

¹ Status of Big Skate (*Beringraja binoculata*)
² Off the U.S. Pacific Coast in 2019



⁴ Ian G. Taylor¹
⁵ Vladlena Gertseva¹
⁶ Andi Stephens²
⁷ Joseph Bizzarro³

⁸ ¹Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and
⁹ Atmospheric Administration, National Marine Fisheries Service, 2725 Montlake Boulevard East,
¹⁰ Seattle, Washington 98112

¹¹ ²Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and
¹² Atmospheric Administration, National Marine Fisheries Service, 2032 S.E. OSU Drive Newport,
¹³ Oregon 97365

¹⁴ ³Southwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and
¹⁵ Atmospheric Administration, National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz,
¹⁶ California 95060

¹⁷ DRAFT SAFE

¹⁸ Disclaimer: This information is distributed solely for the purpose of pre-dissemination peer review
¹⁹ under applicable information quality guidelines. It has not been formally disseminated by NOAA
²⁰ Fisheries. It does not represent and should not be construed to represent any agency
²¹ determination or policy.

²² This report may be cited as:

²³ Taylor, I.G., Gertseva, V., Bizzarro, J., and Stephens, A. Status of Big Skate (*Beringraja*

²⁴ *binoculata*) Off the U.S. West Coast, 2019. Pacific Fishery Management Council, Portland, OR.

²⁵ Available from <http://www.p council.org/groundfish/stock-assessments/>

Acronyms used in this Document

ABC	Allowable Biological Catch
ACL	Annual Catch Limit
ADFG	Alaska Department of Fish and Game
AFSC	Alaska Fisheries Science Center
A-SHOP	At-Sea Hake Observer Program
CalCOM	California Cooperative Groundfish Survey
CDFW	California Department of Fish and Wildlife
CPFV	Commercial Passenger Fishing Vessel
CRFS	California Recreational Fisheries Survey
DFO	Canada's Department of Fisheries and Oceans
IFQ	Individual Fishing Quota
IPHC	International Pacific Halibut Commission
MRFSS	Marine Recreational Fisheries Statistics Survey
NMFS	National Marine Fisheries Service
NORPAC	the North Pacific Database Program
NWFSC	Northwest Fisheries Science Center
ODFW	Oregon Department of Fish and Wildlife
OFL	Overfishing Limit
ORBS	Oregon Recreational Boat Survey
OY	Optimum Yield
PacFIN	Pacific Fisheries Information Network
PFMC	Pacific Fishery Management Council
PSMFC	Pacific States Marine Fisheries Commission
RecFIN	Recreational Fisheries Information Network
SPR	Spawning Potential Ratio
SSC	Scientific and Statistical Committee
SWFSC	Southwest Fisheries Science Center
WCGOP	West Coast Groundfish Observer Program
WDFW	Washington Department of Fish and Wildlife

27 Status of Big Skate (*Beringraja binoculata*)
28 Off the U.S. Pacific Coast in 2019

29 **Contents**

30 Executive Summary	1
31 Stock	1
32 Catches	1
33 Data and Assessment	3
34 Stock Biomass	4
35 Recruitment	7
36 Exploitation status	9
37 Ecosystem Considerations	11
38 Reference Points	11
39 Management Performance	12
40 Unresolved Problems and Major Uncertainties	13
41 Decision Table	13
42 Research and Data Needs	18
43 1 Fishery Data	19
44 1.1 Data	19
45 1.2 Fishery Landings and discards	19
46 1.2.1 Washington Commercial Skate Landings Reconstruction	19
47 1.2.2 Oregon Commercial Skate Landings Reconstruction	20
48 1.2.3 California Catch Reconstruction	21
49 1.2.4 Tribal Catch in Washington	21
50 1.2.5 Fishery Discards	21
51 2 Fishery-Independent Data Sources	23
52 2.1 Indices of abundance	23
53 2.1.1 Alaska Fisheries Science Center (AFSC) Triennial Shelf Survey	23

54	2.1.2	Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey	23
55	2.1.3	Index Standardization	24
56	2.1.4	Internation Pacific Halibut Commission Longline Survey	24
57	2.2	Biological Parameters and Data	26
58	2.2.1	Measurement Details and Conversion Factors	26
59	2.2.2	Fishery dependent length and age composition data	26
60	2.2.3	Survey length and age composition data	26
61	2.2.4	Environmental or Ecosystem Data Included in the Assessment	27
62	3	Assessment	28
63	3.1	Previous Assessments	28
64	3.1.1	History of Modeling Approaches Used for this Stock	28
65	3.2	Model Description	28
66	3.2.1	Modeling Software	28
67	3.2.2	Summary of Data for Fleets and Areas	28
68	3.2.3	Other Specifications	28
69	3.2.4	Data Weighting	29
70	3.2.5	Priors	29
71	3.2.6	Estimated and Fixed Parameters	30
72	3.3	Model Selection and Evaluation	31
73	3.3.1	Key Assumptions and Structural Choices	31
74	3.3.2	Alternate Models Considered	32
75	3.3.3	Convergence	32
76	3.4	Response to the Current STAR Panel Requests	32
77	3.5	Base Case Model Results	33
78	3.5.1	Parameter Estimates	33
79	3.5.2	Fits to the Data	33
80	3.5.3	Uncertainty and Sensitivity Analyses	34
81	3.5.4	Retrospective Analysis	34
82	3.5.5	Likelihood Profiles	35
83	3.5.6	Reference Points	35

85	4 Harvest Projections and Decision Tables	36
86	5 Regional Management Considerations	37
87	6 Research Needs	38
88	7 Acknowledgments	38
89	8 Tables	39
90	8.1 Data Tables	39
91	8.2 Model Results Tables	45
92	9 Figures	61
93	9.0.1 Sensitivity analyses for model	90
94	Appendix A. Detailed fits to length composition data	A-1
95	References	

⁹⁶ **Executive Summary**

⁹⁷ **Stock**

⁹⁸ This assessment reports the status of the Big Skate (*Beringraja binoculata*) resource in U.S.
⁹⁹ waters off the West Coast using data through 2018.

¹⁰⁰ **Catches**

¹⁰¹ Landings and estimated discards of Big Skate were reconstructed for this assessment from
¹⁰² historical records of other species and from species composition data collected in the recent
¹⁰³ fishery. These reflect the fishery from 1916-1994. The current fishery started in 1995. For
¹⁰⁴ records from 1995-2017, Big Skate landings were estimated from species-composition samples
¹⁰⁵ and the landings of “Unspecified Skates”. Beginning in 2017, Big Skate have been recorded
¹⁰⁶ in species-specific landings.

¹⁰⁷ In the current fishery (since 1995), annual total landings of Big Skate have ranged between
¹⁰⁸ 135-528 mt, with landings in 2018 totaling 173 mt.

Table a: Recent Big Skate landings (mt)

Year	Landings
2008	366.00
2009	205.70
2010	196.20
2011	268.40
2012	269.60
2013	135.00
2014	372.40
2015	331.50
2016	411.50
2017	277.60
2018	172.60

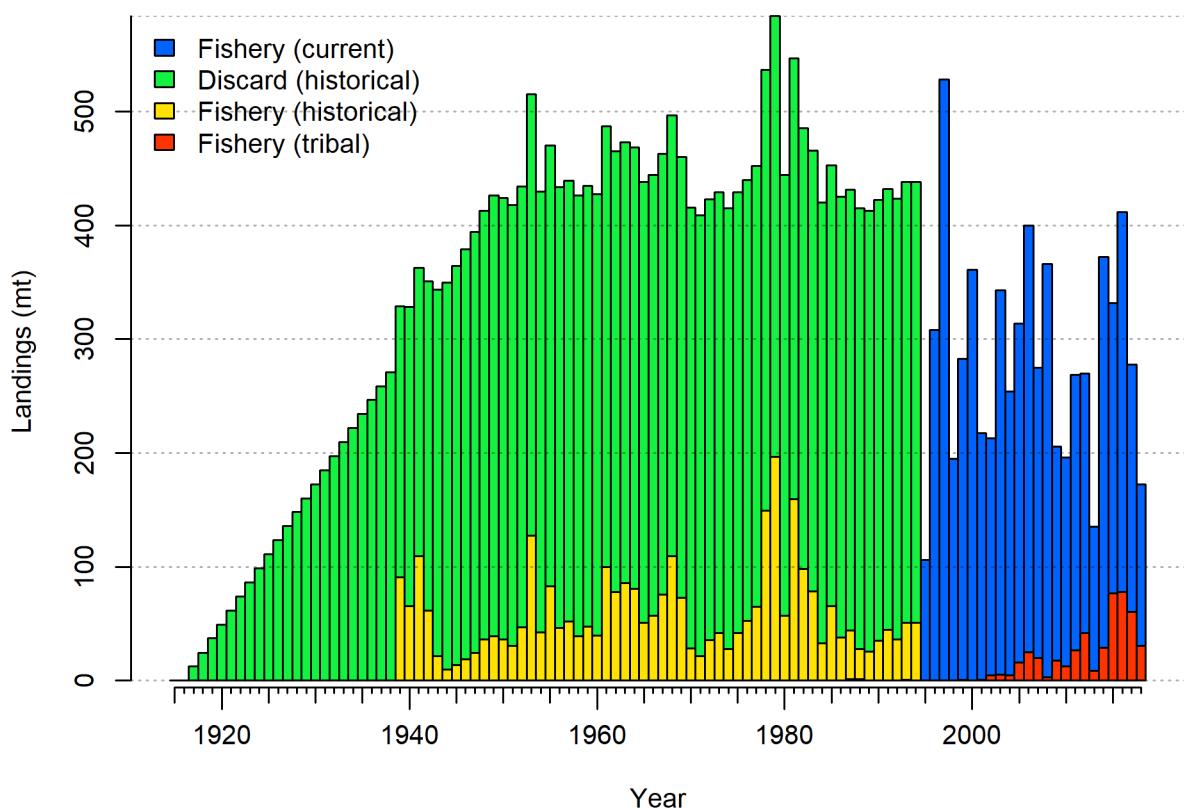


Figure a: Catch history of Big Skate in the model.

¹⁰⁹ **Data and Assessment**

¹¹⁰ This the first full assessment for Big Skate. It is currently managed using an OFL which was
¹¹¹ based on a proxy for F_{MSY} and a 3-year recent average of survey biomass. This assessment
¹¹² uses the newest version of Stock Synthesis (3.30.13). The model begins in 1916, and assumes
¹¹³ the stock was at an unfished equilibrium that year.

¹¹⁴ The assessment relies on two bottom trawl survey indices of abundance, the Triennial Survey
¹¹⁵ from an index covering the period 1980–2004 was used here and the West Coast Groundfish
¹¹⁶ Bottom Trawl (WCGBT) Survey, which began in 2003 and for which data is available through
¹¹⁷ 2018. The triennial survey shows an increasing trend over the 25 year period it covers, which
¹¹⁸ the model is not able to fit as this includes the peak period of the fishery when the stock
¹¹⁹ would have been expected to be declining. The WCGBT Survey also shows an increasing
¹²⁰ trend, with the 5 most recent observations (2014–2018) all falling in the top 6 ever observed
¹²¹ (2004 was the 5th highest observation). The most estimates an increasing trend during this
¹²² period but the slope is more gradual than the trend in the survey. The misfit to these
¹²³ survey indices could be due to some combination of incorrect estimation of the catch history,
¹²⁴ variability in recruitment which is not modeled here, or biological or ecological changes for
¹²⁵ which data are not available.

¹²⁶ Length composition data from the fishery is available starting in 1995 but is sparse until the
¹²⁷ past decade. Most of the ages are also from 2008 onward. This limits the ability of the model
¹²⁸ to estimate any changes composition of the population during the majority of the history of
¹²⁹ the fishery. Estimates of discard rates and mean body weight of discards are available for
¹³⁰ the years 2002 onward and discard length compositions are available starting in 2010.

¹³¹ The age and length data provide evidence for growth patterns and sex-specific differences
¹³² in selectivity that are unusual among groundfish stocks that have been assessed within the
¹³³ U.S. West Coast and are not found in Longnose Skate where the data show little difference
¹³⁴ between the sexes. Growth appears to be almost linear and similar between females and
¹³⁵ males up to about age 7 or over 100 cm at which point male growth appears to stabilize
¹³⁶ while females continue to grow. However, in spite of the similar growth pattern for ages prior
¹³⁷ to 7, males are observed more frequently, with the 70–100 cm length bins often showing 60%
¹³⁸ males. Sex-specific differences in selectivity were included in the model in order to better
¹³⁹ match patterns in the sex ratios in the length composition data. The length and age data
¹⁴⁰ do not cover enough years or show enough evidence of distinct cohorts to reliably estimate
¹⁴¹ deviations in recruitment around the stock-recruit curve.

¹⁴² The scale of the population is not reliably informed by the data due to the combination of
¹⁴³ surveys that show trends which can't be matched by the structure of the model and length
¹⁴⁴ and age data which inform growth and selectivity but provide relatively little information
¹⁴⁵ about changes in stock structure over time. Therefore, a prior on catchability of the WCGBT
¹⁴⁶ Survey (centered at 0.83) was applied in order to provide more stable results.

¹⁴⁷ Although the assessment model requires numerous simplifying assumptions, it represents an

¹⁴⁸ improvement over the simplistic status-quo method of setting management limits, which re-
¹⁴⁹ lies on average survey biomass and an assumption about F_{MSY} . The use of an age-structured
¹⁵⁰ model with estimated growth, selectivity, and natural mortality likely provide a better esti-
¹⁵¹ mate of past dynamics and the impacts of fishing in the future.

¹⁵² Stock Biomass

¹⁵³ The 2018 estimated spawning biomass relative to unfished equilibrium spawning biomass is
¹⁵⁴ above the target of 40% of unfished spawning biomass at 72.5% (95% asymptotic interval: \pm
¹⁵⁵ 55.2%-89.7%) (Figure c). Approximate confidence intervals based on the asymptotic variance
¹⁵⁶ estimates show that the uncertainty in the estimated spawning biomass is high, although
¹⁵⁷ even the lower range of the 95% interval for %unfished is above the 40% reference point, and
¹⁵⁸ all sensitivity analyses explore also show the stock to be at a high level.

Table b: Recent trend in beginning of the year spawning output and (spawning biomass relative to unfished equilibrium spawning biomass)

Year	Spawning Output (mt)	~ 95% confidence interval	Estimated %unfished	~ 95% confidence interval
2010	1059.250	(425.78-1692.72)	0.694	(0.552-0.837)
2011	1068.670	(434.08-1703.26)	0.700	(0.56-0.841)
2012	1073.990	(438.95-1709.03)	0.704	(0.564-0.843)
2013	1079.980	(444.55-1715.41)	0.708	(0.57-0.846)
2014	1094.970	(458.25-1731.69)	0.718	(0.583-0.852)
2015	1095.100	(458.91-1731.29)	0.718	(0.583-0.852)
2016	1097.700	(461.69-1733.71)	0.719	(0.586-0.853)
2017	1093.720	(458.52-1728.92)	0.717	(0.583-0.851)
2018	1097.080	(461.78-1732.38)	0.719	(0.586-0.852)
2019	1106.070	(504.33-1707.81)	0.725	(0.552-0.897)

Spawning output with ~95% asymptotic intervals

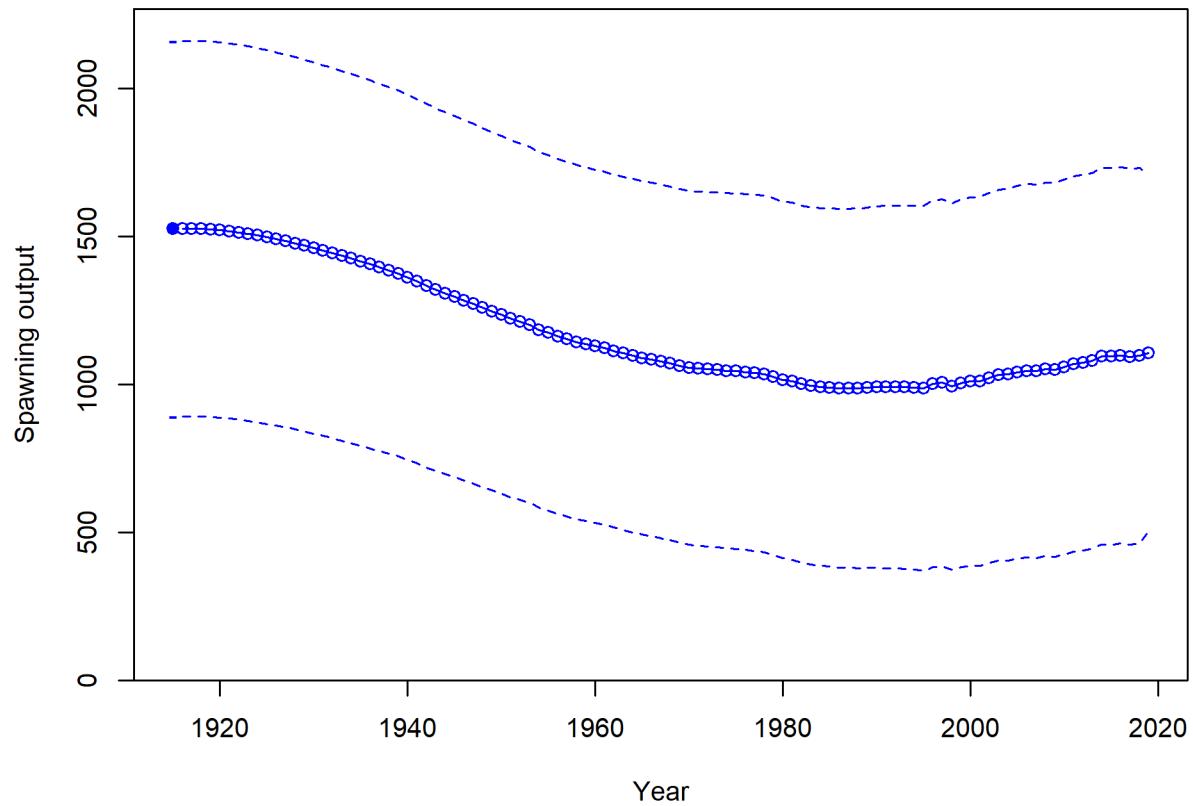


Figure b: Time series of spawning biomass trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base case assessment model.

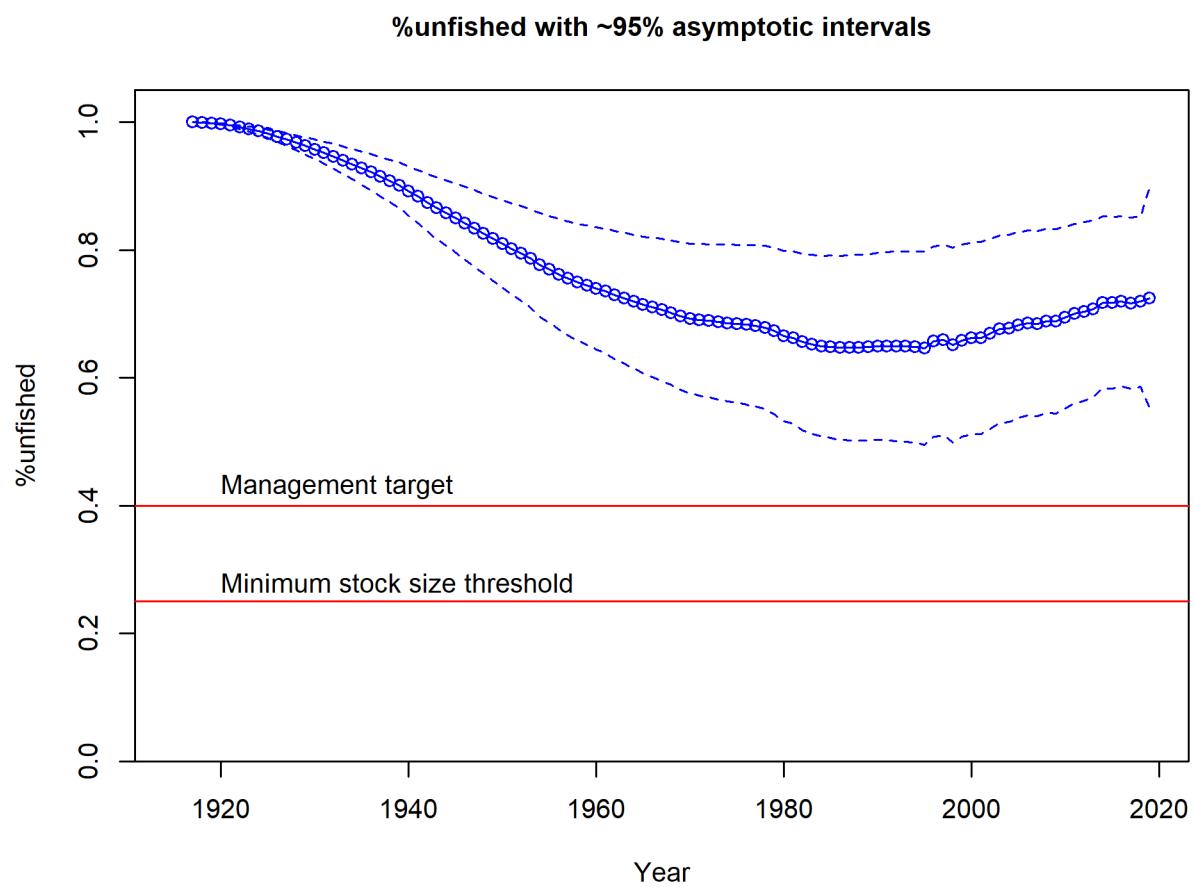


Figure c: Estimated relative %unfished with approximate 95% asymptotic confidence intervals (dashed lines) for the base case assessment model.

