1981	987.46	13.88	177.25	2750.47	3929.05
1982	1028.90	15.85	135.97	1164.98	2345.69
1983	1099.03	9.08	177.95	538.43	1824.49
1984	1104.54	18.75	205.70	4839.14	6168.13
1985	864.53	11.62	157.36	764.24	1797.75
1986	820.79	6.34	142.13	487.32	1456.58
1987	858.67	21.93	188.02	963.74	2032.36
1988	673.04	12.96	194.33	583.98	1464.31
1989	967.97	22.26	186.41	1478.83	2655.48
1990	784.31	19.07	145.97	647.79	1597.14
1991	656.22	85.00	111.81	631.77	1484.81
1992	690.48	106.73	145.68	639.63	1582.53
1993	754.65	78.13	126.00	862.67	1821.44
1994	797.06	97.45	111.49	1054.18	2060.18
1995	837.86	83.74	123.08	647.10	1691.78
1996	749.66	118.51	84.42	1029.72	1982.30
1997	606.85	98.68	73.30	511.97	1290.79
1998	652.29	138.72	92.23	1074.67	1957.91
1999	536.53	113.46	60.49	932.17	1642.65
2000	437.33	63.02	71.70	701.22	1273.26
2001	449.26	82.29	62.18	1278.45	1872.17
2002	447.76	84.49	54.39	801.24	1387.89
2003	443.27	117.29	37.45	1015.28	1613.30
2004	474.74	74.89	84.82	1113.93	1748.38
2005	570.36	53.56	91.91	636.22	1352.05
2006	484.77	57.81	54.33	948.83	1545.75
2007	560.92	73.02	79.42	921.05	1634.41
2008	425.58	57.35	34.58	1161.07	1678.57
2009	395.79	64.61	32.41	783.38	1276.19
2010	340.38	95.30	35.29	442.51	913.48
2011	364.28	70.82	29.06	382.06	846.22
2012	297.84	71.50	24.40	429.73	823.47
2013	352.81	51.63	16.42	233.65	654.51
2014	344.68	34.52	12.29	438.27	829.76
2015	271.55	50.67	10.23	234.29	566.74
2016	209.93	54.51	7.52	299.39	571.35
2017	190.21	46.05	6.92	309.46	552.65
2018	219.47	46.90	7.90	249.07	523.34
2019	274.80	37.06	4.83	228.14	544.84

Table 13. Estimated time series of discard mortalities in numbers (1000 fish) for commercial handlines (D.cH), headboat (D.HB), and general recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	0.00	0.13	7.44	7.57
1982	0.00	0.15	3.49	3.64
1983	0.00	4.07	35.91	39.98
1984	0.00	0.30	27.54	27.84
1985	0.00	0.15	4.76	4.91
1986	0.00	0.85	10.44	11.29
1987	0.00	1.52	27.46	28.98
1988	0.00	0.48	5.39	5.87
1989	0.00	0.84	29.68	30.52
1990	0.00	2.23	22.14	24.37
1991	0.00	1.60	19.49	21.09
1992	0.00	1.09	17.63	18.72
1993	0.00	0.63	15.80	16.43
1994	0.00	1.03	38.00	39.04
1995	0.00	2.87	60.70	63.58
1996	0.00	0.77	39.80	40.58
1997	0.00	3.15	69.53	72.68
1998	0.00	0.76	36.37	37.14
1999	2.98	1.24	64.24	68.46
2000	3.16	3.19	111.00	117.35
2001	5.46	0.72	53.47	59.65
2002	4.64	1.34	98.42	104.40
2003	2.06	1.32	156.63	160.01
2004	3.06	1.55	80.25	84.87
2005	3.26	1.67	89.94	94.87
2006	1.22	0.93	100.37	102.52
2007	1.24	0.88	145.56	147.67
2008	1.49	1.16	126.44	129.09
2009	1.40	2.09	98.21	101.69
2010	1.12	1.21	71.21	73.54
2011	1.36	0.96	50.44	52.76
2012	1.51	1.30	93.64	96.45
2013	2.02	0.50	38.99	41.50
2014	2.22	0.34	67.69	70.25
2015	1.32	0.28	42.12	43.72
2016	1.28	0.25	18.10	19.62
2017	0.96	0.17	9.74	10.87
2018	1.66	0.18	13.26	15.10
2019	1.79	0.12	6.03	7.94

Table 14. Estimated time series of discard mortalities in gutted weight (1000 lb) for commercial handlines (D.cH), headboat (D.HB), and general recreational (D.GR).

Year	D.cH	D.HB	D.GR	Total
1981	0.00	0.48	26.39	26.87
1982	0.00	0.50	11.90	12.40
1983	0.00	15.64	138.18	153.83
1984	0.00	1.06	98.59	99.65
1985	0.00	0.51	16.10	16.60
1986	0.00	2.94	36.10	39.04
1987	0.00	5.41	97.53	102.94
1988	0.00	1.70	18.89	20.59
1989	0.00	2.96	104.97	107.93
1990	0.00	7.72	76.60	84.32
1991	0.00	5.58	68.04	73.62
1992	0.00	3.98	64.32	68.29
1993	0.00	2.26	57.02	59.28
1994	0.00	3.59	131.96	135.55
1995	0.00	9.98	210.88	220.86
1996	0.00	2.67	137.27	139.95
1997	0.00	11.42	252.20	263.62
1998	0.00	2.75	131.25	134.00
1999	12.98	5.39	279.82	298.19
2000	13.68	13.80	480.63	508.11
2001	23.25	3.09	227.86	254.19
2002	19.01	5.49	403.19	427.68
2003	9.14	5.86	696.69	711.69
2004	13.79	7.01	361.59	382.39
2005	14.70	7.52	405.01	427.23
2006	5.11	3.93	421.89	430.93
2007	5.17	3.69	608.82	617.68
2008	6.42	4.99	545.24	556.65
2009	6.03	9.01	424.42	439.47
2010	5.17	5.59	328.88	339.64
2011	6.02	4.29	224.03	234.34
2012	6.51	5.61	404.51	416.63
2013	8.72	2.14	168.62	179.48
2014	10.00	1.54	304.80	316.34
2015	5.71	1.23	182.82	189.75
2016	5.03	0.96	70.84	76.83
2017	4.55	0.82	46.37	51.74
2018	7.70	0.83	61.45	69.99
2019	6.87	0.46	23.11	30.44

Table 15. Estimated status indicators, benchmarks, and related quantities from the base run of the Beaufort catch-age model, conditional on estimated current selectivities averaged across fleets. Also presented are median values and measures of precision (standard errors, SE) from the Monte Carlo/Bootstrap ensemble (MCBE) analysis. Rate estimates (F) are in units of y^{-1}*; status indicators are dimensionless; and biomass estimates are in units of metric tons or pounds, as indicated. Spawning stock biomass (SSB) is measured as total (males and females) mature biomass. The definitions of* MSST *in this assessment is* $\mathrm{MSST} = 75\%\mathrm{SSB}_{\mathrm{MSY}}$.

Quantity	Units	Estimate	Median	SE
F_{MSY}	y^{-1}	0.37	0.35	0.06
B_{MSY}	mt whole	4278.4	4368.7	627.2
$\mathrm{SSB}_{\mathrm{MSY}}$	mt whole	1563.9	1659.4	269.7
MSST	mt whole	1172.9	1244.5	202.3
MSY	1000 lb gutted	1455.1	1453.5	41.6
D_{MSY}	1000 fish	17.6	16.7	4.0
R_{MSY}	1000 age-1 fish	521	509	104
$F_{2017-2019}/F_{\mathrm{MSY}}$	—	2.15	2.27	0.38
$\mathrm{SSB}_{2019}/\mathrm{MSST}$	—	0.20	0.19	0.04
$\mathrm{SSB}_{2019}/\mathrm{SSB}_{\mathrm{MSY}}$	—	0.15	0.14	0.03

Table 16. Results from sensitivity runs of the Beaufort catch-age model.

Run	Description	F_{MSY}	$\mathrm{SSB}_{\mathrm{MSY}}$ (mt)	MSY (1000 lb)	MSY (1000s)	$\mathrm{F}_{\mathrm{current}}/F_{\mathrm{MSY}}$	$\mathrm{SSB}_{2019}/\mathrm{SSB}_{\mathrm{MSY}}$	R0 (1000)
Base	—	0.368	1563.9	1455	111	2.15	0.15	526
S1	Low steepness	0.307	1916.29	1460	107	2.61	0.12	572
S2	High steepness	0.464	1219.14	1470	118	1.67	0.2	488
S3	2014 update steepness	0.297	1991.71	1462	106	2.7	0.11	582
S4	HB alone	0.376	1530.89	1458	112	2.08	0.16	523
S5	Video alone	0.346	1689.86	1461	110	2.22	0.14	544
S6	Wgts = 1	0.364	1568.21	1447	110	2.35	0.13	523
S7	Truncate HB	0.372	1541.27	1457	112	1.7	0.2	529
S8	HB-VID-cHL	0.377	1498.7	1455	112	1.75	0.2	521
S9	q block cHL	0.379	1501.45	1461	113	1.72	0.2	524
S10	RW FD indices	0.347	1668.66	1461	110	1.96	0.17	545
S11	Low Finit	0.363	1589.02	1457	111	2.18	0.15	530
S12	High Finit	0.374	1535.42	1454	111	2.11	0.15	523
S13	High DiscM	0.396	1496.95	1510	117	1.97	0.16	536
S14	Low DiscM	0.343	1627.65	1401	105	2.33	0.14	514
S15	Selex blocks	0.373	1609.16	1454	109	2.25	0.15	532
S16	VID dome-shaped	0.368	1558.97	1455	111	2.13	0.15	526
S17	S2014 M	0.297	2081.01	1516	103	3.06	0.09	283
S18	M scaled to 1+	0.388	1473.35	1448	108	2.23	0.14	390
S19	Low M	0.32	1885.32	1493	105	2.81	0.1	297
S20	High M	0.168	3031.74	1236	92	3.31	0.12	2347
S21	Constant M	0.344	1791.54	1564	112	2.54	0.11	245
S22	S2014 growth-maturity-M	0.303	2872.59	1504	104	2.97	0.13	279
S23	Egg production	0.372	1.37	1471	112	2.12	0.13	523

Table 17. Projection results with fishing mortality rate fixed at $F = 0$ starting in 2022. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.recover = proportion of stochastic projection replicates with* SSB ≥ MSY. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(mt)	S.med(mt)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.recover
2020	301	263	1.01	0.98	225	223	49	49	539	539	25	22	104	91	0.000
2021	296	256	0.95	0.96	212	209	56	55	539	539	24	23	104	98	0.000
2022	287	241	0.00	0.00	274	263	0	0	0	0	0	0	0	0	0.000
2023	325	263	0.00	0.00	498	469	0	0	0	0	0	0	0	0	0.003
2024	409	328	0.00	0.00	812	761	0	0	0	0	0	0	0	0	0.061
2025	466	377	0.00	0.00	1175	1105	0	0	0	0	0	0	0	0	0.248
2026	500	413	0.00	0.00	1565	1475	0	0	0	0	0	0	0	0	0.430
2027	521	436	0.00	0.00	1990	1881	0	0	0	0	0	0	0	0	0.580
2028	535	456	0.00	0.00	2463	2340	0	0	0	0	0	0	0	0	0.714
2029	546	469	0.00	0.00	2976	2840	0	0	0	0	0	0	0	0	0.828

Table 18. Projection results with fishing mortality rate fixed at F = Fcurrent starting in 2022. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.recover = proportion of stochastic projection replicates with* SSB $\geq$ MSY*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(mt)	S.med(mt)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.recover
2020	301	263	1.01	0.98	225	223	49	49	539	539	25	22	104	91	0
2021	296	256	0.95	0.96	212	209	56	55	539	539	24	23	104	98	0
2022	287	241	0.94	0.78	233	229	67	54	650	527	24	17	103	76	0
2023	302	248	0.94	0.78	278	284	76	64	760	648	24	18	104	77	0
2024	327	271	0.94	0.78	306	328	79	69	812	724	26	19	110	82	0
2025	342	285	0.94	0.78	321	357	81	72	839	765	27	20	117	87	0
2026	349	294	0.94	0.78	332	374	85	76	872	808	28	21	121	91	0
2027	353	296	0.94	0.78	345	393	89	81	914	857	29	22	123	94	0
2028	359	302	0.94	0.78	360	412	93	85	953	905	29	22	125	95	0
2029	365	307	0.94	0.78	372	431	95	88	983	943	30	22	127	97	0

Table 19. Projection results with fishing mortality rate fixed at $F = F_{\text{MSY}}$ starting in 2022. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.recover = proportion of stochastic projection replicates with* SSB ≥ MSY. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(mt)	S.med(mt)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.recover
2020	301	263	1.01	0.98	225	223	49	49	539	539	25	22	104	91	0.000
2021	296	256	0.95	0.96	212	209	56	55	539	539	24	23	104	98	0.000
2022	287	241	0.36	0.35	257	247	29	26	289	261	9	8	41	35	0.000
2023	316	257	0.36	0.35	392	371	40	36	427	384	10	8	44	37	0.000
2024	377	304	0.36	0.35	536	509	49	44	551	501	12	10	50	42	0.001
2025	418	337	0.36	0.35	660	631	56	51	654	596	13	11	57	47	0.005
2026	443	361	0.36	0.35	766	733	63	58	752	687	14	12	62	52	0.016
2027	460	378	0.36	0.35	869	831	71	65	852	783	15	13	66	55	0.031
2028	473	392	0.36	0.35	977	930	79	72	955	880	16	13	68	57	0.050
2029	484	402	0.36	0.35	1084	1023	86	78	1051	966	16	13	70	59	0.074

Table 20. Projection results with fishing mortality rate fixed at $F = Frebuild$ starting in 2022. R = number of age-1 recruits (in 1000s), F = fishing mortality rate (per year), S = spawning stock (mt), L = landings expressed in numbers (n, in 1000s) or gutted weight (w, in 1000 lb*), and D = dead discards expressed in numbers (n, in 1000s) or gutted weight (w, in 1000* lb*), pr.recover = proportion of stochastic projection replicates with* SSB ≥ MSY*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b(mt)	S.med(mt)	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.recover
2020	301	264	1.01	0.98	225	223	49	49	539	539	25	22	104	92	0.000
2021	296	254	0.95	0.96	212	209	56	55	539	539	24	23	104	97	0.000
2022	287	242	0.33	0.33	259	248	27	25	264	252	9	8	37	34	0.000
2023	317	258	0.33	0.33	401	375	37	35	395	374	9	8	40	35	0.000
2024	380	301	0.33	0.33	556	518	46	43	518	489	11	9	46	39	0.004
2025	423	339	0.33	0.33	695	647	53	50	622	586	12	10	52	45	0.023
2026	449	362	0.33	0.33	815	760	60	57	721	678	13	11	57	49	0.057
2027	466	374	0.33	0.33	931	866	68	64	823	773	14	12	60	52	0.105
2028	479	388	0.33	0.33	1054	982	76	71	927	870	14	12	63	54	0.155
2029	491	401	0.33	0.33	1175	1093	82	77	1025	958	15	13	65	56	0.202
2030	500	412	0.33	0.33	1284	1193	88	82	1110	1038	15	13	66	57	0.249
2031	507	421	0.33	0.33	1377	1279	92	86	1180	1099	15	13	67	59	0.290
2032	512	428	0.33	0.33	1453	1347	96	89	1236	1153	15	14	68	60	0.328
2033	516	435	0.33	0.33	1515	1407	99	92	1282	1197	16	14	69	61	0.363
2034	519	442	0.33	0.33	1566	1457	101	94	1319	1234	16	14	69	62	0.390
2035	521	444	0.33	0.33	1607	1496	102	96	1348	1263	16	14	70	62	0.416
2036	523	447	0.33	0.33	1639	1528	104	97	1372	1287	16	14	70	63	0.439
2037	524	454	0.33	0.33	1665	1556	105	98	1390	1309	16	14	70	64	0.456
2038	525	455	0.33	0.33	1685	1578	106	100	1404	1326	16	14	70	64	0.472
2039	526	459	0.33	0.33	1700	1599	106	101	1414	1340	16	15	70	65	0.486
2040	526	460	0.33	0.33	1712	1615	107	102	1423	1355	16	15	71	65	0.500

8 Figures

Figure 1. Observed indices of abundance from recreational headboat logbooks and SERFS video survey.

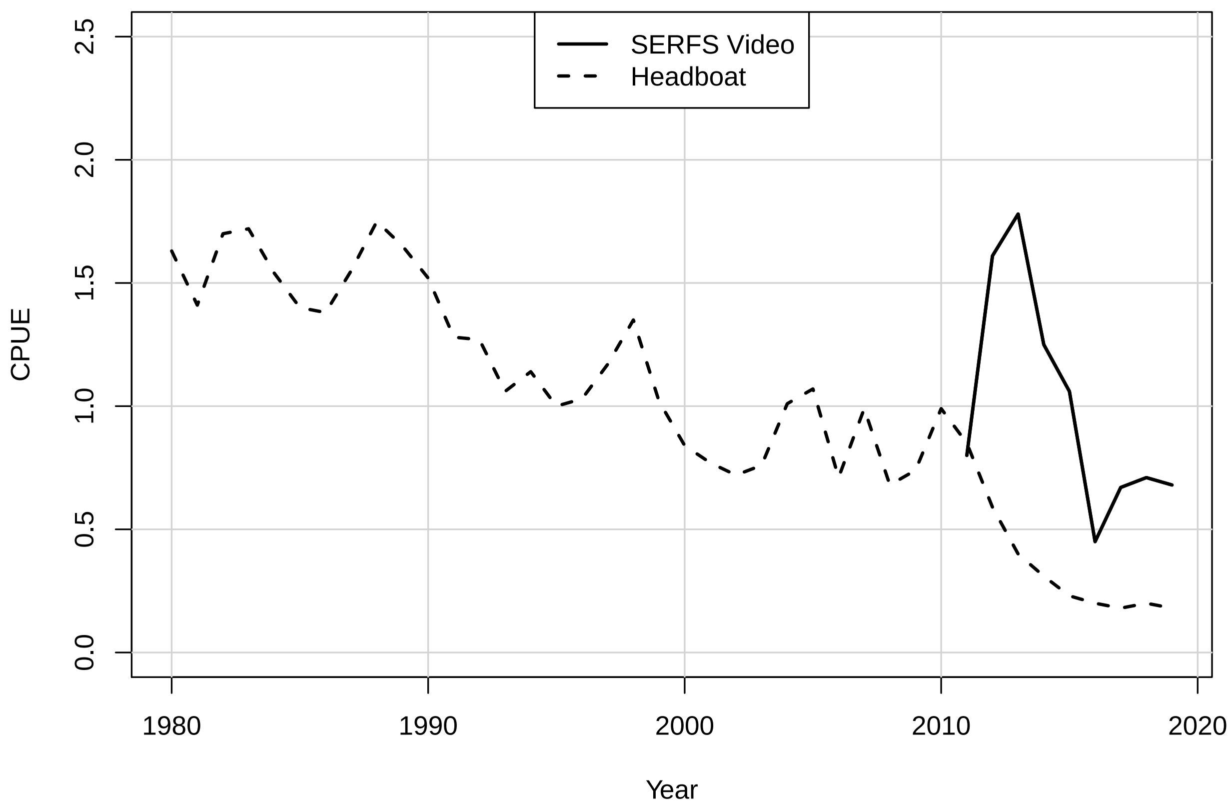


Figure 2. Mean length at age (mm) and estimated upper and lower 95% confidence intervals of the population.

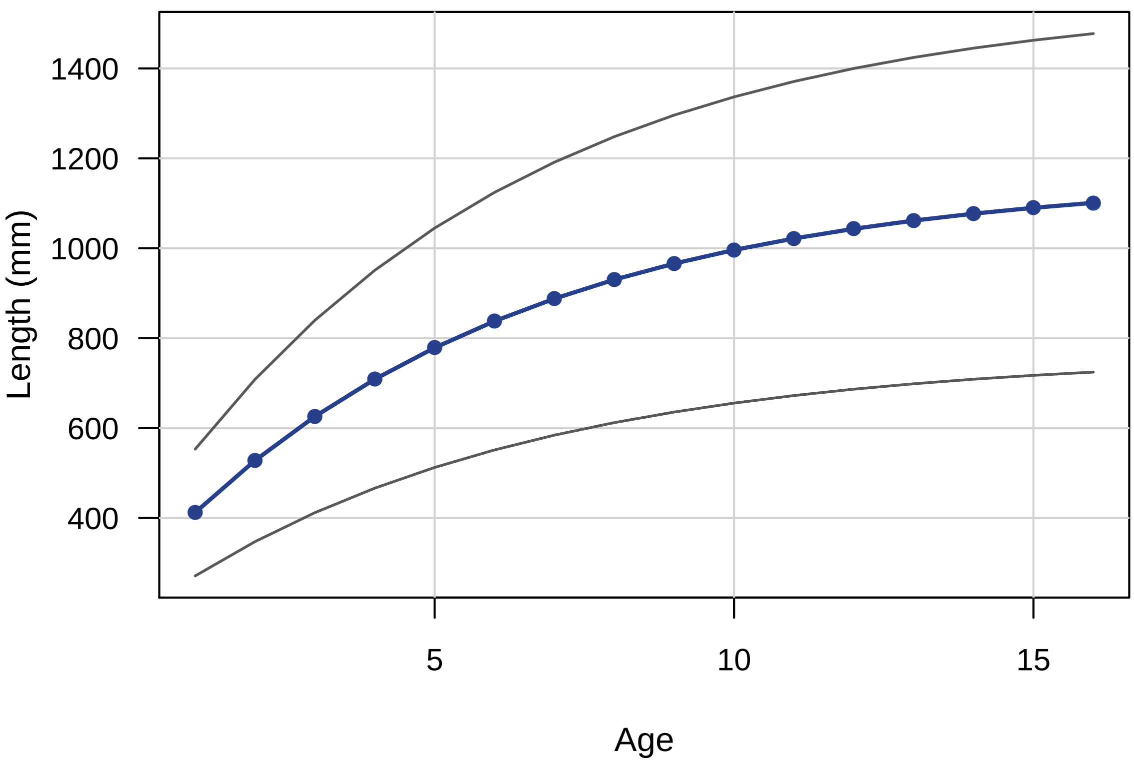


Figure 3. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, cH to commercial handline, cD to commercial diving, HB to headboat, HB.D to headboat discards, and CVT to Chevron traps.