¹⁵⁹ **Recruitment**

¹⁶⁰ Recruitment was assumed to follow the Beverton-Holt stock recruit curve, so uncertainty in
¹⁶¹ estimated recruitment is due to uncertainty in spawning biomass and the unfished equilibrium
¹⁶² recruitment R_0 (Figure d and Table c).

Table c: Recent recruitment for the model.

Year	Estimated Recruitment (1,000s)	~ 95% confidence interval
2010	3435.91	(2128.69 - 5545.9)
2011	3450.01	(2142.11 - 5556.47)
2012	3457.92	(2149.79 - 5562.03)
2013	3466.77	(2158.45 - 5568.12)
2014	3488.68	(2179.48 - 5584.31)
2015	3488.86	(2180.18 - 5583.09)
2016	3492.63	(2184.26 - 5584.72)
2017	3486.86	(2179.33 - 5578.88)
2018	3491.73	(2184.37 - 5581.57)
2019	3504.69	(2186.12 - 5618.57)



Figure d: Time series of estimated Big Skate recruitments for the base-case model with 95% confidence or credibility intervals.

¹⁶³ **Exploitation status**

¹⁶⁴ Harvest rates estimated by the base model indicate catch levels have been below the limits
¹⁶⁵ that would be associated with the SPR = 50% target (Table d and Figure e).

Table d: Recent trend in spawning potential ratio and exploitation for Big Skate in the model. Relative fishing intensity is (1-SPR) divided by 50% (the SPR target) and exploitation is catch divided by age 2+ biomass.

Year	Relative fishing intensity	~ 95% confidence interval	Exploitation rate	~ 95% confidence interval
2009	0.23	(0.12-0.34)	0.01	(0.01-0.02)
2010	0.22	(0.11-0.32)	0.01	(0.01-0.02)
2011	0.29	(0.15-0.42)	0.02	(0.01-0.02)
2012	0.29	(0.15-0.42)	0.02	(0.01-0.02)
2013	0.15	(0.08-0.22)	0.01	(0-0.01)
2014	0.39	(0.22-0.56)	0.02	(0.01-0.03)
2015	0.35	(0.19-0.5)	0.02	(0.01-0.03)
2016	0.43	(0.24-0.61)	0.02	(0.01-0.04)
2017	0.30	(0.16-0.44)	0.02	(0.01-0.02)
2018	0.19	(0.1-0.28)	0.01	(0.01-0.01)

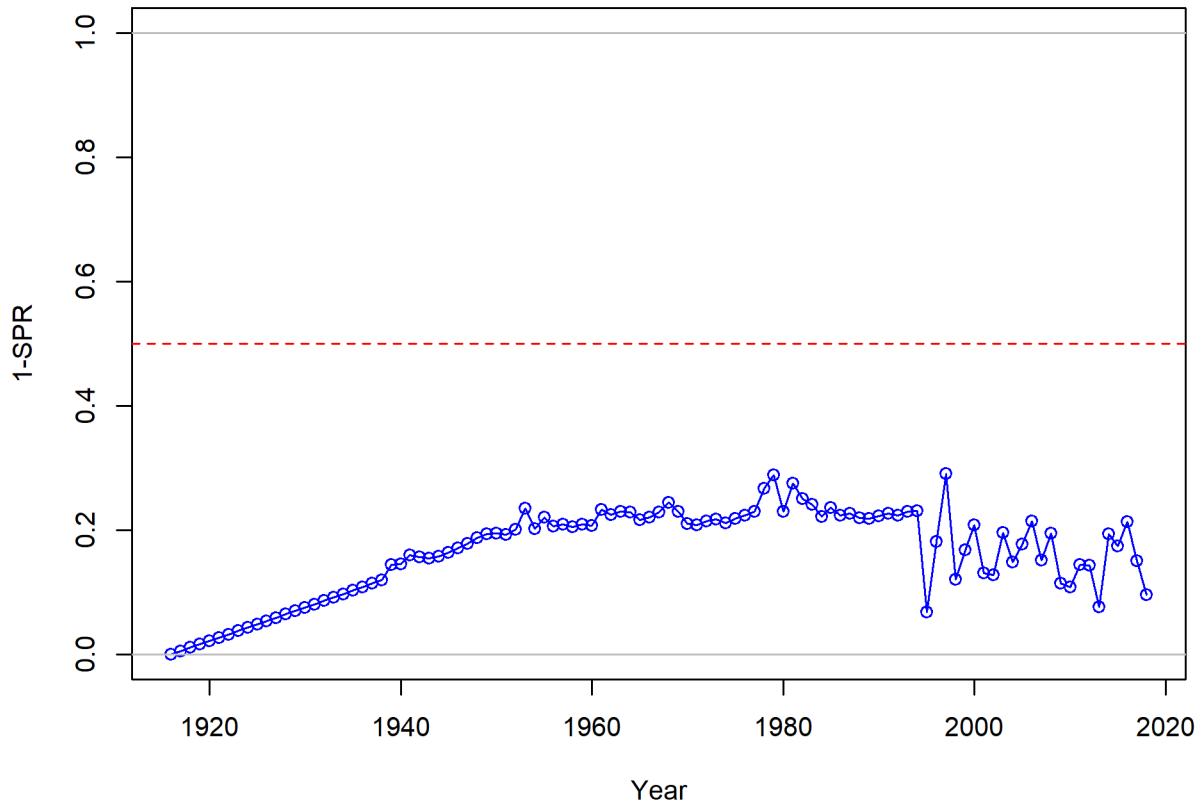


Figure e: Estimated spawning potential ratio (SPR) for the base-case model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR_{50%} harvest rate. The last year in the time series is 2018.

¹⁶⁶ **Ecosystem Considerations**

¹⁶⁷ In this assessment, ecosystem considerations were not explicitly included in the analysis.
¹⁶⁸ This is primarily due to a lack of relevant data and results of analyses (conducted elsewhere)
¹⁶⁹ that could contribute ecosystem-related quantitative information for the assessment.

¹⁷⁰ **Reference Points**

¹⁷¹ This stock assessment estimates that Big Skate in the model is above the biomass target
¹⁷² ($SB_{40\%}$), and well above the minimum stock size threshold ($SB_{25\%}$). The estimated %un-
¹⁷³ fished level for the base model in 2019 is 72.5% (95% asymptotic interval: $\pm 55.2\%-89.7\%$,
¹⁷⁴ corresponding to an unfished spawning biomass of 1106.07 mt (95% asymptotic interval:
¹⁷⁵ 504.33-1707.81 mt) of spawning biomass in the base model (Table [e](#)). Unfished age 1+
¹⁷⁶ biomass was estimated to be 2,426 mt in the base case model. The target spawning biomass
¹⁷⁷ ($SB_{40\%}$) is 610 mt, which corresponds with an equilibrium yield of 558 mt. Equilibrium yield
¹⁷⁸ at the proxy F_{MSY} harvest rate corresponding to $SPR_{50\%}$ is 466 mt (Figure [f](#)).

Table e: Summary of reference points and management quantities for the base case model.

Quantity	Estimate	Low 2.5% limit	High 2.5% limit
Unfished spawning output (mt)	1,526	891	2,161
Unfished age 1+ biomass (mt)	2,426	1,583	3,269
Unfished recruitment (R_0)	4,004	2,395	5,612
Spawning output(2018 mt)	1,097	462	1,732
Depletion (2018)	0.719	0.586	0.852
Reference points based on SB_{40%}			
Proxy spawning output ($B_{40\%}$)	610	373	848
SPR resulting in $B_{40\%}$ ($SPR_{B40\%}$)	0.625	0.625	0.625
Exploitation rate resulting in $B_{40\%}$	0.047	0.043	0.051
Yield with $SPR_{B40\%}$ at $B_{40\%}$ (mt)	558	362	754
Reference points based on SPR proxy for MSY			
Spawning output	305	187	424
SPR_{proxy}	0.5		
Exploitation rate corresponding to SPR_{proxy}	0.069	0.063	0.075
Yield with SPR_{proxy} at SB_{SPR} (mt)	466	303	629
Reference points based on estimated MSY values			
Spawning output at MSY (SB_{MSY})	578	352	804
SPR_{MSY}	0.612	0.608	0.615
Exploitation rate at MSY	0.049	0.045	0.053
Dead Catch MSY (mt)	559	363	755
Retained Catch MSY (mt)	517	337	698

¹⁷⁹ Management Performance

Table f: Recent trend in total catch (mt) relative to the management guidelines. Big skate was managed in the Other Species complex in 2013 and 2014, designated an Ecosystem Component species in 2015 and 2016, and managed with stock-specific harvest specifications since 2017.

Year	OFL (mt; ABC prior to 2011)	ABC (mt)	ACL (mt; OY prior to 2011)	Estimated total catch (mt)
2009				205.70
2010				196.20
2011				268.40
2012				269.60
2013	458.00	317.90	317.90	135.00
2014	458.00	317.90	317.90	372.40
2015				331.50
2016				411.50
2017	541.00	494.00	494.00	277.60
2018	541.00	494.00	494.00	172.60
2019	541.00	494.00	494.00	
2020	541.00	494.00	494.00	

¹⁸⁰ **Unresolved Problems and Major Uncertainties**

¹⁸¹ **To be added**

¹⁸² **Decision Table**

¹⁸³ **Template in Table h and associated discussion to be filled in later**

Table g: Projections of landings, total mortality, OFL, and ACL values based on an SPR target of 50Category 2 Sigma which creates the buffer shown in the right-hand column.

Year	Landings (mt)	Estimated total mortality (mt)	OFL (mt)	ACL (mt)	Buffer
2019	313.16	336.35	541.00	494.00	1.00
2020	313.16	336.32	541.00	494.00	1.00
2021	1042.23	1119.74	1275.51	1119.75	0.87
2022	987.51	1062.58	1222.62	1062.58	0.86
2023	942.80	1015.91	1179.51	1015.91	0.86
2024	906.41	977.59	1145.41	977.59	0.85
2025	876.49	945.64	1118.21	945.64	0.84
2026	850.59	917.76	1095.36	917.76	0.83
2027	828.05	893.39	1075.04	893.39	0.83
2028	805.87	869.37	1056.06	869.37	0.82
2029	784.60	846.33	1037.94	846.33	0.81
2030	764.95	825.07	1020.44	825.07	0.80

Table h: Summary of 10-year projections beginning in 2020 for alternate states of nature based on an axis of uncertainty for the model. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. An entry of “-” indicates that the stock is driven to very low abundance under the particular scenario.

		States of nature					
		Low State		Base State		High State	
	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output
Default harvest, for Low State	2019	-	-	-	-	-	-
	2020	-	-	-	-	-	-
	2021	-	-	-	-	-	-
	2022	-	-	-	-	-	-
	2023	-	-	-	-	-	-
	2024	-	-	-	-	-	-
	2025	-	-	-	-	-	-
	2026	-	-	-	-	-	-
	2027	-	-	-	-	-	-
	2028	-	-	-	-	-	-
Default harvest, for Base State	2019	-	-	-	-	-	-
	2020	-	-	-	-	-	-
	2021	-	-	-	-	-	-
	2022	-	-	-	-	-	-
	2023	-	-	-	-	-	-
	2024	-	-	-	-	-	-
	2025	-	-	-	-	-	-
	2026	-	-	-	-	-	-
	2027	-	-	-	-	-	-
	2028	-	-	-	-	-	-
Default harvest, for High State	2019	-	-	-	-	-	-
	2020	-	-	-	-	-	-
	2021	-	-	-	-	-	-
	2022	-	-	-	-	-	-
	2023	-	-	-	-	-	-
	2024	-	-	-	-	-	-
	2025	-	-	-	-	-	-
	2026	-	-	-	-	-	-
	2027	-	-	-	-	-	-
	2028	-	-	-	-	-	-
Average Catch	2019	-	-	-	-	-	-
	2020	-	-	-	-	-	-
	2021	-	-	-	-	-	-
	2022	-	-	-	-	-	-
	2023	-	-	-	-	-	-
	2024	-	-	-	-	-	-
	2025	-	-	-	-	-	-
	2026	-	-	-	-	-	-
	2027	-	-	-	-	-	-
	2028	-	-	-	-	-	-

Table i: Base case results summary.

Quantity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Landings (mt)	313.160	313.160	1042.228	987.509	942.796	906.409	876.485	850.594	828.055	805.865
Total Est. Catch (mt)	336.345	336.325	1119.745	1062.581	1015.907	977.592	945.644	917.761	893.393	869.365
OFL (mt)	541.00	541.00	1275.51	1222.62	1179.51	1145.41	1118.21	1095.36	1075.04	1056.06
ACL (mt)	494.000	494.000	1119.750	1062.580	1015.910	977.592	945.643	917.762	893.393	869.365
(1-SPR)(1-SPR _{50%})	0.22	0.29	0.29	0.15	0.39	0.35	0.43	0.30	0.19	
Exploitation rate	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.01	
Age 1+ biomass (mt)	17752.6	17914.2	18070.4	18140.7	18203.3	18389.4	18320.0	18306.6	18214.4	18273.9
Spawning Output	1059.2	1068.7	1074.0	1080.0	1095.0	1095.1	1097.7	1093.7	1097.1	1106.1
95% CI	(425.78- 1692.72)	(434.08- 1703.26)	(438.95- 1709.03)	(444.55- 1715.41)	(458.25- 1731.69)	(458.91- 1731.29)	(461.69- 1733.71)	(458.52- 1728.92)	(461.78- 1732.38)	(504.33- 1707.81)
Depletion	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
95% CI	(0.552-0.837)	(0.56-0.841)	(0.564-0.843)	(0.57-0.846)	(0.583-0.852)	(0.583-0.852)	(0.586-0.853)	(0.583-0.851)	(0.586-0.852)	(0.552-0.897)
Recruits	3435.91	3450.01	3457.92	3466.77	3488.68	3488.86	3492.63	3486.86	3491.73	3504.69
95% CI	(2128.69 - 5545.9)	(2142.11 - 5556.47)	(2149.79 - 5562.03)	(2158.45 - 5568.12)	(2179.48 - 5584.31)	(2180.18 - 5583.09)	(2184.26 - 5584.72)	(2179.33 - 5578.88)	(2184.37 - 5581.57)	(2186.12 - 5618.57)

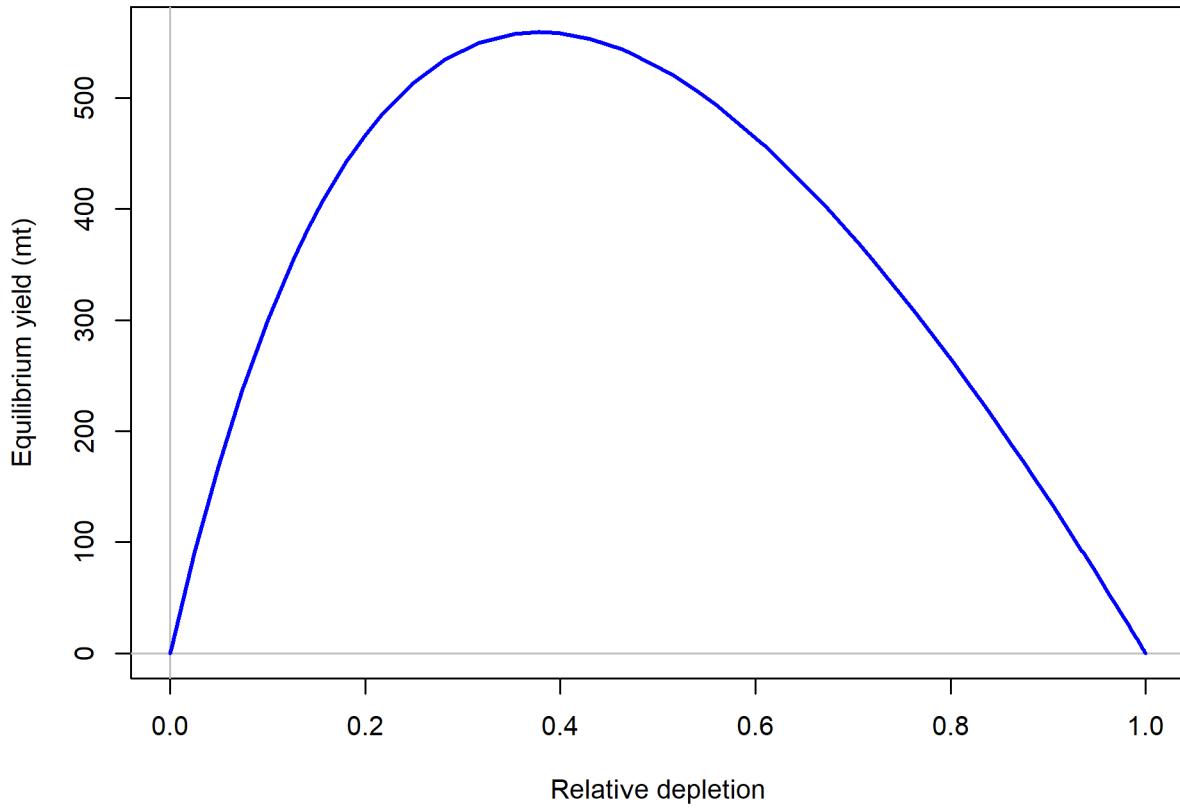


Figure f: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.718.

¹⁸⁴ **Research and Data Needs**

¹⁸⁵ We recommend the following research be conducted before the next assessment:

¹⁸⁶ 1. **Data!:**

¹⁸⁷ 2. **xxxx:**

¹⁸⁸ 3. **xxxx:**

¹⁸⁹ 4. **xxxx:**

¹⁹⁰ 5. **xxxx:**

¹⁹¹ **To be continued**

192 **1 Fishery Data**

193 **1.1 Data**

194 Data used in the Big Skate assessment are summarized in Figure 2. Descriptions of the data
195 sources are in the following sections.

196 **1.2 Fishery Landings and discards**

197 Catch information for Big Skate is very limited, in part because the requirement to sort
198 landings of Big Skate in the shore-based Individual Fishing Quota fishery from landings in
199 the “Unidentified Skate” category was not implemented until June 2015. The historical catch
200 of Big Skate therefore relies on the historical reconstruction of the landings of all skates as
201 well as an analysis of discards of Longnose Skate. The estimated landings for each state and
202 the tribal fishery are provided in Table 1 and shown in Figure 3.

203 **1.2.1 Washington Commercial Skate Landings Reconstruction**

204 Estimates of landings of Big Skate in Washington state were estimated as a fraction of total
205 skate landings as described in (Gertseva, V. 2019a). The approached relied on trawl survey
206 estimates of depth distributions for each species, combined with logbook estimates of fishing
207 depths in each year.