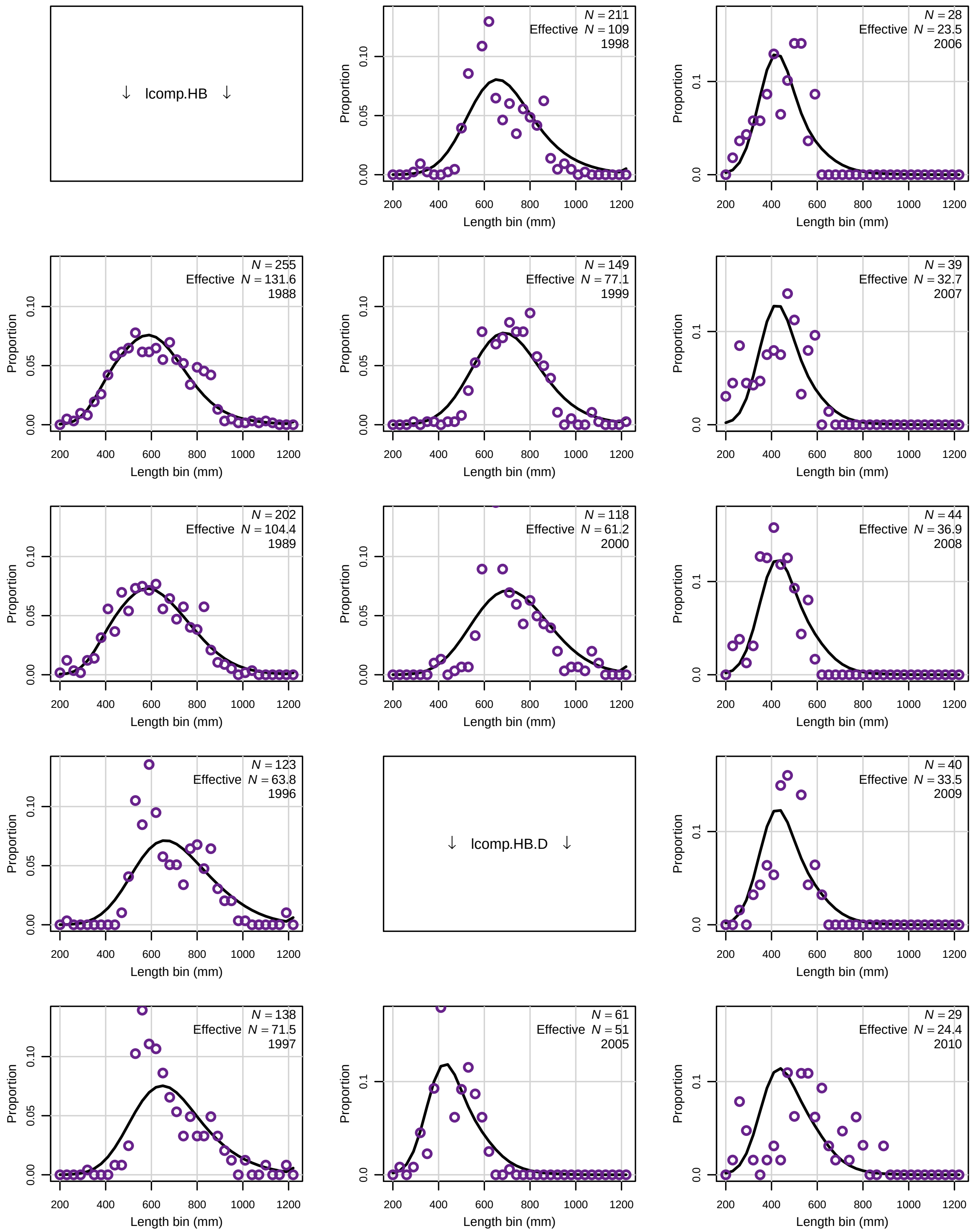


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

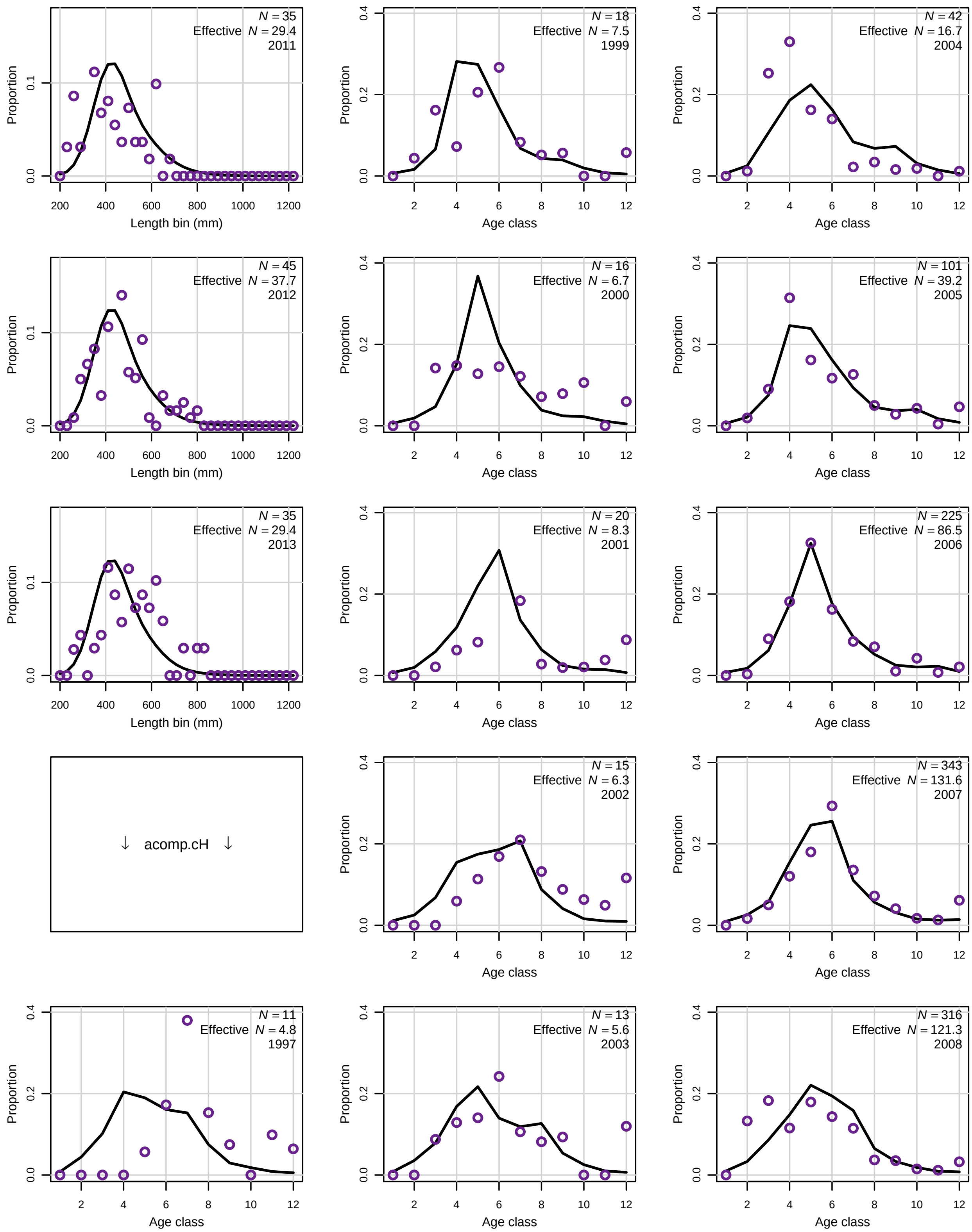


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

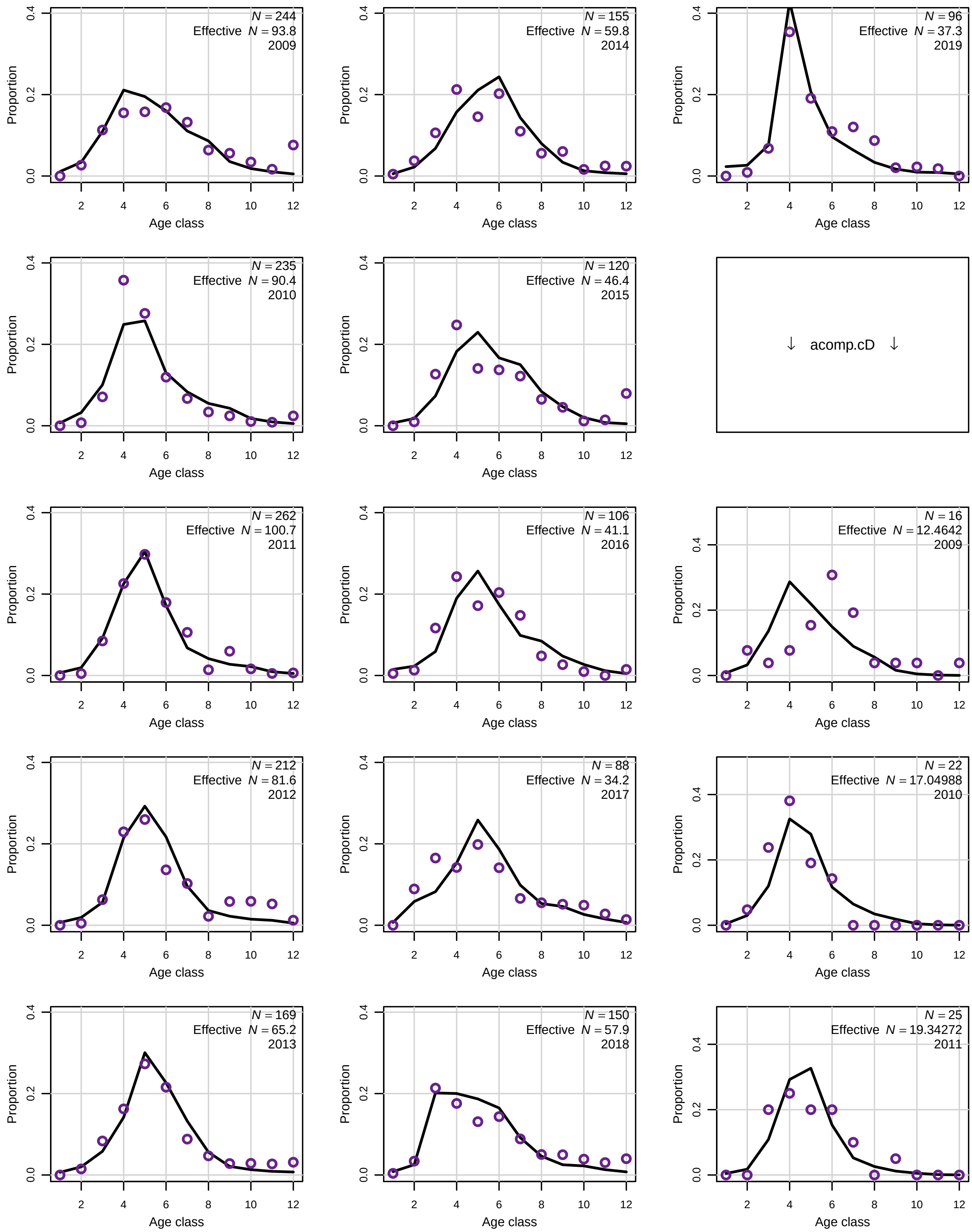


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

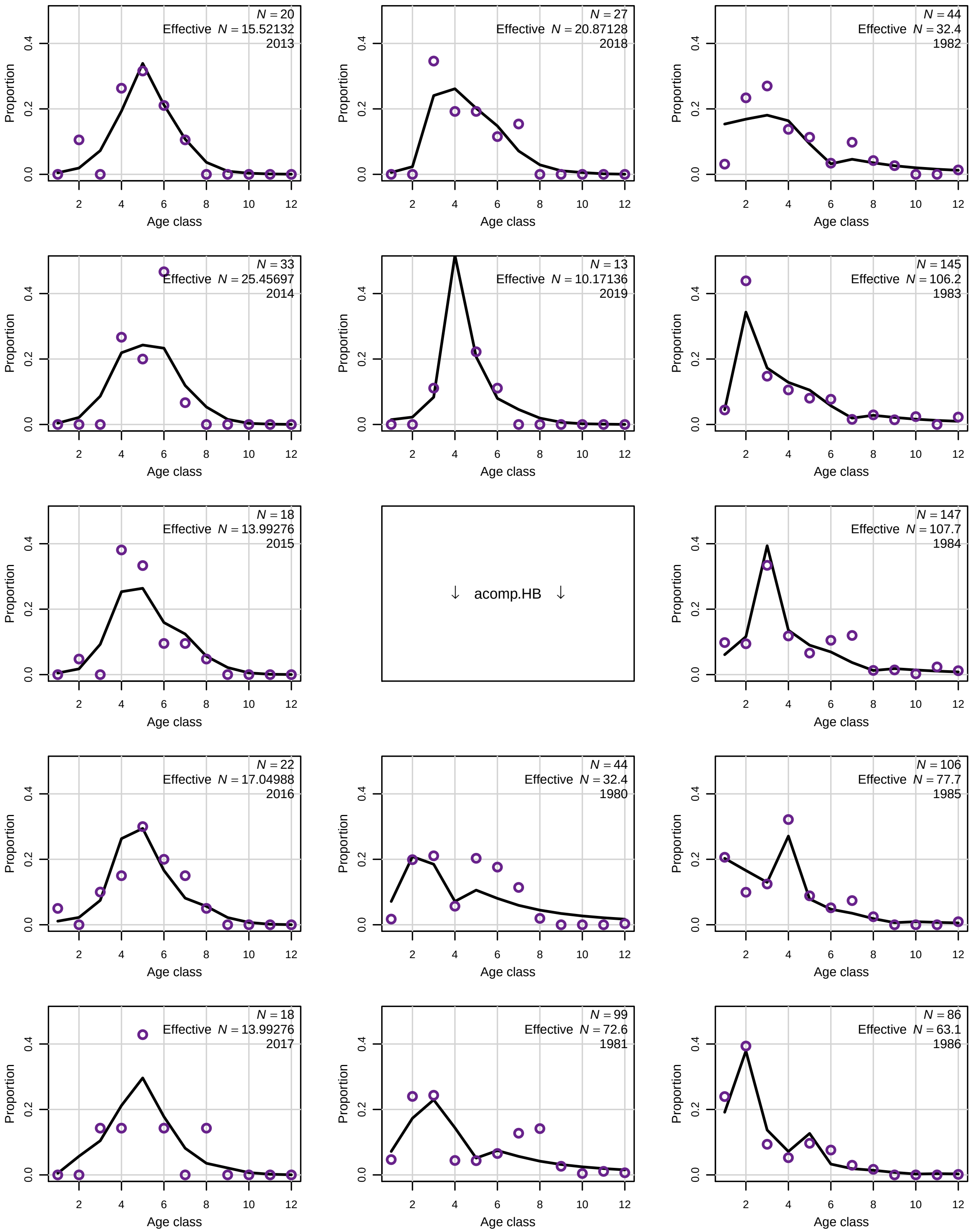


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

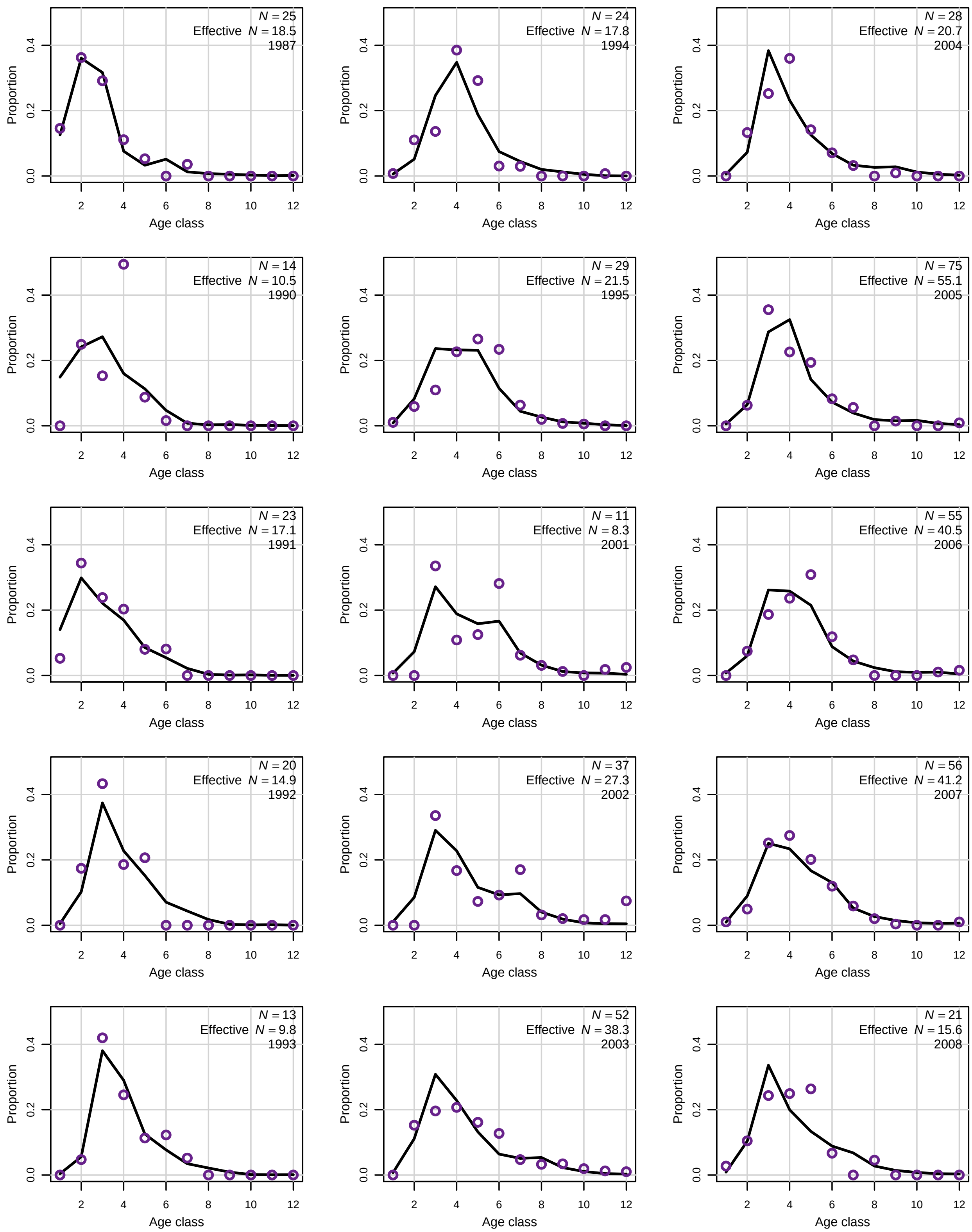


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

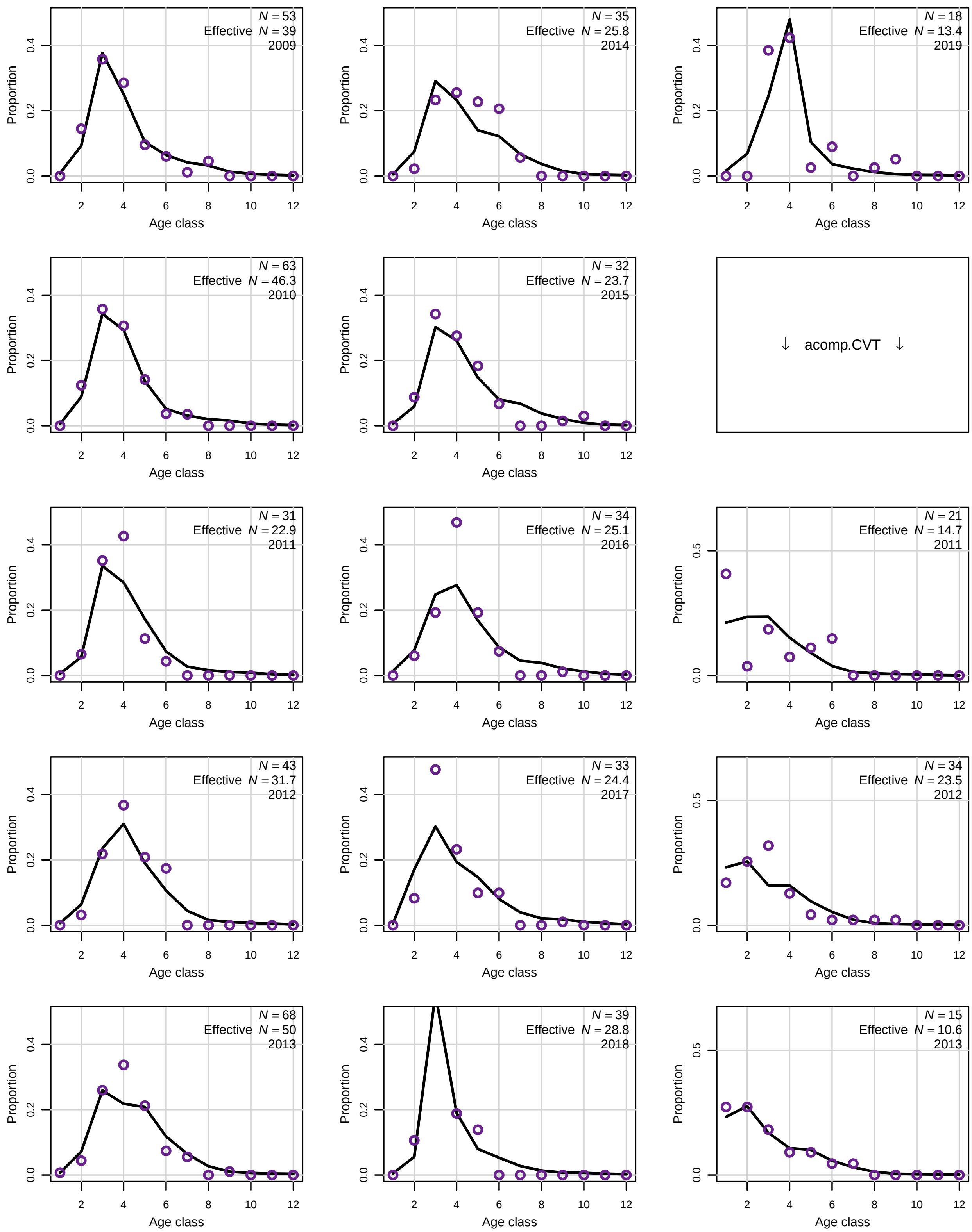


Figure 3. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

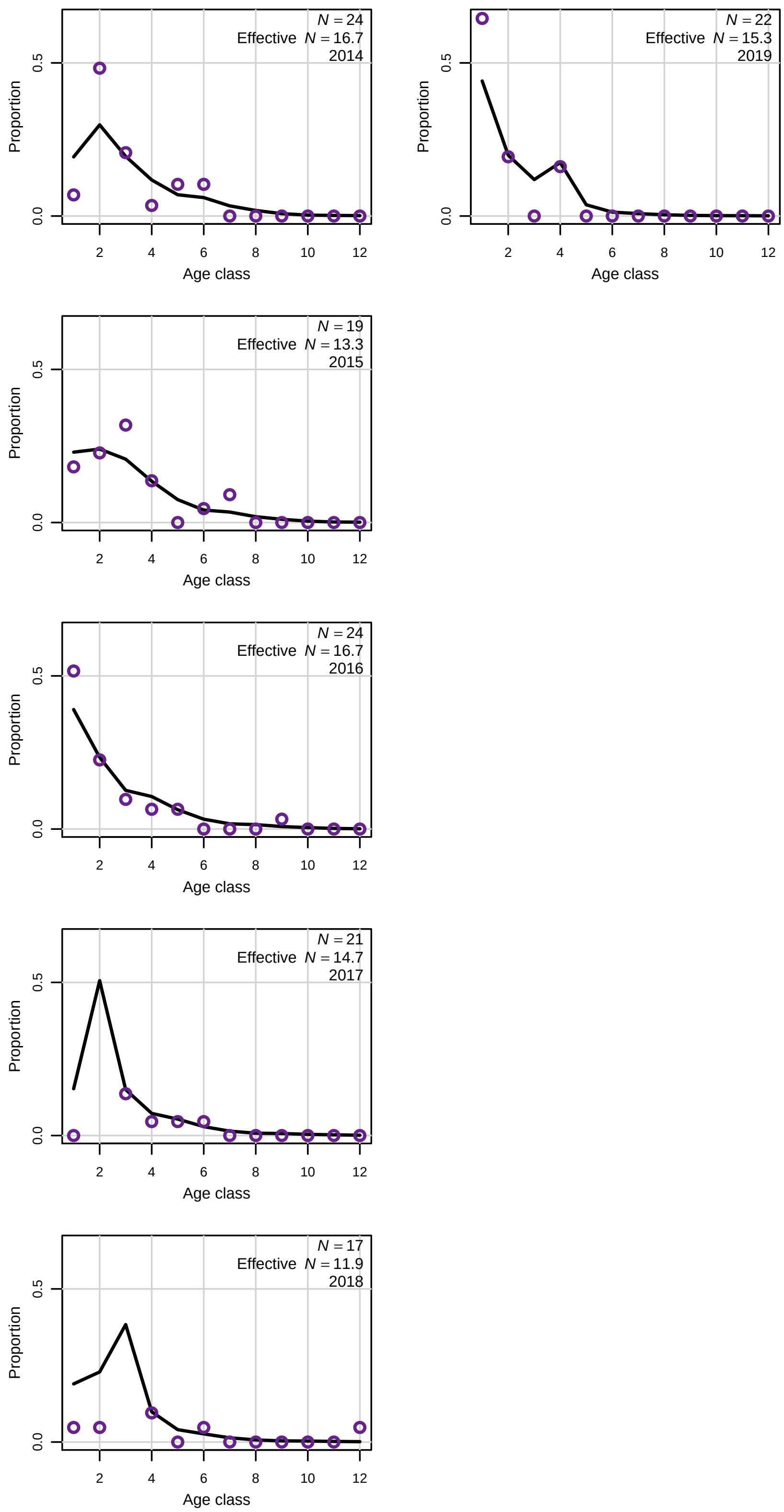


Figure 4. Observed (open circles) and estimated (solid line, circles) commercial handline landings (1000 lb gutted weight). Open and solid circles may be indistinguishable in years with very close fits.

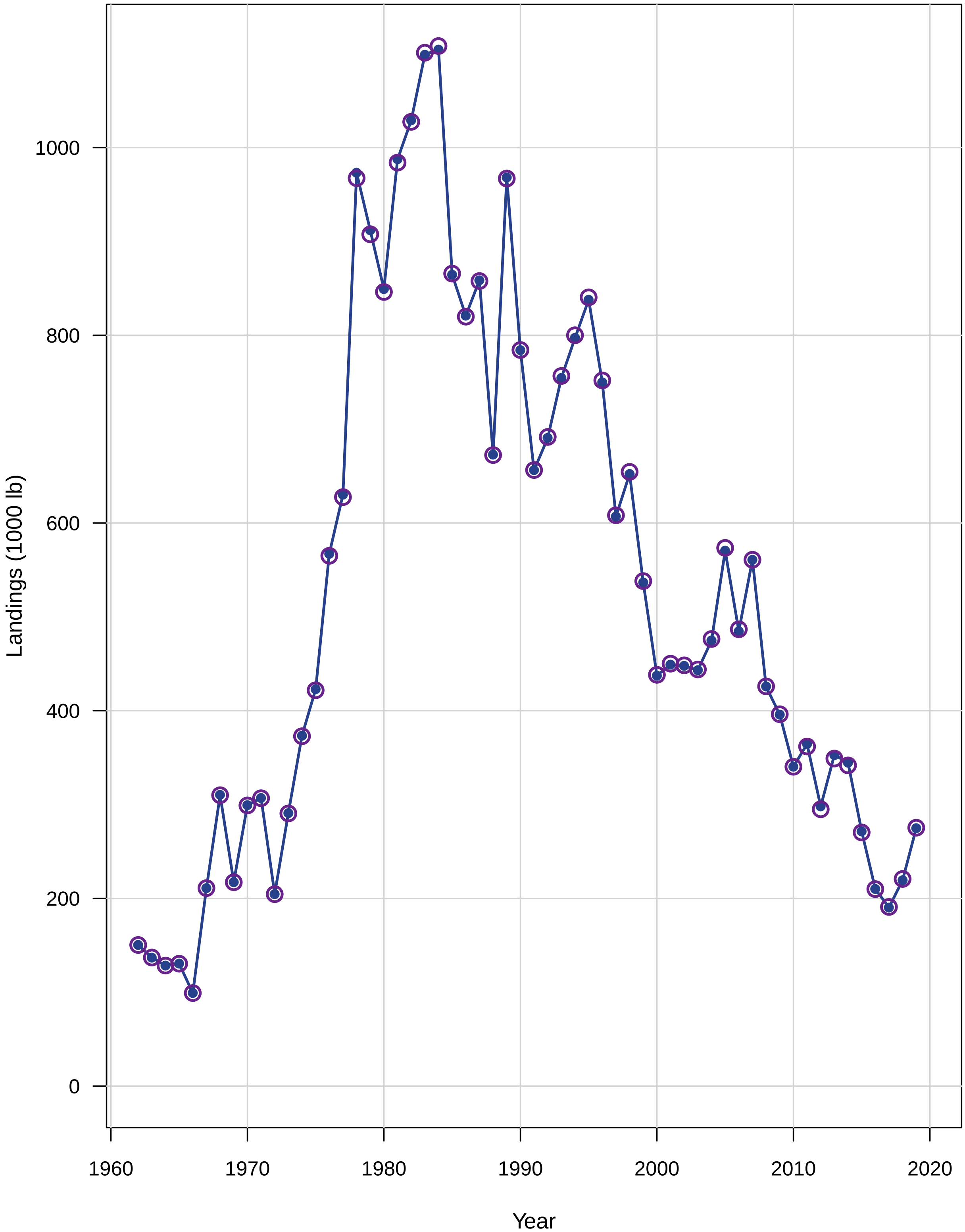


Figure 5. Observed (open circles) and estimated (solid line, circles) commercial diving (1000 lb gutted weight). Open and solid circles may be indistinguishable in years with very close fits.

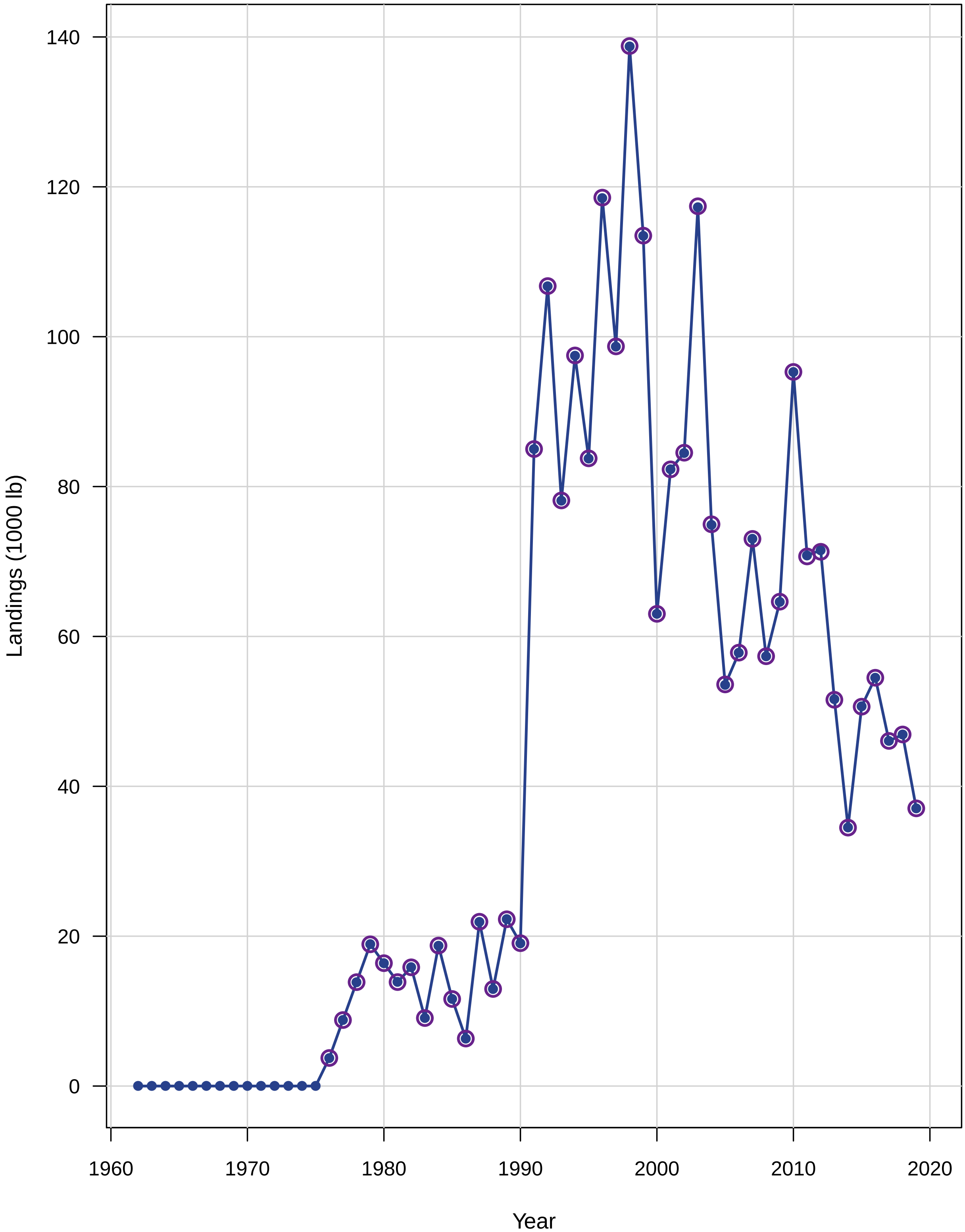


Figure 6. Observed (open circles) and estimated (solid line, circles) headboat landings (1000 fish). Open and solid circles may be indistinguishable in years with very close fits.

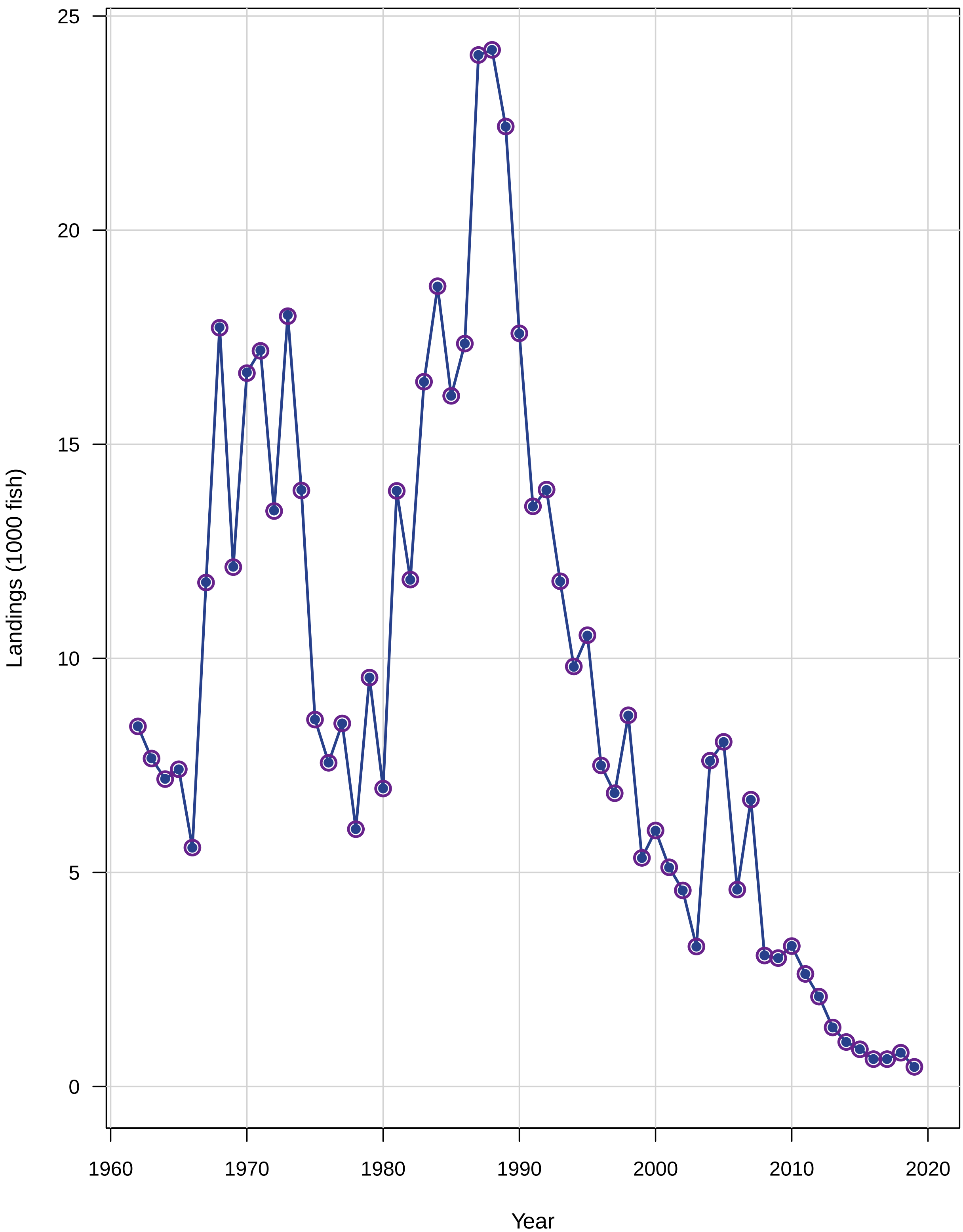


Figure 7. Observed (open circles) and estimated (solid line, circles) general recreational landings (1000 fish). Open and solid circles may be indistinguishable in years with very close fits.

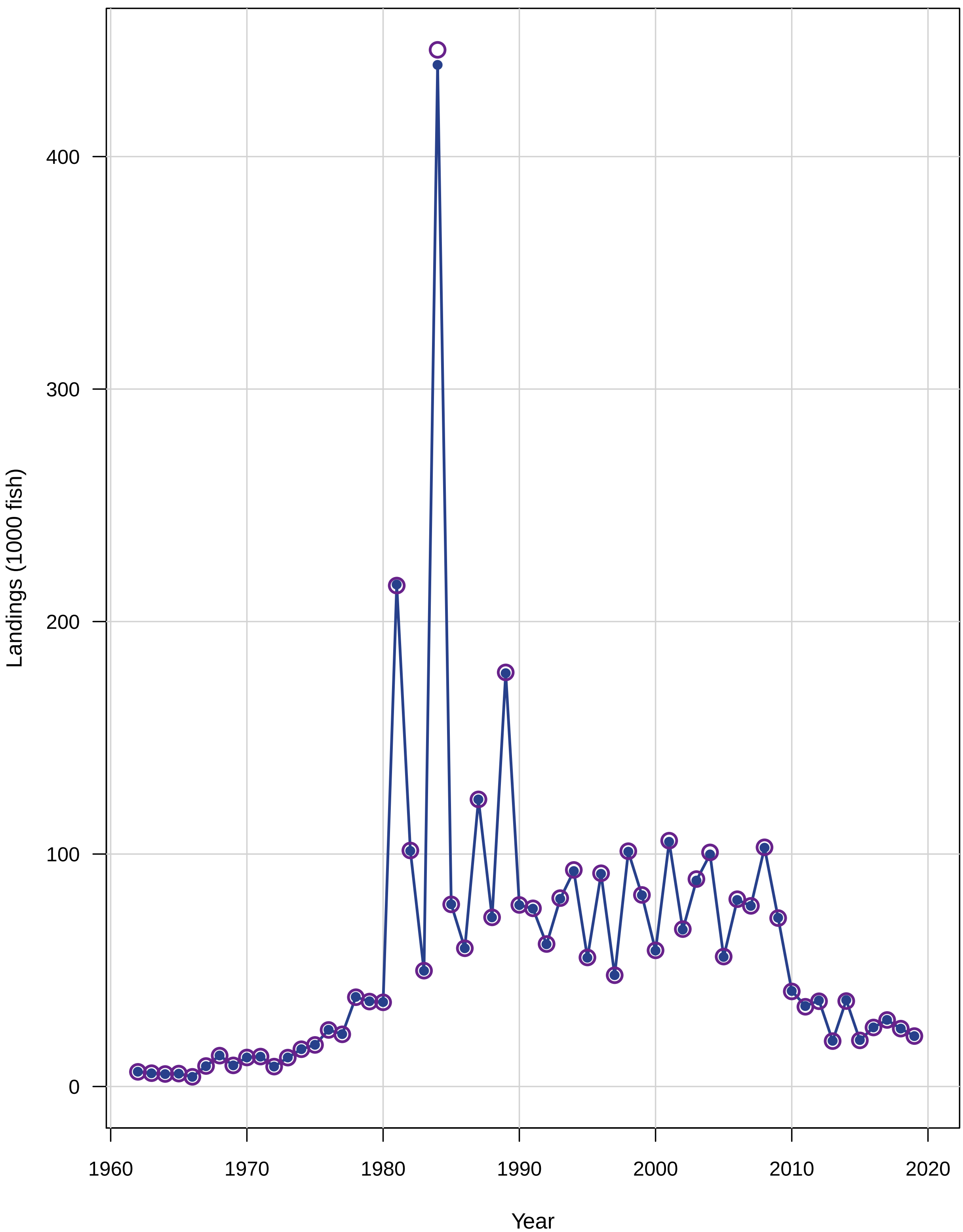


Figure 8. Observed (open circles) and estimated (solid line, circles) commercial handline discard mortalities (1000 dead fish). Open and solid circles may be indistinguishable in years with very close fits.

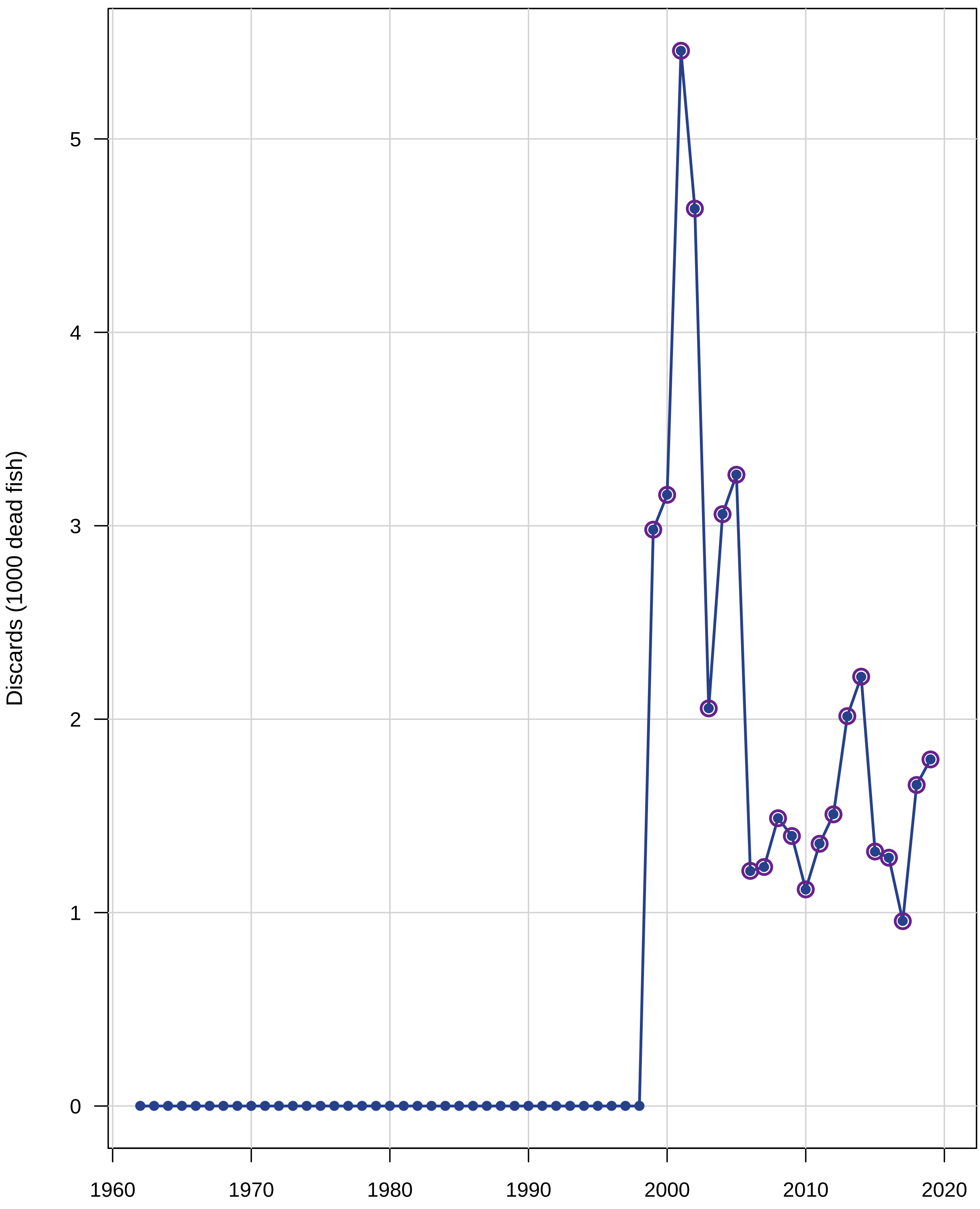


Figure 9. Observed (open circles) and estimated (solid line, circles) headboat discard mortalities (1000 dead fish). Open and solid circles may be indistinguishable in years with very close fits.

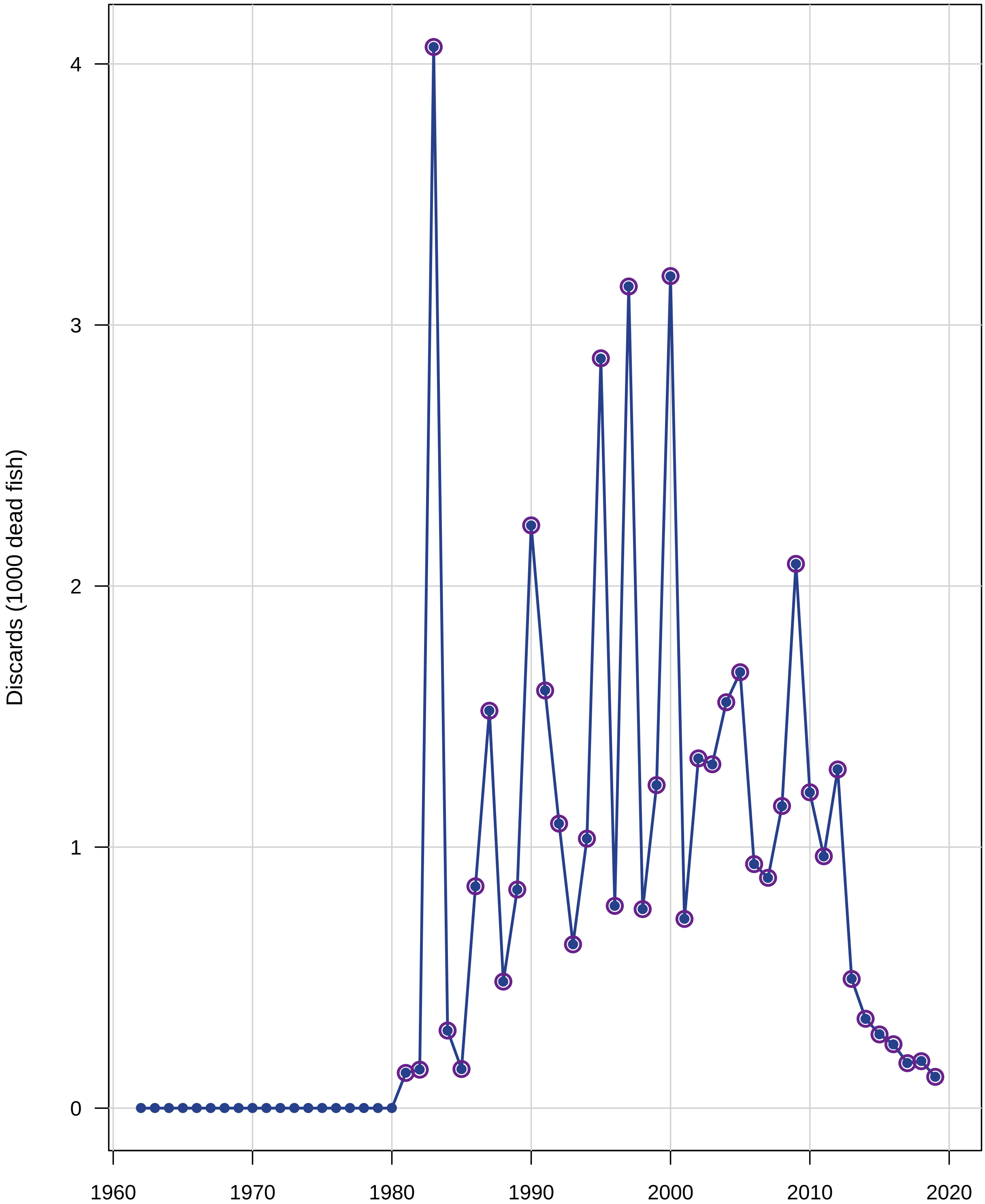


Figure 10. Observed (open circles) and estimated (solid line, circles) general recreational discard mortalities (1000 dead fish). Open and solid circles may be indistinguishable in years with very close fits.

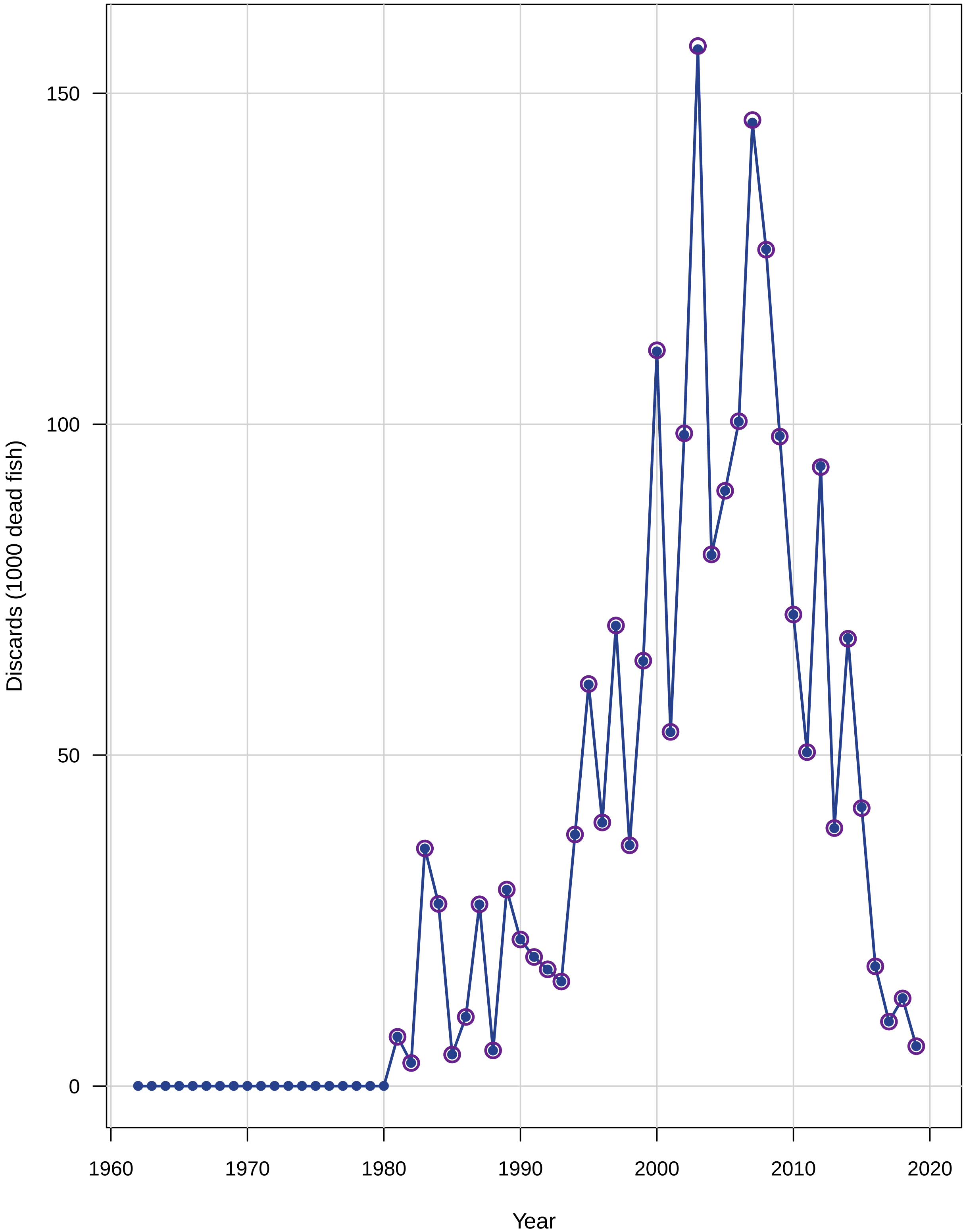


Figure 11. Observed (open circles) and estimated (solid line, circles) index of abundance from headboat. Bottom panel shows the scaled residuals (observed minus predicted divided by the mean residual).

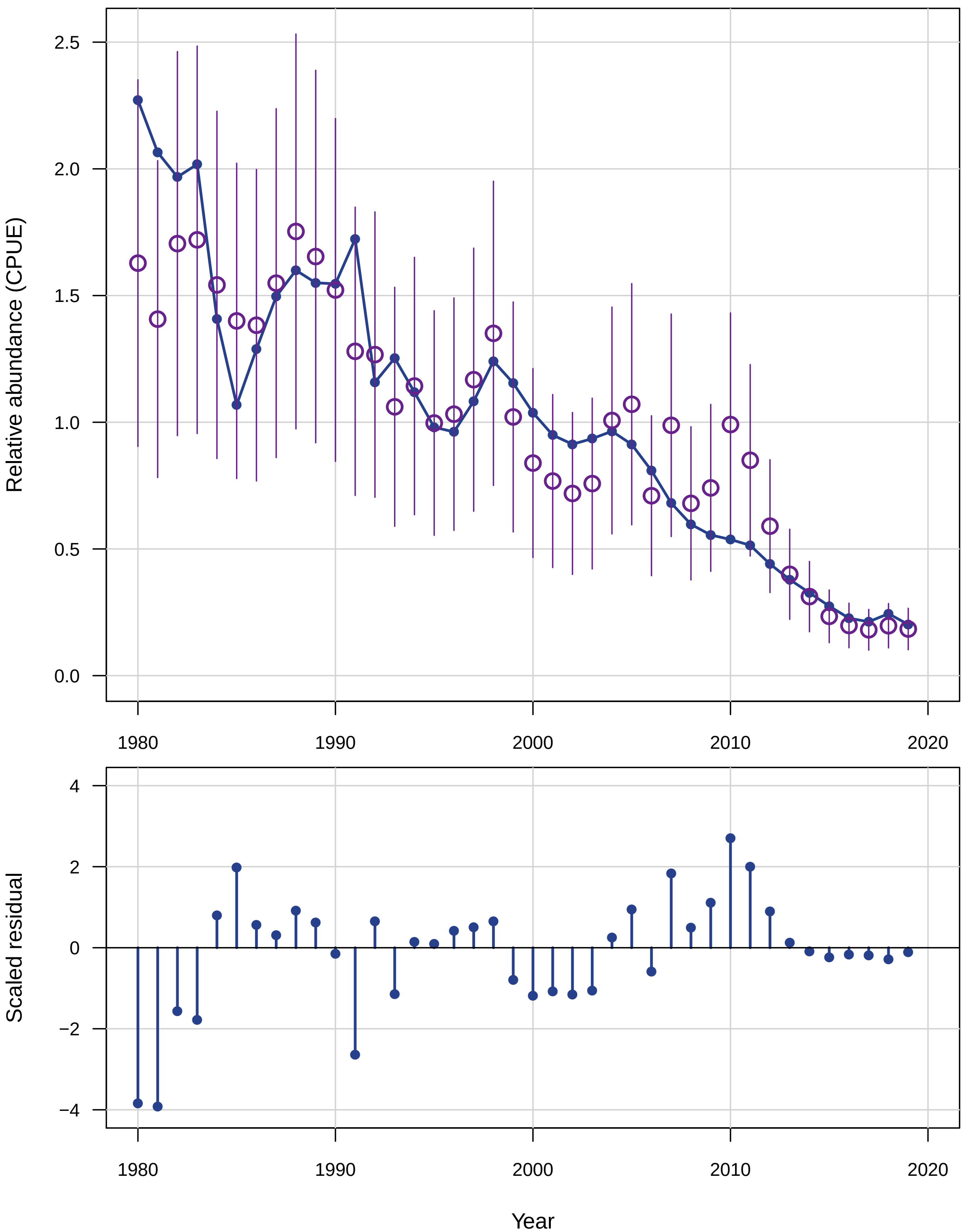


Figure 12. Observed (open circles) and estimated (solid line, circles) index of abundance from SERFS video. Bottom panel shows the scaled residuals (observed minus predicted divided by the mean residual).

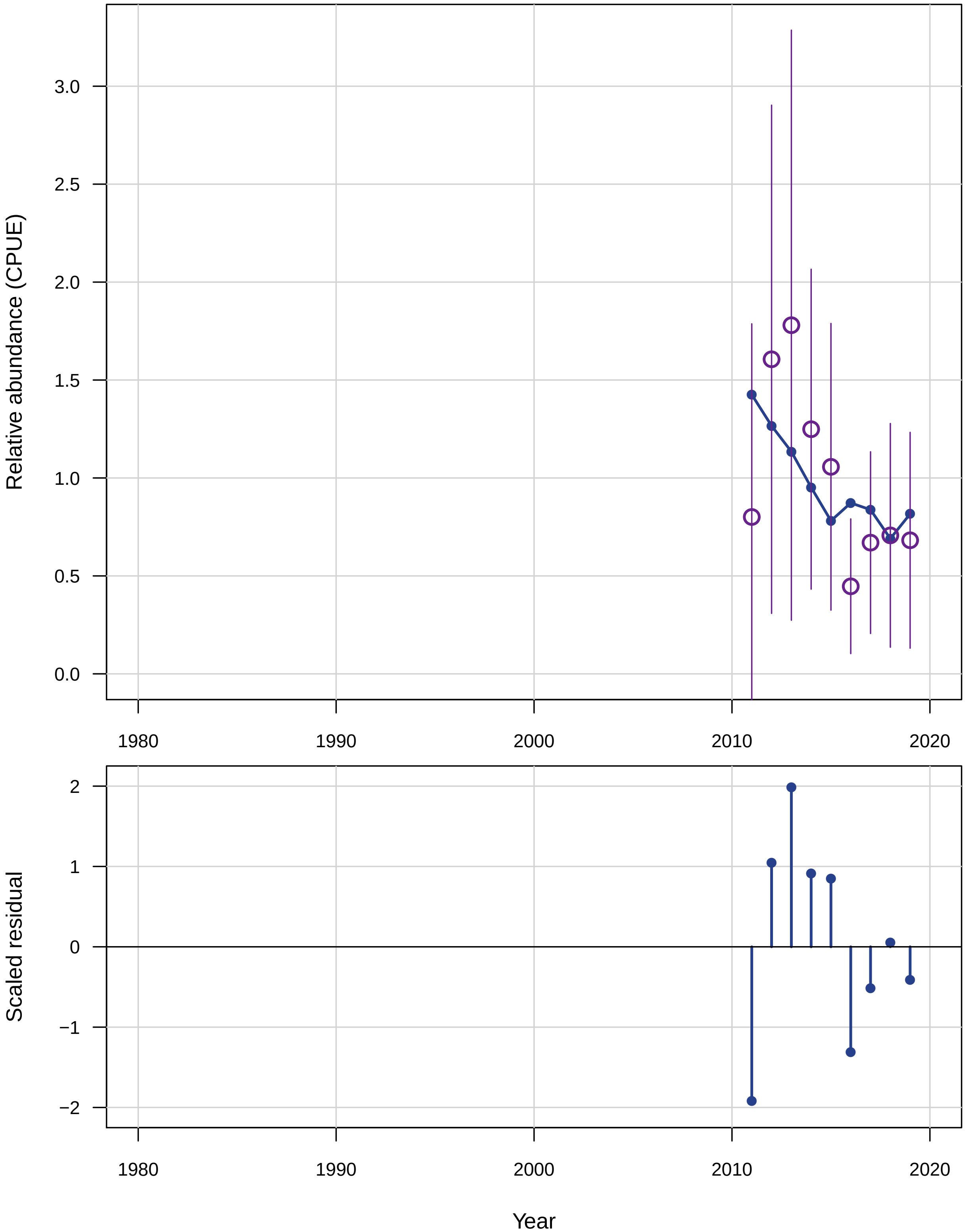


Figure 13. Estimated abundance at age at start of year.

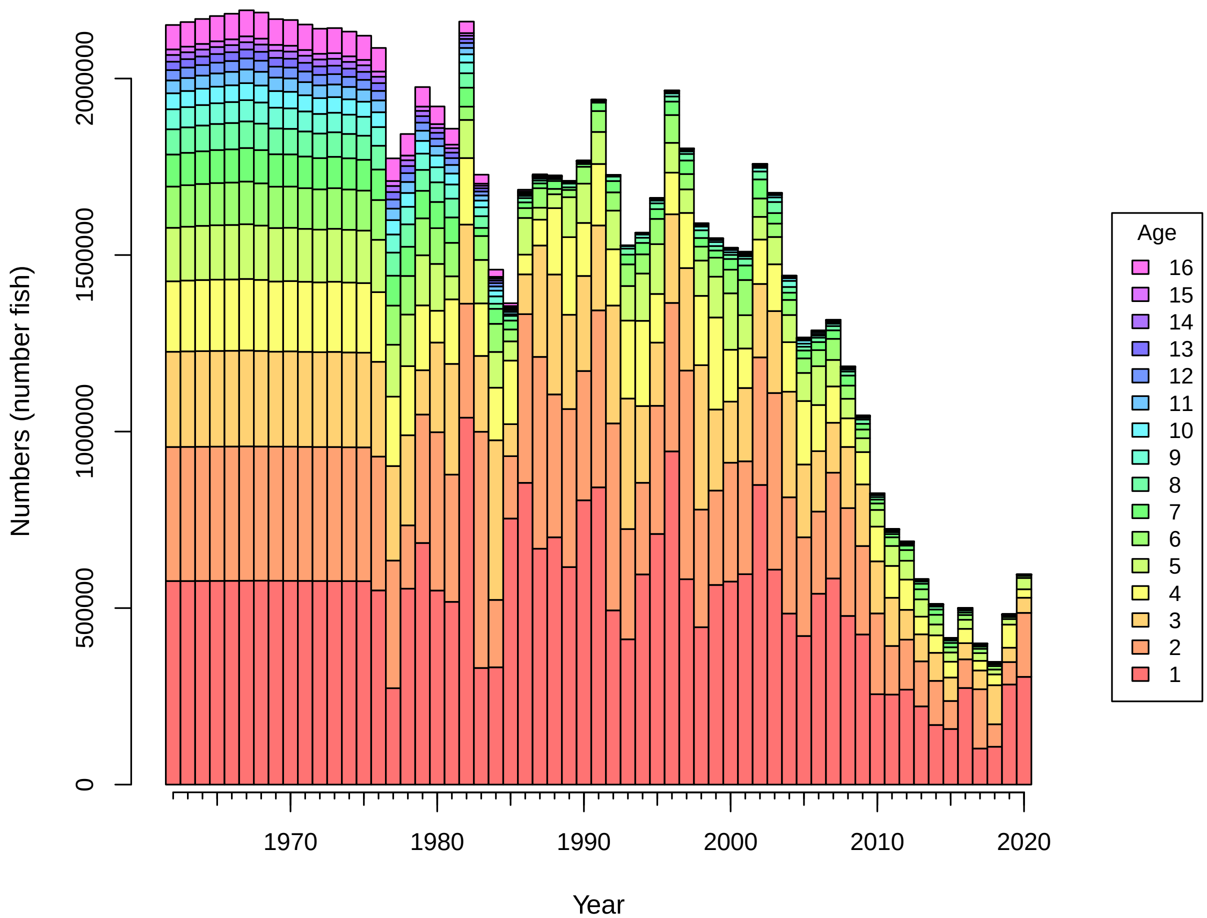


Figure 14. Top panel: Estimated recruitment of age-1 fish. Horizontal dashed line indicates R_{MSY}. Bottom panel: log recruitment deviations (residuals).

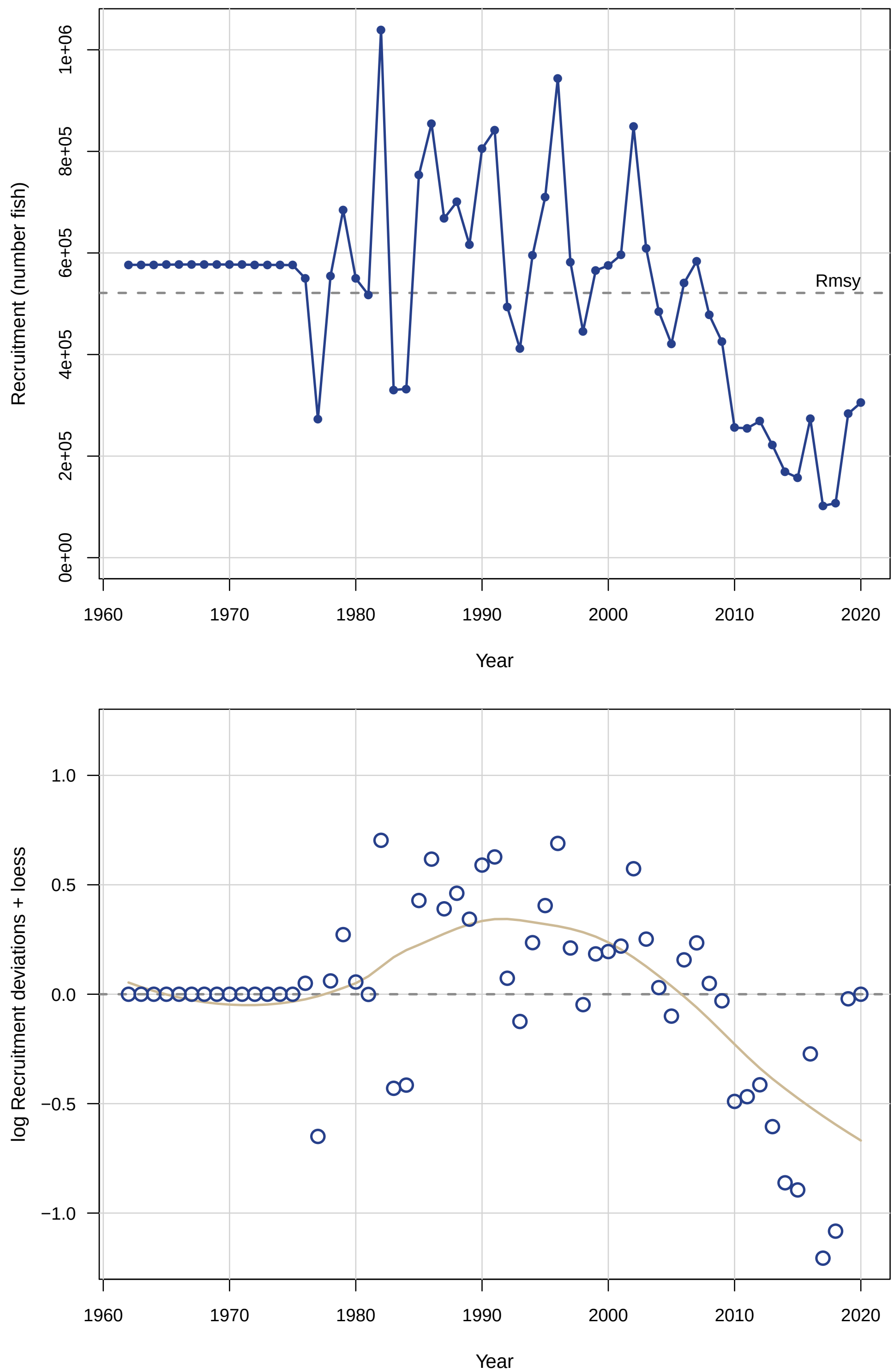


Figure 15. Estimated biomass at age at start of year.

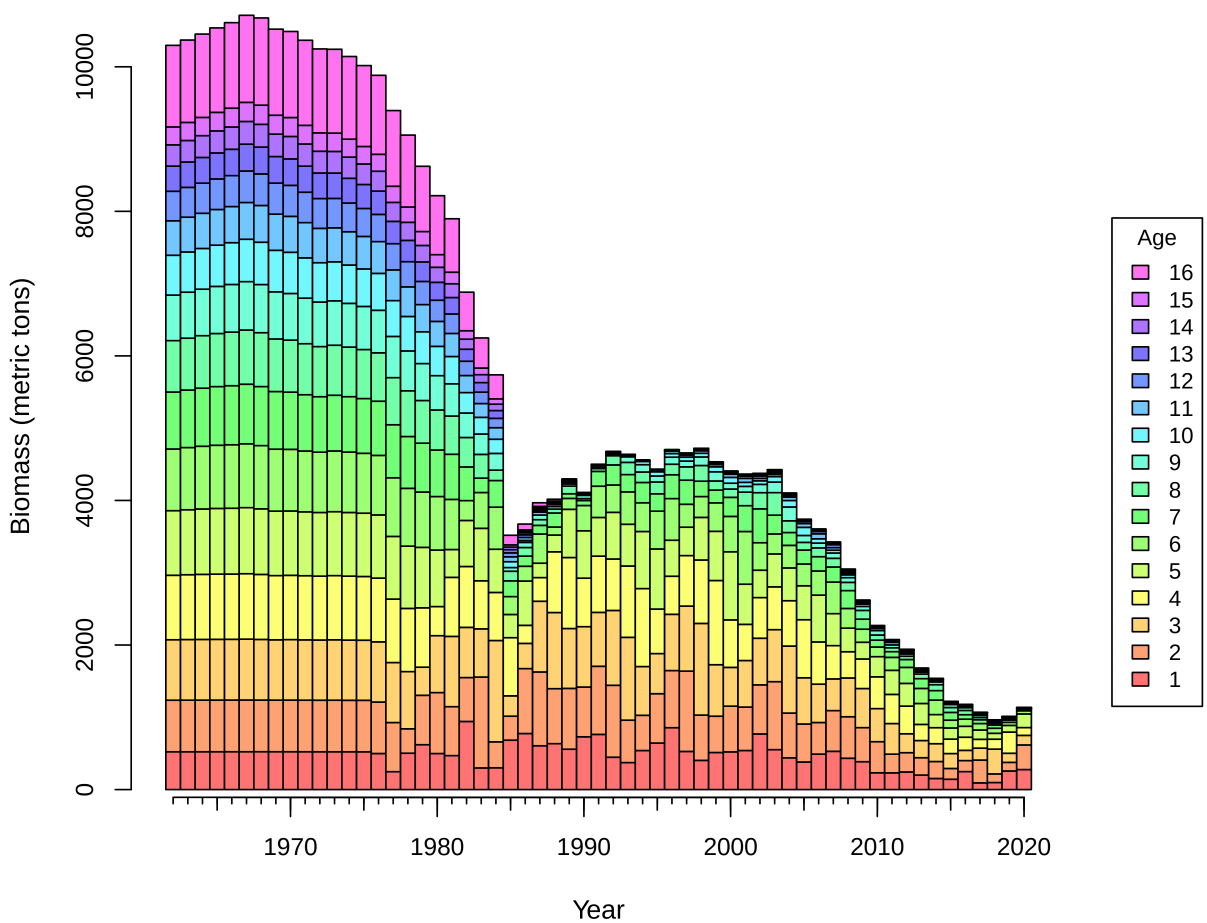


Figure 16. Top panel: Estimated total biomass (mt) at start of year. Horizontal dashed line indicates B_{MSY}*. Bottom panel: Estimated spawning stock (total mature biomass, mt) at start of year, with the horizontal* MSST *line defined as* MSST $= 0.75 \text{SSB}_{MSY}$.

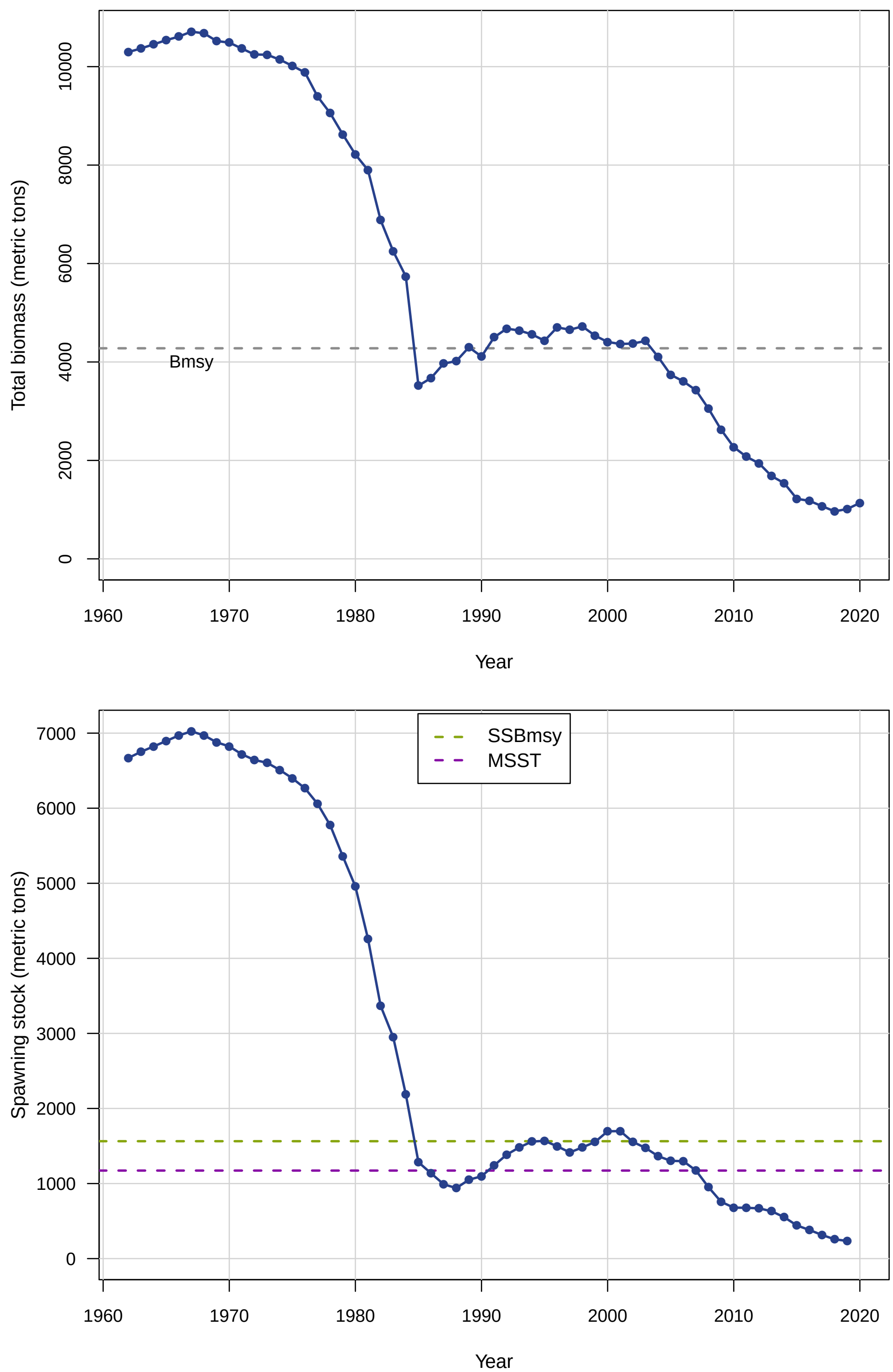
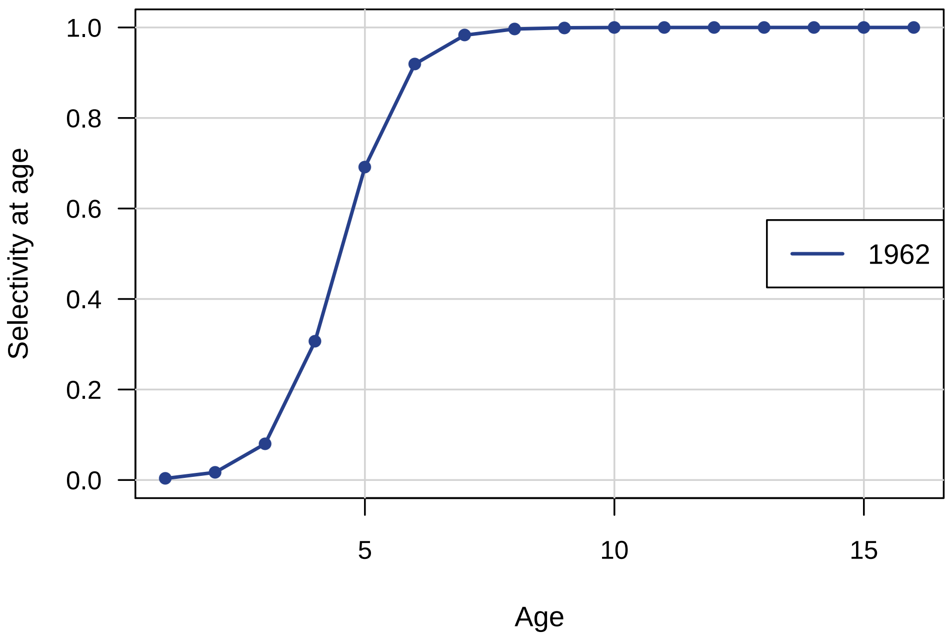


Figure 17. Top panel: Selectivity of commercial handline. Bottom panel: Selectivity of commercial diving. The year indicates the first year of the selectivity block.



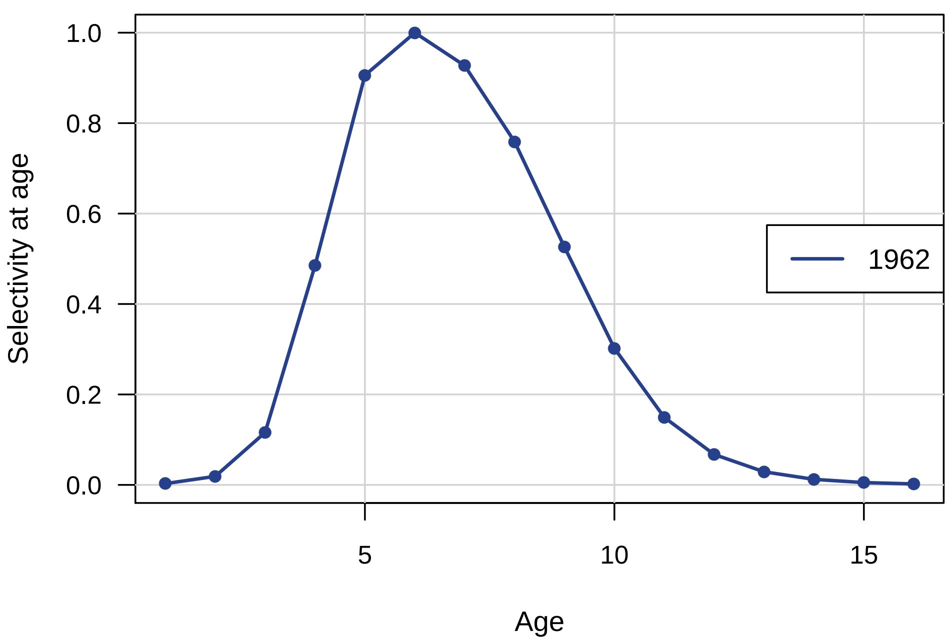


Figure 18. Selectivity of general recreational and headboat fleets. The year indicates the first year of the selectivity block.

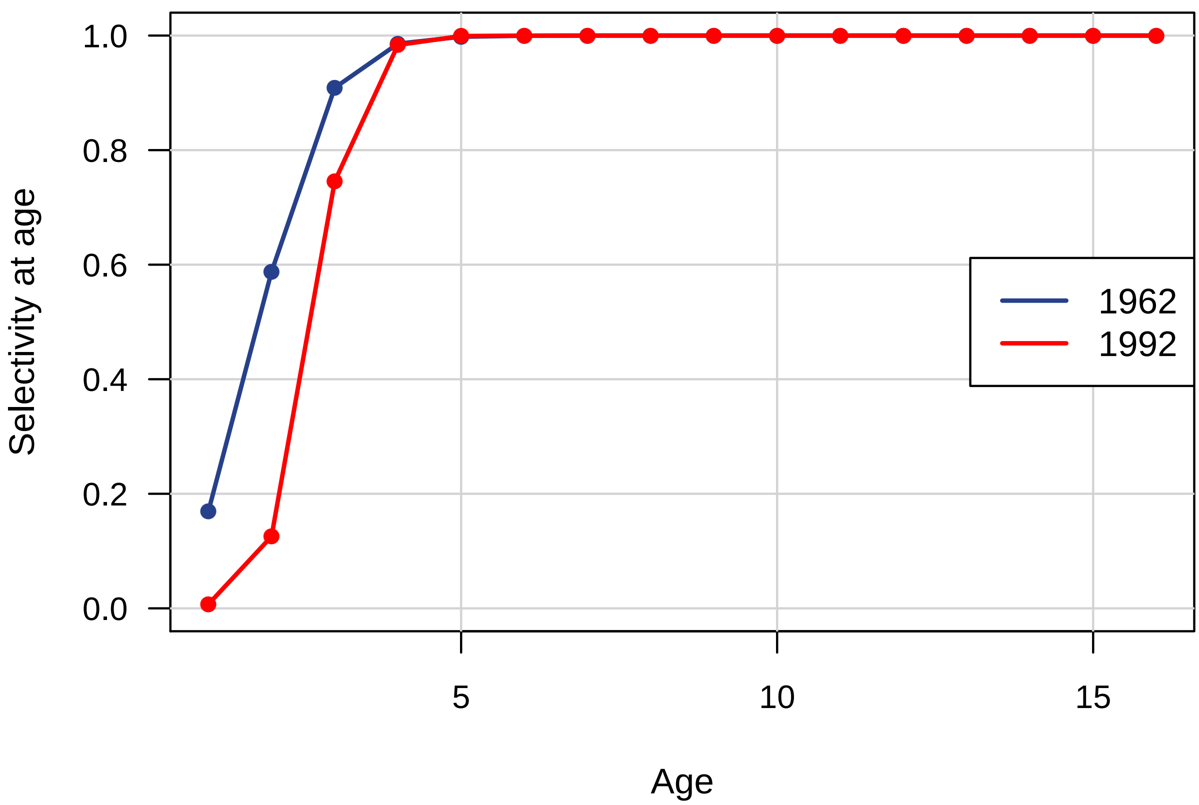


Figure 19. Selectivity of commercial and recreational discard mortalities. The year indicates the first year of the selectivity block.