208 The WCGBT Survey data was used to estimate proportions of longnose and big skates by
209 depth (aggregated into 100m bins) and year for the period of the survey (between 2003 and
210 2018). Big Skate were primarily found in the 0–100m and 100–200m. Trawl logbook data
211 include information on the amount of retained catch of skate (all species combined) within
212 each haul as well depth of catch. The proportion of Big Skate for each depth bin was assigned
213 to the skate catch for each haul within those depth bins and summed to get a total for each
214 year. When survey skate information was available (2003-2018), survey skate proportions
215 were applied by depth and year to account for inter-annual variability in those proportions.
216 Prior to 2003, average proportions from 2003-2007 within each depth bin were applied.

217 These estimated annual proportion of Big Skate relative to all skates from the logbook
218 analysis was then applied to total Washington skate landings by year (provided by WDFW)
219 to account for landings that weren’t included in the available logbook data. Prior to 1987
220 (when no logbook data were available), the average proportion Big Skate within the combined
221 skate category, calculated from 1987-1992 logbook data, was applied to total skate landings
222 in Washington. Estimated Big Skate landings provided by WDFW were used for the period
223 from 2004 forward.

224 **1.2.2 Oregon Commercial Skate Landings Reconstruction**

225 Oregon Department of Fish and Wildlife (ODFW) provided newly reconstructed commercial
226 landings for all observed skate species for the 2019 assessment cycle (1978 – 2018). In
227 addition, the methods were reviewed at a pre-assessment workshop. Historically, skates were
228 landed as a single skate complex in Oregon. In 2009, longnose skates were separated into
229 their own single-species landing category, and in 2014, big skates were also separated. The
230 reconstruction methodology differed by these three time blocks in which species composition
231 collections diverged (1978 – 2008; 2009 – 2014; 2015 – 2018).

232 Species compositions of skate complexes from commercial port sampling are available
233 throughout this time period but are generally limited, which precluded the use of all strata
234 for reconstructing landings. Quarter and port were excluded, retaining gear type, PMFC
235 area, and market category for stratifying reconstructed landings within the three time
236 blocks. Bottom trawl gear types include multiple bottom trawl gears, and account for
237 greater than 98% of skate landings . Minor gear types include primarily bottom longline
238 gear, but also include mid-water trawl, hook and line, shrimp trawl, pot gear and scallop
239 dredge.

240 For bottom trawl gears, trawl logbook areas and adjusted skate catches were matched with
241 strata-specific species compositions. In Time Block 1 (1978 – 2008), all bottom trawl gear
242 types were aggregated due to a lack of specificity in the gear recorded on the fish tickets.
243 However, in Time Blocks 2 and 3, individual bottom trawl gear types were retained. Some
244 borrowing of species compositions was required (31% of strata) and when necessary, borrowed
245 from the closest area or from the most similar gear type . Longline gear landings were
246 reconstructed in a similar fashion as to bottom trawl and required some borrowing among
247 strata as well (25%).

248 Due to insufficient species compositions, mid-water trawl landings were reconstructed using a
249 novel depth-based approach. Available compositions indicate that the proportion by weight
250 of big skates within a composition drops to zero at approximately 100 fathoms, and an inverse
251 relationship is observed for longnose skate, where the proportion by weight is consistently
252 one beyond 100 – 150 fathoms . Complex-level landings were assigned a depth from logbook
253 entries and these species specific depth associations were used to parse out landings by
254 species. The approach differed somewhat by time block . Landings from shrimp trawls were
255 handled using a similar methodology. Finally, very minor landings from hook and line, pot
256 gear and scallop dredges were assigned a single aggregated species composition, as they lack
257 any gear-specific composition samples. Landings from within a time block were apportioned
258 by year using the proportion of the annual ticket landings.

259 Results indicate that the species-specific landings from this reconstruction are very similar
260 to those from Oregon’s commercial catch reconstruction (Karnowski et al. 2014) during the
261 overlapping years but cover a greater time period with methodology more applicable to skates
262 in particular. ODFW intends to incorporate reconstructed skate landings into PacFIN in
263 the future (A. Whitman, ODFW; pers. comm.).

²⁶⁴ **1.2.3 California Catch Reconstruction**

²⁶⁵ A reconstruction of historical skate landings from California waters was developed for the
²⁶⁶ 1916–2017 time period using a combination of commercial catch data (spatially explicit block
²⁶⁷ summary catches and port sample data from 2009-2017) and fishery-independent survey data
²⁶⁸ (Bizzarro, J. 2019). Virtually all landings in California were of “unspecified skate” until
²⁶⁹ species-composition sampling of skate market categories began in 2009.

²⁷⁰ From 2009 through 2017, catch estimates were based on these market category species-
²⁷¹ composition samples, and the average of those species-compositions was hindcast to 2002,
²⁷² based on the assumption that those data were representative of the era of large area closures
²⁷³ in the post-2000 period.

²⁷⁴ For the period from 1936-1980, spatially explicit landings data (the California Department
²⁷⁵ of Fisheries and Wildlife (CDFW) block summary data) were merged with survey data to
²⁷⁶ provide species-specific estimates.

²⁷⁷ For years 1981-2001, a “blended” product of these two approaches was taken, in which
²⁷⁸ a linear weighting scheme blended the two sets of catch estimates through that period.
²⁷⁹ Landings estimates were also scaled upwards by an expansion factor for skates landed as
²⁸⁰ “dressed” based on fish ticket data. Prior to 1981 these data had not been reported and
²⁸¹ skate landings were scaled by the “average” percentage landed as dressed in the 1981-1985
²⁸² time period, but by the late 1980s nearly all skates were landed round.

²⁸³ As no spatial information on catch is available from 1916-1930, and the block summary
²⁸⁴ data were very sparse in the first few years of the CDFW fish ticket program (1931-1934),
²⁸⁵ spatial information from the late 1930’s was used to hindcast to the 1916–1935 time period.
²⁸⁶ However, since Washington and Oregon did not have catch estimates for this year period,
²⁸⁷ the California estimates of catch prior to 1938 were not used as they were subsumed into an
²⁸⁸ estimated of the total catch across all states increasing linearly from 1916 to 1950.

²⁸⁹ **1.2.4 Tribal Catch in Washington**

²⁹⁰ Tribal catch of Big Skate was provided by WDFW as all landings took place in Washington
²⁹¹ State. The landings were estimated from limited state sampling of species compositions in
²⁹² combined skate category. Anecdotal evidence suggest that most of the catch in tribal fishery
²⁹³ is retained, and discard is minimal.

²⁹⁴ **1.2.5 Fishery Discards**

²⁹⁵ Fishery discards of Big Skate are highly uncertain. The method used to estimate discards for
²⁹⁶ Longnose Skate was based on a strong correlation ($R^2 = 95.7\%$) between total mortality of

297 that species, and total mortality of Dover Sole for the years 2009–2017 during which Longnose
298 were landed separately from other skates. In contrast, the sorting requirement for Big Skate
299 occurred too recently to provide an adequate range of years for this type of correlation.
300 Furthermore, there is greater uncertainty in the total mortality for the shallow-water species
301 with which Big Skate most often co-occurs, such as Sand Sole and Starry Flounder, than
302 there is for Dover Sole, which has been the subject of recurring stock assessments.

303 Both what discard rate information is available and anecdotal information from those in-
304 volved in the fishery for both skate species indicate that discarding for Big Skate and Long-
305 nose Skate in the years prior to 1995 were driven by the same market forced and the discard
306 rates were similar. Therefore, the discard rate for Longnose Skate was used as a proxy for
307 the discards of Big Skate in order to estimate Big Skate discards.

308 The reconstructed landings of Big Skate for the period 1950–1995 had a mean of 63.1 t with
309 no significant trend (a linear model fit to the data increased from 62.8 t in 1950 to 63.5 in
310 1995. The estimated tribal catch prior to 1995 averaged less than 1 t and was not included
311 in this analysis of Big Skate discards for the years prior to 1995.

312 The mean discard rate for LN was 92.46%, also with no significant linear trend (the linear
313 fit decreased from 92.8% in 1950 to 92.1% in 1995). An estimate of the mean annual discard
314 amount can therefore be calculated as from the mean discard rate and the mean landings as
315 $\bar{L}/(1 - \bar{d})$ where \bar{L} is the mean landings across that time period and \bar{d} is the mean discards
316 (Figure ??).

317 Two alternative methods were used to estimate the mean annual discard amount: applying
318 the annual LN discard rates to the annual BS catch, and applying 3-year moving averages
319 of these two quantities. The use of the annual values resulted in an implausibly high degree
320 of annual variability among the estimates, with the most extreme being a spike of 2146.4 in
321 1979 compared to 1032.7 t the year before and 654.0 the year after. The use of the 3-year
322 moving average dampened this variability and these estimates were retained for a sensitivity
323 analysis (Figure ??).

324 A discard mortality rate of 50 percent was assumed for all discards, following the assumption
325 used for the Longnose Skate assessment conducted for the U.S. West Coast in 2007 (???)
326 The same rate has been used for skates in the trawl fishery in British Columbia, based on
327 an approximate average of these reported rates. In 2015, PFMC’s Groundfish Management
328 Team (GMT) conducted a comprehensive literature review of skate discard mortality, and
329 concluded that the current assumption regarding Big Skate discard mortality is consistent
330 with existing reported rates for other similar species.

331 Estimation of discard rates (discards amount relative to total catch) during the period of the
332 West Coast Groundfish Observer Program (WCGOP), which began in 2002, was hindered
333 by the landings of Big Skate primarily occurring in the “unspecified skate” category prior
334 to 2015. Therefore, a discard rate was computed using the combination of Big Skate and
335 unspecified skate under the assumption that the vast majority of the unspecified skates were

³³⁶ Big Skate. A coefficient of variation was calculated for the by bootstrapping vessels within
³³⁷ ports because the observer program randomly chooses vessels within ports to be observed.
³³⁸ For the years after the catch share program was implemented in 2011, the trawl fishery was
³³⁹ subject to 100% observer coverage and discarding is assumed to be known with minimal
³⁴⁰ error (CV = 0.01).

³⁴¹ The mean body weight of discarded Big Skates, calculated from the weight and count of
³⁴² baskets of discarded Big Skate, was available for the years 2002–2017.

³⁴³ 2 Fishery-Independent Data Sources

³⁴⁴ 2.1 Indices of abundance

³⁴⁵ 2.1.1 Alaska Fisheries Science Center (AFSC) Triennial Shelf Survey

³⁴⁶ Research surveys have been used since the 1970s to provide fishery-independent information
³⁴⁷ about the abundance, distribution, and biological characteristics of Big Skate. A coast-
³⁴⁸ wide survey was conducted in 1977 (Gunderson, Donald Raymond and Sample, Terrance M.
³⁴⁹ [1980](#)) by the Alaska Fisheries Science Center, and repeated every three years through 2001.
³⁵⁰ The final year of this survey, 2004, was conducted by the NWFSC according to the AFSC
³⁵¹ protocol. We refer to this as the **Triennial Survey**.

³⁵² The survey design used equally-spaced transects from which searches for tows in a specific
³⁵³ depth range were initiated. The depth range and latitudinal range was not consistent across
³⁵⁴ years, but all years in the period 1980–2004 included the area from 40° 10'N north to the
³⁵⁵ Canadian border and a depth range that included 55–366 meters, which spans the range
³⁵⁶ where the vast majority of Big Skate encountered in all trawl surveys. Therefore the index
³⁵⁷ was based on this depth range. The survey as conducted in 1977 had incomplete coverage
³⁵⁸ and is not believed to be comparable to the later years, and is not used in the index.

³⁵⁹ 2.1.2 Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl ³⁶⁰ Survey

³⁶¹ In 2003, the NWFSC took over an ongoing slope survey the AFSC had been conducting,
³⁶² and expanded it spatially to include the continental shelf. This survey, referred to in this
³⁶³ document as the “WCGBT Survey” or “WCGBTS”, is conducted annually. It uses a random-
³⁶⁴ grid design covering the coastal waters from a depth of 55 m to 1,280 m from late-May
³⁶⁵ to early-October (Bradburn, M.J. and Keller, A.A and Horness, B.H. [2011](#), Keller, A.A.
³⁶⁶ and Wallace, J.R. and Methot, R.D. [2017](#)). Four chartered industry vessels are used each
³⁶⁷ year (with the exception of 2013 when the U.S. federal-government shutdown curtailed the
³⁶⁸ survey).

369 **2.1.3 Index Standardization**

370 The index standardization methods for the two bottom trawl surveys matched that used for
371 Longnose Skate and additional detail is provided in (Gertseva, V. [2019a](#)). The data from both
372 surveys was analyzed using a spatio-temporal delta-model (Thorson, J. T. and Shelton, A.
373 O. and Ward, E. J. and Skaug, H. J. [2015](#)), implemented as an R package VAST (Thorson,
374 James T. and Barnett, Lewis A. K. [2017](#)) and publicly available online (<https://github.com/James-Thorson/VAST>). Spatial and spatio-temporal variation is specifically included
375 in both encounter probability and positive catch rates, a logit-link for encounter probability,
376 and a log-link for positive catch rates. Vessel-year effects were included for each unique
377 combination of vessel and year in the database for the WCGBT Survey but not the Triennial
378 survey. Further details regarding model structure are available in the user manual (https://github.com/James-Thorson/VAST/blob/master/examples/VAST_user_manual.pdf).
380

381 Spatial patterns in the survey estimates show Big Skate widely distributed along the coast,
382 with higher densities in the central and more northern areas and closer to shore [7](#).

383 **2.1.4 Internation Pacific Halibut Commission Longline Survey**

384 The IPHC has conducted an annual longline survey for Pacific Halibut off the coast of Oregon
385 and Washington since 1997 (no surveys were performed in 1998 or 2000). Beginning in 1999,
386 this has been a fixed station design, with 84 locations in this area (station locations differed
387 in 1997, and are therefore not comparable with subsequent surveys). 400 to 800 hooks have
388 been deployed at each station in 100-hook groups (typically called “skates” although that
389 term will be avoided here to avoid confusion). The gear used to conduct the survey was
390 designed to efficiently sample Pacific Halibut and used 16/0 (#3) circle hooks baited with
391 Chum Salmon.

392 In some years from 2011 onward, additional stations were added to the survey to sample
393 Yelloweye Rockfish. These stations were excluded from the analysis, as were additional
394 stations added in 2013, 2014, and 2017, off the coast of California (south of 42 degrees
395 latitude). Some variability in exact sampling location is practically unavoidable, and leeway
396 is given in the IPHC methods to center the set on the target coordinates while allowing wind
397 and currents to dictate the actual direction in which the gear is deployed. This can result in
398 different habitats being accessed at each fixed deployment location across years. One station
399 that was very close to the U.S. Canada border had the mid-point of the set in Canada in 2
400 out of the 19 years of the survey. For consistency among years, all samples from this station
401 were included in the analysis, including those in Canada.

402 In most years, bycatch of non-halibut species has been recorded during this survey on the
403 first 20 hooks of each 100-hook group, although in 2003 only 10% of the hooks were observed
404 for bycatch, and starting in 2012, some stations had 100% of the hooks observed for bycatch.
405 Combining these observation pattern with the number of hooks deployed each year, resulted

406 in most stations having 80, 100, 120, 140, or 160 hooks observed, with a mean of 144 hooks
407 and a maximum of 800 hooks observed. The depth range of the 84 stations considered was
408 42—530 m, thus extending beyond the range of Big Skate, but 74% of the stations were
409 shallower than 200 m. Big Skate have been observed at 51 of the 84 the standard stations
410 that were retained for this analysis, but no station had Big Skates observed in more than 12
411 out of the 19 years of survey data, and only 10% of the station/year combinations had at least
412 one observed Big Skate (Figure X). Of those station/year combinations with at least
413 one Big Skate observed, the Big Skates were observed on an average of 1.3% of the hooks
414 observed. The highest proportion was 10 Big Skates out of 81 hooks observed at one station.

415 The IPHC longline survey catch data were standardized using a Generalized Linear Model
416 (GLM) with binomial error structure. Catch-per-hook was modeled, rather than catch per
417 station due to the variability in the number of hooks deployed and observed each year. The
418 binomial error structure was considered logical, given the binary nature of capturing (or not)
419 a Longnose Skate on each longline hook. The modeling approach is identical to that which
420 has been applied in the past for Yelloweye Rockfish (???), and Spiny Dogfish (Gertseva,
421 V. 2019b). MCMC sampling of the GLM parameters was used to estimate the variability
422 around each index estimate. The median index estimates themselves were approximately
423 equal to the observed mean catch rate in each year (Figure Y). In recent years, the IPHC
424 standardization of the index of halibut abundance has included an adjustment to account
425 for missing baits on hooks returned empty in an effort to account for reduced catchability
426 of the gear that may result from the lost bait. This adjustment was not included in the
427 analysis for Big Skate although it could be considered in future years.

428 **2.2 Biological Parameters and Data**

429 **2.2.1 Measurement Details and Conversion Factors**

430 Some size measurements were taken as either disc width or inter-spiracle width rather than
431 total length. A conversion from disc width to total length was estimated as $L = 1.3399 * W$
432 based on from 95 samples from WCGBT Survey where both measurements collected (R-
433 squared = 0.9983). Little sex difference observed, so using single relationship for both sexes
434 (Figure 14). This estimate is similar to the conversion estimated by Ebert (2008) for Big
435 Skate in Alaska. The inter-spiracle width to total length was converted based on estimates
436 from Downs & Cheng (???:

437
$$L = 12.111 + 9.761 * ISW \text{ (females),}$$

438
$$L = 3.824 + 10.927 * ISW \text{ (males).}$$

439 **2.2.2 Fishery dependent length and age composition data**

440 Fishery length composition data was available from PacFIN were available for the years
441 1995–2018 (with the exception of 2000) as shown in Table 3. Ages were available from only
442 2004, 2008–2012, and 2018. These were all represented as conditioned on length in order to
443 provide more detailed information about the relationship between age and length, to reduce
444 any influence of size-based selectivity on the age composition, and to ensure independence
445 from the length samples. Furthermore, the samples from Washington in 2009 were sampled
446 using a length-stratified system, so should only be treated as conditioned on length.

447 Length compositions of Big Skate discarded in commercial fisheries measured by the West
448 Coast Groundfish Observer program were available for the years 2010–2017.

449 The input sample sizes for the length compositions were calculated via the Stewart Method
450 (Ian Stewart, personal communication, IPHC):

451
$$\text{Input } N = N_{\text{hauls}} + 0.138 * N_{\text{fish}} \text{ if } N_{\text{fish}}/N_{\text{hauls}} \text{ is } < 44,$$

452
$$\text{Input } N = 7.06 * N_{\text{hauls}} \text{ if } N_{\text{fish}}/N_{\text{hauls}} \text{ is } \geq 44.$$

453 However, no haul had greater than 44 Big Skate sampled, so only the first formula was used.

454 **2.2.3 Survey length and age composition data**

455 Lengths of Big Skate were only collected form the Triennial survey in 1998, 2001, and 2004,
456 but 1998 had only 3 samples and were excluded from this analysis. Length compositions were

⁴⁵⁷ available for all years of the WCGBT Survey. Sample sizes for both surveys are provided in
⁴⁵⁸ Table 4. The WCGBT Survey used disc width for the years 2006 and 2007 and total length
⁴⁵⁹ in all other years. Those samples where only disc width was measured were converted to
⁴⁶⁰ total length using the formula above.

⁴⁶¹ The length compositions from the fishery and each of the two surveys aggregated across all
⁴⁶² years is shown in Figure 9.

⁴⁶³ Ages were available from the WCGBT Survey in the years 2009, 2010, 2016, 2017, and 2018.
⁴⁶⁴ No ages were available from the Triennial Survey.

⁴⁶⁵ Ageing Precision and Bias

⁴⁶⁶ Ages of Big Skate were all estimated based on growth band counts of sectioned vertebrae.
⁴⁶⁷ Ageing precision and bias were estimated using double-reads of 518 Big Skate vertebrae using
⁴⁶⁸ the approach of Punt et al. (???). The results showed strong agreement among readers
⁴⁶⁹ (Figure ??), with a standard deviation of the ageing error increasing from about 0.4 at age
⁴⁷⁰ 0 to 1.6 years at age 15 (Figure 13).

⁴⁷¹ Weight-Length

⁴⁷² The mean weight as a function of length was estimated from 1159 samples from the WCGBT
⁴⁷³ Survey using a linear regression on a log-log scale. Sex was not found to be a significant
⁴⁷⁴ predictor, so a single relationship was estimated: $Weight = 0.0000074924 * Length^{2.9925}$
⁴⁷⁵ (Figure 14).