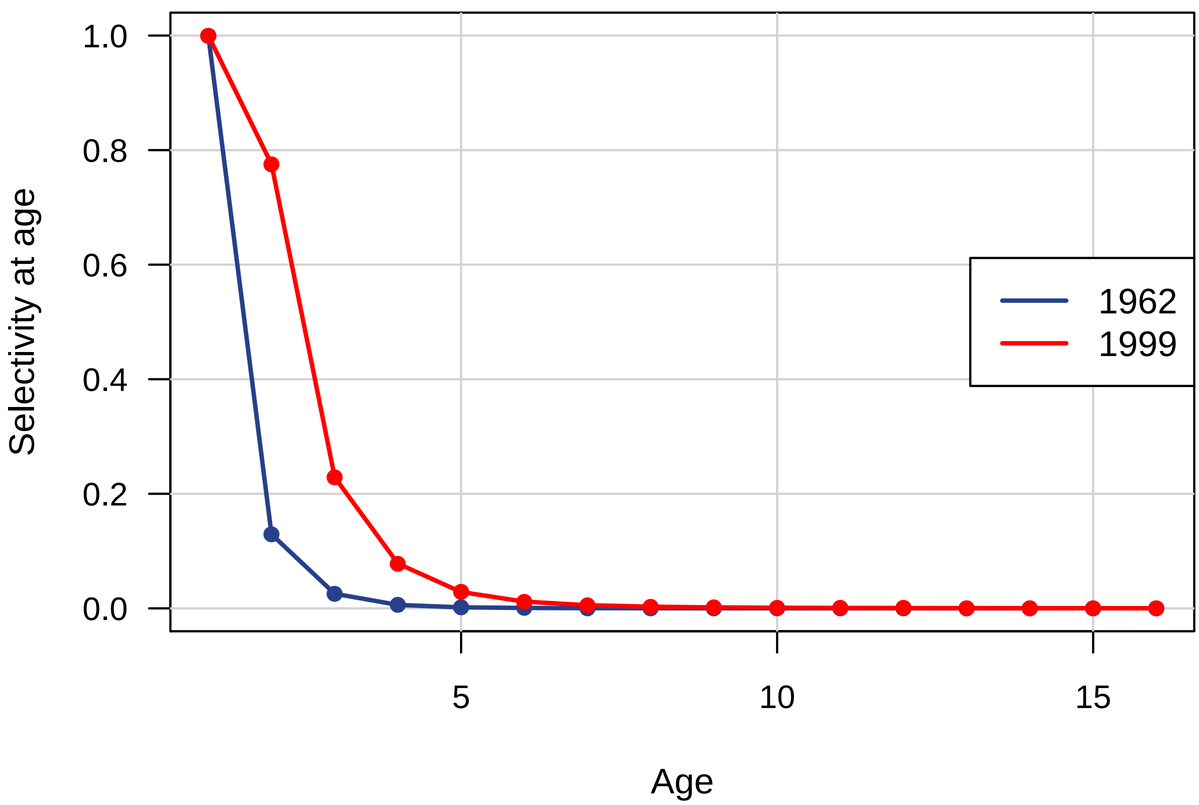


Figure 20. Average selectivities from the terminal assessment years, weighted by geometric mean Fs from the last three assessment years, and used in computation of benchmarks and projections. Top panel: average selectivity applied to landings. Middle panel: average selectivity applied to discard mortalities. Bottom panel: total average selectivity.

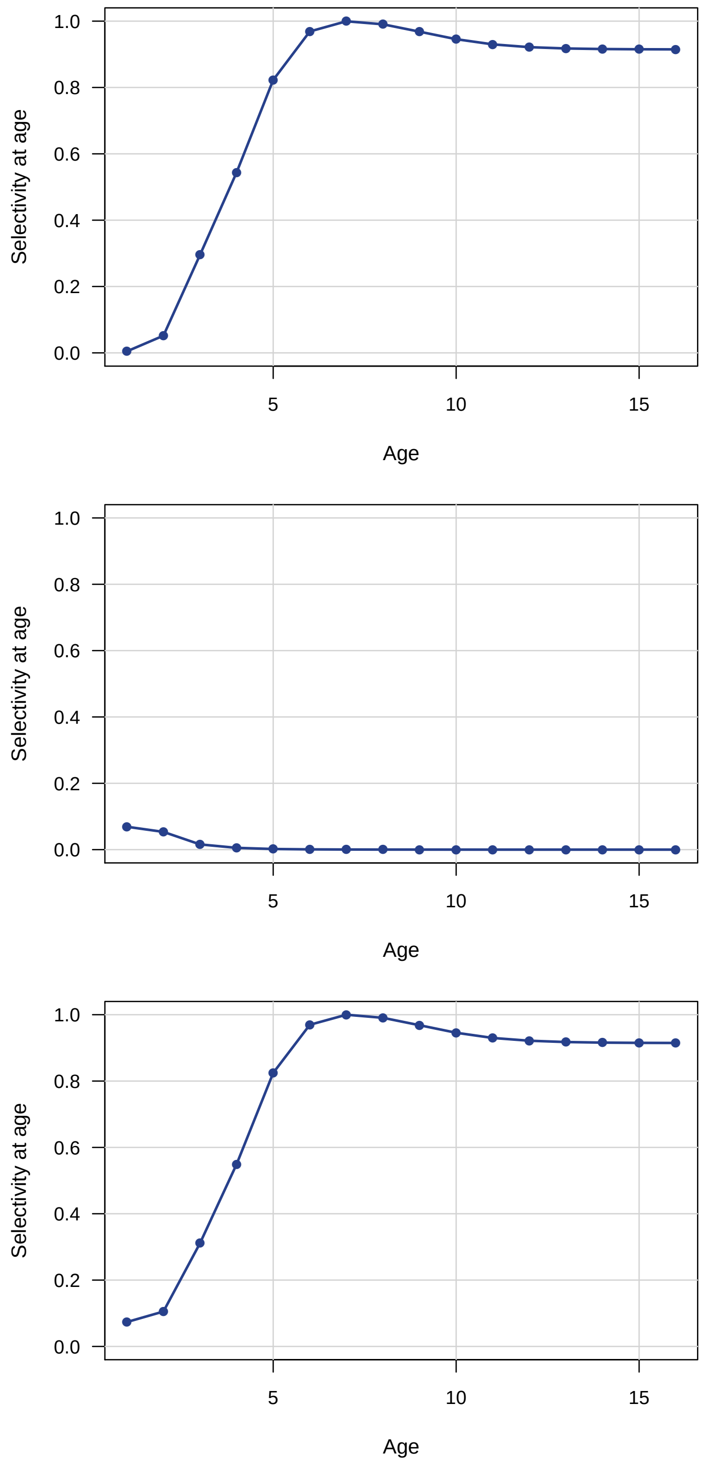
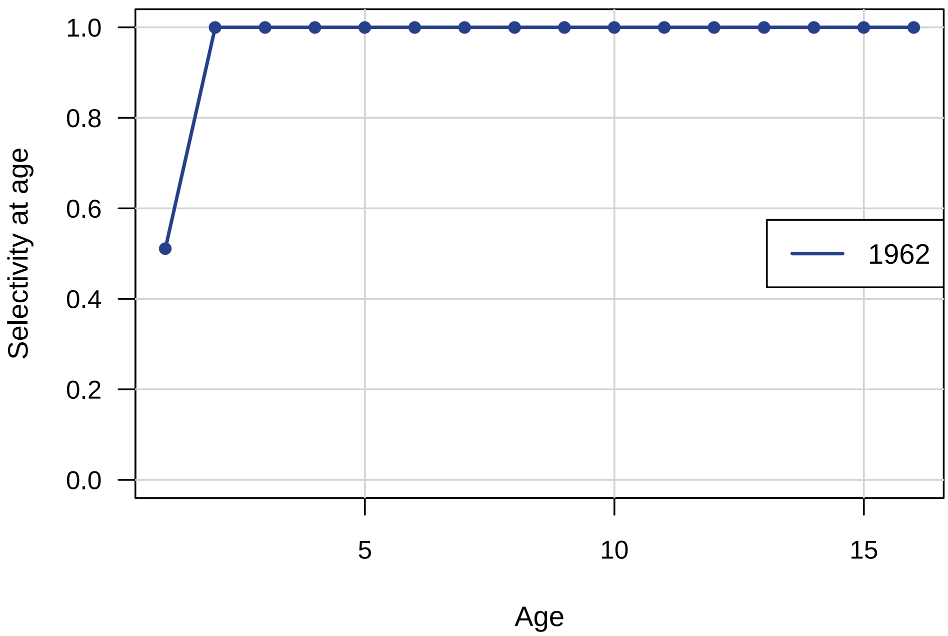


Figure 21. Top panel: Selectivity of SERFS video index. Bottom panel: Selectivity of the SERFS chevron trap. The year indicates the first year of the selectivity block.



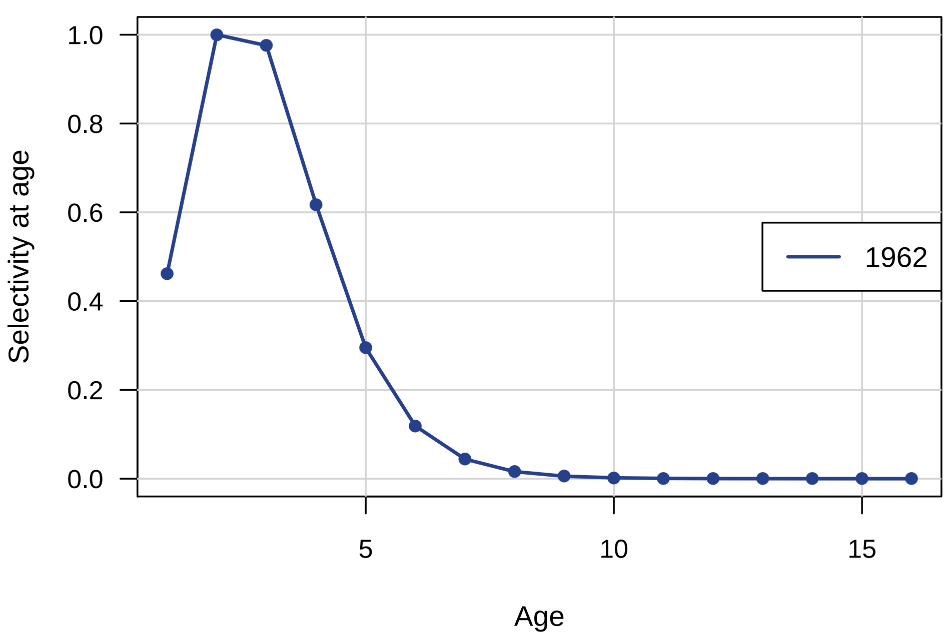


Figure 22. Estimated fully selected fishing mortality rate (per year) by fleet. cH refers to commercial handlines, cD to commercial diving, HB to headboat, GR to general recreational, cH.D to commercial discard mortalities, HB.D to headboat discard mortalities, and GR.D to general recreational discard mortalities.

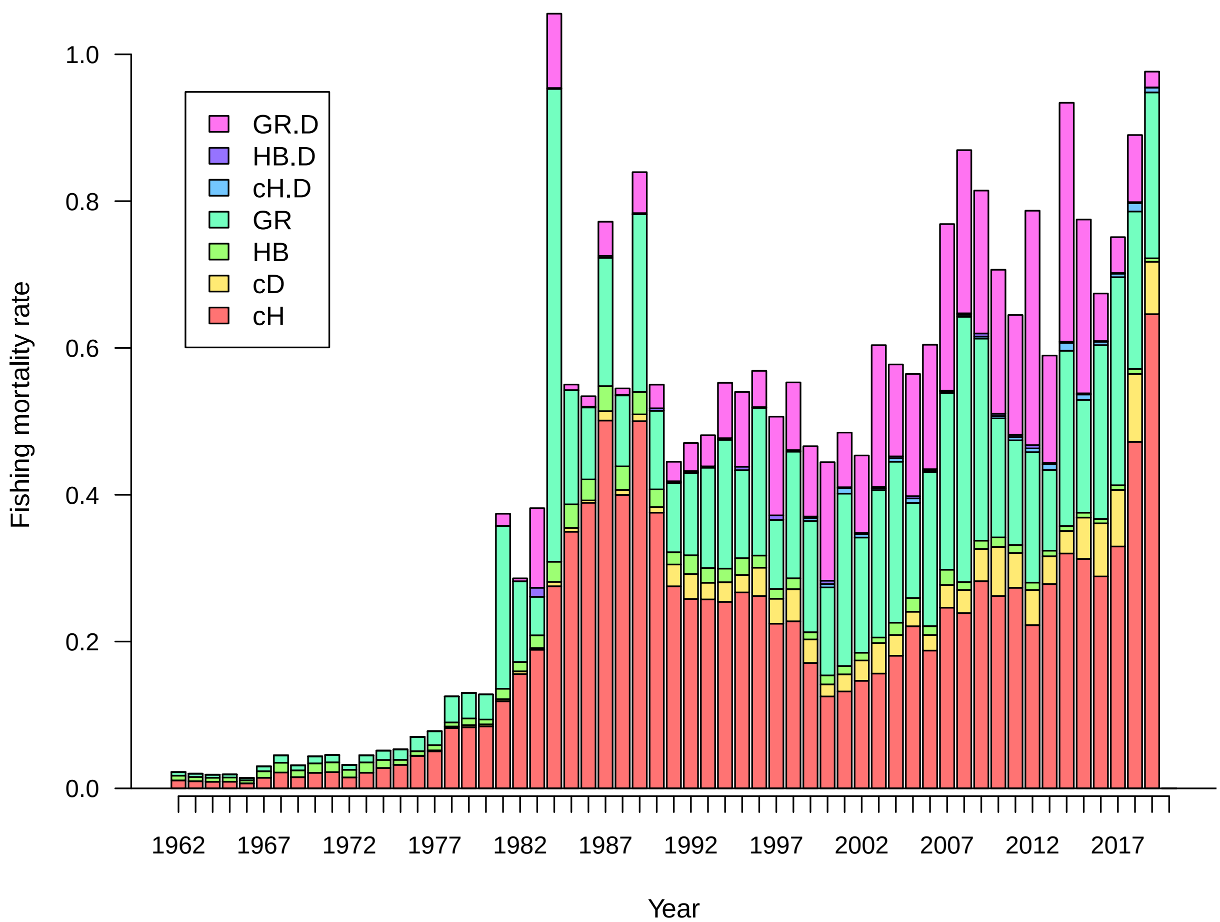


Figure 23. Estimated landings in numbers by fleet from the catch-age model. cH refers to commercial handlines, cD to commercial diving, HB to headboat, GR to general recreational.

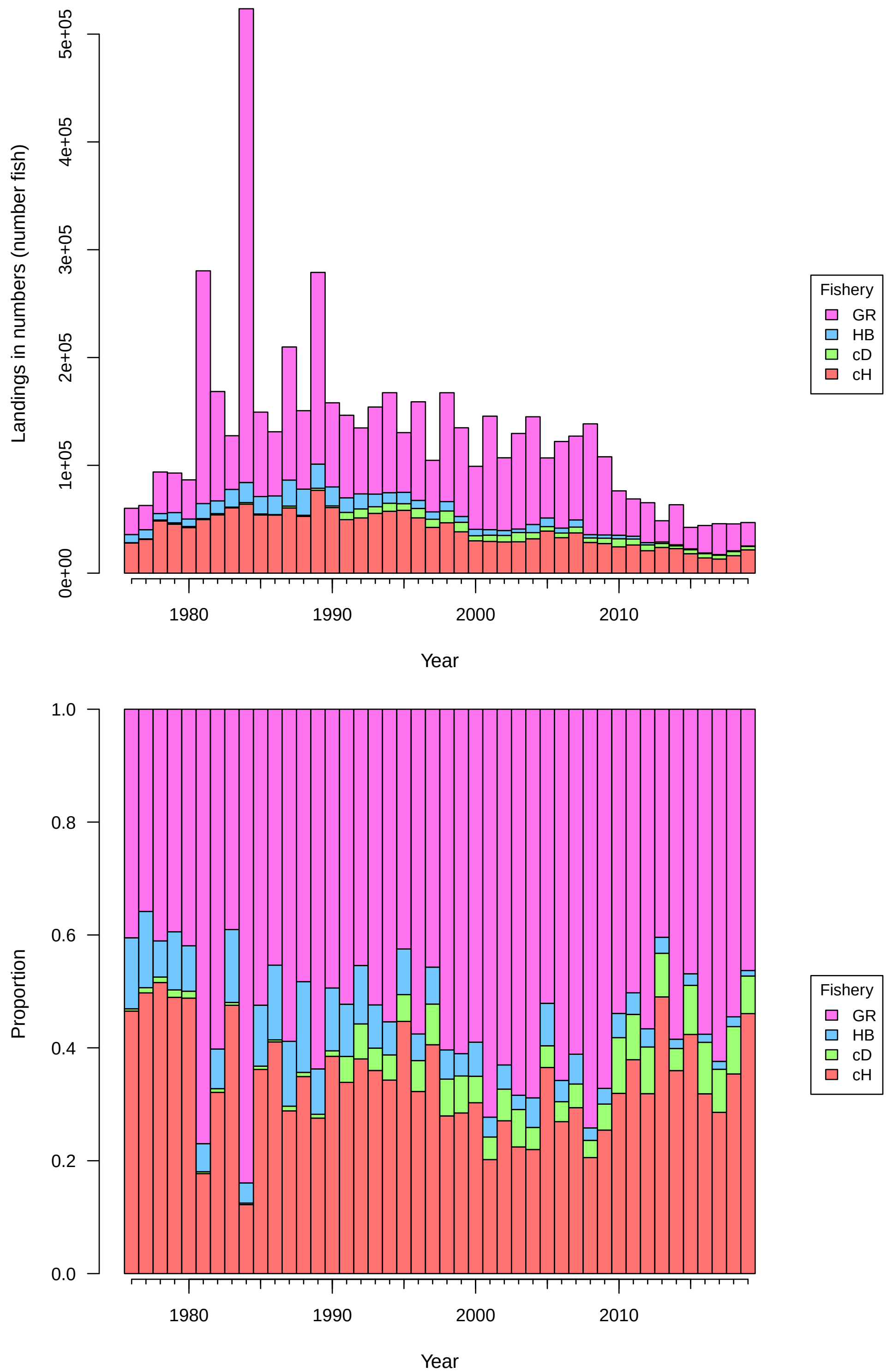


Figure 24. Estimated landings in gutted weight by fleet from the catch-age model. cH refers to commercial handlines, cD to commercial diving, HB to headboat, GR to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of MSY.

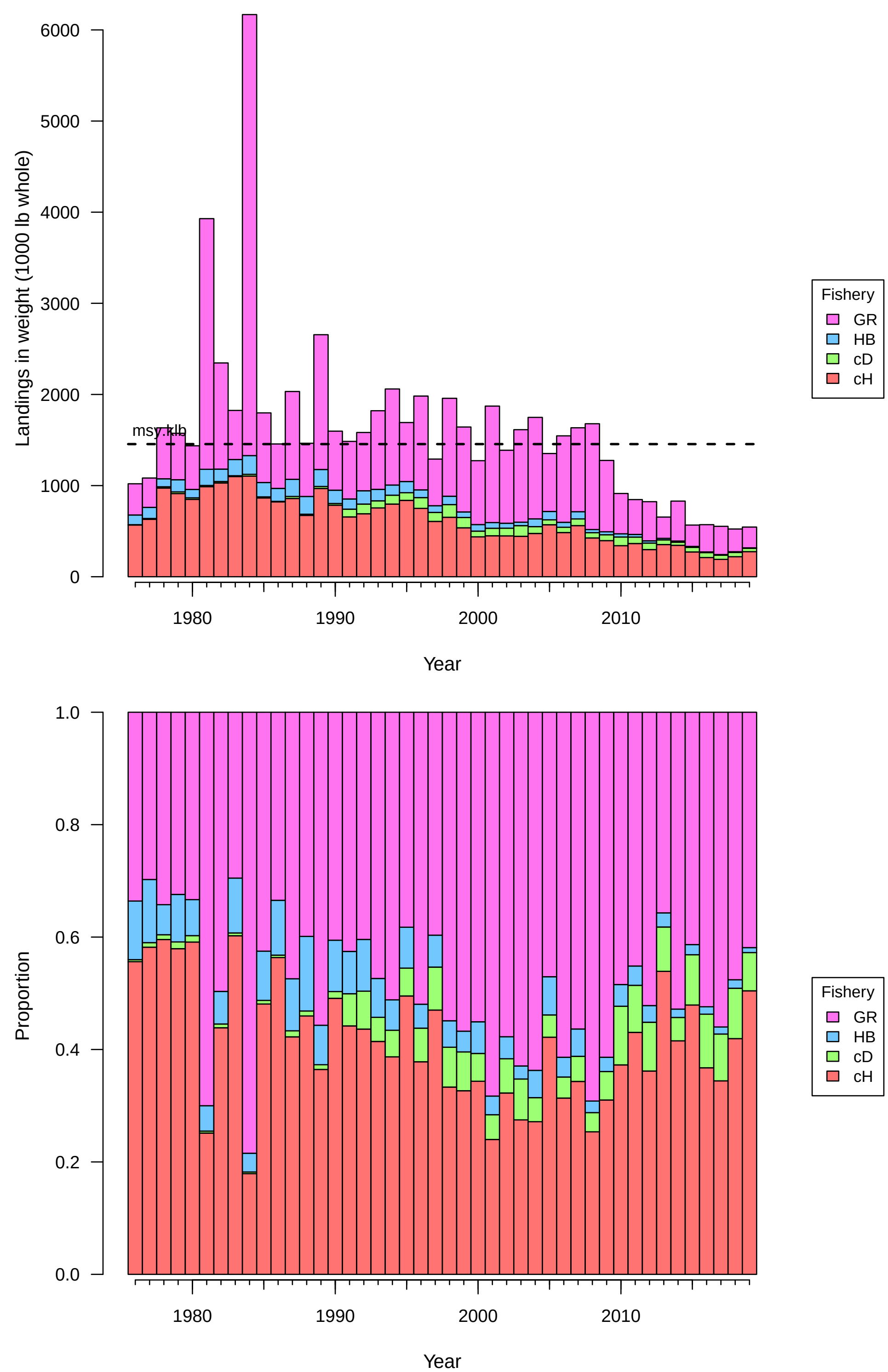


Figure 25. Estimated discard mortalities in numbers by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, GR to general recreational.

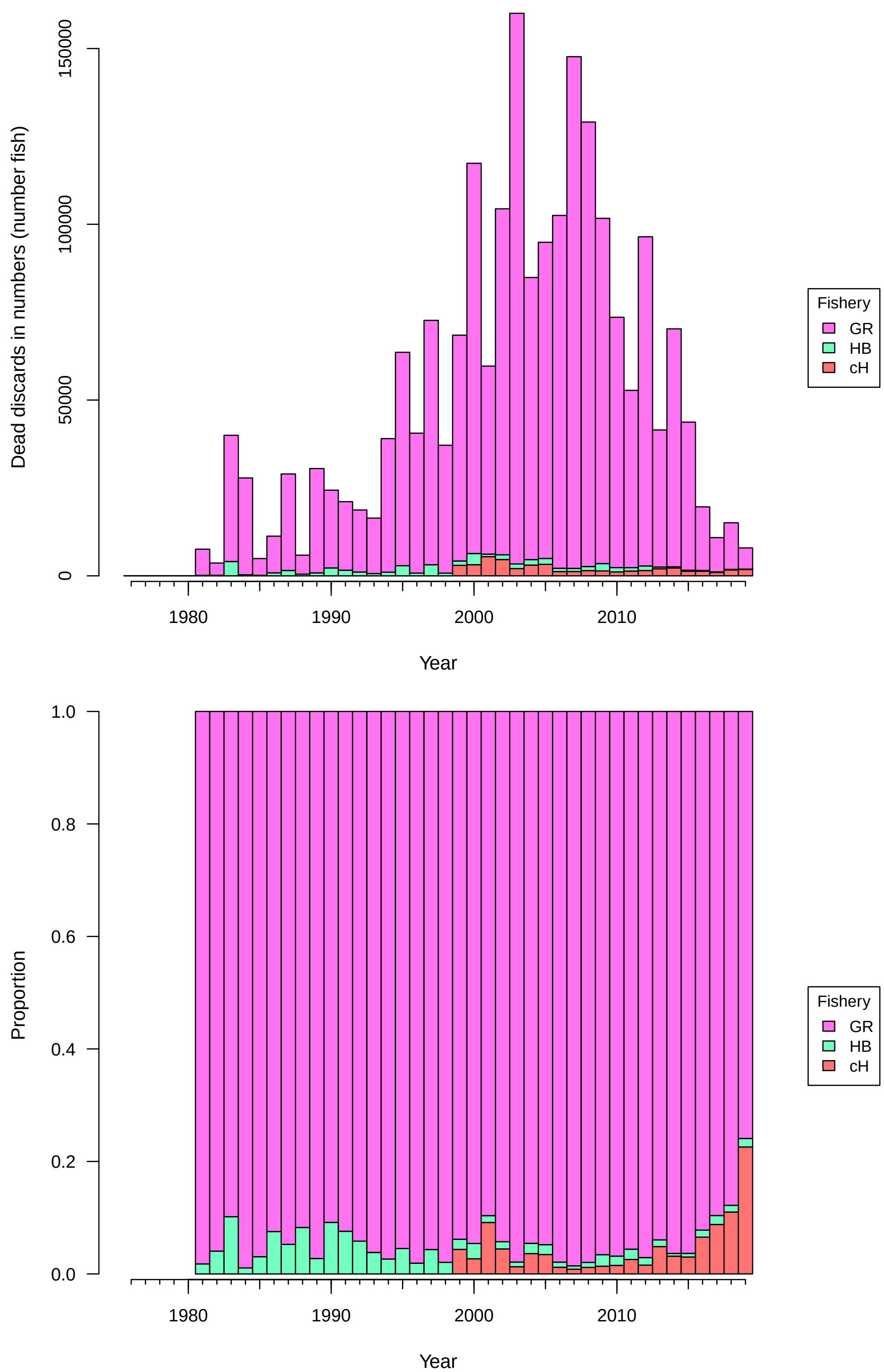


Figure 26. Estimated discard mortalities in gutted weight by fleet from the catch-age model. cH refers to commercial handlines, HB to headboat, GR to general recreational.

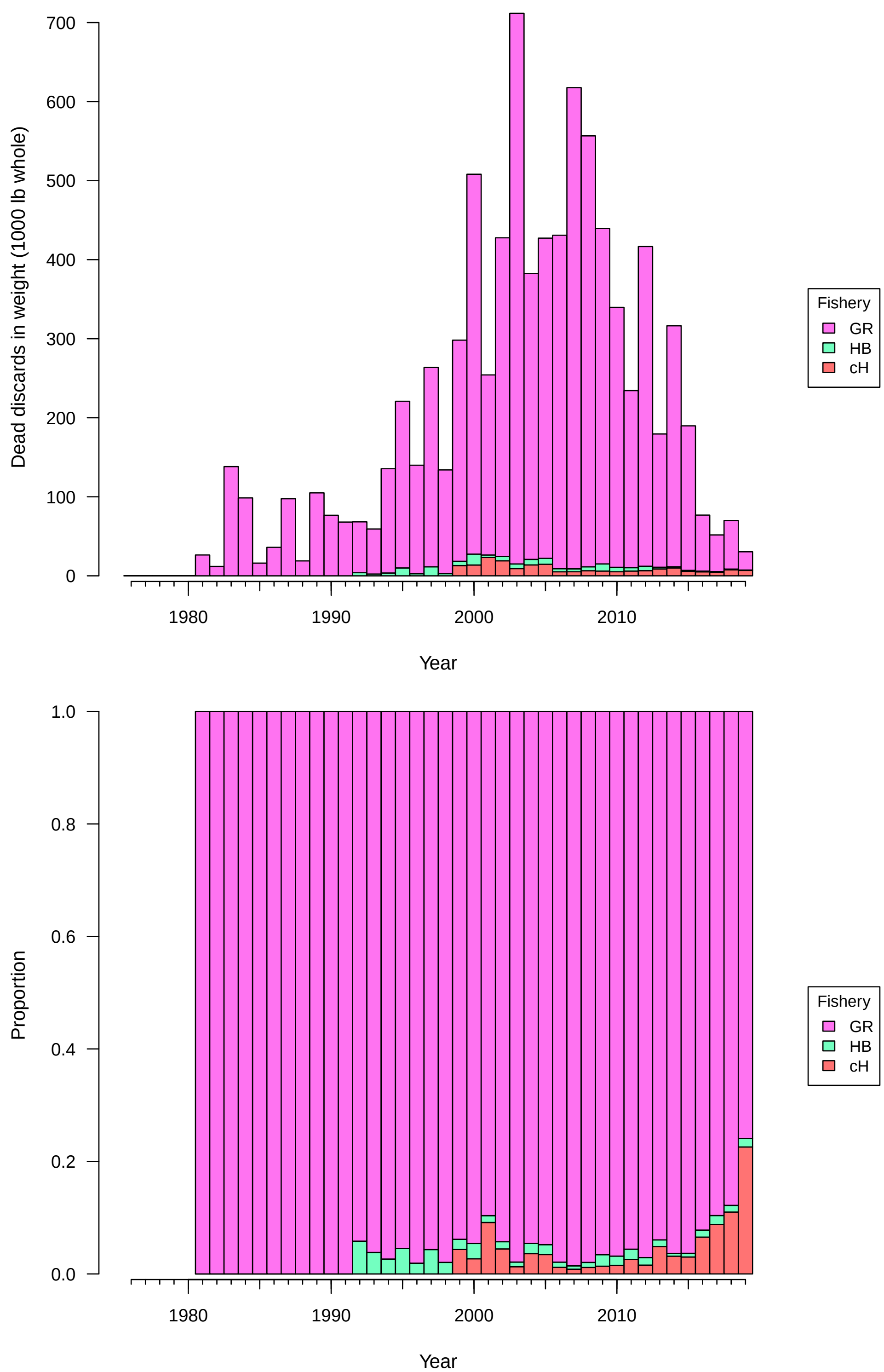


Figure 27. Top panel: Beverton–Holt spawner-recruit curves, with and without lognormal bias correction. The expected (upper) curve was used for computing management benchmarks. Bottom panel: log of recruits (number age-1 fish) per spawner as a function of spawners.

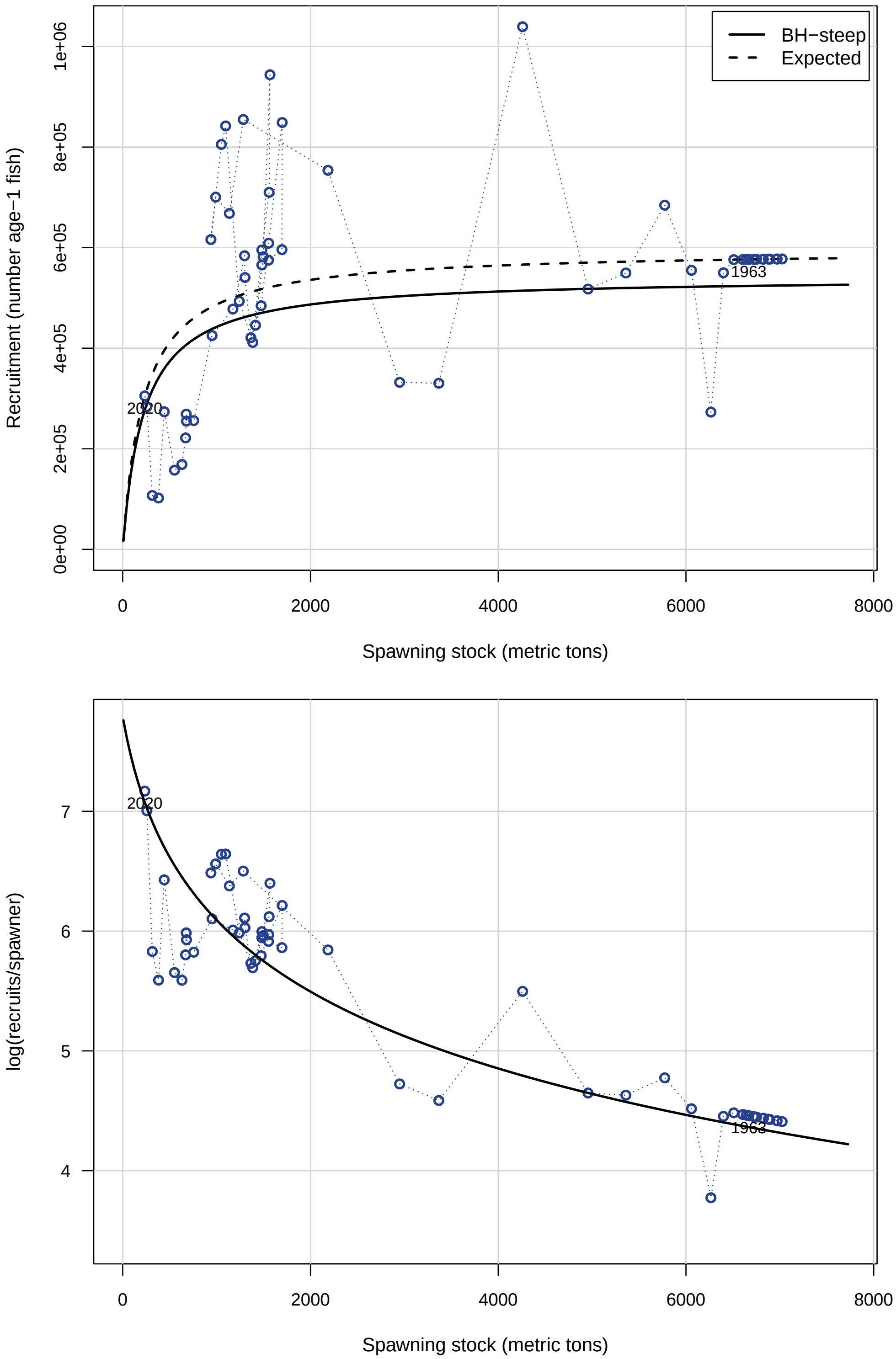


Figure 28. Probability densities of spawner-recruit quantities R0 (unfished recruitment of age-1 fish), steepness, unfished spawners per recruit, and standard deviation of recruitment residuals in log space. Solid vertical lines represent point estimates or values from the base run of the Beaufort Assessment Model; dashed vertical lines represent medians from the MCB runs.