⁴⁷⁶ Sex Ratio, Maturity, and Fecundity

⁴⁷⁷ The female maturity relationship was based on visual maturity estimates from port sam-
⁴⁷⁸ plers ($n = 278$, of which 241 were from Oregon and 37 from Washington, with 24 mature
⁴⁷⁹ specimens) as well as 55 samples from the WCGBT Survey (of which 4 were mature). The
⁴⁸⁰ resulting relationship was $L_{50\%} = 148.2453$ with a slope parameter of $Beta = -0.13155$ in
⁴⁸¹ the relationship $M = (1 + Beta(L - L_{50\%}))^{-1}$ (Figure 15).

⁴⁸² 2.2.4 Environmental or Ecosystem Data Included in the Assessment

⁴⁸³ In this assessment, neither environmental nor ecosystem considerations were explicitly in-
⁴⁸⁴ cluded in the analysis. This is primarily due to a lack of relevant data or results of analyses
⁴⁸⁵ that could contribute ecosystem-related quantitative information for the assessment.

486 **3 Assessment**

487 **3.1 Previous Assessments**

488 **3.1.1 History of Modeling Approaches Used for this Stock**

489 No previous stock assessment has been conducted for Big Skate. The current management
490 is based on an OFL estimate calculated from a proxy for F_{MSY} and average survey biomass
491 from the WCGBT Survey during the years 2010–2012 (???). The F_{MSY} estimate was based
492 on the product of an assumed F_{MSY}/M ratio and an M estimate of 0.162 based on the
493 maximum age of 26 reported by McFarlane and King (McFarlane GA and King JR 2006).
494 Values were sampled from an assumed distribution around all these quantities to develop a
495 measure of uncertainty around the OFL estimate.

496 **3.2 Model Description**

497 **3.2.1 Modeling Software**

498 The STAT team used Stock Synthesis version 3.30.13 (Methot, Richard D. and Wetzel,
499 Chantell R. (2013), (??)). The r4ss package version 1.35.1 (Taylor et al. 2019) was used to
500 post-process the output data from Stock Synthesis.

501 **3.2.2 Summary of Data for Fleets and Areas**

502 Catch is divided among 4 fleets in the base model: *Fishery (current)* combines all non-tribal
503 sources of catch for the years 1995 onward, *Discard (historical)* includes the estimated discard
504 amount calculated from the estimated Longnose Skate discard rate as described above. The
505 input catch for this fleet was 50% of the total estimate to account for the assumed 50%
506 discard mortality rate. This data covers the period 1916–1994. *Fishery (historical)* includes
507 the reconstructed landings estimates from each of the three states for 1916–1994. *Tribal*
508 includes the estimates of catch of Big Skate by treaty tribes.

509 **3.2.3 Other Specifications**

510 This assessment covers the U.S. West Coast stock of Big Skate in off the coasts of Washington,
511 Oregon and California, the area bounded by the U.S.-Canada border to the north, and the
512 U.S.-Mexico border to the south. The population is treated as a single coastwide stock

513 with no net movement in or out of the area. Females and males are modeled separately as
514 there is evidence for differences in growth based on both the age and length data, as well as
515 patterns in the sex ratios associated with the length composition data. Natural Mortality
516 is estimated within the model using natural mortality prior developed by Hamel (2015). A
517 Beverton-Holt stock-recruit function is assumed with no deviations from the spawner-recruit
518 curve estimated.

519 The length composition data are stratified into 37 5-cm bins, ranging between 20 and 200
520 cm and the age data are stratified into ages 0–15+, conditioned on the same length bin
521 structure. The population dynamics are computed over a larger range of lengths age ages,
522 with the 5-cm length bins extending up to 250 cm and the numbers-at-age computed up to
523 age 20.

524 3.2.4 Data Weighting

525 The Francis (2011) data weighting method “TA1.8” as implemented in the r4ss package was
526 used for all length and age composition data.

527 3.2.5 Priors

528 *Natural mortality*

529 A log-normal prior for natural mortality was based on a meta-analysis completed by Hamel
530 (2015). The Hamel prior for M is lognormal($\ln(5.4/\text{max age})$, .438), which based on the
531 single 15-year-old fish observed out of 1034 ages from the WCGBT Survey. This results in
532 lognormal($\log(0.36)=-1.021651$, 0.438) prior.

533 *Survey catchability*

534 The lack of contrast in the data resulted in unstable model results under a variety of con-
535 figurations. To keep biomass estimates within a plausibel range, a prior was applied to the
536 catchability parameter (q) for the WCGBT Survey. This same prior was developed for the
537 2007 Longnose Skate assessment (???) and is being used for the current Longnose Skate
538 assessment (Gertseva, V. 2019a). The prior for the WCGBT Survey was derived as follows.

539 The WCGBT Survey covers the full latitudinal range of longnose skate modeled in the
540 assessment, and thus, the latitudinal availability factor was assumed to be one (complete
541 latitudinal coverage). The survey coverage exceeds the maximum depth distribution of
542 longnose skate but may not fully cover the shallow end of the skate distribution. A range of
543 95 to 100 percent was assumed for the depth availability. A range of 75 to 95 percent was
544 assumed for vertical availability on the basis that longnose skate are known to bury in the

545 mud and therefore some may be unavailable to the bottom trawl gear. The largest bounds
546 were placed on the probability of capture, given a fish is in the net path. It is known that
547 flatfish can be herded by trawl gear, and it is possible that this could also occur for skates.
548 However, it is also possible that skate could avoid the trawl nets. For capture probability,
549 a range of 75 to 150 percent was assumed. Best estimates for each factors were set at the
550 midpoint of the range for individual factors, except for the probability of capture, which was
551 given a value of one. The overall estimate for the survey catchability was thus estimated to
552 be 0.83 and the consequent bounds on catch, and the best assumption are: (0.53, 1.43) and
553 0.83 respectively. The best estimate was equated to the median of a lognormal distribution
554 and the bounds to 99 percent of that distribution. This resulted in a normal prior on $\log(q)$,
555 with a mean of -0.188, and standard deviation of 0.187.

556 3.2.6 Estimated and Fixed Parameters

557 A full list of all estimated and fixed parameters is provided in Tables 6.

558 The base model has a total of 44 estimated parameters in the following categories:

- 559 • 1 natural mortality parameter applied to both sexes,
- 560 • 6 parameters related to female growth and the variability in length age age,
- 561 • 2 parameters related to male growth relative to female growth,
- 562 • 1 stock-recruit parameter ($\log(R_0)$) controlling equilibrium recruitment)
- 563 • 3 catchability parameters (1 for the WCGBT Survey and 1 each for the early and late
564 periods of the Triennial Survey)
- 565 • 2 extra standard deviation parameters (1 for each survey), and
- 566 • 29 selectivity parameters, including 16 related to time-varying retention rate

567 The estimated parameters are described in greater detail below and a full list of all estimated
568 and parameters is provided in Table 6.

569 *Growth.*

570 Examination of patterns of age-at-length and length-at-age indicated unusual patterns of
571 growth for Big Skate, including almost linear growth for the early years during which both
572 sexes appeared to have similar average size, followed by strong differences in size at older
573 ages. This led to the choice to model growth using the “growth cessation model” recently
574 developed by Maunder et al. (2018). The estimated growth curves are shown in Figure 16.
575 This model provided two key advantages over the more common von Bertalanffy growth

576 model in the case of Big Skate: it allowed essentially linear growth for the early years and it
577 allowed growth for the earlier ages to be similar between females and males while diverging
578 at older ages. The growth cessation model also improve the negative log likelihood by 45
579 units relative to the von Bertalanffy growth model.

580 *Natural Mortality.*

581 Male natural mortality was assumed equal to the value estimated for females. Sensitivity
582 analyses were used to test the impact of both the prior on natural mortality and the
583 assumption of equal natural mortality for both sexes.

584 *Selectivity.*

585 A double-normal selectivity function was used for all fleets to allow consideration of both
586 asymptotic and dome-shaped patterns. For the fishery and the Triennial survey, the dif-
587 ference in likelihood between dome-shaped and asymptotic patterns was very small and in
588 the case of the Triennial survey, the dome-shape occurred at a length beyond almost all
589 observations, indicating that this shape was likely driven by fit to other data sources, such
590 as the index, rather than the length composition data. The WCGBT Survey was allowed
591 to remain dome-shaped as this survey had the selectivity peak at a smaller length than the
592 other fleets and the likelihood was improved by the dome-shape. The WCGBT Survey also
593 has the shortest hauls, with 15 minutes or less of bottom contact, so larger skates may be
594 better able to escape the net.

595 In order to fit a strong skew in the sex ratios toward males for the length bins in which
596 the majority of the samples were found, it was necessary to estimate a sex-specific offset
597 of selectivity. Two offset parameters were estimated for all fleets, one for the difference in
598 length at peak selectivity and another for the maximum selectivity. The ascending slope was
599 assumed equal in all cases, as was the descending slope for the WCGBT Survey.

600 *Other Estimated Parameters.*

601 *Other Fixed Parameters.*

602 Steepness was fixed at 0.4.

603 3.3 Model Selection and Evaluation

604 3.3.1 Key Assumptions and Structural Choices

605 **To be added**

606 **3.3.2 Alternate Models Considered**

607 **To be added**

608 **3.3.3 Convergence**

609 **To be added**

610 **3.4 Response to the Current STAR Panel Requests**

611 **Request No. 1:**

612

613 **Rationale:** xxx

614 **STAT Response:** xxx

615 **Request No. 2:**

616

617 **Rationale:** xxx

618 **STAT Response:** xxx

619 **Request No. 3:**

620

621 **Rationale:** x.

622 **STAT Response:** xxx

623 **Request No. 4:**

624

625 **Rationale:** xxx

626 **STAT Response:** xxx

627 **Request No. 5:**

628

629 **Rationale:** xxx

630 **STAT Response:** xxx

631 **3.5 Base Case Model Results**

632 The following description of the model results reflects a base model that incorporates all of
633 the changes made during the STAR panel (see previous section). The base model parameter
634 estimates and their approximate asymptotic standard errors are shown in Table 6 and the
635 likelihood components are in Table 7. Estimates of derived reference points and approximate
636 95% asymptotic confidence intervals are shown in Table e. Time-series of estimated stock
637 size over time are shown in Table 8.

638 **3.5.1 Parameter Estimates**

639 The additional survey variability (process error added directly to each year's input variabil-
640 ity) for all surveys was estimated within the model.

641 (Figure 30).

642 The stock-recruit curve ... Figure 31 with estimated recruitments also shown.

643 **3.5.2 Fits to the Data**

644 Model fits to the indices of abundance, fishery length composition, survey length composition,
645 discard rates, mean body weight, and conditional age-at-length observations are all discussed
646 below.

647 The observed indices show much more variability than the model expectation, with the fit to
648 the WCGBT Survey essentially a flat line (Figure 18) and the fit to the Triennial Survey only
649 showing a noticeable change over time due to the separate catchability parameter estimated
650 for the early and late periods (Figure 19).

651 The fits to the length data are much better thanks to the combination of the growth cessation
652 model and the sex-specific offsets to selectivity (Figures 20–21).

653 The conditional age-at-length data is likewise fit reasonably well, with some patterns in
654 residuals showing variability among years, but no clear pattern that is consistent across
655 years (Figures 22 and 23).

656 Sex ratio data is not included in the likelihood as such, but a part of the length composition
657 likelihood in which the proportions of females and males are included in a single vector
658 compared to the model expectations in the multinomial likelihood. The patterns in sex ratio
659 by length bin show fewer females than males for the middle range of sizes (70–120 cm), with
660 a shift to almost 100% females for the largest size bins (over 130 cm). The use of sex-specific

661 growth curves was adequate to fit the ratios for the largest bins, but ratio skews toward
662 males at lengths where the mean ages are similar for females and males. The fit to this part
663 of the sex ratio pattern required an offset is selectivity.

664 3.5.3 Uncertainty and Sensitivity Analyses

665 A number of sensitivity analyses were conducted, including:

- 666 1. Setting all selectivity curves to be asymptotic
- 667 2. Setting all selectivity curves to be dome-shaped
- 668 3. Removing the sex-specific offset on the selectivity curves
- 669 4. Removing the prior on catchability for the WCGBT Survey
- 670 5. Estimating a single catchability for all years in the Triennial Survey
- 671 6. Estimating separate natural mortality parameters for males and females
- 672 7. Removing the prior on natural mortality
- 673 8. Using the von Bertalanffy growth model
- 674 9. Using the Richards growth model
- 675 10. Tuning the sample sizes using the McAllister-Ianelli method
- 676 11. Estimating historic discards based on 3yr average of discard rates and landings
- 677 12. Changeing discard mortality from 0.5 to 0.4
- 678 13. Changeing discard mortality from 0.5 to 0.6

679 Results of these sensitivities are shown in Figures 33 to 35, and Tables 9 to 11.

680 **Additional text to be added**

681 3.5.4 Retrospective Analysis

682 **To be added**

683 **3.5.5 Likelihood Profiles**

684 Likelihood profiles were conducted over $\log(R_0)$, stock-recruit steepness (h) and natural
685 mortality (M).

686 Results of these profiles are shown in Figures 37 to 42.

687 **Additional text to be added**

688 **3.5.6 Reference Points**

689 Reference points were calculated using the estimated selectivities and catch distribution
690 among fleets in the most recent year of the model, (2017). Sustainable total yield (landings
691 plus discards) were 466 mt when using an $SPR_{50\%}$ reference harvest rate and with a 95%
692 confidence interval of 303 mt based on estimates of uncertainty. The spawning biomass
693 equivalent to 40% of the unfished level ($SB_{40\%}$) was 610 mt.

694 (Figure 28

695 The 2018 spawning biomass relative to unfished equilibrium spawning biomass is
696 above/below the target of 40% of unfished levels (Figure 29). The relative fishing intensity,
697 $(1 - SPR)/(1 - SPR_{50\%})$, has been xxx the management target for the entire time series
698 of the model.

699 Table e shows the full suite of estimated reference points for the base model and Figure 43
700 shows the equilibrium curve based on a steepness value xxx.

⁷⁰¹ **4 Harvest Projections and Decision Tables**

⁷⁰² The forecasts of stock abundance and yield were developed using the final base model, with
⁷⁰³ the forecasted projections of the OFL presented in Table [g](#).

⁷⁰⁴ The forecasted projections of the OFL for each model are presented in Table [h](#).

⁷⁰⁵ **5 Regional Management Considerations**

₇₀₆ **6 Research Needs**

₇₀₇ There are a number of areas of research that could improve the stock assessment for Big
₇₀₈ Skate. Below are issues identified by the STAT team and the STAR panel:

₇₀₉ 1. Data!:

₇₁₀ 2. xxxx:

₇₁₁ 3. xxxx:

₇₁₂ 4. xxxx:

₇₁₃ 5. xxxx:

₇₁₄ **7 Acknowledgments**

₇₁₅ The authors gratefully acknowledge the time and effort reviewers Stacey Miller, Jim Hastie
₇₁₆ and Owen Hamel put into making this a polished document.

⁷¹⁷ 8 Tables

⁷¹⁸ 8.1 Data Tables

Table 1: Landings by source. Landings are reconstructed histories 1916-1995.

Year	CA (mt)	OR (mt)	WA (mt)	Tribal (mt)	Total (mt)
1916	78.30	0.00	0.00	0.00	78.30
1917	80.10	0.00	0.00	0.00	80.10
1918	101.20	0.00	0.00	0.00	101.20
1919	75.20	0.00	0.00	0.00	75.20
1920	122.00	0.00	0.00	0.00	122.00
1921	17.80	0.00	0.00	0.00	17.80
1922	30.80	0.00	0.00	0.00	30.80
1923	34.20	0.00	0.00	0.00	34.20
1924	33.40	0.00	0.00	0.00	33.40
1925	46.70	0.00	0.00	0.00	46.70
1926	59.30	0.00	0.00	0.00	59.30
1927	67.10	0.00	0.00	0.00	67.10
1928	116.70	0.00	0.00	0.00	116.70
1929	107.50	0.00	0.00	0.00	107.50
1930	70.80	0.00	0.00	0.00	70.80
1931	43.60	0.00	0.00	0.00	43.60
1932	73.30	0.00	0.00	0.00	73.30
1933	46.50	0.00	0.00	0.00	46.50
1934	57.40	0.00	0.00	0.00	57.40
1935	70.60	0.00	0.00	0.00	70.60
1936	87.70	0.00	0.00	0.00	87.70
1937	115.40	0.00	0.00	0.00	115.40
1938	99.40	0.00	0.00	0.00	99.40
1939	90.90	0.00	0.00	0.00	90.90
1940	60.30	5.30	0.00	0.00	65.70
1941	53.10	56.40	0.00	0.00	109.40
1942	27.00	34.40	0.00	0.00	61.40
1943	20.40	0.90	0.00	0.00	21.30
1944	7.80	1.60	0.00	0.00	9.50
1945	13.30	0.30	0.00	0.00	13.50
1946	17.10	1.80	0.00	0.00	18.90
1947	24.10	0.00	0.00	0.00	24.10
1948	30.70	5.70	0.00	0.00	36.30
1949	31.90	0.00	7.20	0.00	39.10
1950	32.20	2.10	2.10	0.00	36.40
1951	21.70	4.70	3.90	0.00	30.30

Continued on next page

Table 1: Landings by source. Landings are reconstructed histories 1916-1995.

Year	CA (mt)	OR (mt)	WA (mt)	Tribal (mt)	Total (mt)
1952	39.10	0.10	7.80	0.00	46.90
1953	124.90	1.20	1.60	0.00	127.60
1954	38.80	2.30	1.20	0.00	42.40
1955	45.70	35.60	1.60	0.00	82.90
1956	40.40	2.60	3.10	0.00	46.10
1957	49.50	0.00	2.50	0.00	52.00
1958	38.80	0.00	0.20	0.00	38.90
1959	46.50	0.00	0.80	0.00	47.30
1960	39.20	0.00	0.70	0.00	39.80
1961	54.40	40.90	4.60	0.00	99.80
1962	44.40	27.90	5.20	0.00	77.60
1963	53.20	30.40	2.10	0.00	85.70
1964	49.90	28.30	2.70	0.00	80.90
1965	34.30	12.80	3.50	0.00	50.60
1966	36.40	20.10	0.60	0.00	57.00
1967	53.30	15.60	6.60	0.00	75.50
1968	55.30	45.40	8.80	0.00	109.50
1969	32.50	33.80	6.60	0.00	72.90
1970	16.30	11.90	0.10	0.00	28.20
1971	18.50	3.10	0.00	0.00	21.60
1972	33.50	2.00	0.10	0.00	35.60
1973	40.70	0.90	0.00	0.00	41.70
1974	21.90	5.90	0.10	0.00	27.80
1975	39.80	2.00	0.00	0.00	41.80
1976	20.70	31.30	0.20	0.00	52.20
1977	32.80	31.50	0.60	0.00	64.90
1978	67.70	77.30	4.00	0.00	149.10
1979	90.50	75.50	30.40	0.00	196.40
1980	17.60	34.10	5.20	0.00	56.90
1981	138.00	14.80	6.50	0.00	159.30
1982	78.30	5.20	14.60	0.00	98.10
1983	55.30	14.20	8.90	0.00	78.40
1984	26.20	4.90	1.60	0.00	32.70
1985	60.30	0.40	4.90	0.00	65.60
1986	27.20	1.60	8.90	0.00	37.80
1987	22.60	1.90	18.40	1.00	43.90
1988	15.30	0.30	10.90	1.20	27.60
1989	18.90	0.20	6.20	0.00	25.30
1990	25.10	0.00	9.60	0.10	34.90
1991	22.80	0.20	21.50	0.10	44.60
1992	24.60	0.30	11.20	0.00	36.10

Continued on next page

Table 1: Landings by source. Landings are reconstructed histories 1916-1995.