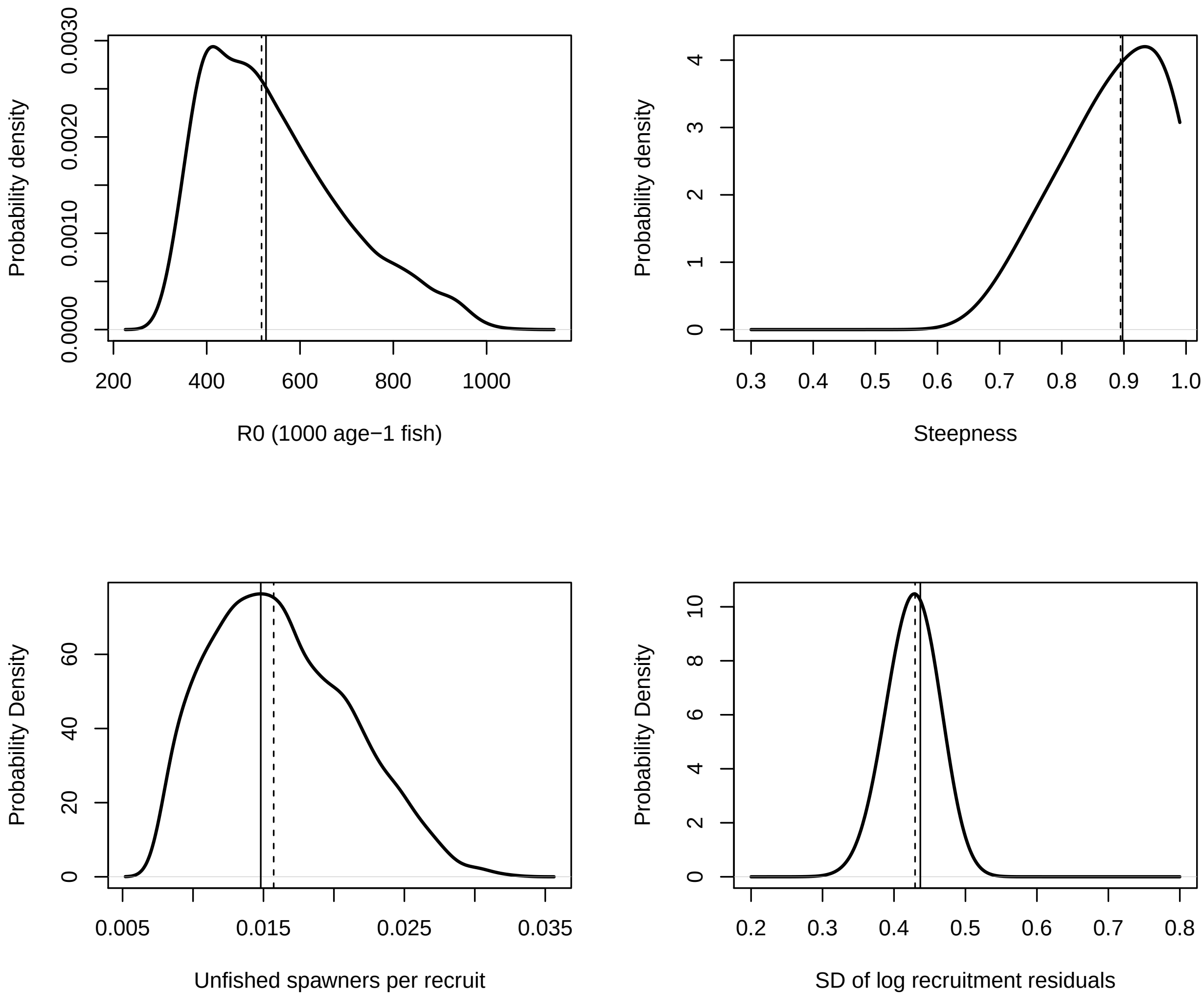


Figure 29. Top panel: yield per recruit. Bottom panel: spawning potential ratio (spawning biomass per recruit relative to that at the unfished level), from which the X% level of SPR provides $F_{X\%}$. Both curves are based on average selectivity from the end of the assessment period.

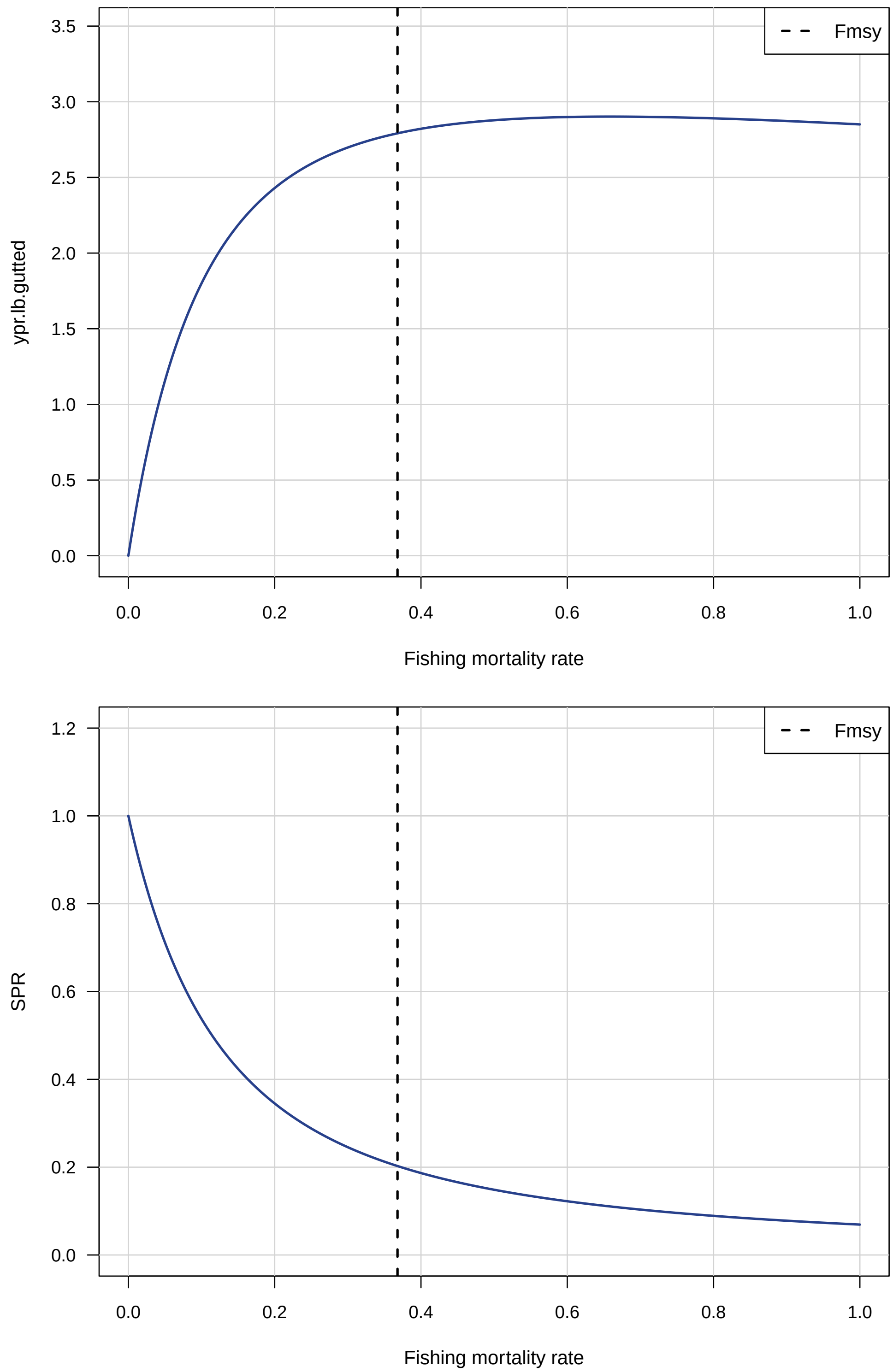


Figure 30. Top panel: equilibrium landings. The peak occurs where fishing rate is $F_{\mathrm{MSY}} = 0.37$ *and equilibrium landings are* MSY = 1455.1 *(1000 lb gutted). Bottom panel: equilibrium spawning biomass. Both curves are based on average selectivity from the end of the assessment period.*

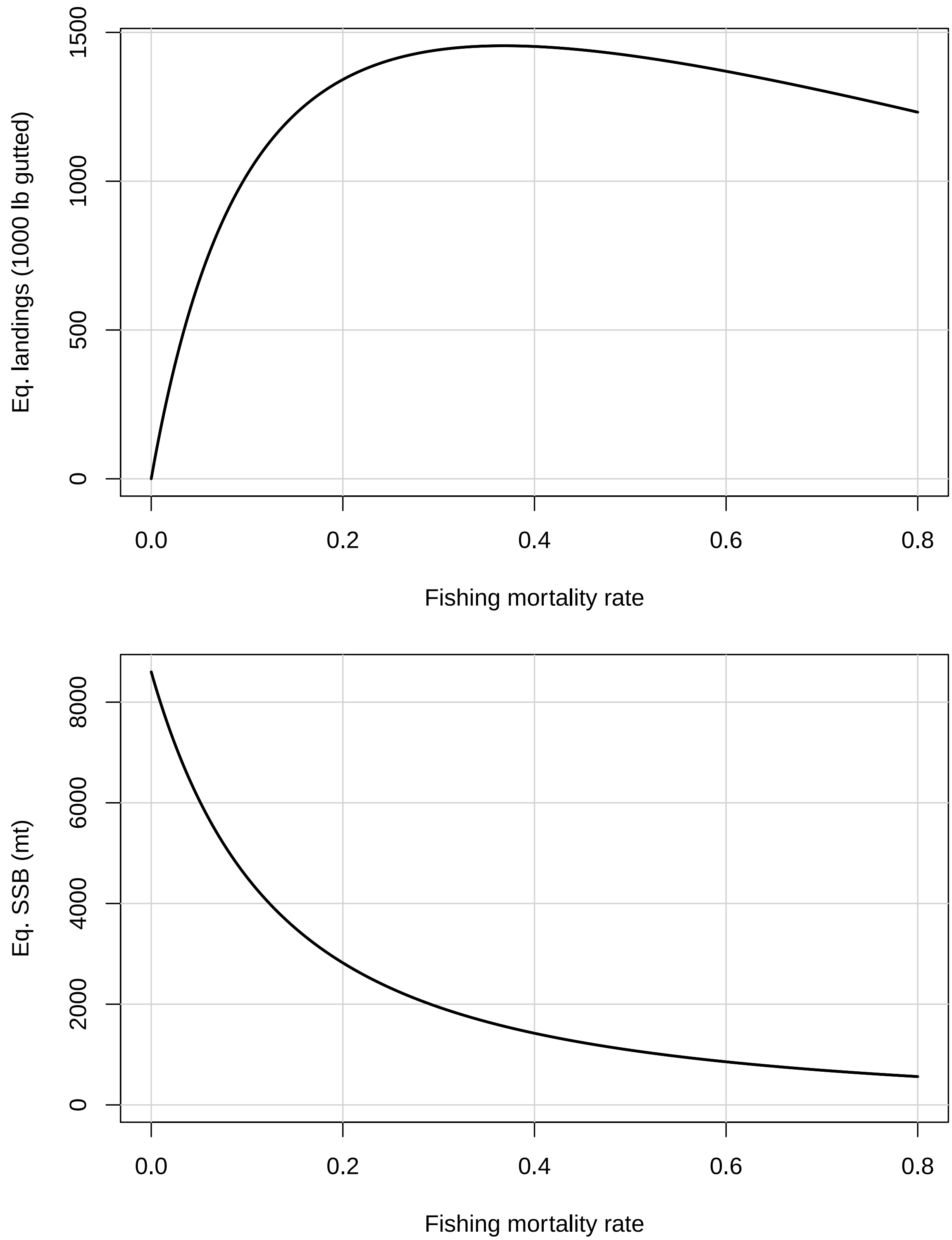


Figure 31. Top panel: equilibrium landings as a function of equilibrium biomass, which itself is a function of fishing mortality rate. The peak occurs where equilibrium biomass is $B_{\mathrm{MSY}} = 4278.4$ *mt and equilibrium landings are* $\mathrm{MSY} = 1455.1$ *(1000 lb gutted). Bottom panel: equilibrium discard mortality as a function of equilibrium biomass.*

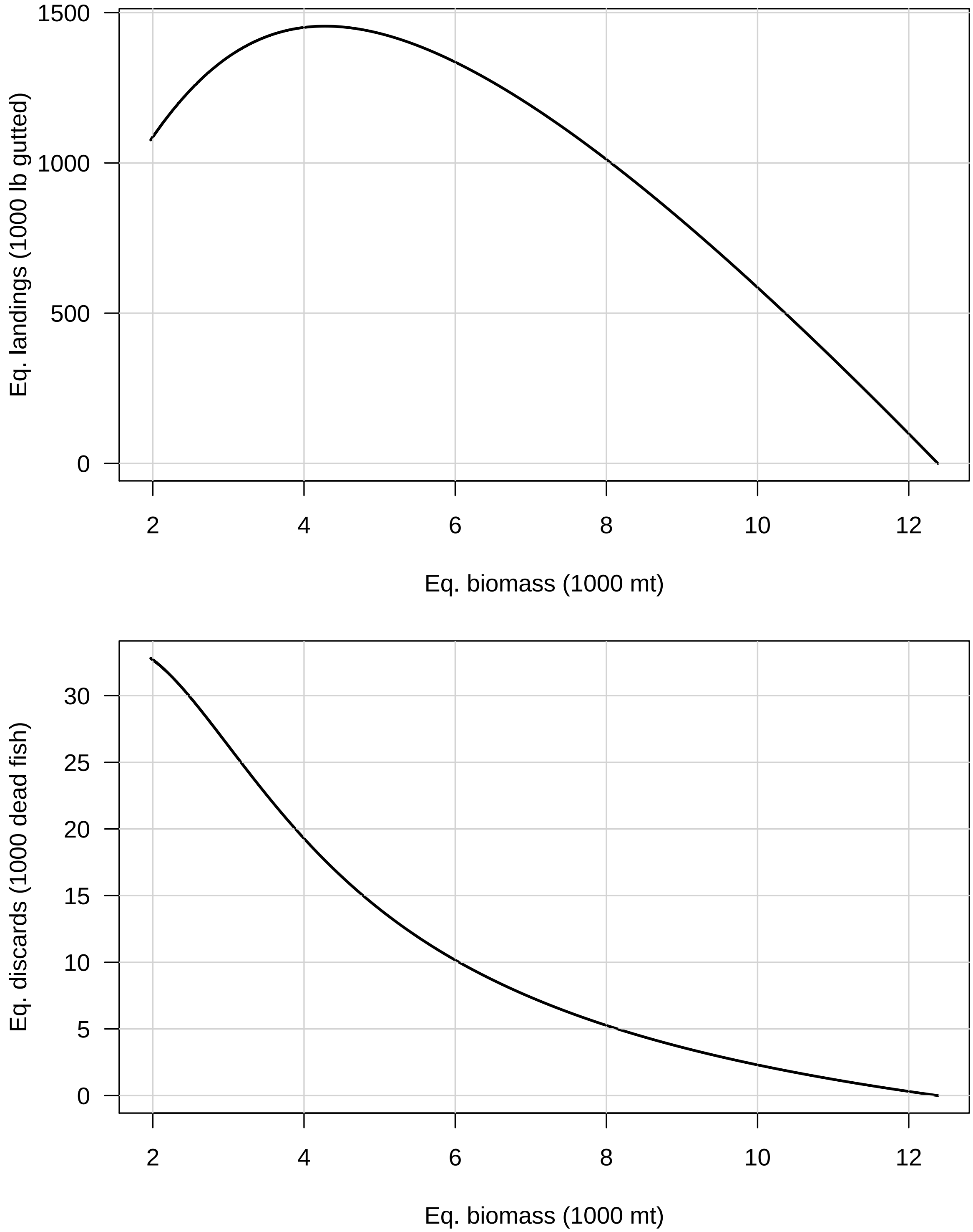


Figure 32. Probability densities of MSY*-related benchmarks from MCBE analysis of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.*

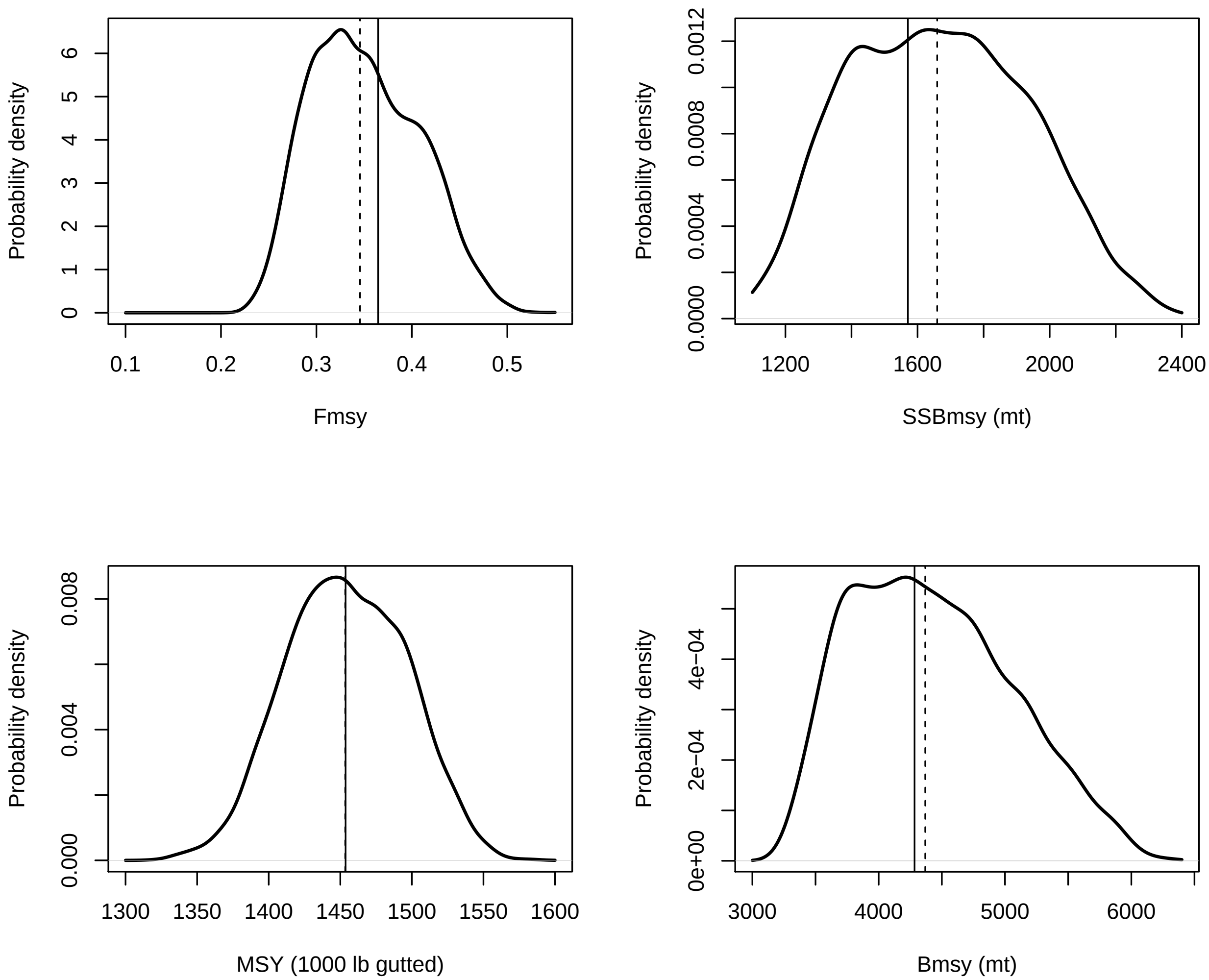


Figure 33. Estimated time series relative to benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model; dashed lines represent median values; gray error bands indicate 5^{th} *and* 95^{th} *percentiles of the MCBE trials. Top panel: spawning biomass relative to the minimum stock size threshold,* $\text{MSST} = 0.75\text{SSB}_{\text{MSY}}$. *Bottom panel: F relative to* F_{MSY}.

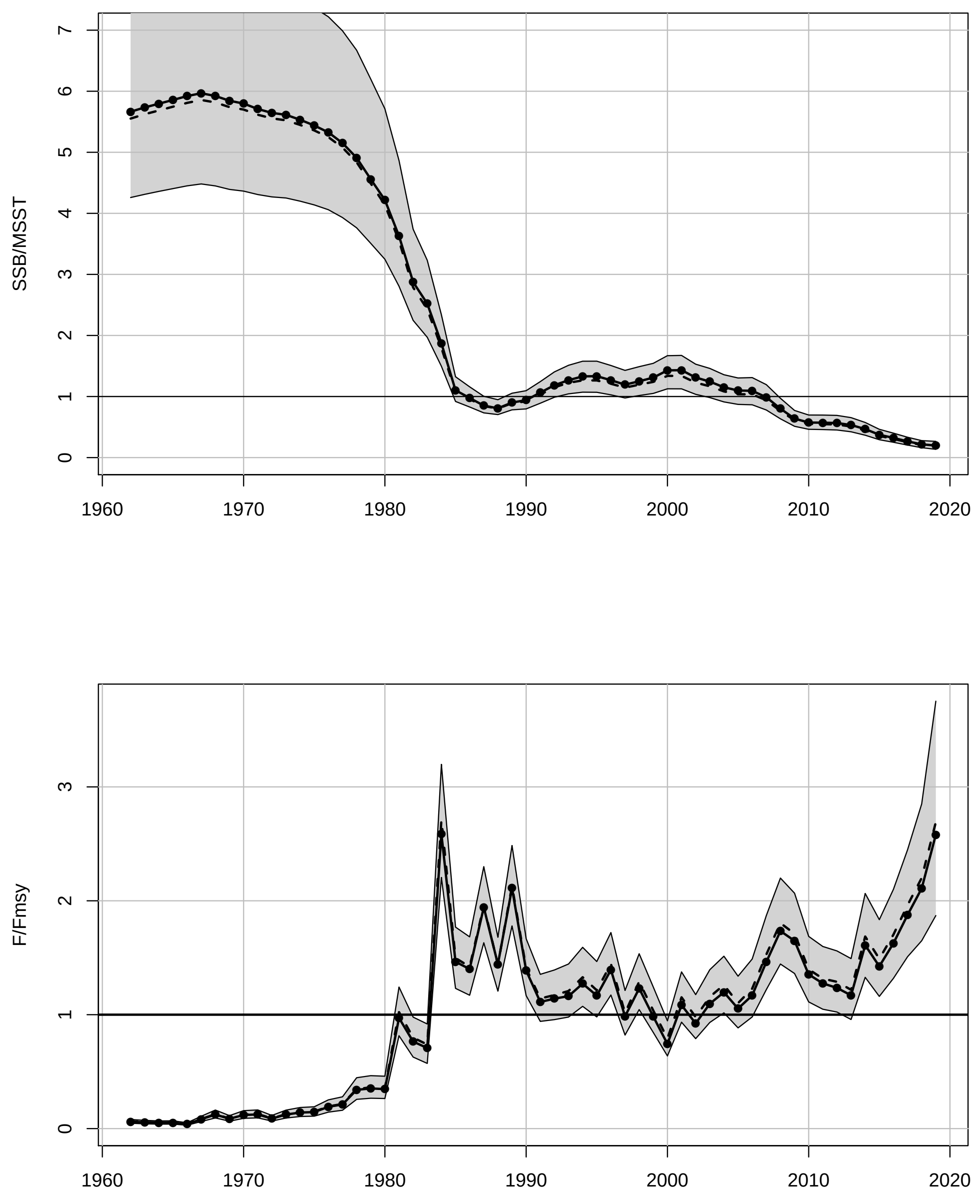


Figure 34. Probability densities of terminal status estimates from MCBE analysis of the Beaufort Assessment Model. MSST indicates MSST = $0.75\text{SSB}_{\text{MSY}}$. *Solid vertical lines represent point estimates from the base run; dashed vertical lines represent median values.*

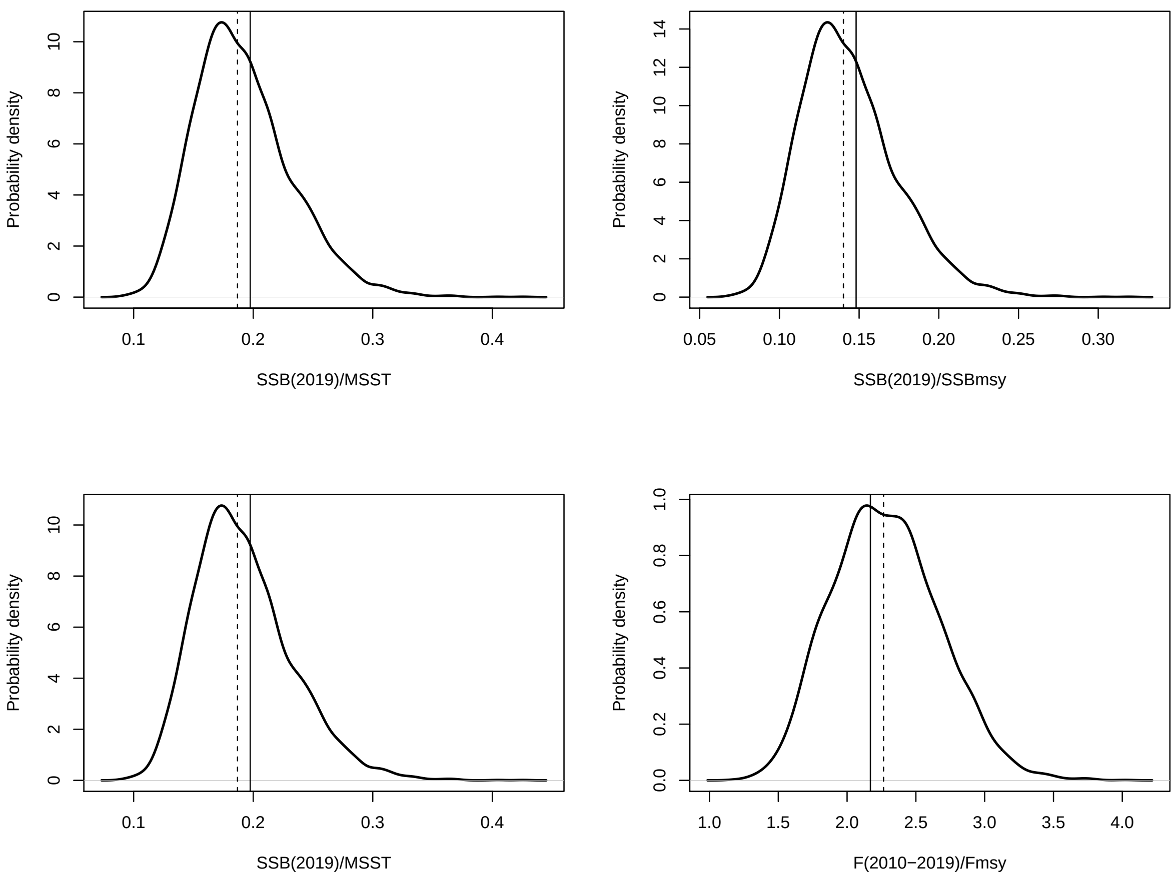


Figure 35. Phase plots of terminal status estimates from MCBE analysis of the Beaufort Assessment Model. The intersection of crosshairs indicates estimates from the base run; lengths of crosshairs defined by 5^{th} and 95^{th} percentiles. Proportion of runs falling in each quadrant indicated.

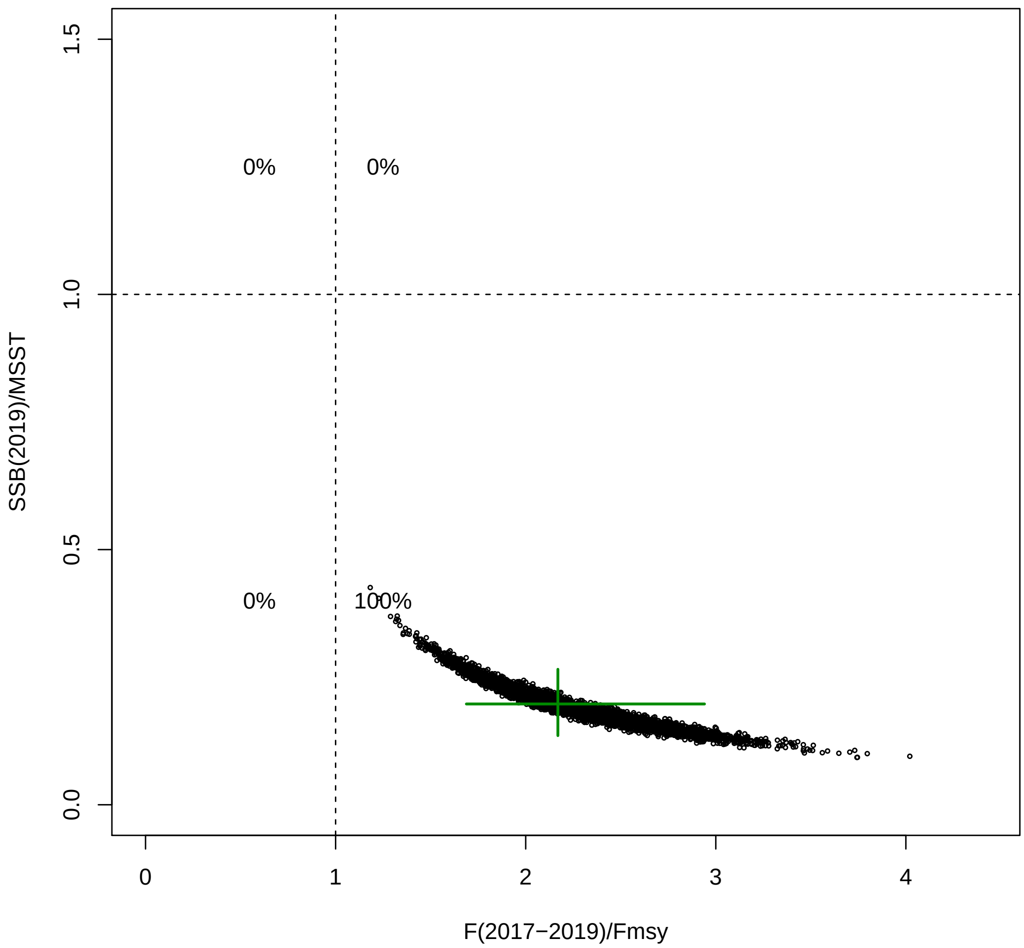


Figure 36. Age structure relative to the equilibrium expected at MSY*.*

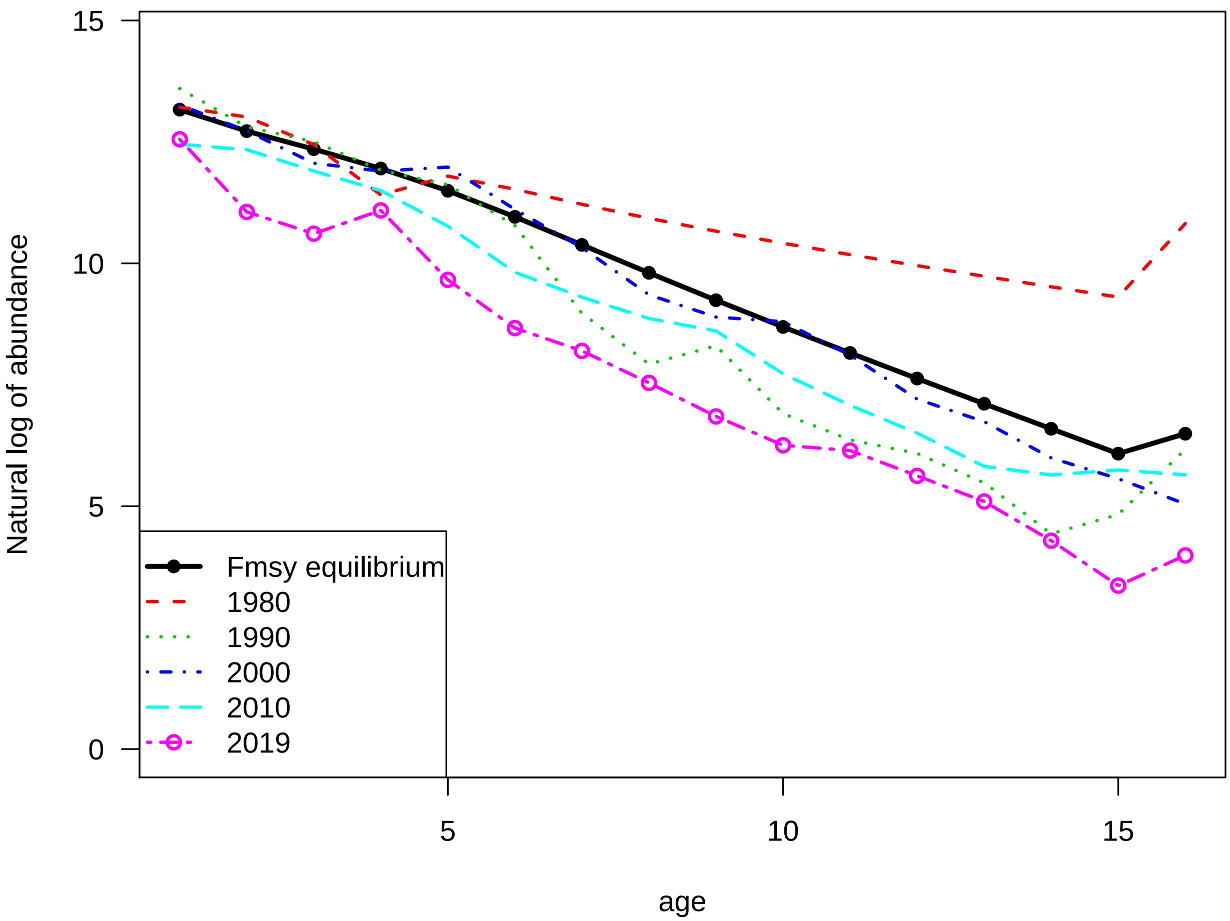


Figure 37. Comparison of results from this update assessment and from the previous, SEDAR-10 benchmark assessment. Top panel: F relative to F_{MSY}*. Bottom panel: spawning biomass relative to the minimum stock size threshold (*$MSST = 0.75SSB_{MSY}$*).*