Year	CA (mt)	OR (mt)	WA (mt)	Tribal (mt)	Total (mt)
1993	29.00	0.20	21.00	0.60	50.70
1994	27.70	2.50	20.50	0.10	50.70
1995	43.00	41.20	21.80	0.10	106.00
1996	146.70	138.50	22.80	0.10	308.10
1997	228.40	215.40	84.00	0.20	528.00
1998	120.50	51.40	22.70	0.20	194.90
1999	109.50	131.30	41.40	0.40	282.60
2000	69.40	193.60	97.70	0.30	361.00
2001	75.30	115.10	26.70	0.40	217.50
2002	34.70	102.80	70.80	4.80	213.10
2003	48.80	223.00	65.70	5.40	342.80
2004	45.20	105.90	98.00	4.60	253.80
2005	33.40	151.30	113.10	15.70	313.40
2006	102.40	206.60	66.20	24.90	400.00
2007	35.50	190.40	29.10	19.90	274.90
2008	46.00	280.10	36.80	3.20	366.00
2009	9.60	162.00	16.50	17.50	205.70
2010	1.20	157.50	25.00	12.50	196.20
2011	0.50	231.50	10.00	26.40	268.40
2012	6.80	216.30	5.00	41.60	269.60
2013	20.90	92.30	13.00	8.80	135.00
2014	41.00	286.00	16.80	28.60	372.40
2015	35.20	218.80	1.00	76.60	331.50
2016	15.00	317.50	1.20	77.80	411.50
2017	28.00	188.00	1.40	60.20	277.60
2018	23.80	115.80	2.40	30.60	172.60

Table 2: Index inputs.

Year	WCGBTS		Triennial		IPHC	
	Obs	se_log	Obs	se_log	Obs	se_log
1980			467.83	0.53		
1983			911.85	0.30		
1986			996.75	0.29		
1989			1431.65	0.22		
1992			2426.18	0.20		
1995			497.24	0.26		
1998			2437.75	0.20		
1999					0.00	0.17
2001			1669.73	0.23	0.00	0.29
2002					0.00	0.53
2003	8170.51	0.20			0.00	0.43
2004	14349.00	0.18	3674.14	0.19	0.00	0.20
2005	12122.52	0.16			0.00	0.18
2006	9273.79	0.18			0.00	0.64
2007	8137.47	0.18			0.00	0.34
2008	5494.76	0.21			0.00	0.81
2009	10721.30	0.17			0.00	0.48
2010	11475.29	0.14			0.00	0.24
2011	8029.69	0.16			0.00	0.20
2012	11593.79	0.16			0.00	0.61
2013	11521.85	0.17			0.00	0.20
2014	19855.79	0.13			0.00	0.19
2015	19251.41	0.13			0.00	0.16
2016	17141.95	0.15			0.00	0.17
2017	13237.37	0.14			0.00	0.18
2018	14568.79	0.14			0.00	0.26

Table 3: PacFIN Samples.

Year	CA		OR		WA		All Landings		Discards	
	Ntows	Nfish	Ntows	Nfish	Ntows	Nfish	Ntows	Nfish	Ntows	Nfish
Lengths										
1995			6	55			6	55		
1996			3	8			3	8		
1997			1	14			1	14		
1998			1	2			1	2		
1999			1	8			1	8		
2000										
2001			3	43			3	43		
2002			6	199			6	199		
2003			9	202			9	202		
2004			2	27	2	12	4	39		
2005			7	123	6	87	13	210		
2006			13	310	15	191	28	501		
2007	1	1	10	128	9	172	20	301		
2008			10	94	8	94	18	188		
2009	8	32	17	234	1	18	26	284		
2010	2	8	15	186			17	194	149	349
2011	2	2	29	418	4	9	35	429	554	1518
2012	3	43	24	477	3	38	30	558	544	1405
2013	11	201	11	252	8	168	30	621	443	987
2014	15	217	11	237	5	249	31	703	676	1625
2015	25	237	21	411	2	5	48	653	688	1557
2016	14	181	34	444	7	98	55	723	652	1456
2017	14	239	50	668	12	47	76	954	508	1248
2018	15	133	46	552	14	98	75	783		
Ages										
2004					2	11	2	11		
2008			8	80			8	80		
2009			10	87	8	65	18	152		
2010			10	102			10	102		
2011			21	202			21	202		
2012			12	120			12	120		
2018			6	39	13	93	19	132		

Table 4: Samples from the surveys.

NA.	Triennial		WCGBTS		IPHC	
	Triennial	NA..1	WCGBTS	NA..2	IPHC	NA..3
Year	Ntows	Nfish	Ntows	Nfish	Nsets	Nfish
Lengths						
2001	41	81				
2003			60	197		
2004	39	100	81	262		
2005			99	328		
2006			67	154		
2007			76	192		
2008			53	159		
2009			82	305		
2010			130	466		
2011			99	360		
2012			104	395		
2013			84	316		
2014			149	552	14	54
2015			134	546		
2016			105	422		
2017			125	496		
2018			123	331		
Ages						
2009			77	230		
2010			124	333		
2016			100	138		
2017			110	164		
2018			118	169		

₇₂₀ **8.2 Model Results Tables**

Table 5: Results from 100 jitters from the base case model.

Description	Value	NA	NA
Returned to base case	-	-	-
Found local minimum	-	-	-
Found better solution	-	-	-
Error in likelihood	-	-	-
Total	100	100	100

Table 6: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD)).

No.	Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
1	NatM_p_1_Fem_GP_1	0.384	1	(0.01, 0.8)	OK	0.014	Log_Norm (-1.02165, 0.0438)
2	L_at_Amin_Fem_GP_1	20.393	2	(10, 40)	OK	1.020	None
3	Linf_Fem_GP_1	176.000	2	(100, 300)	OK	3.927	None
4	VonBert_K_Fem_GP_1	11.994	1	(0.005, 30)	OK	0.312	None
5	Cessation_Fem_GP_1	3.877	3	(0.1, 5)	OK	6.181	None
6	SD_young_Fem_GP_1	5.683	5	(1, 20)	OK	0.916	None
7	SD_old_Fem_GP_1	7.378	5	(1, 20)	OK	0.886	None
8	Wtlen_1_Fem_GP_1	0.000	-3	(0, 3)			None
9	Wtlen_2_Fem_GP_1	2.993	-3	(2, 4)			None
10	Mat50%_Fem_GP_1	148.245	-3	(10, 140)			None
11	Mat_slope_Fem_GP_1	-0.132	-3	(-0.09, -0.05)			None
12	Eggs/kg_inter_Fem_GP_1	0.500	-3	(-3, 3)			None
13	Eggs/kg_slope_wt_Fem_GP_1	0.000	-3	(-3, 3)			None
14	NatM_p_1_Mal_GP_1	0.000	-2	(-3, 3)			None
15	L_at_Amin_Mal_GP_1	0.000	-2	(-1, 1)			None
16	Linf_Mal_GP_1	-0.381	2	(-1, 1)	OK	0.025	None
17	VonBert_K_Mal_GP_1	0.109	3	(-10, 20)	OK	0.032	None
18	Cessation_Mal_GP_1	0.200	-3	(-3, 3)			None
19	SD_young_Mal_GP_1	0.000	-5	(-1, 1)			None
20	SD_old_Mal_GP_1	0.000	-5	(-1, 1)			None
21	Wtlen_1_Mal_GP_1	0.000	-3	(0, 3)			None
22	Wtlen_2_Mal_GP_1	2.993	-3	(2, 4)			None
23	CohortGrowDev	1.000	-5	(0, 2)			None
24	FracFemale_GP_1	0.500	-99	(0.001, 0.999)			None
25	SR_LN(R0)	8.295	1	(5, 15)	OK	0.205	None
26	SR_BH_stEEP	0.400	-3	(0.2, 1)			None

Continued on next page

Table 6: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD)).

No.	Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
27	SR_sigmaR	0.300	-2	(0, 0.4)			None
28	SR_regime	0.000	-1	(-2, 2)			None
29	SR_autocorr	0.000	-99	(0, 0)			None
78	LnQ_base_WCGBT5(5)	-0.144	1	(-2, 2)	OK	0.187	Normal (-0.188, 0.187)
79	Q_extraSD_WCGBT5(5)	0.161	5	(0, 2)	OK	0.057	None
80	LnQ_base_Triennial(6)	-1.382	1	(-10, 2)	OK	0.559	None
81	Q_extraSD_Triennial(6)	0.365	5	(0, 2)	OK	0.146	None
82	LnQ_base_Triennial(6)_1995	-1.065	1	(-7, 0)	OK	0.559	None
83	Size_DblN_peak_(1)	86.826	4	(80, 150)	OK	4.112	None
84	Size_DblN_top_logit_(1)	-15.000	-5	(-15, 4)			None
85	Size_DblN_ascend_se_(1)	7.064	4	(-1, 9)	OK	0.126	None
86	Size_DblN_descend_se_(1)	20.000	-5	(-1, 20)			None
87	Size_DblN_start_logit_(1)	-999.000	-4	(-999, 9)			None
88	Size_DblN_end_logit_(1)	-999.000	-5	(-999, 9)			None
89	Retain_L_infl_(1)	66.645	2	(15, 150)	OK	0.629	None
90	Retain_L_width_(1)	4.962	2	(0.1, 10)	OK	0.350	None
91	Retain_L_asymptote_logit_(1)	2.111	3	(-10, 20)	OK	0.352	None
92	Retain_L_maleoffset_(1)	0.000	-3	(0, 0)			None
93	DiscMort_L_infl_(1)	5.000	-4	(5, 15)			None
94	DiscMort_L_width_(1)	0.000	-4	(0.001, 10)			None
95	DiscMort_L_level_old_(1)	0.500	-5	(0, 1)			None
96	DiscMort_L_male_offset_(1)	0.000	-5	(0, 0)			None
97	SzSel_Fem_Peak_(1)	-4.986	4	(-50, 50)	OK	2.038	None
98	SzSel_Fem_Ascend_(1)	0.000	-4	(-5, 5)			None
99	SzSel_Fem_Descend_(1)	0.000	-4	(-5, 5)			None
100	SzSel_Fem_Final_(1)	0.000	-4	(-5, 5)			None
101	SzSel_Fem_Scale_(1)	0.774	4	(0.5, 1.5)	OK	0.083	None

Continued on next page

Table 6: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD)).

No.	Parameter	Value	Phase	Bounds	Status	SD	Prior	(Exp.Val, SD)
102	Size_DblN_peak_WCGBT5(5)	72.392	4	(50, 150)	OK	5.639	None	
103	Size_DblN_top_logit_WCGBT5(5)	-15.000	-5	(-15, 4)			None	
104	Size_DblN_ascend_se_WCGBT5(5)	6.440	4	(-1, 9)	OK	0.371	None	
105	Size_DblN_descend_se_WCGBT5(5)	10.061	5	(-1, 20)	OK	1.621	None	
106	Size_DblN_start_logit_WCGBT5(5)	-5.000	-4	(-999, 9)			None	
107	Size_DblN_end_logit_WCGBT5(5)	-999.000	-5	(-999, 9)			None	
108	SzSel_Fem_Peak_WCGBT5(5)	-7.134	4	(-50, 50)	OK	3.982	None	
109	SzSel_Fem_Ascend_WCGBT5(5)	0.000	-4	(-5, 5)			None	
110	SzSel_Fem_Descend_WCGBT5(5)	0.000	-4	(-5, 5)			None	
111	SzSel_Fem_Final_WCGBT5(5)	0.000	-4	(-5, 5)			None	
112	SzSel_Fem_Scale_WCGBT5(5)	0.743	4	(0.5, 1.5)	OK	0.121	None	
113	Size_DblN_peak_Triennial(6)	176.755	4	(50, 180)	OK	26.076	None	
114	Size_DblN_top_logit_Triennial(6)	-15.000	-5	(-15, 4)			None	
115	Size_DblN_ascend_se_Triennial(6)	8.481	4	(-1, 9)	OK	0.381	None	
116	Size_DblN_descend_se_Triennial(6)	20.000	-5	(-1, 20)			None	
117	Size_DblN_start_logit_Triennial(6)	-4.025	4	(-15, 9)	OK	0.527	None	
118	Size_DblN_end_logit_Triennial(6)	-999.000	-5	(-999, 9)			None	
119	SzSel_Fem_Peak_Triennial(6)	0.000	-4	(-50, 50)			None	
120	SzSel_Fem_Ascend_Triennial(6)	0.000	-4	(-5, 5)			None	
121	SzSel_Fem_Descend_Triennial(6)	0.000	-4	(-5, 5)			None	
122	SzSel_Fem_Final_Triennial(6)	0.000	-4	(-5, 5)			None	
123	SzSel_Fem_Scale_Triennial(6)	0.600	4	(0.5, 1.5)	OK	0.128	None	
124	Retain_L_asymptote_logit_2005	2.325	4	(-10, 20)	OK	0.562	None	
125	Retain_L_asymptote_logit_2006	3.330	4	(-10, 20)	OK	1.315	None	
126	Retain_L_asymptote_logit_2007	4.000	4	(-10, 20)	OK	2.027	None	
127	Retain_L_asymptote_logit_2008	11.158	4	(-10, 20)	OK	111.095	None	

Table 6: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD)).

No.	Parameter	Value	Phase	Bounds	Status	SD	Prior	(Exp.Val, SD)
128	Retain_L_asymptote_logit_2009	4.991	4	(-10, 20)	OK	3.975	None	
129	Retain_L_asymptote_logit_2010	13.248	4	(-10, 20)	OK	88.075	None	
130	Retain_L_asymptote_logit_2011	14.665	4	(-10, 20)	OK	73.786	None	
131	Retain_L_asymptote_logit_2012	13.918	4	(-10, 20)	OK	81.260	None	
132	Retain_L_asymptote_logit_2013	3.475	4	(-10, 20)	OK	0.337	None	
133	Retain_L_asymptote_logit_2014	3.653	4	(-10, 20)	OK	0.279	None	
134	Retain_L_asymptote_logit_2015	3.430	4	(-10, 20)	OK	0.263	None	
135	Retain_L_asymptote_logit_2016	2.901	4	(-10, 20)	OK	0.193	None	
136	Retain_L_asymptote_logit_2017	2.822	4	(-10, 20)	OK	0.192	None	

Table 7: Likelihood components from the base model.

Likelihood component	Value
TOTAL	1097.30
Catch	0.00
Survey	-98.12
Length composition	763.02
Age composition	421.52
Recruitment	10.88
Forecast recruitment	0.00
Parameter priors	0.00
Parameter soft bounds	0.01

Table 8: Time-series of population estimates from the base-case model. Relative exploitation rate is $(1 - SPR)/(1 - SPR_{50\%})$.

Year	Total biomass (mt)	Spawning biomass (mt)	Depletion	Age-0 recruits	Total catch (mt)	Relative exploitation rate	SPR
1916	24263	1526	0.000	4004	0	0.00	1.00
1917	24263	1526	0.000	4004	12	0.00	0.99
1918	24251	1525	0.999	4003	25	0.00	0.99
1919	24228	1524	0.998	4001	37	0.00	0.98
1920	24196	1521	0.997	3999	49	0.00	0.98
1921	24156	1518	0.995	3996	62	0.00	0.97
1922	24108	1514	0.992	3992	74	0.00	0.97
1923	24054	1510	0.989	3987	86	0.00	0.96
1924	23994	1504	0.986	3982	99	0.00	0.96
1925	23928	1498	0.982	3976	111	0.00	0.95
1926	23857	1492	0.977	3969	123	0.01	0.95
1927	23780	1485	0.973	3962	136	0.01	0.94
1928	23699	1477	0.968	3954	148	0.01	0.94
1929	23614	1469	0.963	3946	160	0.01	0.93
1930	23524	1461	0.957	3938	172	0.01	0.92
1931	23430	1453	0.952	3929	185	0.01	0.92
1932	23332	1444	0.946	3920	197	0.01	0.91
1933	23231	1435	0.940	3911	210	0.01	0.91
1934	23126	1426	0.934	3901	222	0.01	0.90
1935	23018	1416	0.928	3890	234	0.01	0.90
1936	22907	1406	0.921	3880	246	0.01	0.89
1937	22794	1396	0.915	3868	259	0.01	0.89
1938	22677	1386	0.908	3857	271	0.01	0.88
1939	22558	1375	0.901	3845	329	0.02	0.86
1940	22393	1361	0.892	3830	329	0.02	0.86
1941	22242	1348	0.884	3815	363	0.02	0.84
1942	22069	1334	0.874	3798	351	0.02	0.84
1943	21922	1320	0.865	3783	343	0.02	0.85
1944	21794	1308	0.857	3769	350	0.02	0.84
1945	21669	1296	0.850	3754	364	0.02	0.84
1946	21539	1284	0.842	3740	379	0.02	0.83
1947	21402	1272	0.834	3725	394	0.02	0.82
1948	21258	1260	0.826	3710	412	0.02	0.81
1949	21106	1248	0.818	3694	426	0.02	0.81
1950	20951	1235	0.809	3679	424	0.02	0.81
1951	20808	1223	0.802	3664	418	0.02	0.81
1952	20681	1212	0.794	3650	434	0.02	0.80

Continues next page

Table 8: Time-series of population estimates from the base-case model. Relative exploitation rate is $(1 - SPR)/(1 - SPR_{50\%})$.

Year	Total biomass (mt)	Spawning biomass (mt)	Depletion	Age-0 recruits	Total catch (mt)	Relative exploitation rate	SPR
1953	20546	1201	0.787	3634	515	0.03	0.76
1954	20341	1185	0.776	3613	430	0.02	0.80
1955	20232	1174	0.770	3599	470	0.02	0.78
1956	20090	1162	0.762	3583	434	0.02	0.79
1957	19992	1153	0.755	3570	439	0.02	0.79
1958	19892	1144	0.750	3558	426	0.02	0.80
1959	19809	1136	0.745	3547	435	0.02	0.79
1960	19720	1129	0.740	3537	427	0.02	0.79
1961	19641	1122	0.735	3528	487	0.03	0.77
1962	19506	1113	0.729	3515	465	0.03	0.77
1963	19401	1105	0.724	3504	473	0.03	0.77
1964	19293	1097	0.719	3492	468	0.03	0.77
1965	19197	1090	0.714	3481	438	0.02	0.78
1966	19136	1084	0.710	3473	444	0.02	0.78
1967	19071	1078	0.706	3464	463	0.03	0.77
1968	18991	1071	0.702	3453	497	0.03	0.76
1969	18881	1062	0.696	3440	460	0.03	0.77
1970	18812	1056	0.692	3432	416	0.02	0.79
1971	18788	1054	0.690	3427	409	0.02	0.79
1972	18770	1052	0.689	3424	423	0.02	0.79
1973	18737	1049	0.687	3420	429	0.02	0.78
1974	18697	1046	0.686	3416	415	0.02	0.79
1975	18671	1045	0.684	3414	429	0.02	0.78
1976	18631	1042	0.683	3410	440	0.02	0.78
1977	18584	1039	0.681	3406	452	0.03	0.77
1978	18527	1036	0.679	3400	536	0.03	0.73
1979	18393	1027	0.673	3387	584	0.03	0.71
1980	18224	1015	0.665	3368	444	0.03	0.77
1981	18202	1011	0.663	3362	547	0.03	0.72
1982	18083	1001	0.656	3346	486	0.03	0.75
1983	18030	995	0.652	3336	466	0.03	0.76
1984	17998	991	0.649	3329	420	0.02	0.78
1985	18008	989	0.648	3327	453	0.03	0.76
1986	17981	987	0.647	3323	425	0.03	0.78
1987	17977	987	0.647	3323	431	0.03	0.77
1988	17965	987	0.647	3324	415	0.02	0.78
1989	17965	989	0.648	3326	413	0.02	0.78

Continues next page

Table 8: Time-series of population estimates from the base-case model. Relative exploitation rate is $(1 - SPR)/(1 - SPR_{50\%})$.