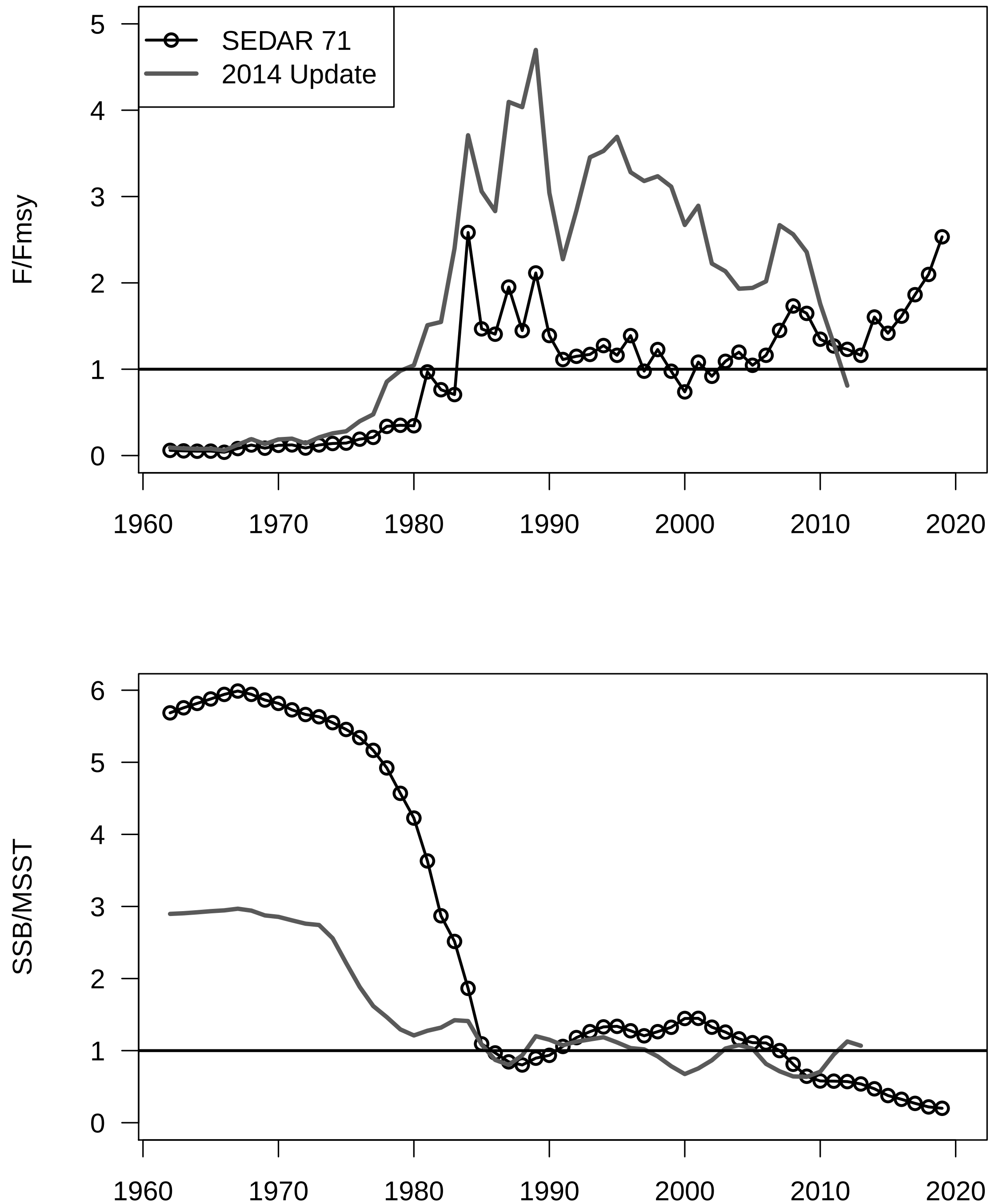
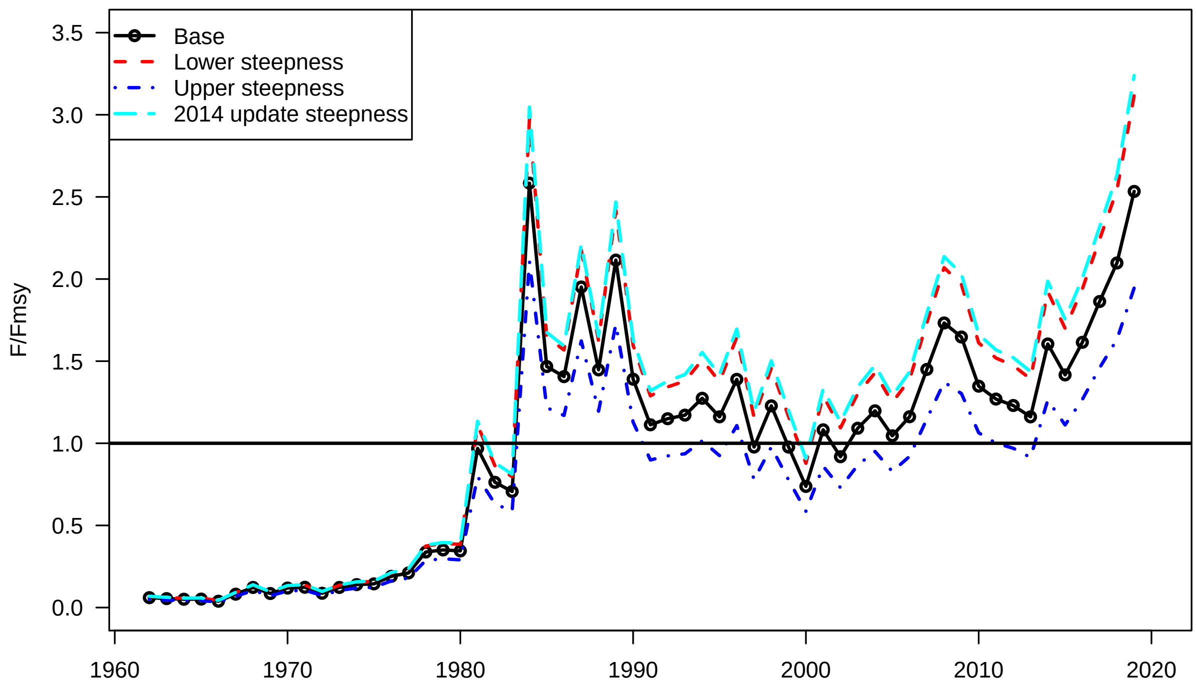


Figure 38. Sensitivity to steepness (sensitivity runs S1–S3). Top panel: Ratio of F to F_{MSY}*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$.



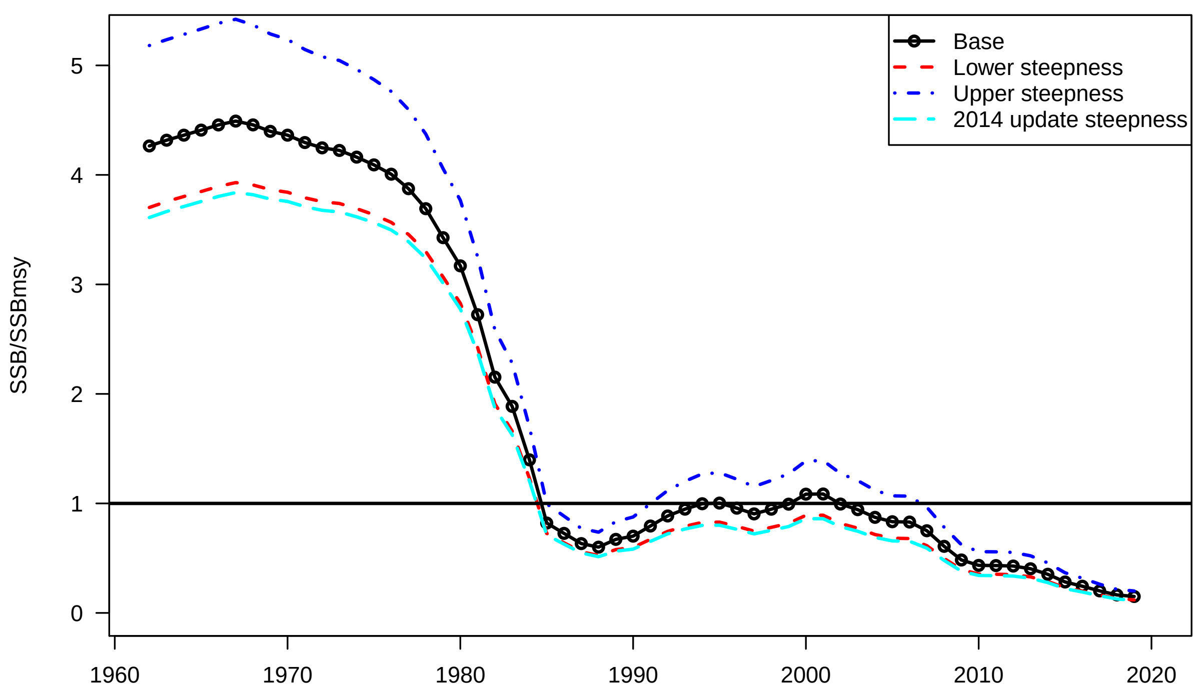


Figure 39. Sensitivity to base run indices and weighting (sensitivity runs S4–S6). Top panel: Ratio of F to F_{MSY}. *Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$.

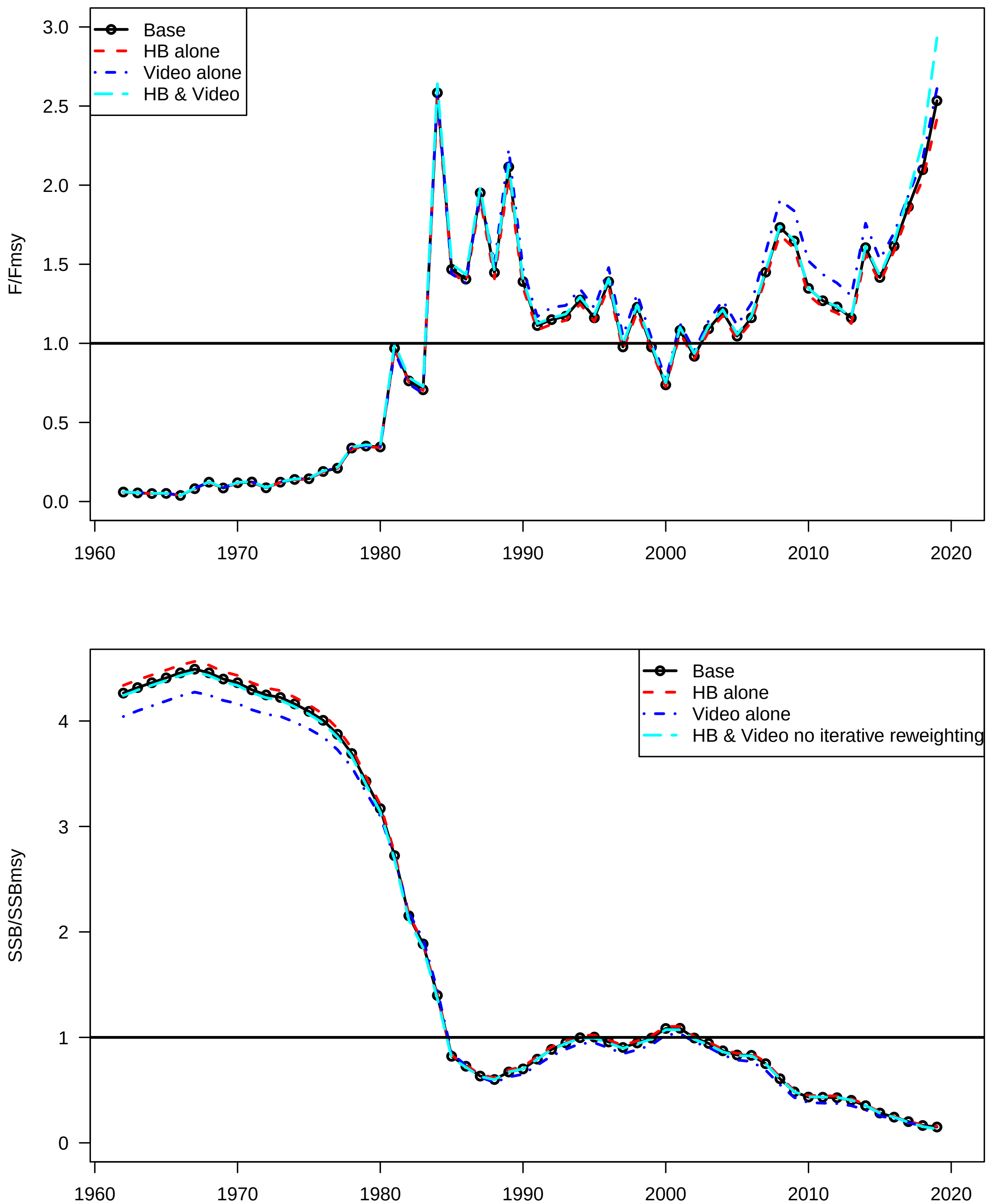


Figure 40. Sensitivity to included indices, duration, and catchability block (sensitivity runs S7–S9). Top panel: Ratio of F *to* F_{MSY}*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$*.*

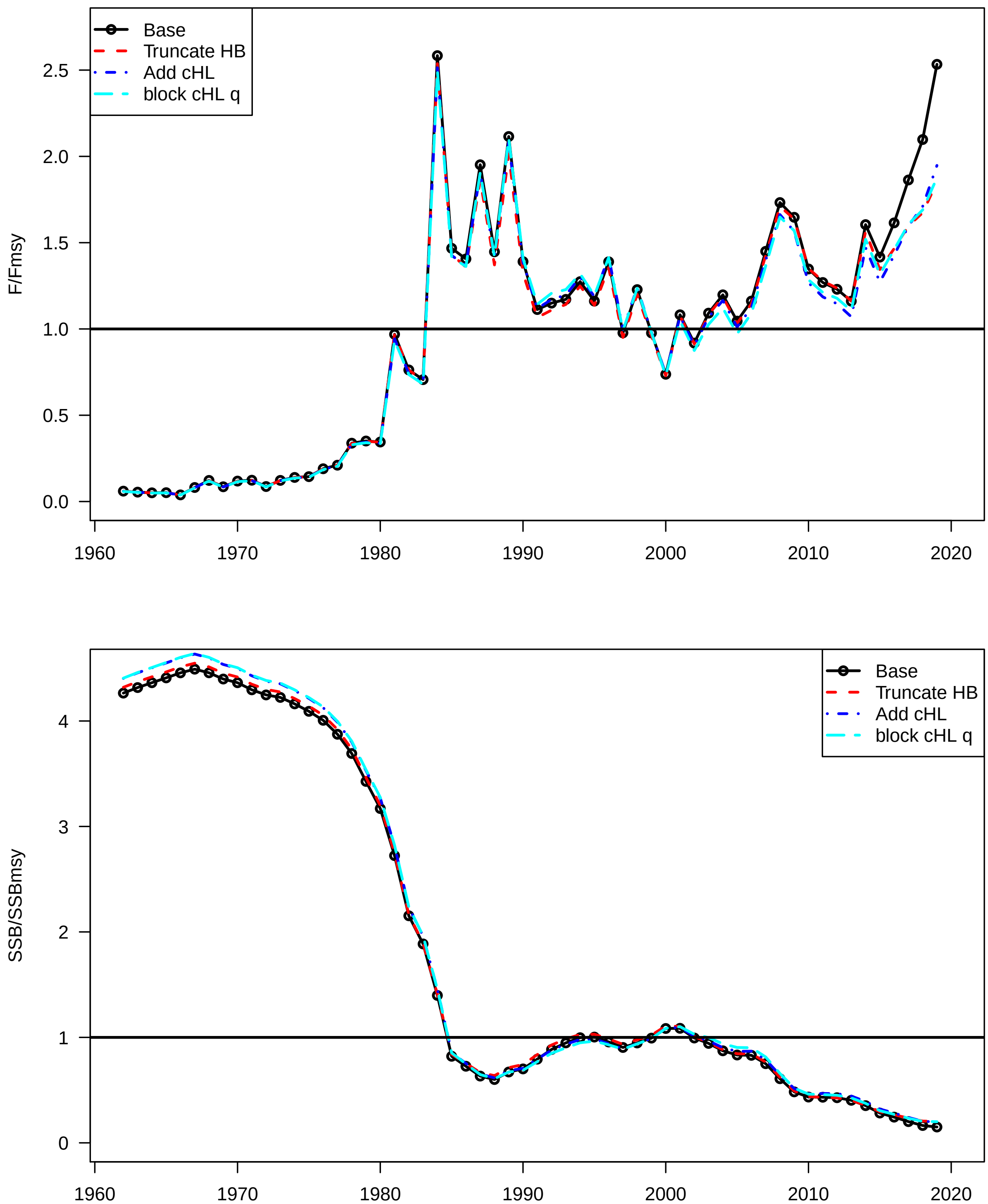


Figure 41. Sensitivity to random walk on dependent indices (sensitivity runs S10). Top panel: Ratio of F to F_{MSY}. *Bottom panel: Ratio of* SSB *to* SSB_{MSY}.

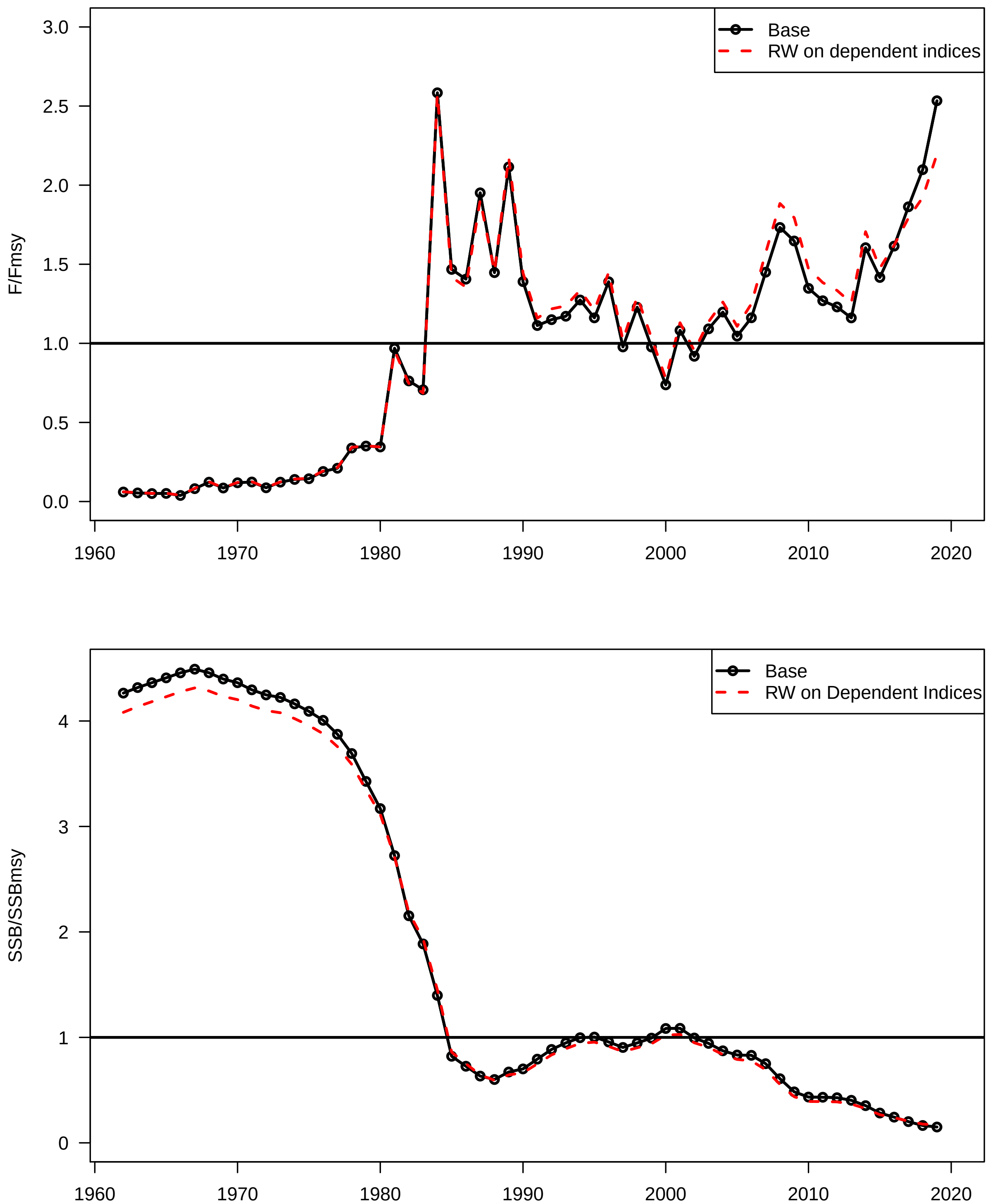


Figure 42. Sensitivity to initialization (1962) fishing mortality rate (sensitivity runs S11–S12). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$.

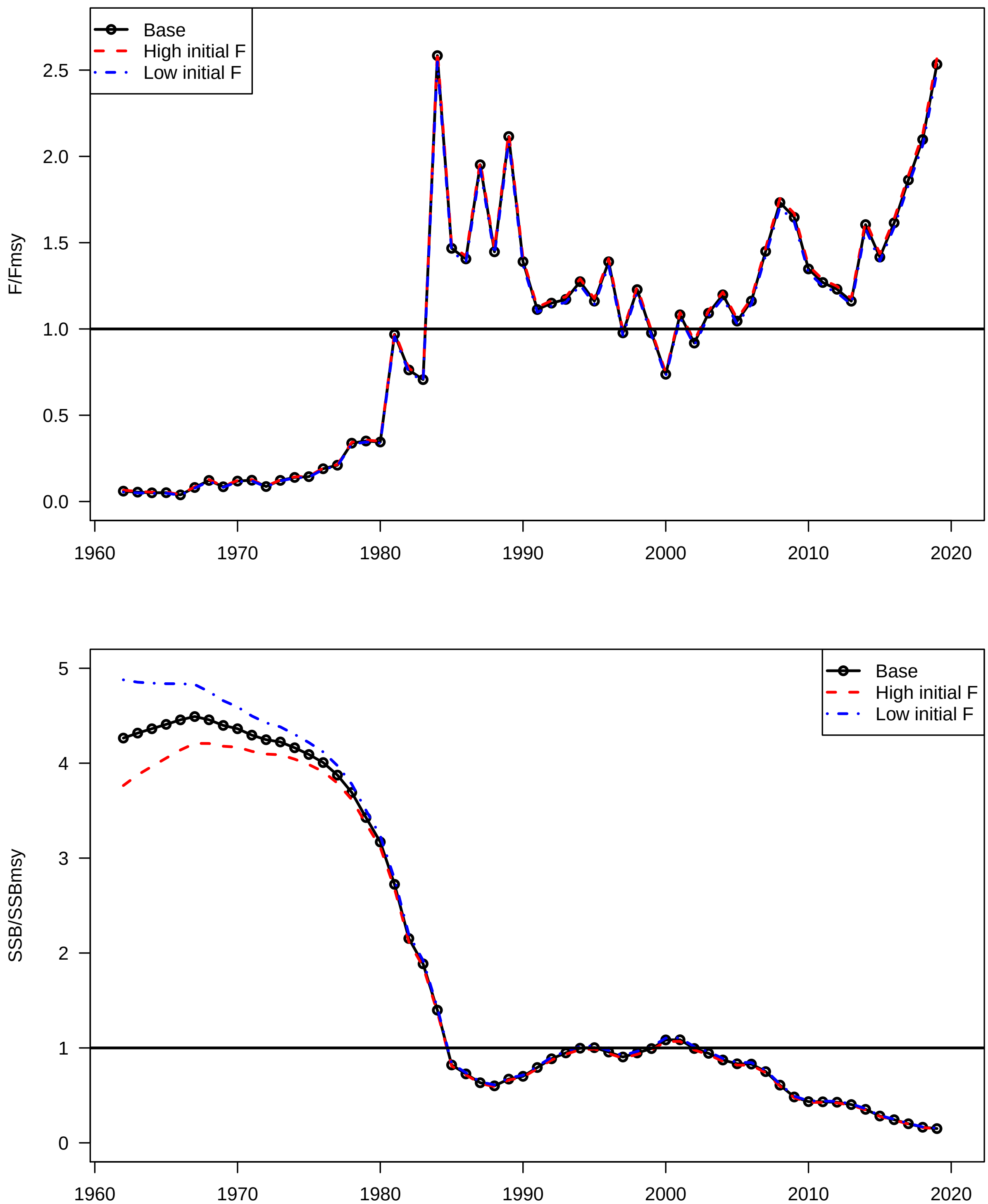


Figure 43. Sensitivity to the discard mortality rate (sensitivity runs S13 and S14). Top panel: Ratio of F to F_{MSY}. *Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$.

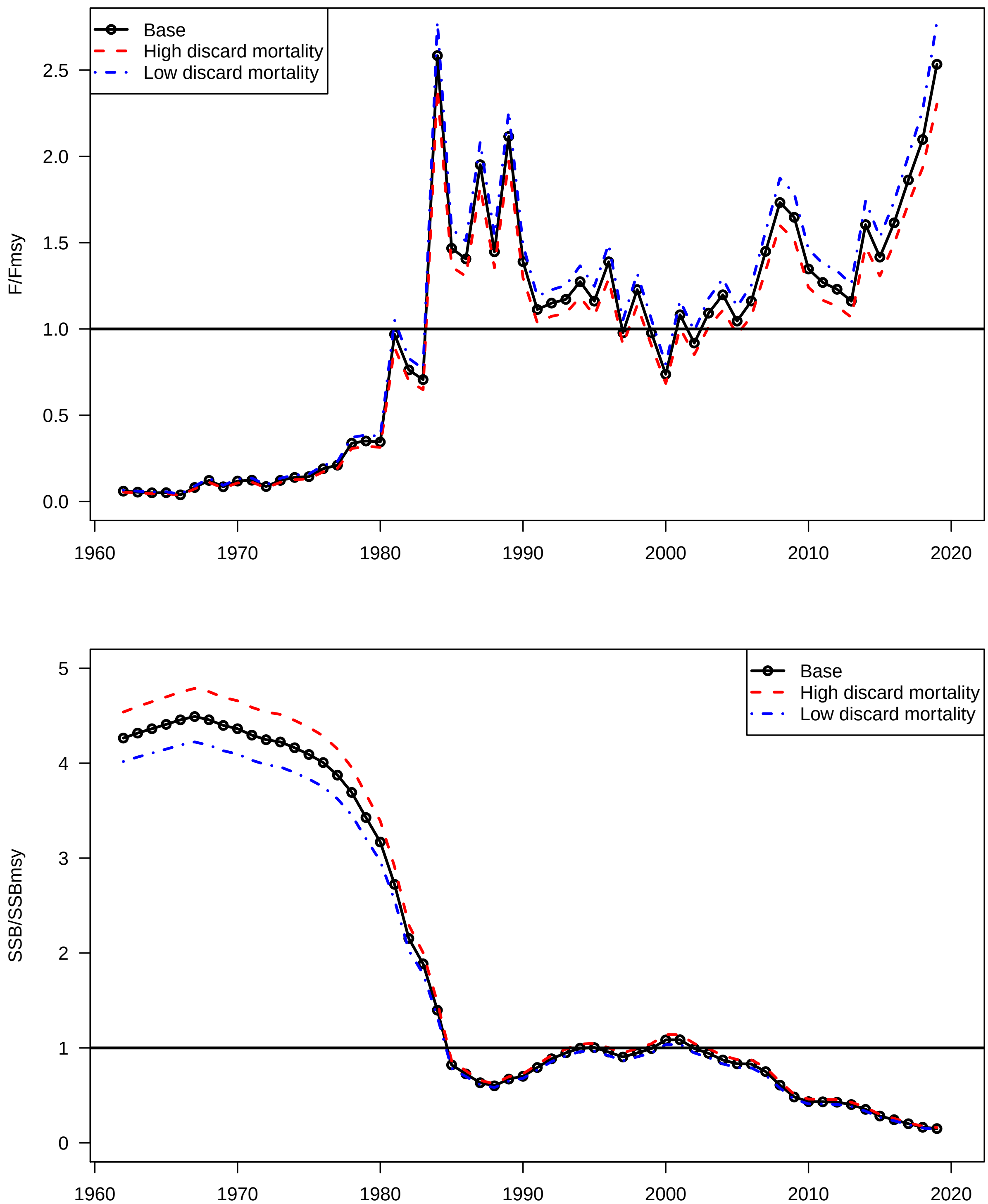


Figure 44. Sensitivity to size limit blocks and SERFS video index selectivity (sensitivity runs S15 and S16). Top panel: Ratio of F to F_{MSY}*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$*.*

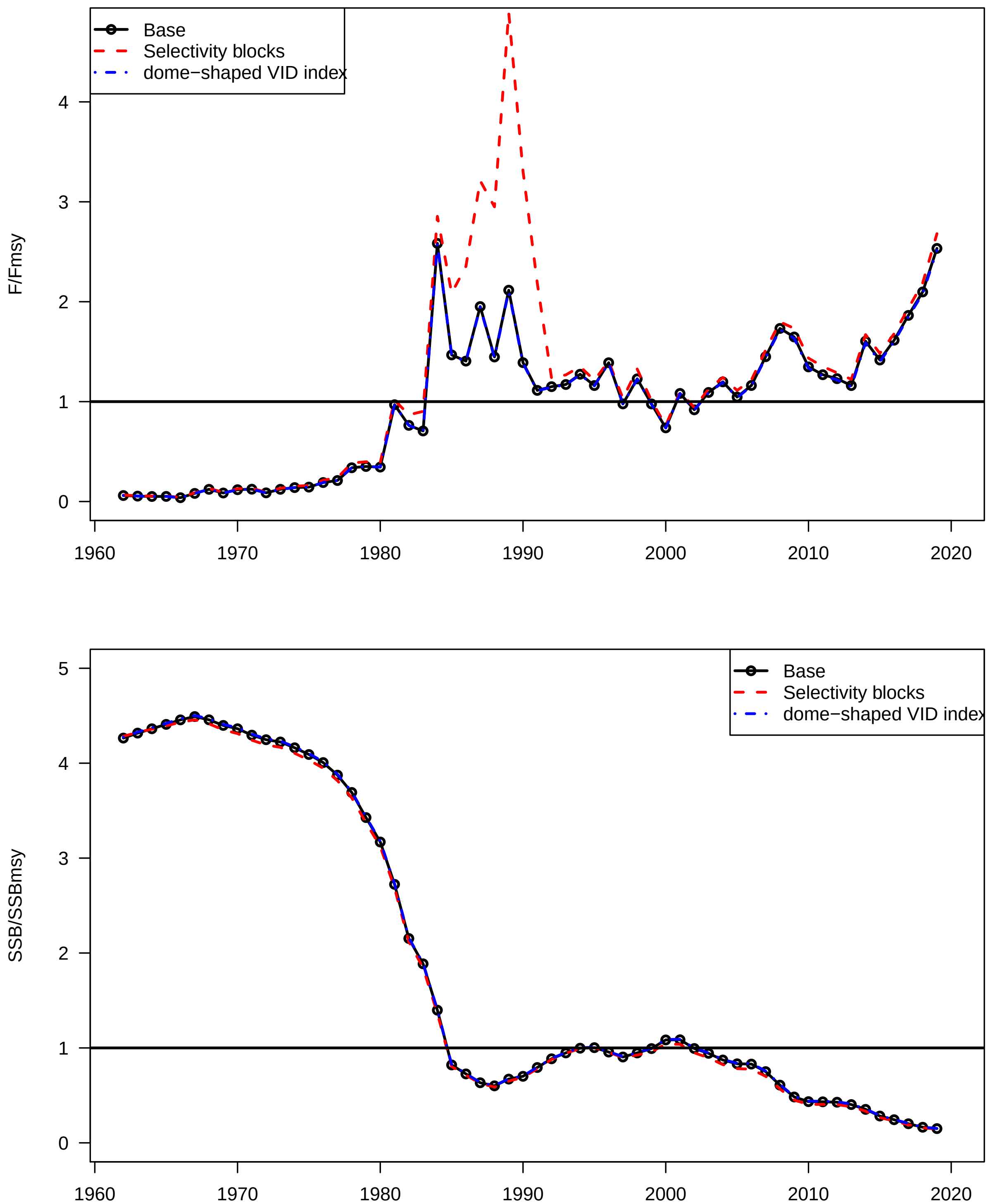


Figure 45. Sensitivity to changes in natural mortality scaling (sensitivity runs S17–S18). Top panel: Ratio of F to F_{MSY}*. Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$*.*