Year	Total biomass (mt)	Spawning biomass (mt)	Depletion	Age-0 recruits	Total catch (mt)	Relative exploitation rate	SPR
1990	17967	991	0.649	3329	422	0.02	0.78
1991	17960	991	0.650	3330	432	0.03	0.77
1992	17944	991	0.649	3329	424	0.02	0.78
1993	17938	990	0.649	3329	438	0.03	0.77
1994	17921	989	0.648	3326	438	0.03	0.77
1995	17905	987	0.647	3323	119	0.01	0.93
1996	18199	1003	0.657	3348	347	0.02	0.82
1997	18257	1006	0.659	3353	594	0.03	0.71
1998	18075	994	0.651	3334	219	0.01	0.88
1999	18268	1004	0.658	3351	318	0.02	0.83
2000	18354	1010	0.662	3360	406	0.02	0.79
2001	18349	1010	0.662	3361	245	0.01	0.87
2002	18500	1021	0.669	3377	239	0.01	0.87
2003	18643	1032	0.676	3394	385	0.02	0.80
2004	18635	1034	0.677	3397	285	0.02	0.85
2005	18723	1042	0.683	3409	347	0.02	0.82
2006	18747	1046	0.685	3416	429	0.02	0.79
2007	18697	1045	0.685	3414	292	0.02	0.85
2008	18786	1051	0.689	3423	387	0.02	0.81
2009	18783	1050	0.688	3422	217	0.01	0.89
2010	18946	1059	0.694	3436	207	0.01	0.89
2011	19107	1069	0.700	3450	282	0.02	0.86
2012	19180	1074	0.704	3458	282	0.02	0.86
2013	19245	1080	0.708	3467	144	0.01	0.92
2014	19436	1095	0.718	3489	397	0.02	0.81
2015	19370	1095	0.718	3489	351	0.02	0.83
2016	19357	1098	0.719	3493	441	0.02	0.79
2017	19265	1094	0.717	3487	297	0.02	0.85
2018	19324	1097	0.719	3492	185	0.01	0.90
2019	19491	1106	0.725	3505			

Table 9: Sensitivity of the base model to assumptions about selectivity and catchability.

Label	Base model	Sel all asymptotic	Sel all domed	Sel no sex offset	Q no prior on WCGBTS	Q no offset on triennial
TOTAL like	441.63	441.41	441.63	441.63	441.13	444.19
Survey like	-9.78	-9.78	-9.78	-9.78	-10.06	-8.37
Length comp like	366.25	366.14	366.25	366.25	366.93	366.81
Age comp like	110.51	110.44	110.51	110.51	110.12	110.30
Parm priors like	1.12	1.09	1.12	1.12	0.66	1.99
Size at age like	0.00	0.00	0.00	0.00	0.00	0.00
Recr Virgin millions	4.00	3.95	4.00	4.00	2.81	3.33
log(R0)	8.29	8.28	8.29	8.29	7.94	8.11
NatM Female	0.38	0.38	0.38	0.38	0.38	0.39
NatM Male	0.38	0.38	0.38	0.38	0.38	0.39
Linf Female	176.00	175.90	176.00	176.00	175.97	176.05
Linf Male	120.24	120.20	120.24	120.24	120.38	120.21
Q WCGBTS	0.87	0.87	0.87	0.87	1.48	1.03
SSB Virgin thousand mt	1.53	1.52	1.53	1.53	1.16	1.22
SSB 2019 thousand mt	1.11	1.10	1.11	1.11	0.65	0.78
Bratio 2019	0.72	0.72	0.72	0.72	0.56	0.64
SPRratio 2018	0.19	0.19	0.19	0.19	0.31	0.25
Ret Catch MSY	517.36	513.43	517.36	517.36	380.95	425.03
Dead Catch MSY	559.33	555.07	559.33	559.33	410.59	458.73

Table 10: Sensitivity of the base model to assumptions about catches.

Label	Base model	Discards based on 3yr averages	Discard mortality 0 4	Discard mortality 0 6
TOTAL like	441.63	440.89	441.18	442.05
Survey like	-9.78	-10.00	-10.08	-9.50
Length comp like	366.25	365.86	366.41	366.12
Age comp like	110.51	110.53	110.46	110.54
Parm priors like	1.12	1.13	1.06	1.17
Size at age like	0.00	0.00	0.00	0.00
Recr Virgin millions	4.00	3.91	4.02	4.01
log(R0)	8.29	8.27	8.30	8.30
NatM Female	0.38	0.38	0.38	0.38
NatM Male	0.38	0.38	0.38	0.38
Linf Female	176.00	176.08	176.04	175.95
Linf Male	120.24	120.24	120.25	120.24
Q WCGBTS	0.87	0.90	0.88	0.85
SSB Virgin thousand mt	1.53	1.49	1.55	1.51
SSB 2019 thousand mt	1.11	1.03	1.09	1.13
Bratio 2019	0.72	0.69	0.70	0.75
SPRratio 2018	0.19	0.20	0.19	0.19
Ret Catch MSY	517.36	505.17	532.98	506.35
Dead Catch MSY	559.33	545.81	567.38	555.88

Table 11: Sensitivity of the base model to assumptions about biology and misc.

Label	Base model	Bio separate M by sex	Bio no M prior	Bio von bertalanffy growth	Bio Richards growth	Misc McAllister Janelli tuning
TOTAL like	441.63	441.14	437.95	486.39	497.09	1132.64
Survey like	-9.78	-9.86	-9.71	-9.80	-9.73	-9.76
Length comp like	366.25	364.91	365.51	404.62	387.88	572.70
Age comp like	110.51	111.02	108.63	117.88	144.80	594.48
Parm priors like	1.12	1.45	0.01	0.04	0.01	4.59
Size at age like	0.00	0.00	0.00	0.00	0.00	0.00
Recr Virgin millions	4.00	3.47	6.29	3.26	0.00	4.82
log(R0)	8.29	8.15	8.75	8.09	8.02	8.48
NatM Female	0.38	0.39	0.45	0.36	0.36	0.41
NatM Male	0.38	0.36	0.45	0.36	0.36	0.41
Linf Female	176.00	176.07	175.91		2666.88	177.98
Linf Male	120.24	119.90	120.98		137.29	120.30
Q WCGBTS	0.87	0.88	0.81	0.83	0.85	0.87
SSB Virgin thousand mt	1.53	1.28	1.12	1.37	0.00	1.42
SSB 2019 thousand mt	1.11	0.86	0.84	0.90	0.00	1.04
Bratio 2019	0.72	0.67	0.75	0.65	0.00	0.73
SPRratio 2018	0.19	0.23	0.17	0.24	0.89	0.19
Ret Catch MSY	517.36	456.10	564.75	446.68	0.00	530.89
Dead Catch MSY	559.33	492.46	610.56	482.14	0.00	573.72

Table 12: Summaries of key assessment outputs and likelihood values from the retrospective analysis. Note that male growth parameters are exponential offsets from female parameters, and depletion and SPR ratio are for the year of 2017. The base model includes all of the data. Retro1 removes the last year of data (2016), Retro2 removes the last two years of data, Retro3 removes three years and Retro4 removes four years.

Label	Base	Retro1	Retro2	Retro3	Retro4
Female natural mortality	0.26	0.26	0.26	0.26	0.26
Steepness	0.72	0.72	0.72	0.72	0.72
lnR0	8.16	8.09	8.07	8.04	8.08
Total Biomass (mt)	2796.86	2593.78	2568.77	2498.07	2650.36
Depletion	57.41	53.57	50.74	50.72	54.78
SPR ratio	0.72	0.76	0.79	0.80	0.74
Female Lmin	12.43	12.45	12.90	12.63	13.03
Female Lmax	33.31	33.50	33.39	33.37	33.46
Female K	0.25	0.24	0.24	0.25	0.23
Male Lmin (offset)	0.00	0.00	0.00	0.00	0.00
Male Lmax (offset)	-0.16	-0.16	-0.15	-0.16	-0.15
Male K (offset)	-0.29	-0.30	-0.43	-0.41	-0.56
Negative log-likelihood	1097.30	1047.56	1009.37	961.81	897.04
No. parameters	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	0.00	0.00	0.00	0.00
Equilibrium catch	-98.12	-92.00	-89.12	-81.75	-80.59
Survey	763.02	739.90	720.39	700.10	670.66
Length composition	421.52	390.56	369.97	336.26	299.84
Age composition	10.88	9.09	8.12	7.20	7.12
Recruitment	0.00	0.00	0.00	0.00	0.00
Forecast Recruitment	0.00	0.00	0.00	0.00	0.00
Parameter priors	0.01	0.01	0.01	0.01	0.01

Table 13: Summaries of key assessment outputs and likelihood values from selected likelihood profile runs on virgin recruitment ($\ln R_0$) and steepness. Note that male growth parameters are exponential offsets from female parameters, and depletion and SPR ratio are for the year of 2017.

Label	R07400	R07800	R08200	R08600	R09000	h0410	h0570	h0710	h0870	h0990
Female M	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Steepness	0.72	0.72	0.72	0.72	0.72	0.41	0.57	0.71	0.87	0.99
lnR0	7.40	7.80	8.20	8.60	9.00	8.34	8.21	8.16	8.13	8.11
Total biomass (m)	1623.19	2113.03	2894.72	4173.95	6142.97	3313.42	2943.85	2802.69	2712.12	2667.97
Depletion (%)	46.83	49.83	58.31	66.23	71.80	51.20	55.27	57.32	58.81	59.60
SPR ratio	1.05	0.91	0.70	0.49	0.34	0.68	0.71	0.72	0.72	0.73
Female Lmin	12.16	12.41	12.43	12.39	12.36	12.43	12.44	12.43	12.43	12.43
Female Lmax	34.29	33.83	33.26	32.76	32.42	33.19	33.28	33.31	33.33	33.34
Female K	0.24	0.25	0.25	0.26	0.26	0.25	0.25	0.25	0.25	0.25
Male Lmin (offset)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Male Lmax (offset)	-0.18	-0.17	-0.16	-0.15	-0.15	-0.16	-0.16	-0.16	-0.16	-0.16
Male K (offset)	-0.22	-0.31	-0.29	-0.24	-0.21	-0.27	-0.29	-0.29	-0.30	-0.30
Negative log-likelihood										
TOTAL	1117.15	1101.02	1097.33	1099.69	1102.95	1101.35	1098.58	1097.35	1096.72	1100.21
Catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equil_catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Survey	-100.10	-99.20	-97.99	-97.00	-96.37	-98.27	-98.18	-98.12	-98.06	-98.03
Length_comp	761.18	760.12	763.44	767.61	770.76	765.11	763.69	763.05	762.58	762.33
Age_comp	437.32	427.37	421.09	418.57	417.98	420.58	421.24	421.51	421.68	421.77
Recruitment	18.74	12.72	10.80	10.50	10.58	12.55	11.40	10.90	10.56	10.38
Forecast_Recruitment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parm_priors	0.00	0.00	0.00	0.00	0.00	1.38	0.42	0.01	-0.04	3.76
Parm_softbounds	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Parm_devs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crash_Pen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 14: Summaries of key assessment outputs and likelihood values from selected likelihood profile runs on female natural mortality. Note that male growth parameters are exponential offsets from female parameters, and depletion and SPR ratio are for the year of 2017.

Label	M0220	M0260	M0300	M0350	M0400
Female M	0.22	0.26	0.30	0.35	0.40
Steepness	0.72	0.72	0.72	0.72	0.72
lnR0	7.67	8.20	8.95	12.21	31.00
Total biomass (m)	2259.39	2861.79	4632.81	89473.50	9753570000000.00
Depletion (%)	47.72	58.15	68.08	79.27	79.74
SPR ratio	0.97	0.70	0.41	0.02	0.00
Female Lmin	12.39	12.44	12.43	12.39	12.24
Female Lmax	33.23	33.31	33.31	33.25	33.73
Female K	0.25	0.25	0.25	0.25	0.24
Male Lmin (offset)	0.00	0.00	0.00	0.00	0.00
Male Lmax (offset)	-0.16	-0.16	-0.15	-0.15	-0.15
Male K (offset)	-0.27	-0.30	-0.31	-0.32	-0.36
Negative log-likelihood					
TOTAL	1102.66	1096.96	1092.96	1089.92	1091.52
Catch	0.00	0.00	0.00	0.00	0.00
Equil_catch	0.00	0.00	0.00	0.00	0.00
Survey	-97.79	-98.14	-98.33	-98.33	-98.95
Length_comp	765.50	762.85	760.88	759.19	755.26
Age_comp	422.97	421.41	420.05	418.75	425.16
Recruitment	11.91	10.82	10.30	10.05	9.54
Forecast_Recruitment	0.00	0.00	0.00	0.00	0.00
Parm_priors	0.06	0.00	0.06	0.25	0.51
Parm_softbounds	0.01	0.01	0.01	0.00	0.00
Parm_devs	0.00	0.00	0.00	0.00	0.00
Crash_Pen	0.00	0.00	0.00	0.00	0.00

Table 15: Projection of potential OFL, spawning biomass, and depletion for the base case model.

Yr	OFL contribution (mt)	ACL landings (mt)	Age 5+ biomass (mt)	Spawning Biomass (mt)	Depletion
2019	1274.290	1185.906	18438.000	1106.070	0.725
2020	1211.220	1125.230	17564.900	1048.210	0.687
2021	1159.120	1074.895	16847.100	993.337	0.651
2022	1117.470	1034.993	16248.300	941.818	0.617
2023	1083.860	1003.371	15744.500	893.809	0.586
2024	1055.150	976.699	15309.700	849.368	0.557
2025	1029.120	952.644	14919.700	808.738	0.530
2026	1004.390	929.838	14555.100	772.649	0.506
2027	980.334	907.640	14202.800	742.174	0.486
2028	956.747	885.819	13859.300	717.965	0.470
2029	933.761	864.469	13527.100	699.544	0.458
2030	911.621	843.793	13209.600	684.888	0.449

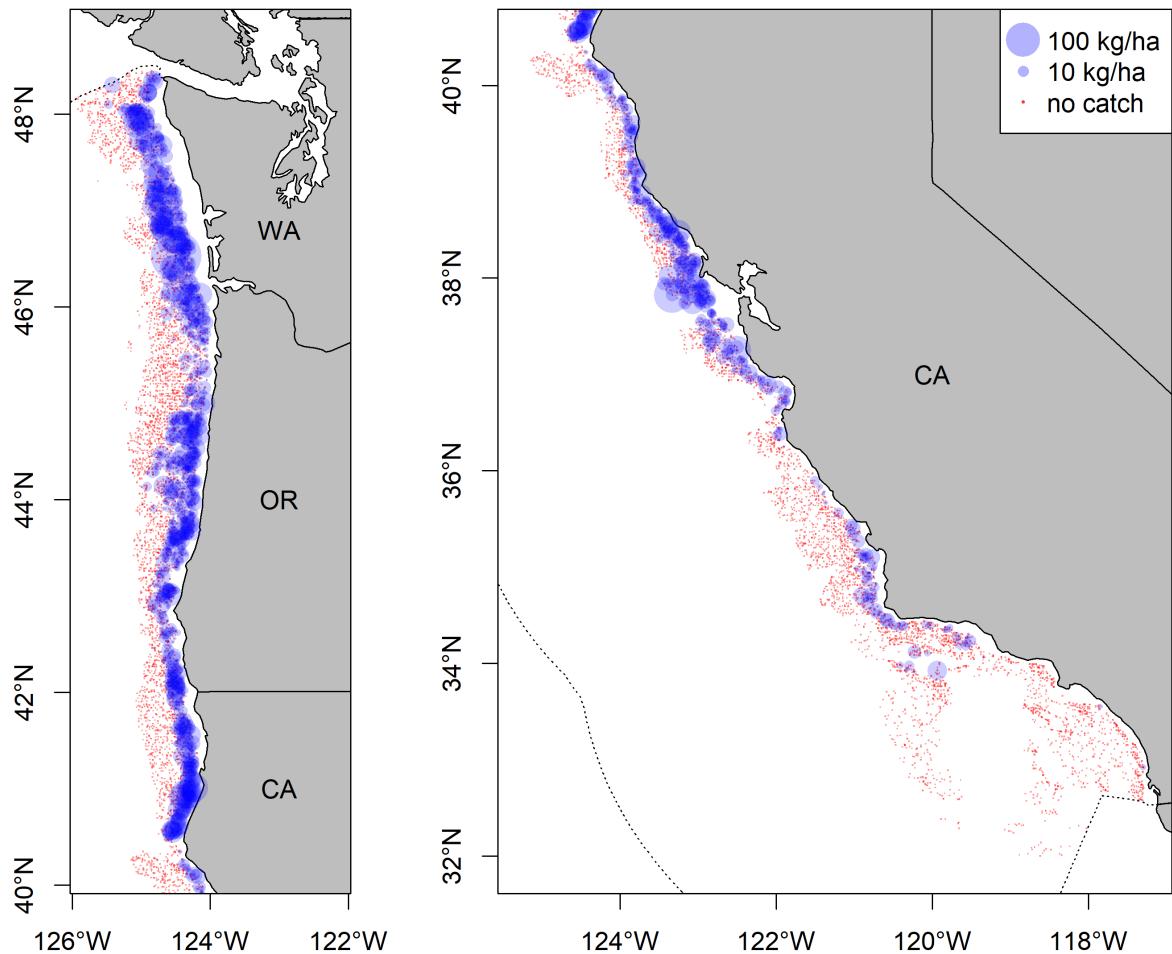


Figure 1: Map showing the distribution of Big Skate within the area covered by the West Coast Groundfish Bottom Trawl Survey aggregated over the years 2003–2018.

721 **9 Figures**

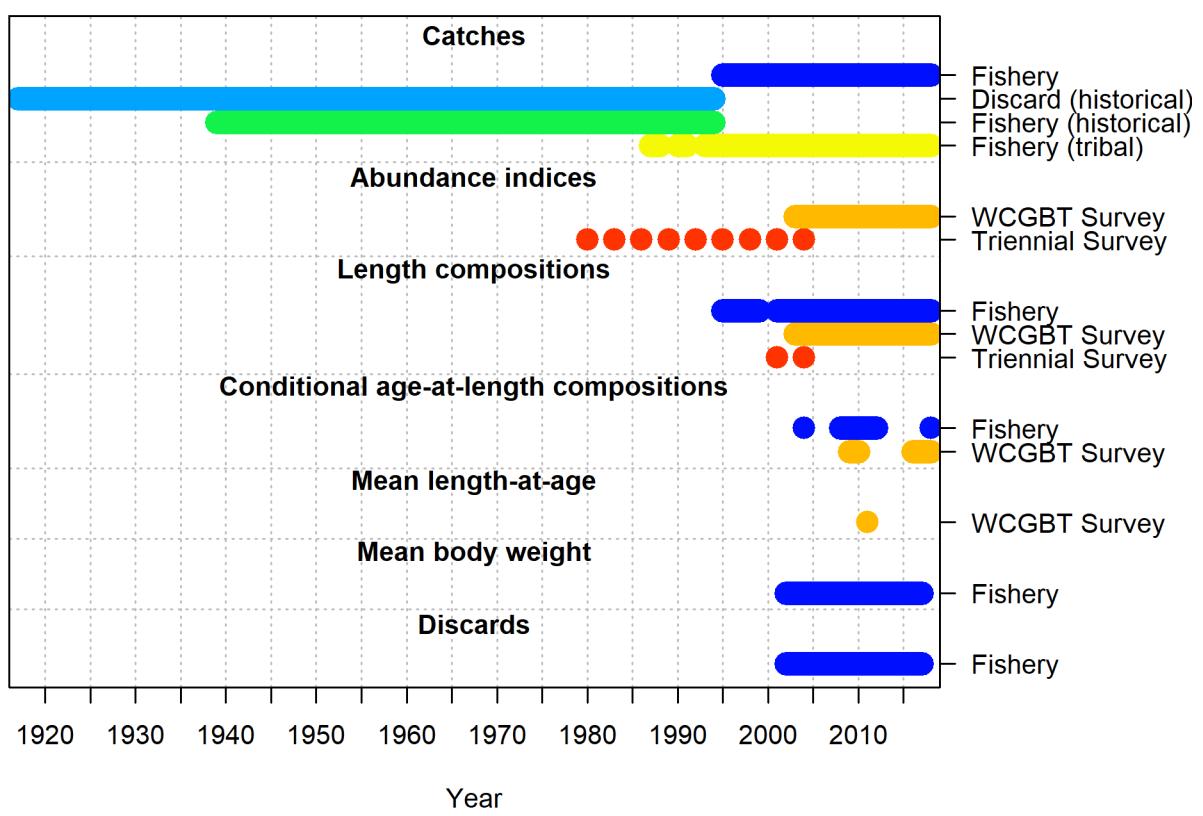


Figure 2: Summary of data sources used in the model.