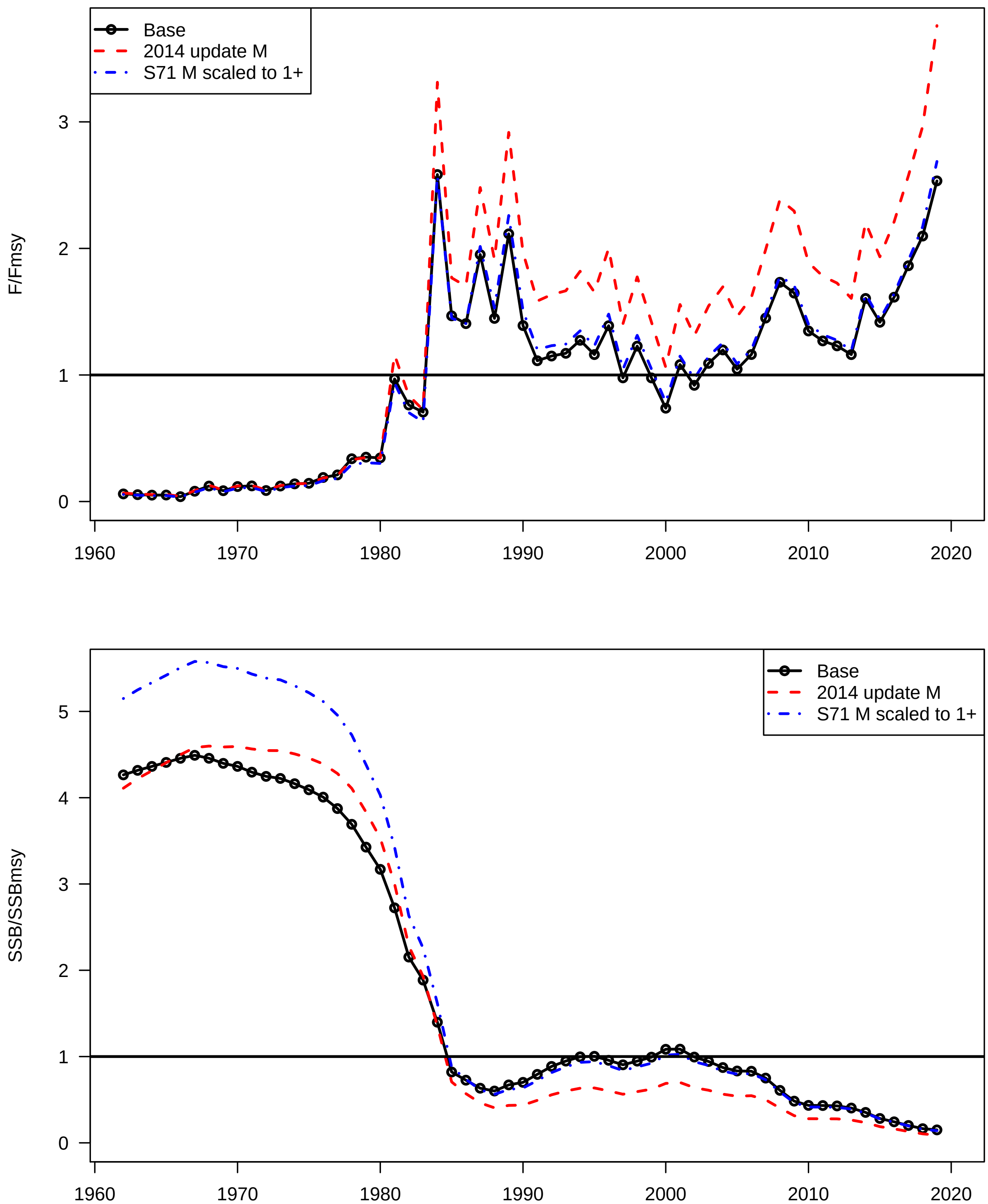


Figure 46. Sensitivity to changes in natural mortality magnitude (sensitivity runs S19–S21). Top panel: Ratio of F to F_{MSY}*. Bottom panel: Ratio of* SSB *to* SSB_{MSY}*.*

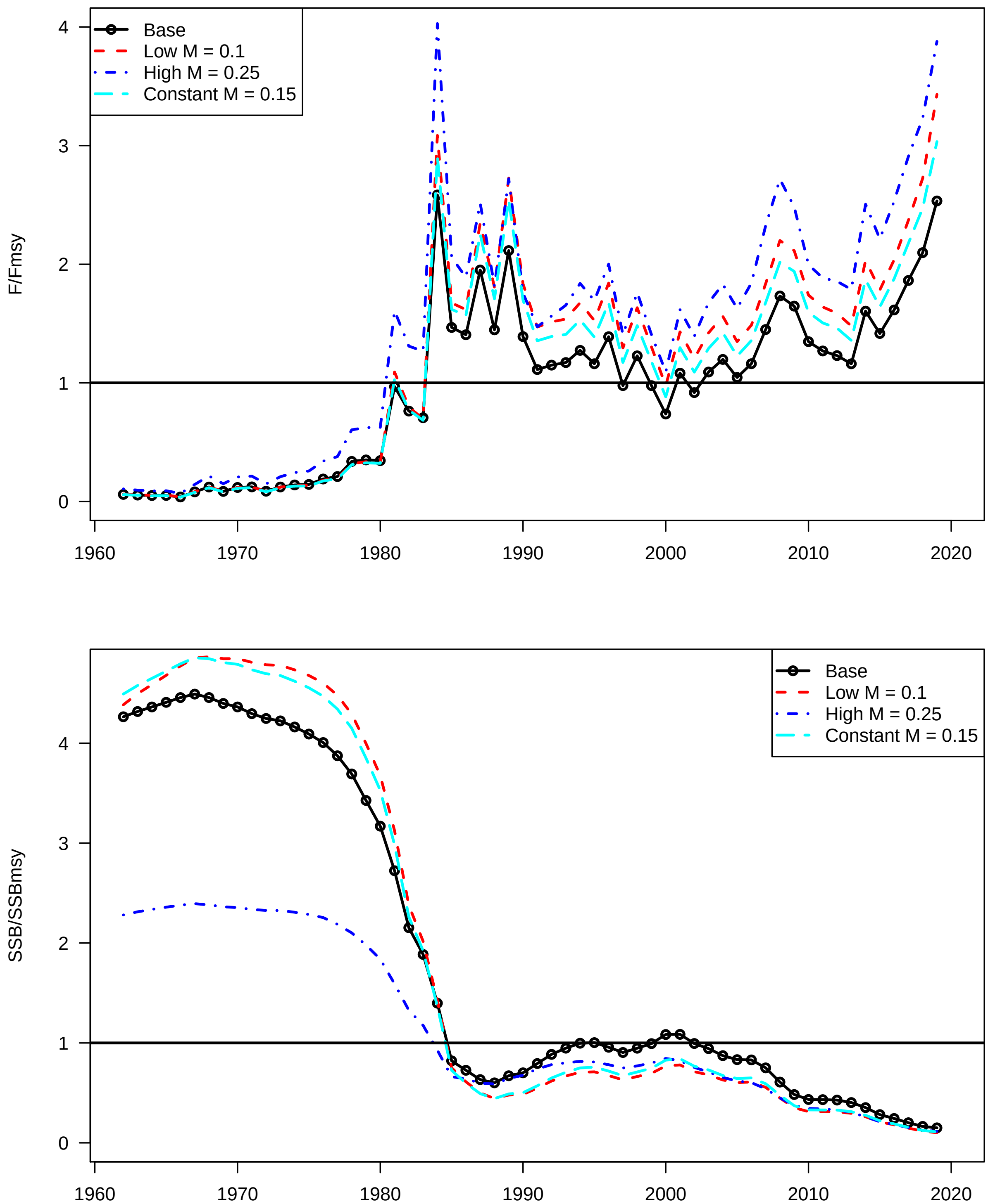
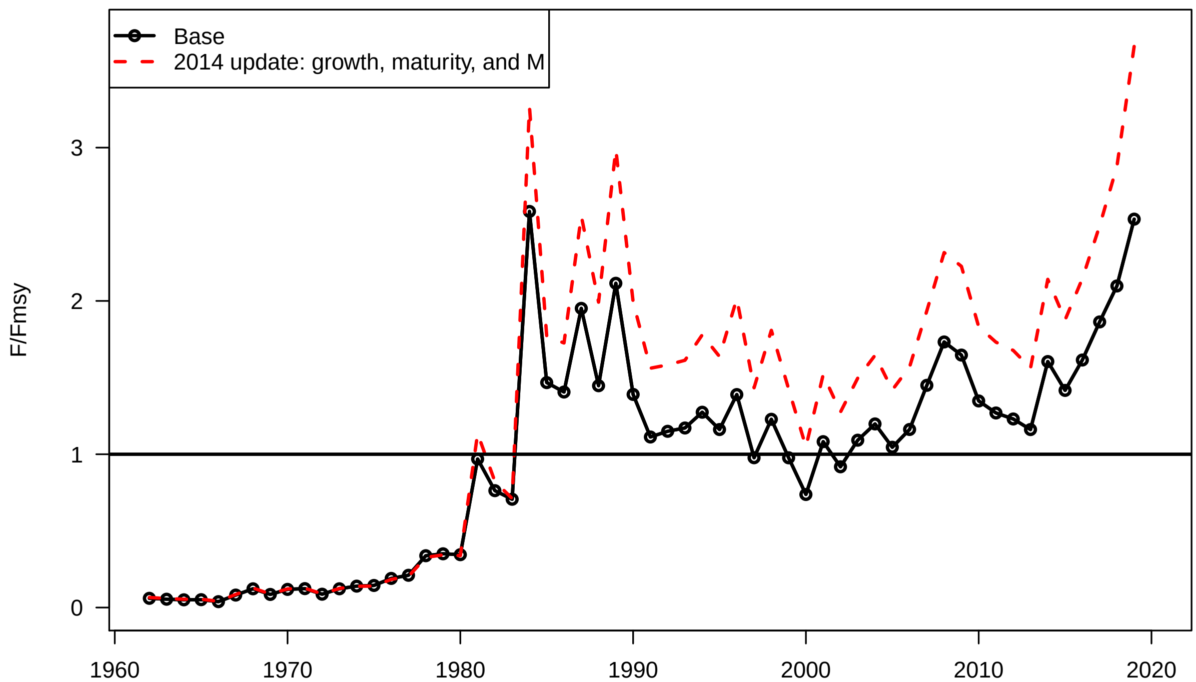


Figure 47. Sensitivity to life history parameters (sensitivity run S22). Top panel: Ratio of F to F_{MSY}*. Bottom panel: Ratio of* SSB *to* SSB_{MSY}*.*



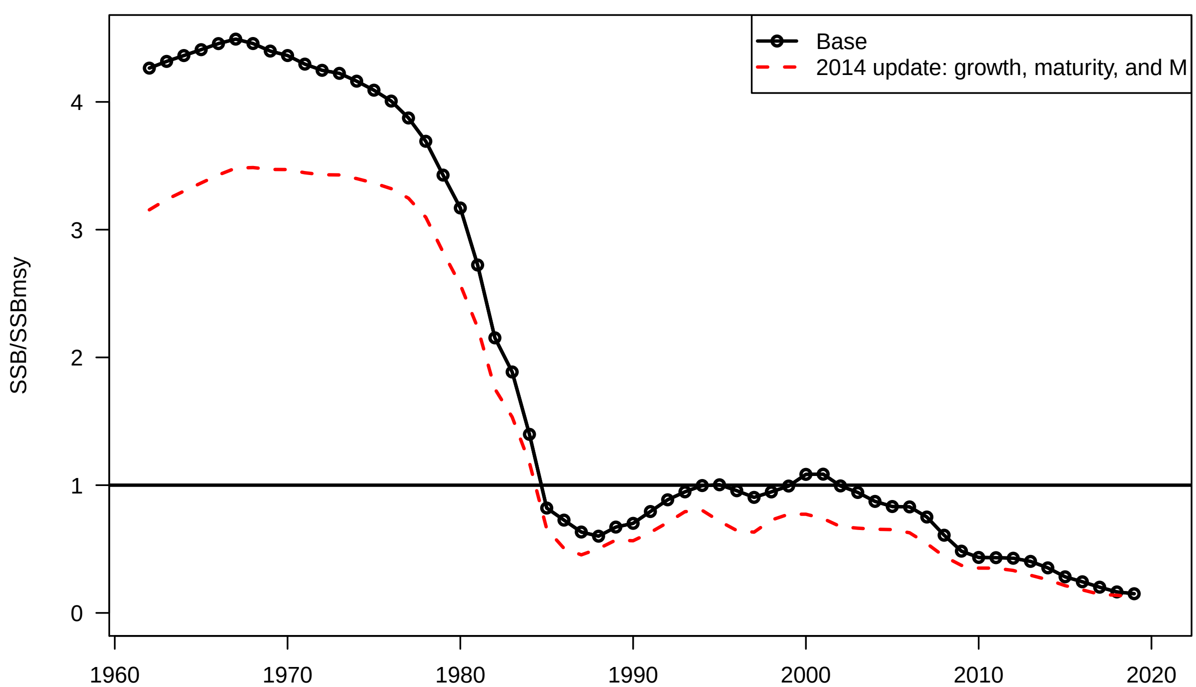


Figure 48. Sensitivity to measure of reproductive potential (sensitivity runs S23). Top panel: Ratio of F to F_{MSY}. *Bottom panel: Ratio of* SSB *to* $\mathrm{SSB}_{\mathrm{MSY}}$.

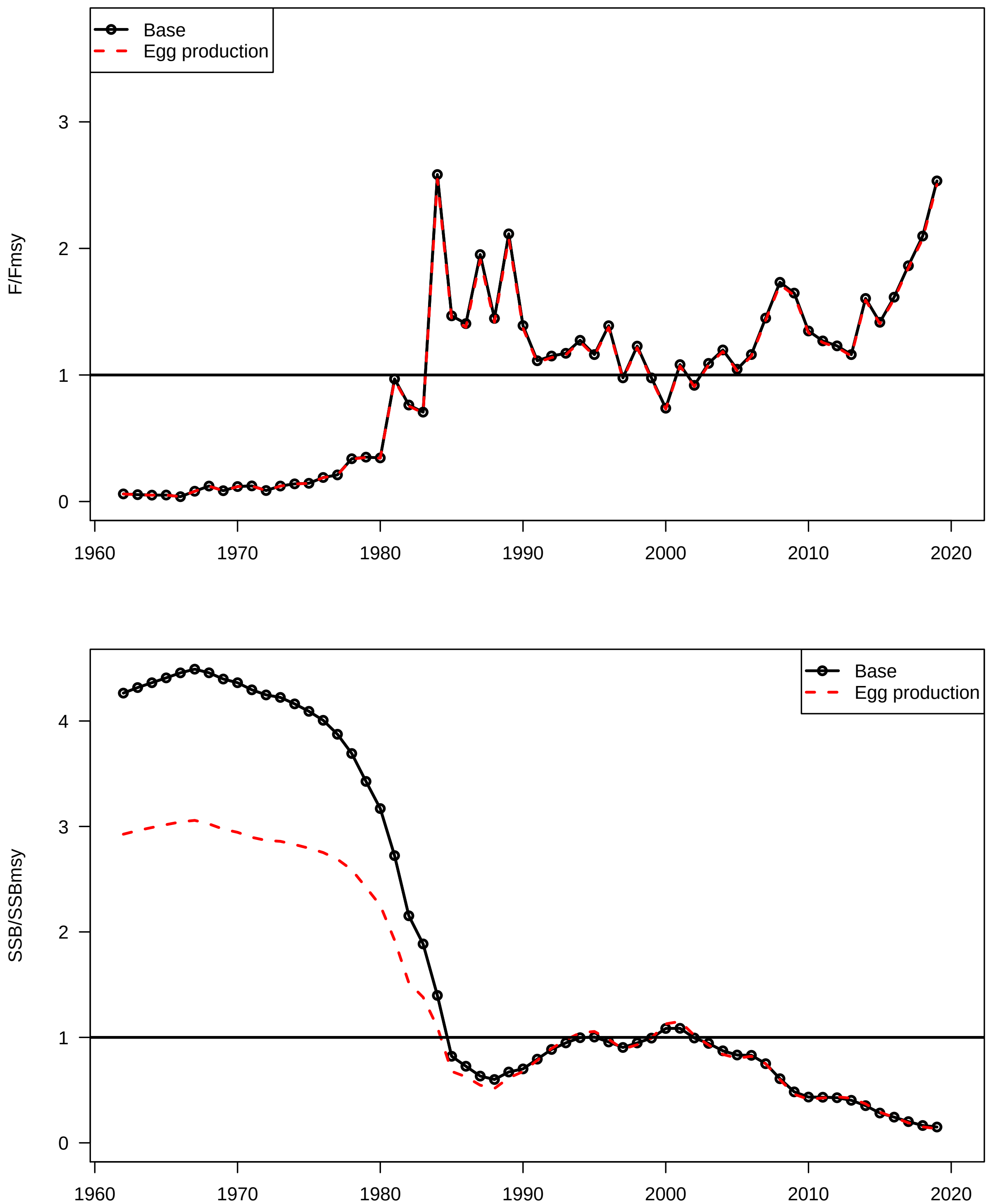


Figure 49. Phase plot of terminal status indicators from sensitivity runs of the Beaufort Assessment Model.

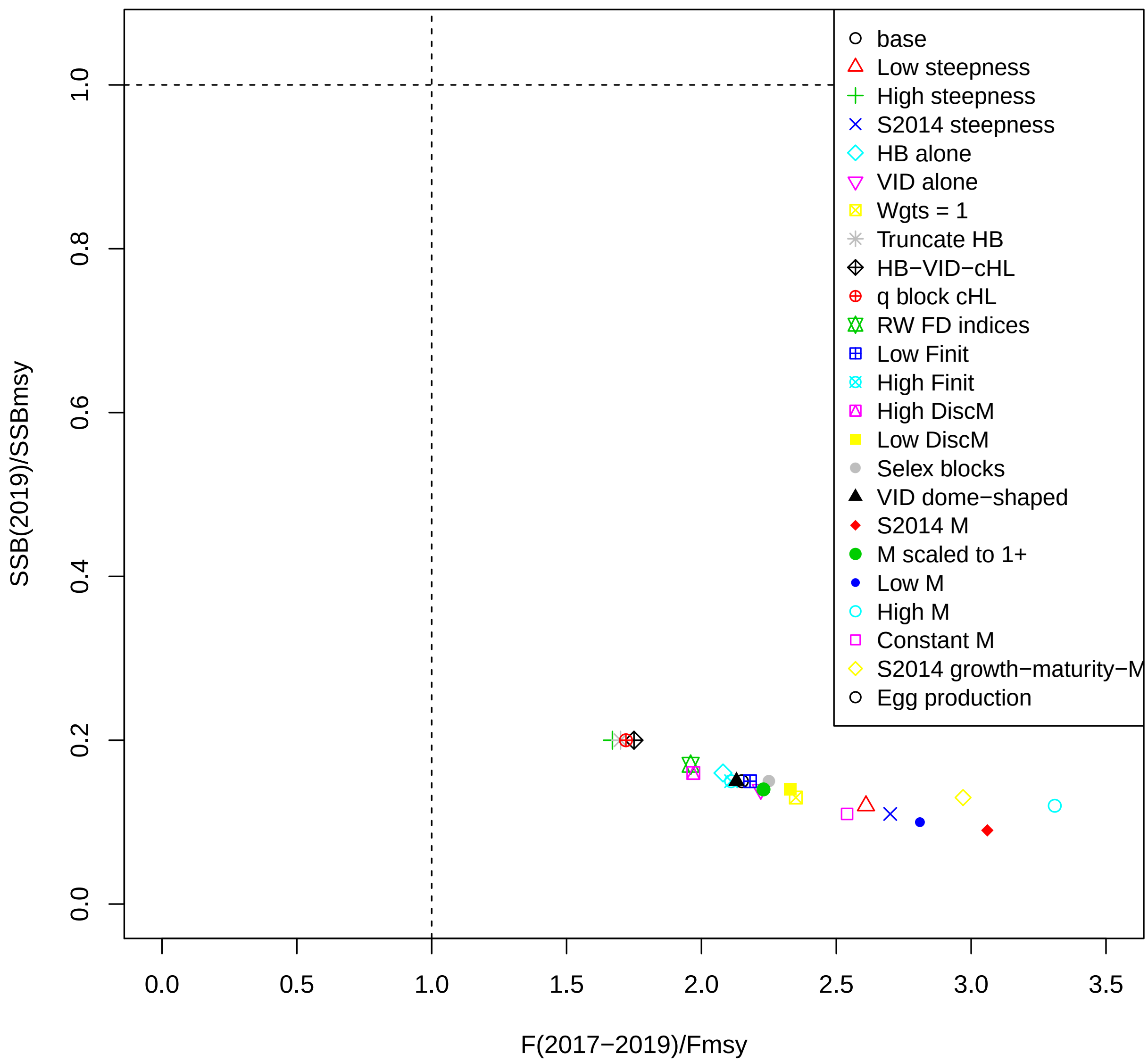


Figure 50. Retrospective analyses. Sensitivity to terminal year of data. Top panel: Fishing mortality rates. Middle panel: Recruits. Bottom panel: Spawning biomass. Closed circles show terminal-year estimates. Imperceptible lines overlap results of the base run.

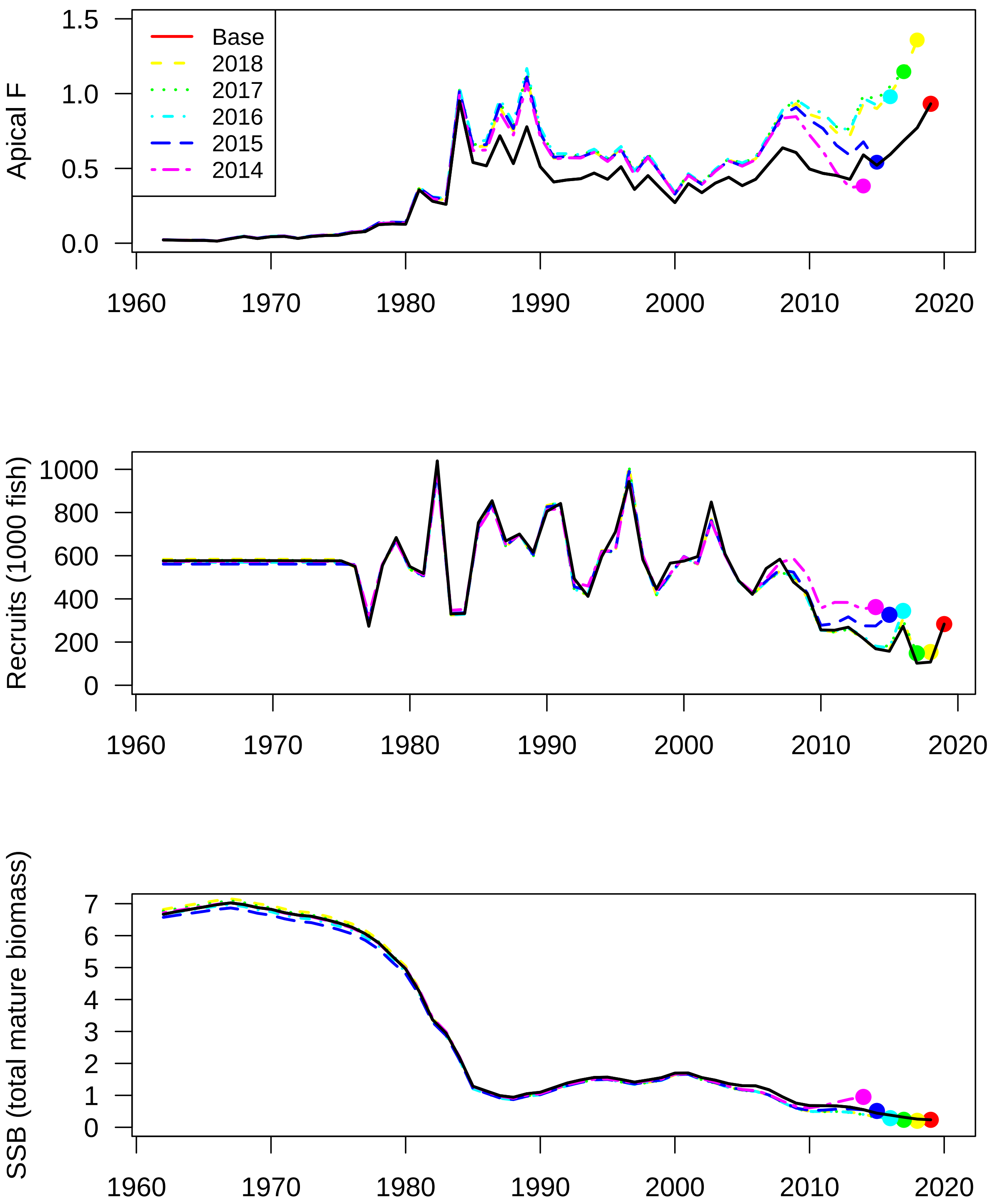


Figure 51. Sensitivity of status indicators. Top panel: Ratio of F to $F_{\rm MSY}$. Bottom panel: Ratio of SSB *to* $\rm SSB_{MSY}$.

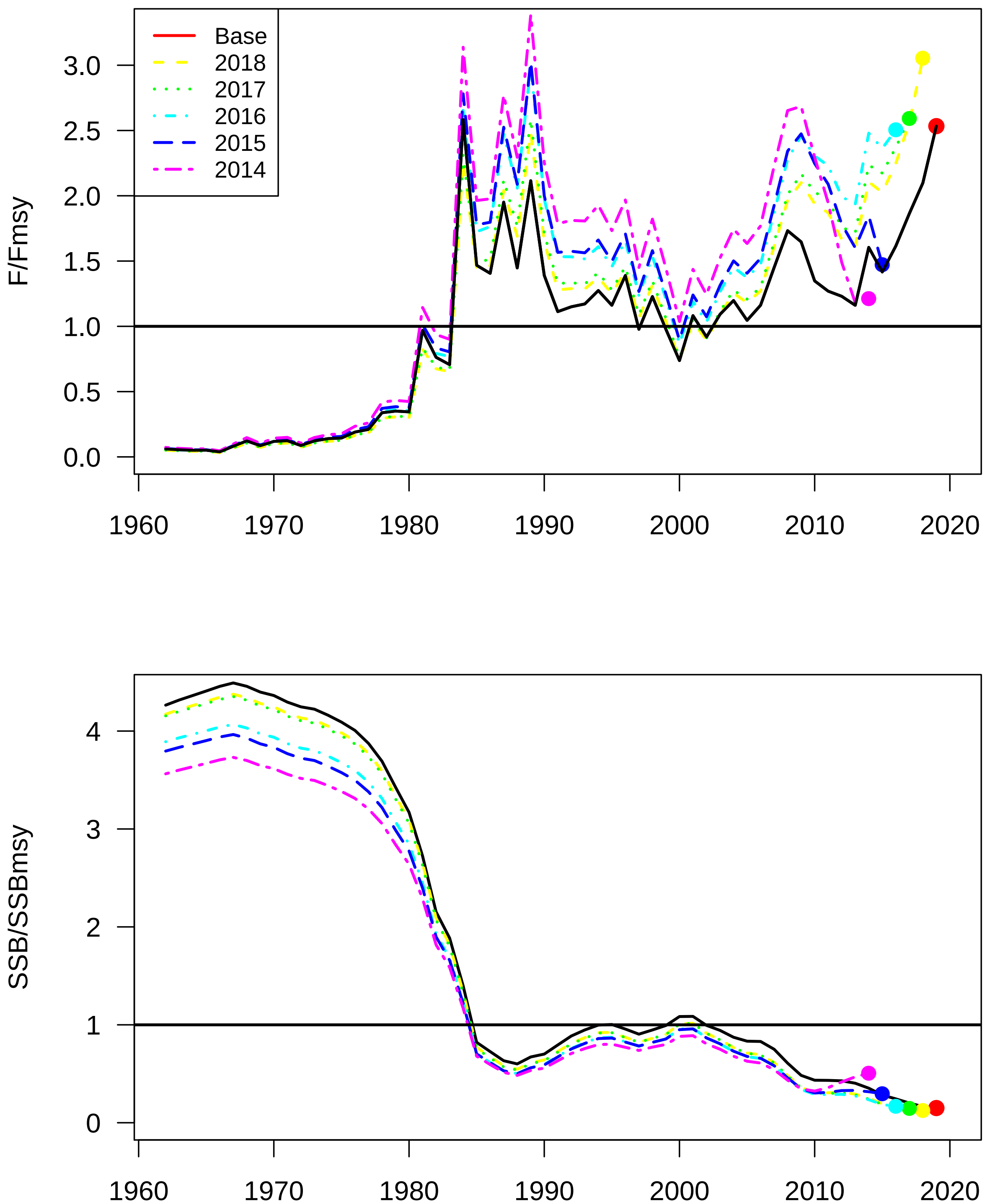


Figure 52. Projection results under scenario 1—fishing mortality rate fixed at F = 0, with 2022 as the first year of new regulations. The interim years (2020–2021) use a mean of the 2017–2019 landings. In all panels, expected values represented by solid lines, median values represented by dashed lines, and uncertainty represented by thin lines corresponding to 5^{th} *and* 95^{th} *percentiles of replicate projections. Horizontal lines mark* MSY*-related quantities from the base run (solid blue lines) and medians from the ensemble model runs(dashed green lines). Spawning stock (SSB) is at time of peak spawning.*

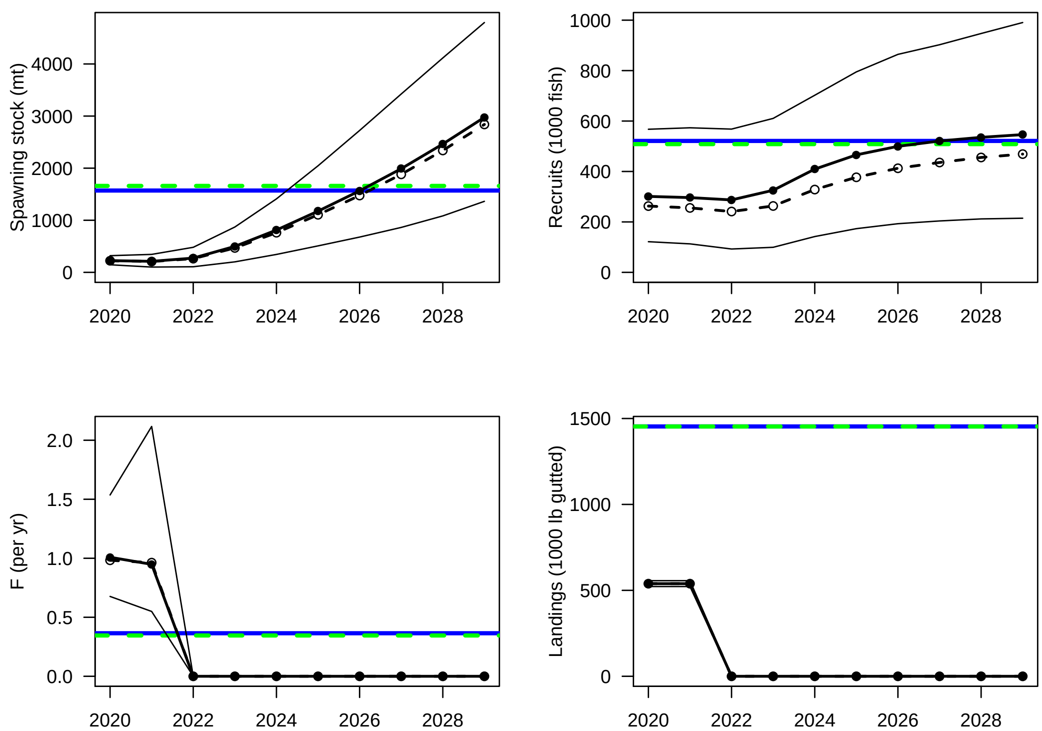


Figure 53. Projected probability of rebuilding under scenario 1—fishing mortality rate at $F = 0$. *The curve represents the proportion of projection replicates for which* SSB *has reached the replicate-specific* $\mathrm{SSB_{MSY}}$, *with reference line at 0.5.*

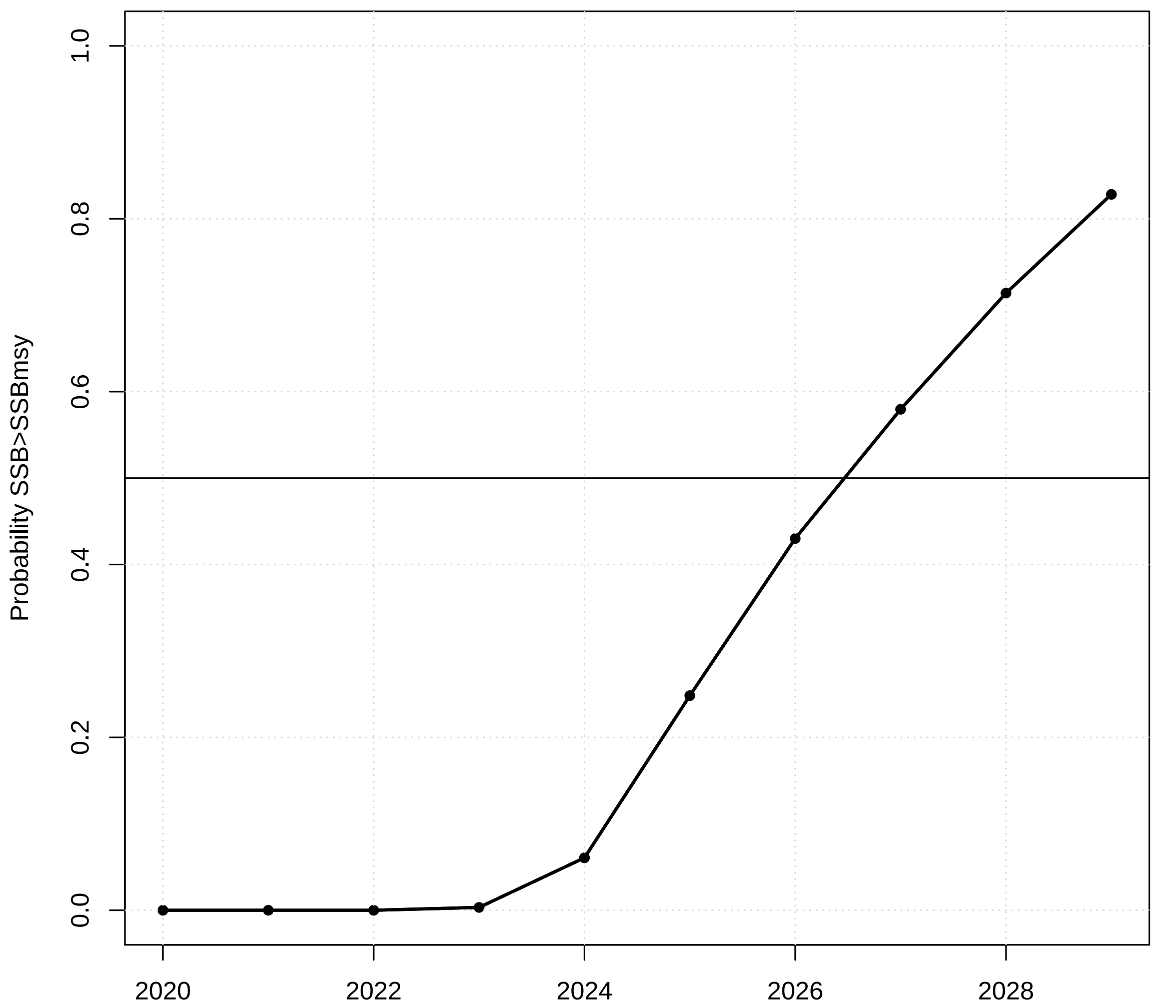


Figure 54. Projection results under scenario 2—fishing mortality rate fixed at F_{current}, with 2022 as the first year of new regulations. The interim years (2020–2021) use a mean of the 2017–2019 landings. In all panels, expected values represented by solid lines, median values represented by dashed lines, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Horizontal lines mark MSY-related quantities from the base run (solid blue lines) and medians from the ensemble model runs(dashed green lines). Spawning stock (SSB) is at time of peak spawning.