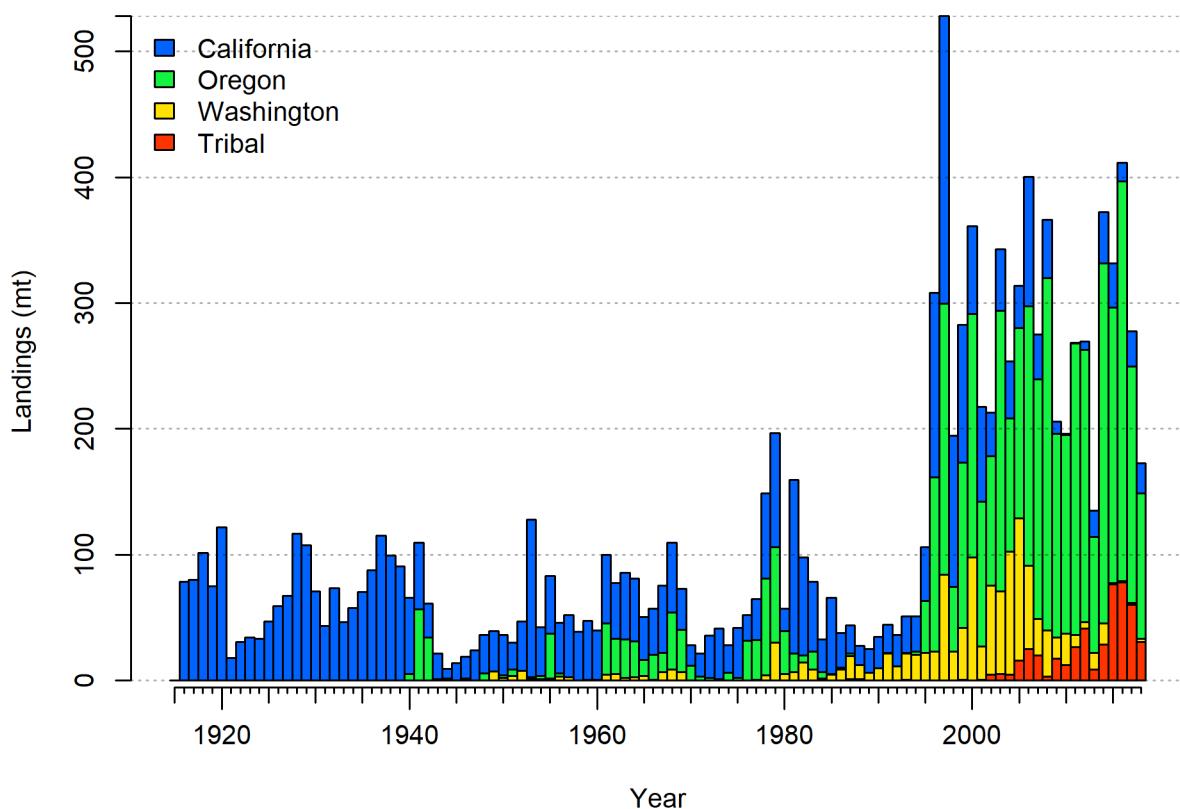


Figure 3: Reconstructed landings by area. Tribal catch was all landed in Washington.

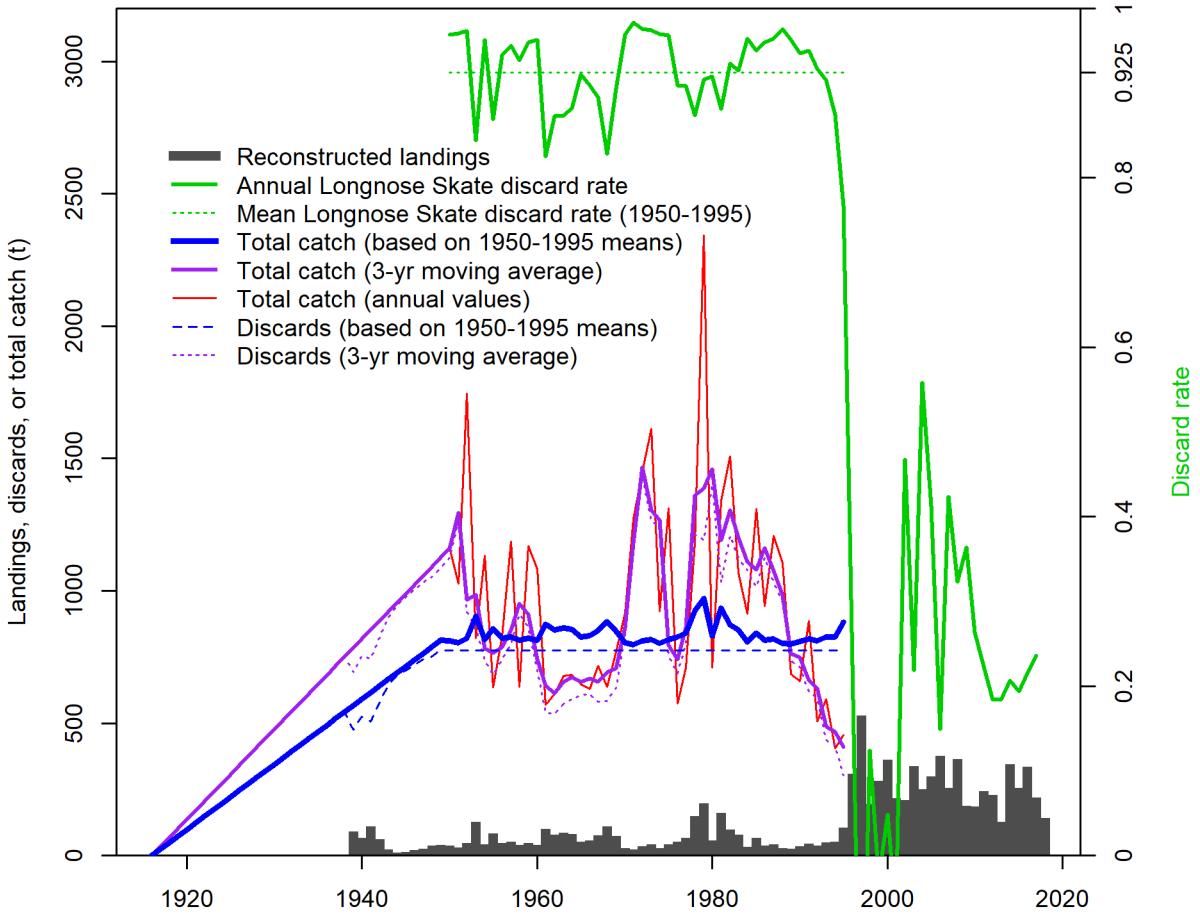


Figure 4: Estimated total catch using different assumptions for discards.

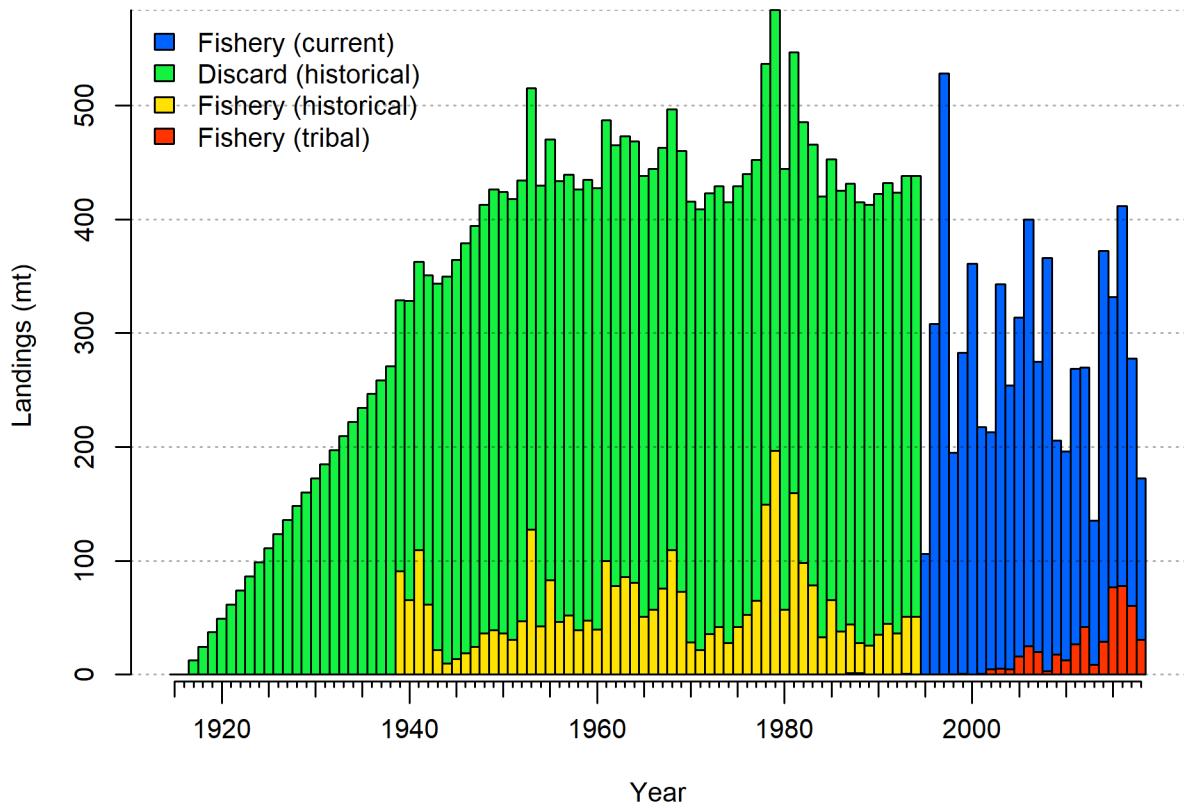


Figure 5: Catch data input to the model under assumed fleet structure. The historical discards shown in green have been scaled to account for an assumed 50% discard mortality. Discards during the period from 1995 onward are not represented here as they are estimated within the model.

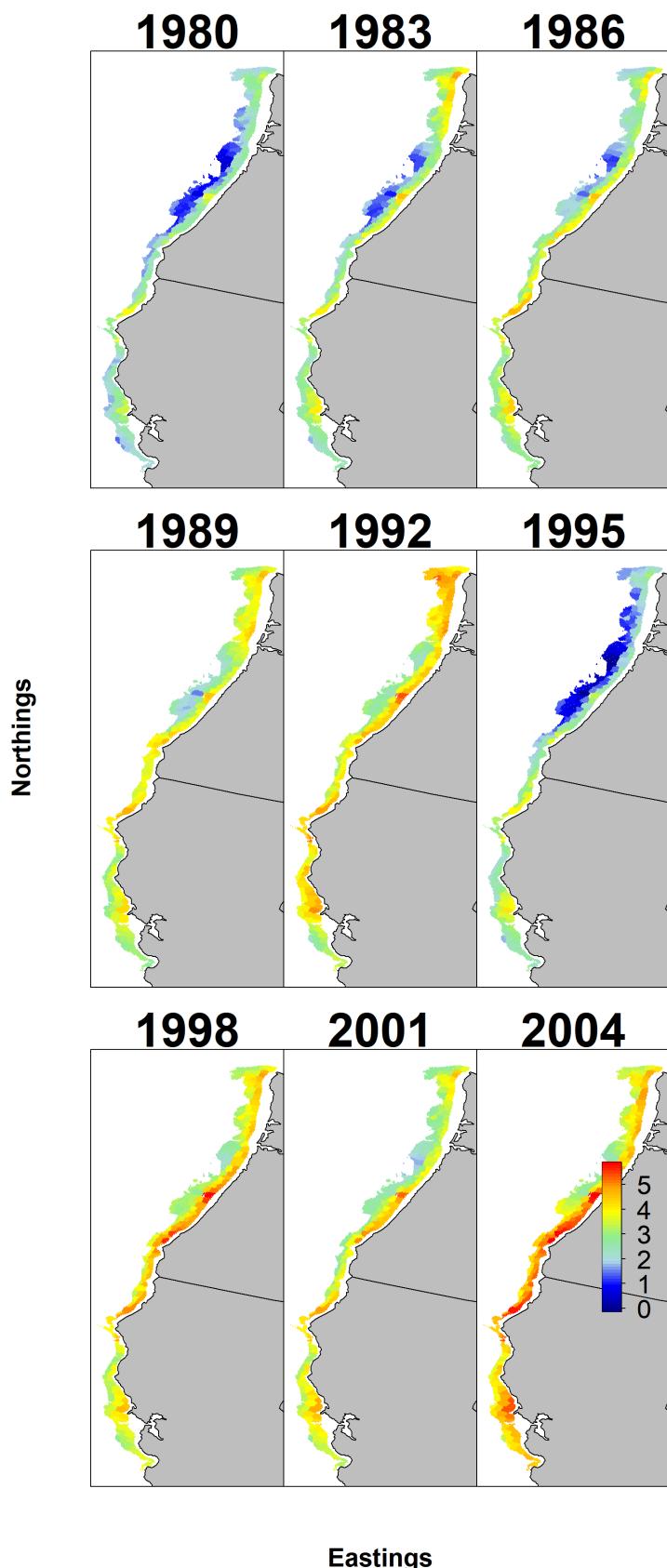


Figure 6: Map of estimated density by year for Big Skate in the Triennial survey.
66

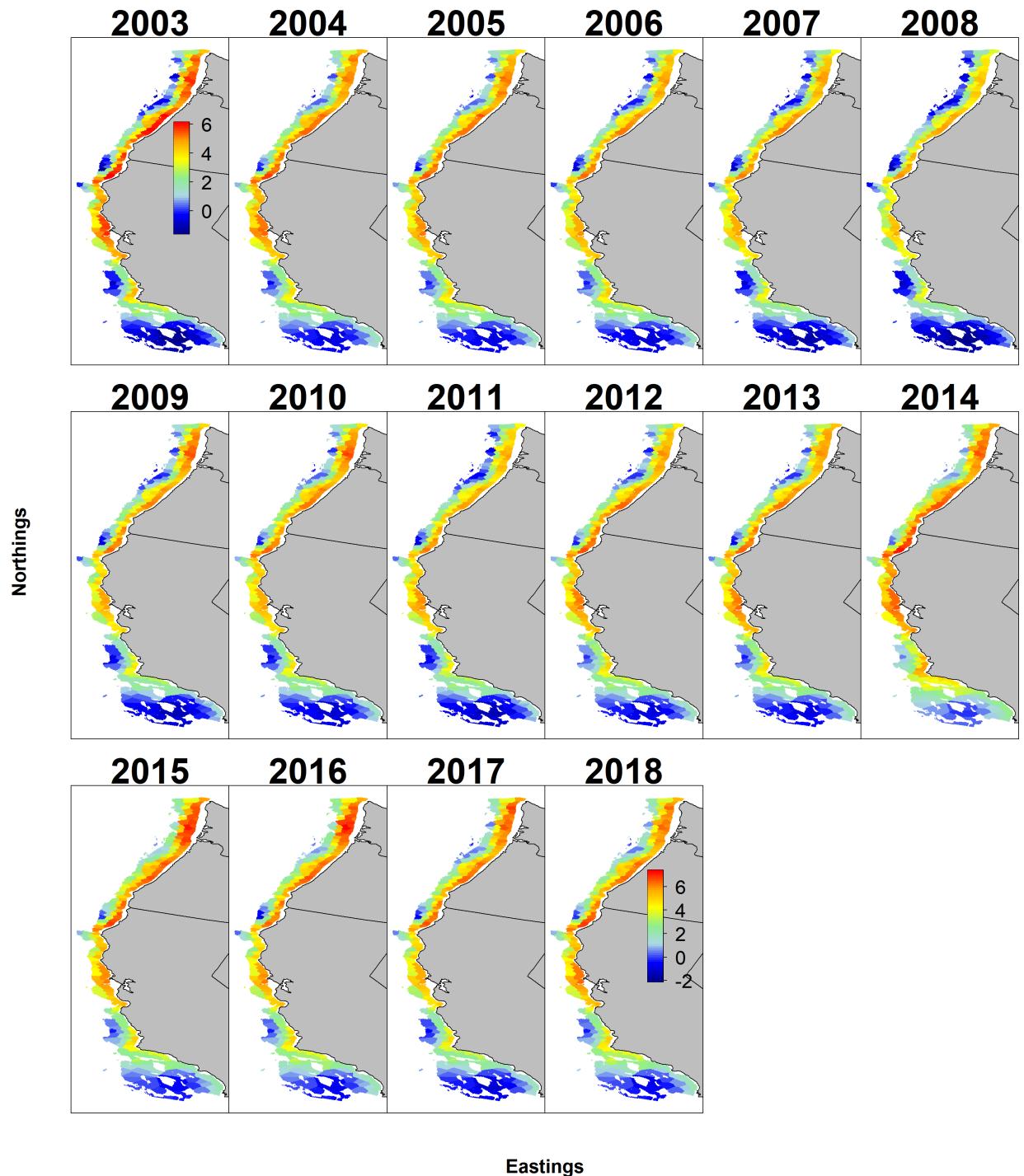


Figure 7: Map of estimated density by year for Big Skate in the WCGBT Survey.