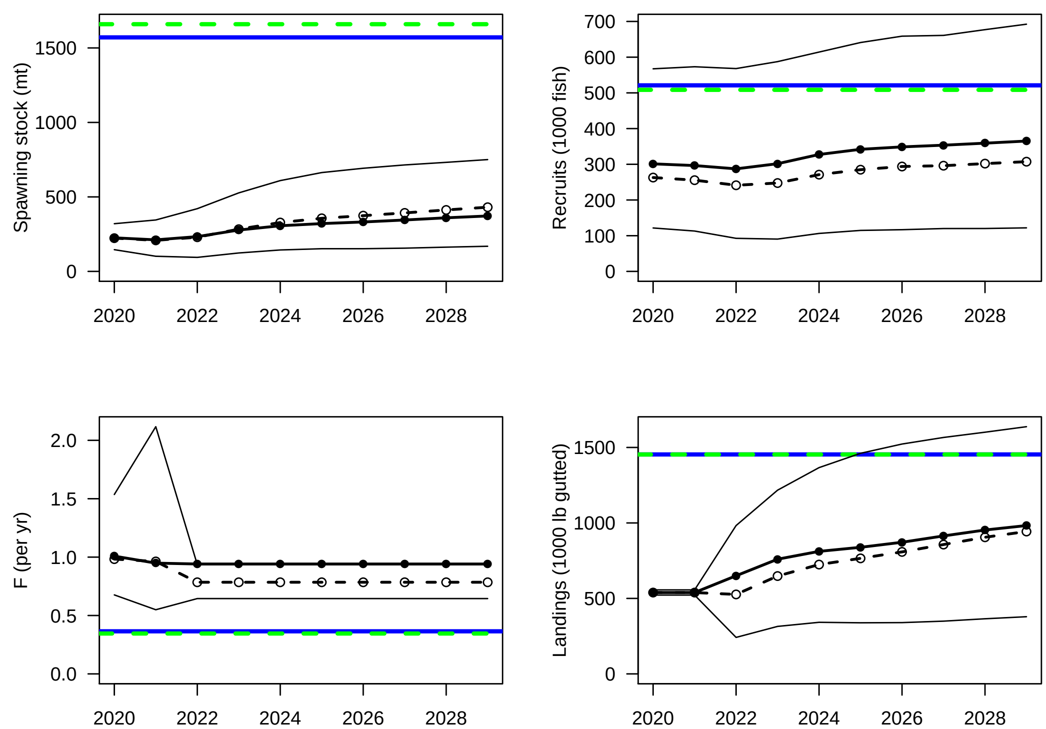


Figure 55. Projected probability of rebuilding under scenario 2—fishing mortality rate at $F = F_{\text{current}}$. The curve represents the proportion of projection replicates for which SSB *has reached the replicate-specific* SSB_{MSY}*, with reference line at 0.5.*

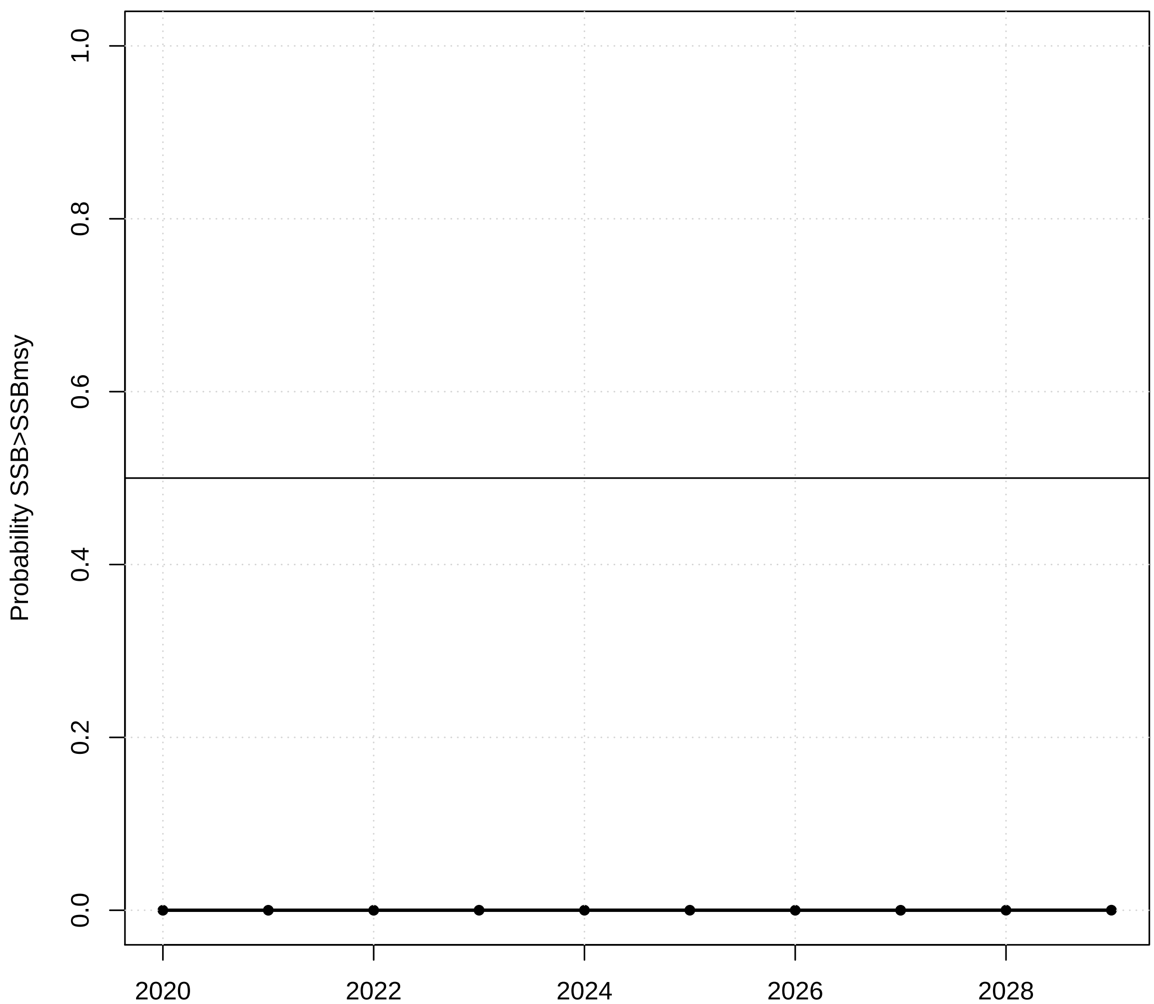


Figure 56. Projection results under scenario 3—fishing mortality rate fixed at $F = F_{\mathrm{MSY}}$, with 2022 as the first year of new regulations. The interim years (2020–2021) use a mean of the 2017–2019 landings. In all panels, expected values represented by solid lines, median values represented by dashed lines, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Horizontal lines mark MSY*-related quantities from the base run (solid blue lines) and medians from the ensemble model runs(dashed green lines). Spawning stock (SSB) is at time of peak spawning.*

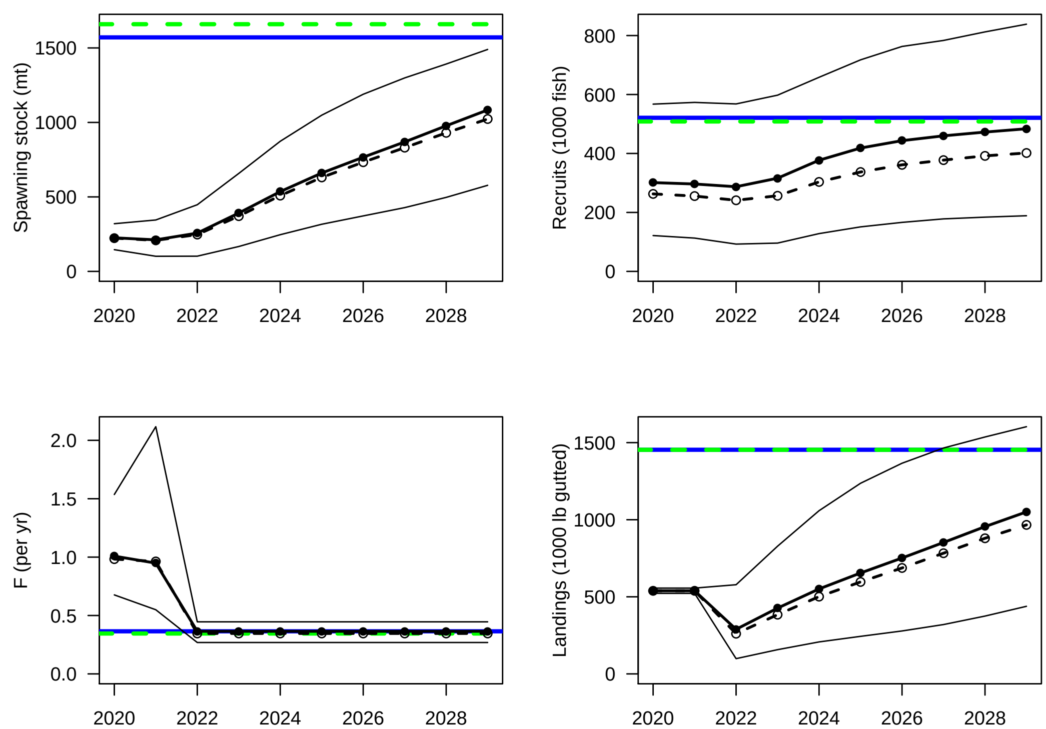


Figure 57. Projected probability of rebuilding under scenario 3—fishing mortality rate at $F = F_{\mathrm{MSY}}$. The curve represents the proportion of projection replicates for which SSB *has reached the replicate-specific* $\mathrm{SSB}_{\mathrm{MSY}}$*, with reference line at 0.5.*

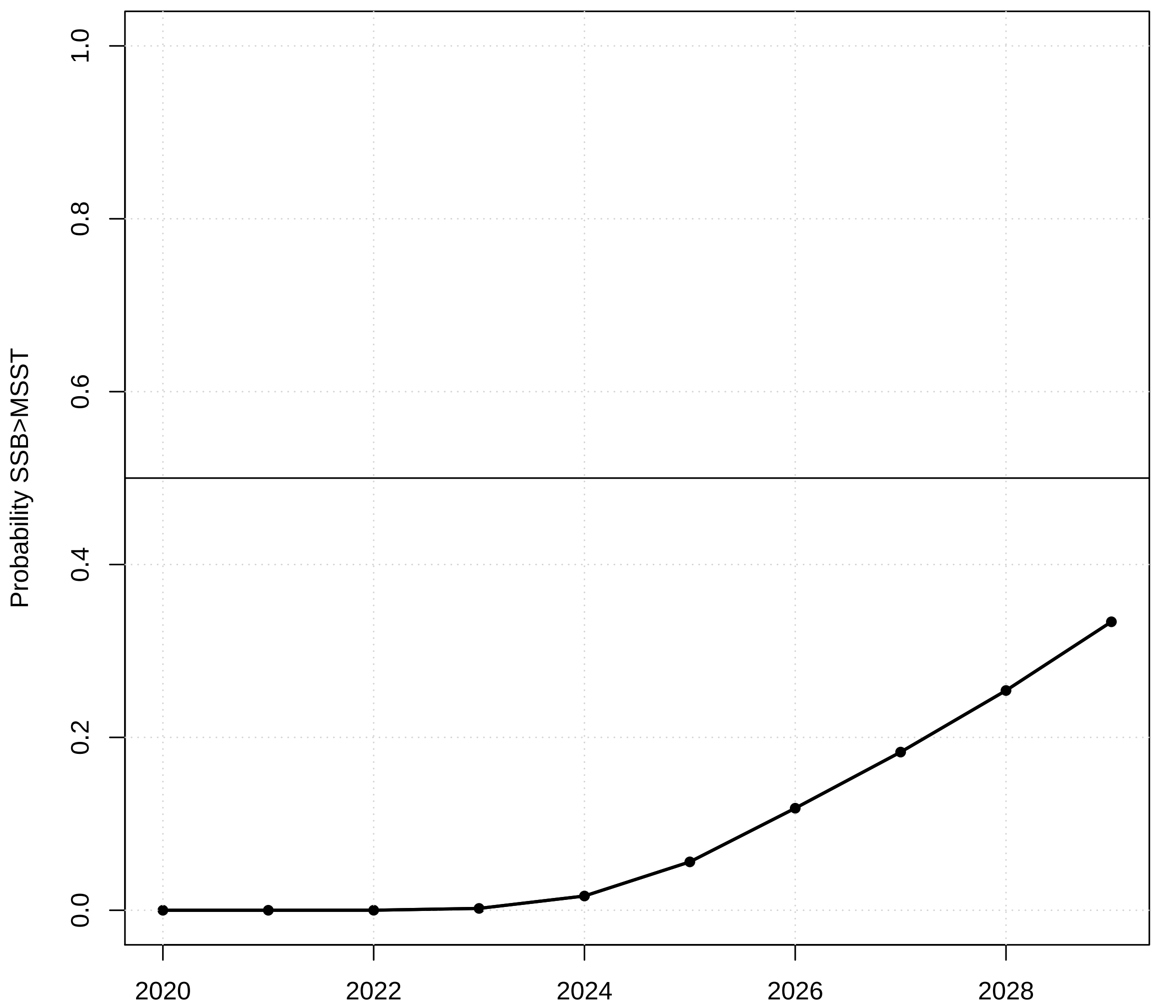


Figure 58. Projection results under scenario 4—fishing mortality rate fixed at $F = F_{\text{rebuild}}$, with 2022 as the first year of new regulations. The interim years (2020–2021) use a mean of the 2017–2019 landings. In all panels, expected values represented by solid lines, median values represented by dashed lines, and uncertainty represented by thin lines corresponding to 5^{th} and 95^{th} percentiles of replicate projections. Horizontal lines mark MSY*-related quantities from the base run (solid blue lines) and medians from the ensemble model runs(dashed green lines). Spawning stock (SSB) is at time of peak spawning.*

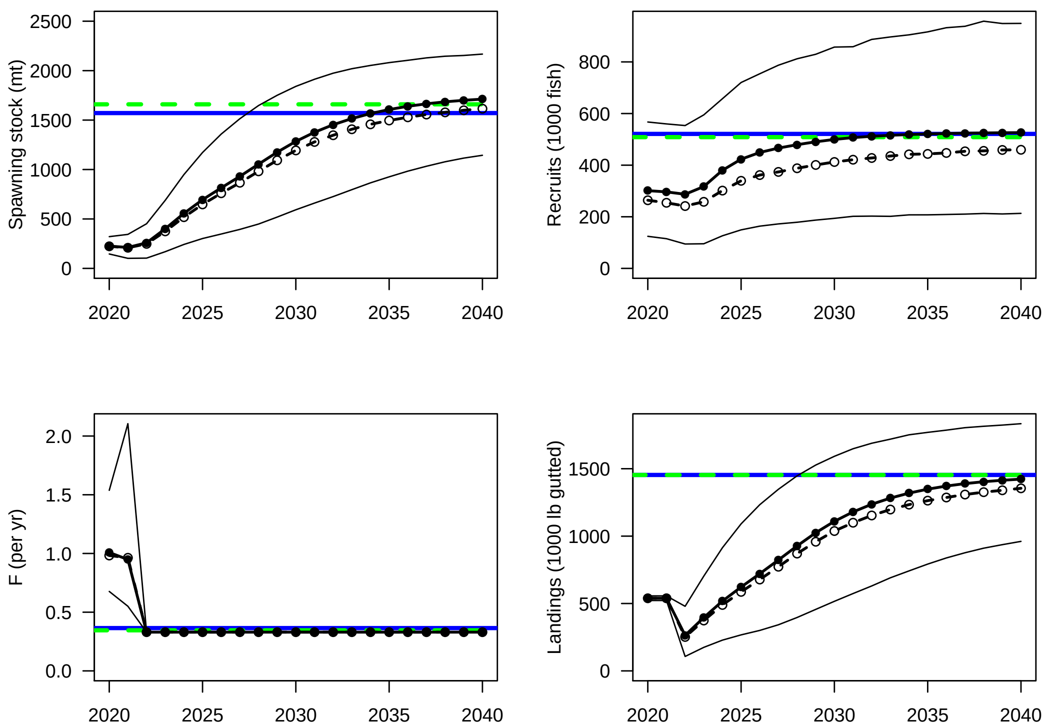
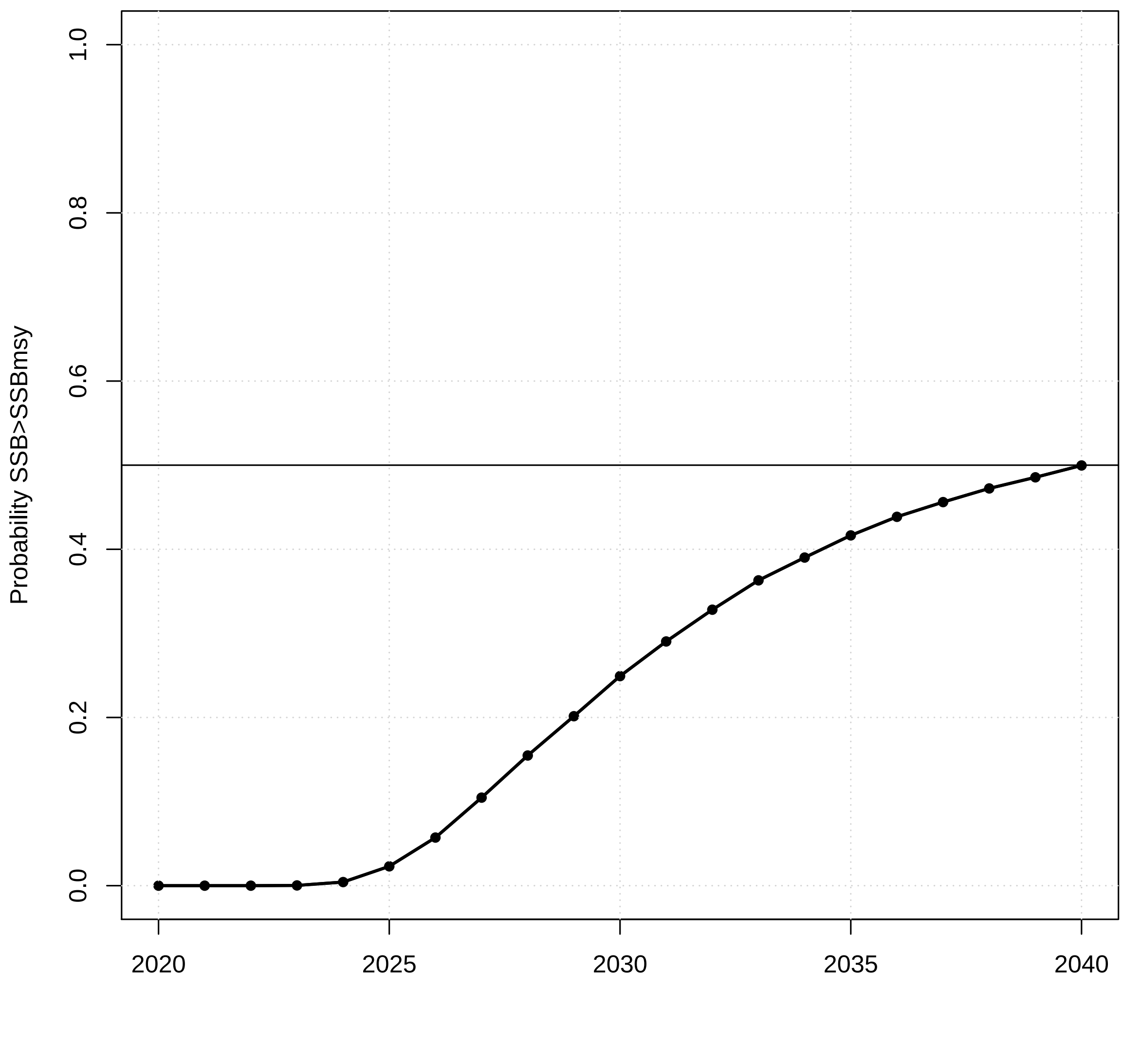


Figure 59. Projected probability of rebuilding under scenario 4—fishing mortality rate at $F = F_{\text{rebuild}}$. The curve represents the proportion of projection replicates for which SSB *has reached the replicate-specific* SSB_{MSY}*, with reference line at 0.5.*



Appendix A Abbreviations and symbols

Table 21. Acronyms and abbreviations used in this report

Symbol	Meaning
ABC	Acceptable Biological Catch
AW	Assessment Workshop (here, for gag)
ASY	Average Sustainable Yield
B	Total biomass of stock
BAM	Beaufort Assessment Model (an integrated, statistical catch-age formulation)
CPUE	Catch per unit effort; used after adjustment as an index of abundance
CV	Coefficient of variation
CVT	SERFS chevron trap gear
DW	Data Workshop (here, for gag)
F	Instantaneous rate of fishing mortality
$F_{30\%}$	Fishing mortality rate at which $F_{30\%}$ can be attained
F_{MSY}	Fishing mortality rate at which MSY can be attained
FHWAR	The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey
FL	State of Florida
FWRI	Fish and Wildlife Research Institute (Florida)
GA	State of Georgia
GLM	Generalized linear model
GW	Gutted weight of a fish
K	Average size of stock when not exploited by man (carrying capacity); or, Brody growth coefficient of the von Bertalanffy equation
kg	Kilogram(s); 1 kg is about 2.2 lb.
klb	Thousand pounds; thousands of pounds
lb	Pound(s); 1 lb is about 0.454 kg
m	Meter(s); 1 m is about 3.28 feet.
M	Instantaneous rate of natural (non-fishing) mortality
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program, a fishery-independent data collection program of SCDNR
MCB	Monte Carlo/Bootstrap, an approach to quantifying uncertainty in model results
MCBE	Monte Carlo/Bootstrap Ensemble approach, another name for MCB
MFMT	Maximum fishing-mortality threshold; a limit reference point used in U.S. fishery management; typically based on F_{MSY} or its proxy
mm	Millimeter(s); 1 inch = 25.4 mm
MRFSS	Marine Recreational Fisheries Statistics Survey, a data-collection program of NMFS, predecessor of MRIP
MRIP	Marine Recreational Information Program, a data-collection program of NMFS, descended from MRFSS
MSST	Minimum stock-size threshold; a limit reference point used in U.S. fishery management.
MSY	Maximum sustainable yield (per year)
mt	Metric ton(s). One mt is 1000 kg, or about 2205 lb.
N	Number of fish in a stock
NC	State of North Carolina
NMFS	National Marine Fisheries Service, same as "NOAA Fisheries Service"
NOAA	National Oceanic and Atmospheric Administration; parent agency of NMFS
OY	Optimum yield; SFA specifies that OY $\leq$ MSY.
PSE	Proportional standard error
R	Recruitment
SAFMC	South Atlantic Fishery Management Council (also, Council)
SC	State of South Carolina
SCDNR	Department of Natural Resources of SC
SDNR	Standard deviation of normalized residuals
SEDAR	SouthEast Data Assessment and Review process
SERFS	SouthEast Reef Fish Survey
SFA	Sustainable Fisheries Act; the Magnuson–Stevens Act, as amended
SL	Standard length (of a fish)
SRHS	Southeast Region Headboat Survey, conducted by NMFS-Beaufort laboratory
SPR	Spawning potential ratio
SSB	Spawning stock biomass; mature biomass of males and females
SSB_{MSY}	Level of SSB at which MSY can be attained
TIP	Trip Interview Program, a fishery-dependent biodata collection program of NMFS
TL	Total length (of a fish), as opposed to FL (fork length) or SL (standard length)
VID	SERFS video gear
VPA	Virtual population analysis, an age-structured assessment
WW	Whole weight, as opposed to GW (gutted weight)
yr	Year(s)

Appendix B Parameter estimates from the Beaufort Assessment Model

```
# Number of parameters = 399  Objective function value = 14373.8  Maximum gradient component = 0.00664831
# Linf:
1161.30000000
# K:
0.168000000000
# t0:
-1.11000000000
# len_cv_val:
0.174519372731
# Linf_L:
1155.30000000
# K_L:
0.154000000000
# t0_L:
-2.16000000000
# len_cv_val_L:
0.123657388509
# log_Nage_dev:
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
 0.00000000000 0.00000000000 0.00000000000 0.00000000000
# log_R0:
13.1751211634
# steep:
0.897896537479
# rec_sigma:
0.436840016785
# R_autocorr:
0.00000000000
# log_rec_dev:
 0.0527969047811 -0.648385997393 0.0654476707358 0.273848109109 0.0565782518860 -0.000697528446234 0.701912168885 -0.430911667320 -0.416659228641
0.427535100209 0.619719792470 0.392532676284 0.460625704838 0.342305543365 0.582986563044 0.623609954092 0.0659373990708 -0.147154445990
0.240442835810 0.393658568195 0.685888852817 0.208108490810 -0.0453853916389 0.188432526672 0.189752702160 0.213275829425 0.575282149239 0.246781949757
0.0278829857196 -0.100990512933 0.163839507976 0.236371191815 0.0488436409664 -0.0266354549058 -0.486023920602 -0.470362799746 -0.408721390395
-0.603044891544 -0.859124447940 -0.890464795698 -0.275531021658 -1.20417994043 -1.07100820940 0.000884574554172
# log_dm_HB_lc:
0.0961642556431
# log_dm_HB_D_lc:
1.61908727060
# log_dm_cH_ac:
-0.480524116655
# log_dm_cD_ac:
1.19114359137
# log_dm_HB_ac:
1.03457752964
# log_dm_GR_ac:
0.00000000000
# log_dm_CVT_ac:
0.757691513725
# selpar_A50_cH1:
4.50626117801
# selpar_slope_cH1:
1.62318145458
1.62378000000
# selpar_A50_cD2:
4.14320232910
# selpar_slope_cD2:
1.90394772103
# selpar_A502_cD2:
4.57378256460
# selpar_slope2_cD2:
0.856744455175
# selpar_A50_HB1:
1.80381404718
# selpar_slope_HB1:
1.96355598043
# selpar_A50_HB2:
2.57452604183
# selpar_slope_HB2:
3.40102814596
# selpar_age2logit_D:
1.25210535673
# selpar_A50_CVT:
1.36962161737
# selpar_slope_CVT:
1.85120035706
# selpar_A502_CVT:
2.17637228484
# selpar_slope2_CVT:
1.03578780396
# log_q_cH:
-8.00009036824
# log_q_HB:
-13.0672840875
# log_q_VID:
-12.6673443346
# q_RW_log_dev_cH:
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
0.00000000000 0.00000000000 0.00000000000 0.00000000000
# q_RW_log_dev_HB:
```

```
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
# M_constant:
0.140000000000
# log_avg_F_cH:
-2.15749065605
# log_F_dev_cH:
 -2.36471775756 -2.46762344557 -2.54325994026 -2.53810426125 -2.82393968473 -2.07355614196 -1.67810842791 -2.02239278495 -1.69213644156 -1.65069977334
-2.04729528972 -1.68823483917 -1.42285114453 -1.28167534066 -0.964939257576 -0.828011616490 -0.340653655382 -0.329387383844 -0.315943640225 0.0228465574760
0.292385309194 0.484510790737 0.859145975071 1.09520780039 1.20117981318 1.45316665547 1.22927008268 1.45454332070 1.16746798237 0.857386296273
0.793907608047 0.792774376736 0.783300304736 0.836187841200 0.821639689497 0.669989201921 0.685178870224 0.399742783740 0.0889585339037 0.140820116675
0.244654368005 0.309553259339 0.454312567520 0.655306489272 0.493956394165 0.766210318529 0.735256569122 0.899723295420 0.824737997120 0.866347979206
0.659298058840 0.883738652818 1.02277196708 0.999756040510 0.921136351399 1.05502102272 1.41653496522 1.73560462020
# log_avg_F_cD:
-4.09946566042
# log_F_dev_cD:
 -3.48594820975 -2.61163359011 -2.11843790253 -1.74207164688 -1.78944452705 -1.77636228281 -1.48799163511 -2.00577333023 -1.00557482775 -1.14747430721
-1.66618304977 -0.264821814609 -0.913314038233 -0.580273478982 -0.804131975372 0.579530189672 0.714717432574 0.319215792107 0.482415816237 0.373758341956
0.861841709224 0.737600373549 0.991404332809 0.673616893043 0.00725079238989 0.356979781318 0.527555330551 0.942188624696 0.555371196093 0.197170925025
0.263995884925 0.643592658219 0.659645480802 0.992485583298 1.41090076517 1.06512002805 1.07313439240 0.836594164430 0.628909083151 1.23824444313
1.49098331196 1.55486792721 1.73761827054 1.48272709185
# log_avg_F_HB:
-4.46558043194
# log_F_dev_HB:
 -0.581782172182 -0.681478931865 -0.752395228470 -0.726255072275 -1.01579137660 -0.270188474095 0.148392338284 -0.223259748353 0.100159264843 0.140020793283
 -0.102139982523 0.193045307398 -0.0556061728921 -0.533357013541 -0.645283514468 -0.476793430886 -0.739485286929 -0.243485242773 -0.571340492278
0.209775023011 0.0993827558846 0.403928902665 0.860342570738 1.01454682275 0.900288229878 1.07531939463 1.01808855911 0.965732542452 0.733804512711
0.368000228624 0.768896671866 0.522410976194 0.462590349240 0.675217310365 0.343559297821 0.138276775206 0.226477884745 -0.171455606317 0.0533468248453
-0.0218946777143 -0.0905853116148 -0.454981874960 0.349509804290 0.471430609875 0.0339394065179 0.580528554414 -0.0851377543417 -0.0333796612344
0.0948633449546 -0.0820793121273 -0.145845296439 -0.412751914941 -0.558728753046 -0.557781434512 -0.668947419608 -0.609522085509 -0.557978414442
-0.882163399656
# log_avg_F_GR:
-2.72310443298
# log_F_dev_GR:
 -2.61000535290 -2.71081344860 -2.77982196561 -2.75420966658 -3.04479337217 -2.30015713067 -1.88193037330 -2.25327460665 -1.93061067190 -1.88999950605
-2.29490591622 -1.91874367626 -1.65553359451 -1.53863795798 -1.21750687582 -1.24448207128 -0.624827762187 -0.642545511513 -0.663139151119 1.20932518002
0.505002310139 -0.231373415986 2.27641233193 0.852471296643 0.389991285485 0.967193811932 0.375950145176 1.29437258510 0.481504915213 0.357258193061
0.505891219696 0.703619146349 0.966542283985 0.592361704561 1.10233817190 0.339541312800 0.939447971996 0.821099873020 0.591249999273 1.25898167880
0.856786069682 1.10215447236 1.18216541757 0.663755191211 1.15162744788 1.28876646570 1.68609896002 1.40925964866 0.881131979470 0.751355067416
0.979713384763 0.499847502819 1.27286699588 0.830396995833 1.27200143529 1.44799605447 1.15019672100 1.23063680018
# log_avg_F_cH_D:
-5.36611991922
# log_F_dev_cH_D:
 -0.0510032099078 -0.0126352899444 0.494569498254 0.0634301358616 -0.605976219603 0.0275421799452 0.262106593831 -0.823104178617 -0.886872624164
-0.577951164680 -0.522641418210 -0.414564603269 -0.0577405241003 0.0986513741936 0.485539420012 0.829337320125 0.462503874354 -0.00748590152051
0.0331414209891 0.898991954608 0.304161361844
# log_avg_F_HB_D:
-6.39241202817
# log_F_dev_HB_D:
 -1.73341168302 -2.30087158694 1.99743537692 -0.421651585188 -1.94404719254 -0.378939108950 0.435252996808 -0.751509963624 -0.0588532784571 0.672304147195
0.270850543597 0.354234656104 0.0303705394965 0.201077326055 1.06901654940 -0.547753411593 1.29887604920 0.147133756690 0.0964744772074 1.02232100604
-0.497361913552 -0.152253414063 -0.0246958747492 0.376912102172 0.618268904031 -0.0595851538656 -0.197451250044 0.197168849430 0.904814458068 0.689018380524
0.628389208150 0.974595740112 0.107510998365 -0.0134074880046 -0.0499505081823 -0.637690308438 -0.652972547751 -0.296469047137 -1.37315074946
# log_avg_F_GR_D:
-2.60452173289
# log_F_dev_GR_D:
 -1.51204806310 -2.92500365326 0.388153326687 0.318600044039 -2.27355659187 -1.65850654833 -0.460378811698 -2.13131264023 -0.278854145310 -0.821340518859
-1.01687678983 -0.649997351258 -0.531548741950 0.0188972823771 0.332005882605 -0.396775833188 0.606166612877 0.224222023054 0.258109572252 0.784777815300
0.0154886341140 0.356488282042 0.965682155838 0.532800480148 0.816713154442 0.828556657139 1.12023570829 1.10282967302 0.969257057783 0.976194785121
0.796898036086 1.46579465750 0.686125605859 1.48522579832 1.16686182510 -0.123393663392 -0.406968780396 0.214891212884 -1.24441415021
# F_init:
0.0317799516718
```

SEDAR

Southeast Data, Assessment, and Review

SEDAR 71

South Atlantic Gag

Section III: Addendum

April 2021

SEDAR
4055 Faber Place Drive, Suite 201 North Charleston, SC 29405

Addendum to SEDAR 71 South Atlantic Gag Grouper Stock Assessment Report

April 21, 2021

Research Recommendations

- Develop methods to characterize length and age composition of gag grouper observed on videos from SERFS fishery independent surveys. Trap sampling of gag was limited and potentially biased due to size selectivity of the gear.

- Implement systematic age sampling for the general recreational and commercial sectors. Age samples were important for this assessment for identifying strong year classes but sample sizes were limited, particularly for the general recreational sector, which accounts for the majority of the recent landings.

- Better characterize the reproductive dynamics of gag including sex ratio, maturity schedule, batch fecundity, spawning seasonality and spawning frequency, as well as the potential for sperm limitation. Mature male and female biomass was the measure of reproductive potential for this assessment, but may be biased if reproductive parameters vary significantly with size and age, or if sex ratio and other life history characteristics have varied considerably over time.

- Age-dependent natural mortality was estimated by indirect methods (Lorenzen) for this assessment. Telemetry- and conventional-tagging programs can provide alternative estimates of natural mortality.

- Better characterize population and fishery dynamics of gag during their residency in estuaries. Gag spend their first year of life in estuaries, and differences in natural mortality, growth, or harvest between the estuarine phase and the offshore stock could induce biases in the assessment.

- Investigate potential sources of recent recruitment declines in gag in the South Atlantic. Gag recruitment has been low over the last 10 years, possibly due to overharvest or external environmental factors. Non-traditional datasets, such as inshore estuarine surveys and larval bridge net surveys, may be helpful in better understanding recruitment dynamics of gag.