Big Skate per 100 observed hooks in IPHC longline survey

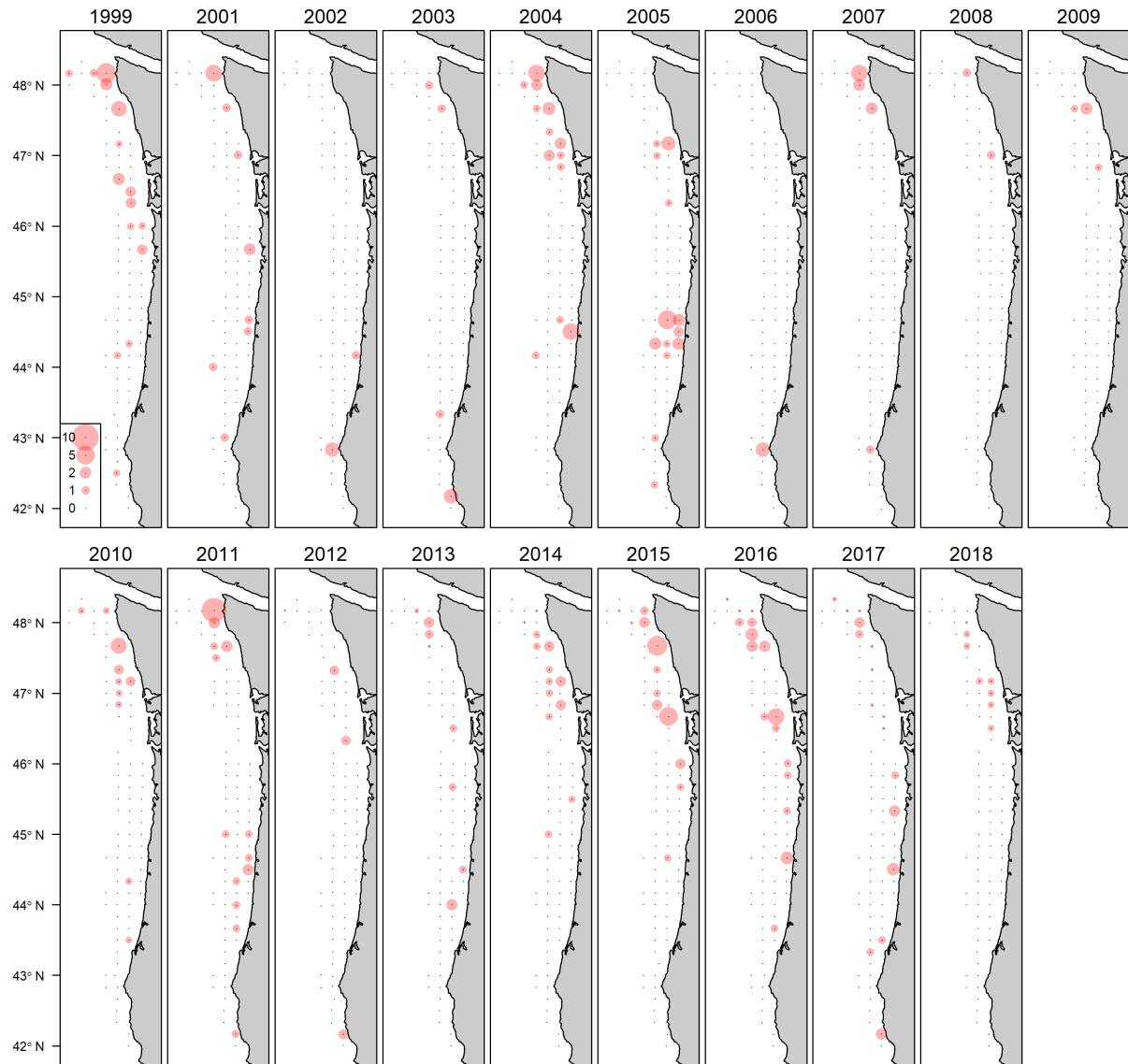
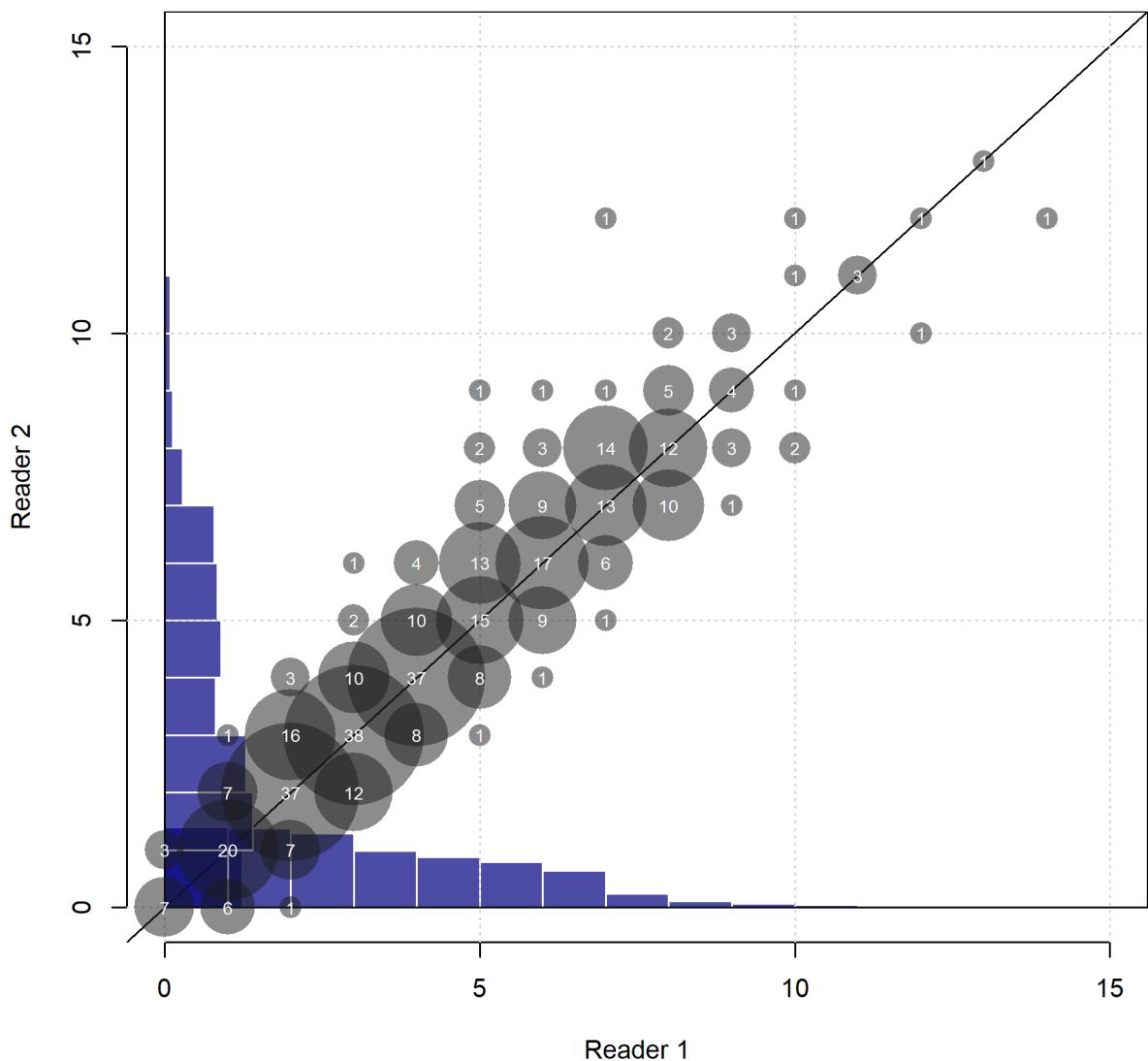


Figure 8: Map of catch rates by year for Big Skate in the International Pacific Halibut Commission longline survey.



722

723 Reader 1 vs Reader 2.png

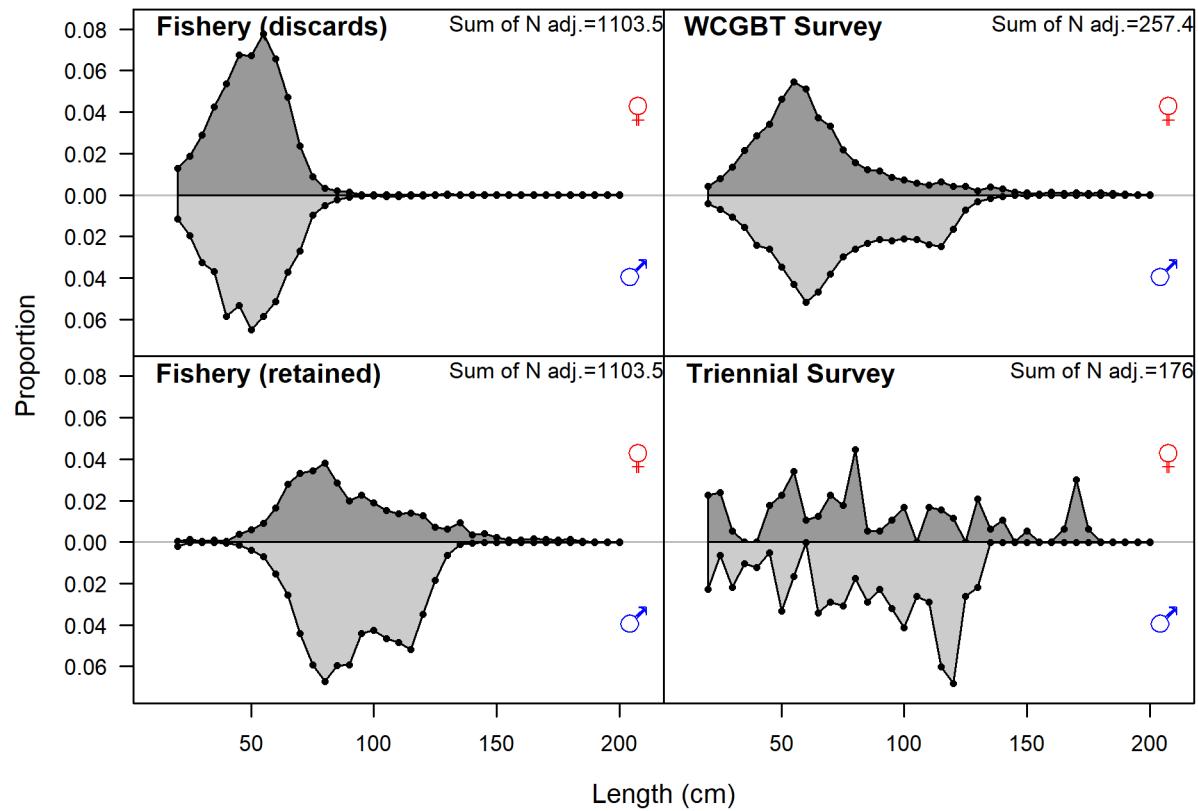


Figure 9: Length comp data, aggregated across time by fleet.

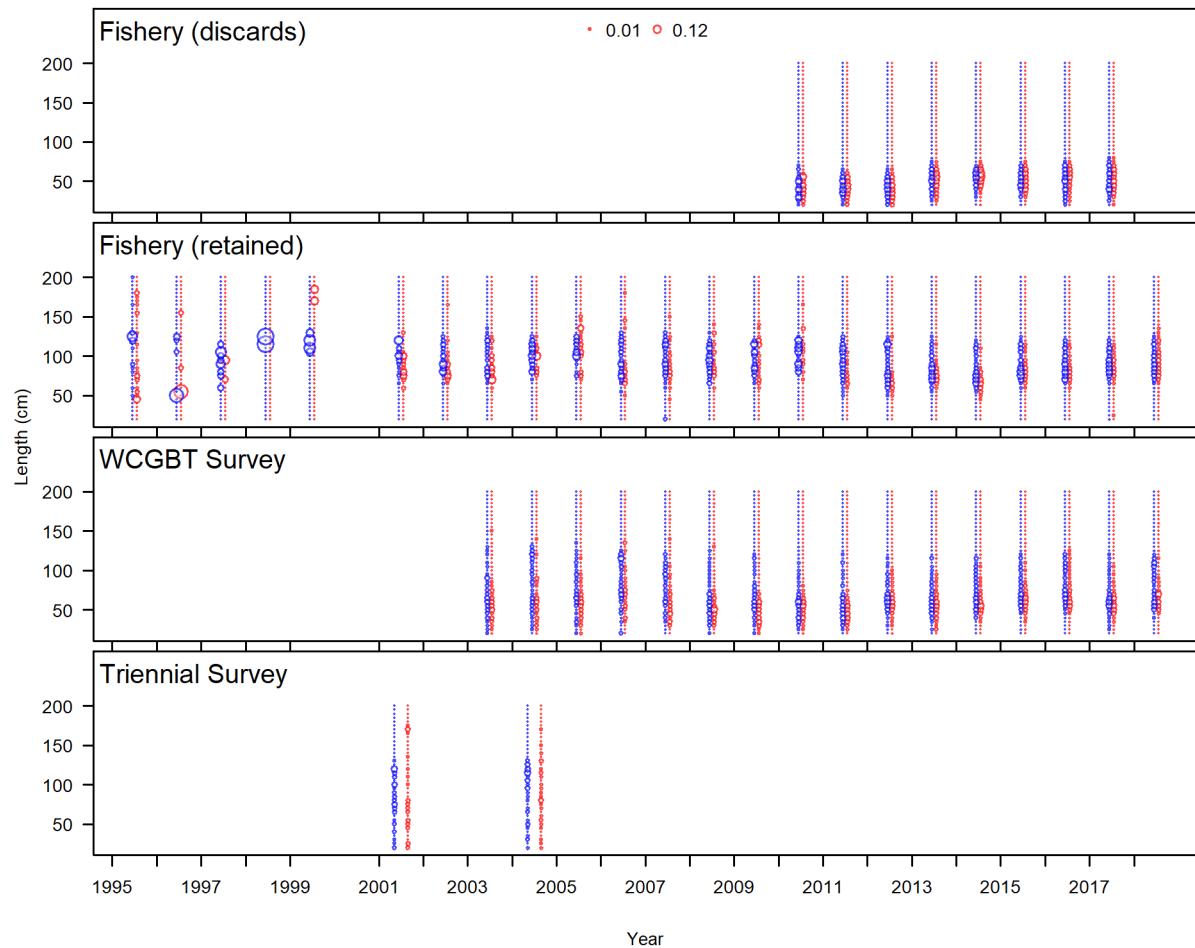


Figure 10: Length comp data for all years and fleets. Bubble size indicates the observed proportions, with females in red and males in blue.

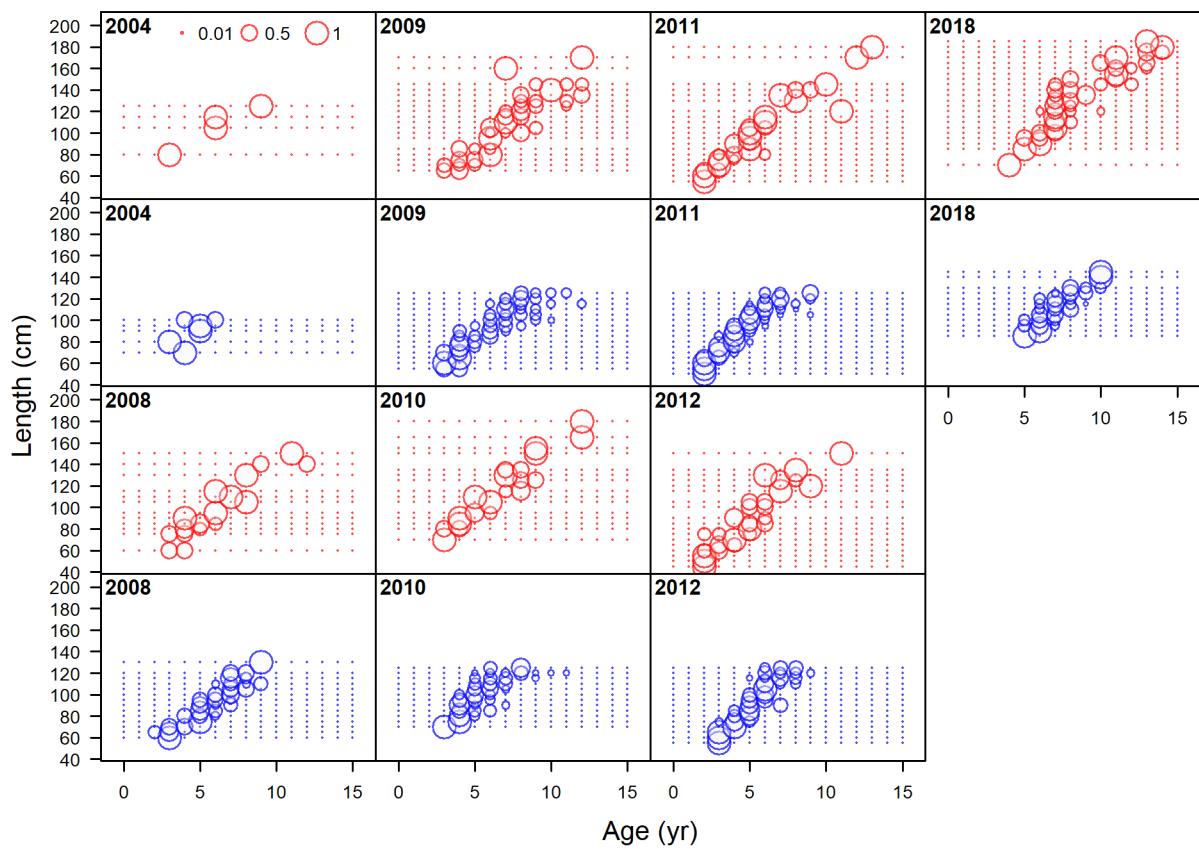


Figure 11: Conditional age-at-length data from the fishery.

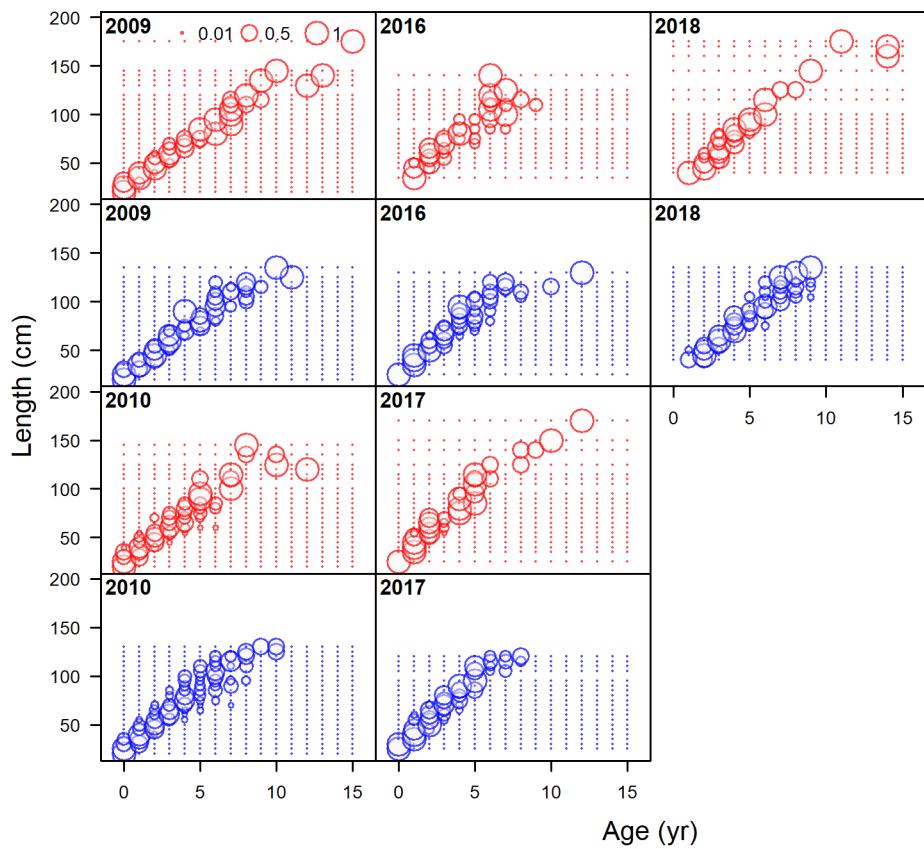


Figure 12: Conditional age-at-length data from the WCGBT Survey.

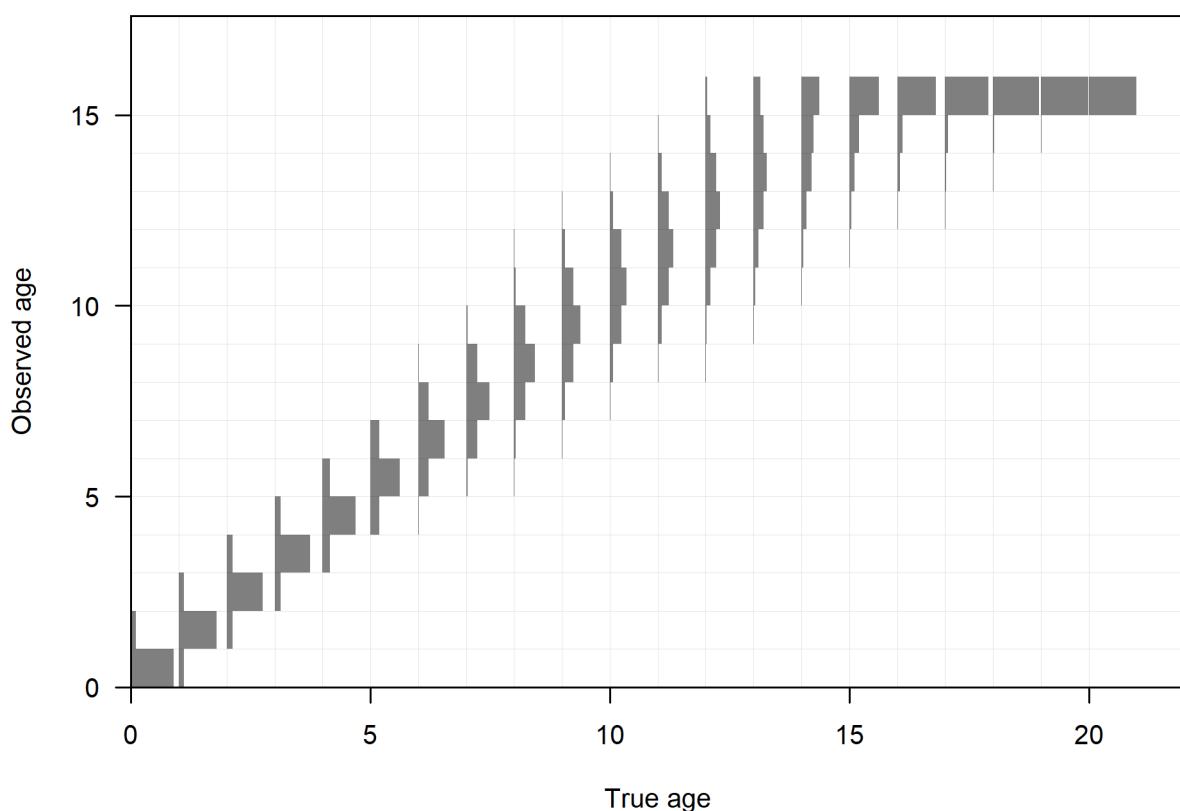


Figure 13: Estimated ageing imprecision.

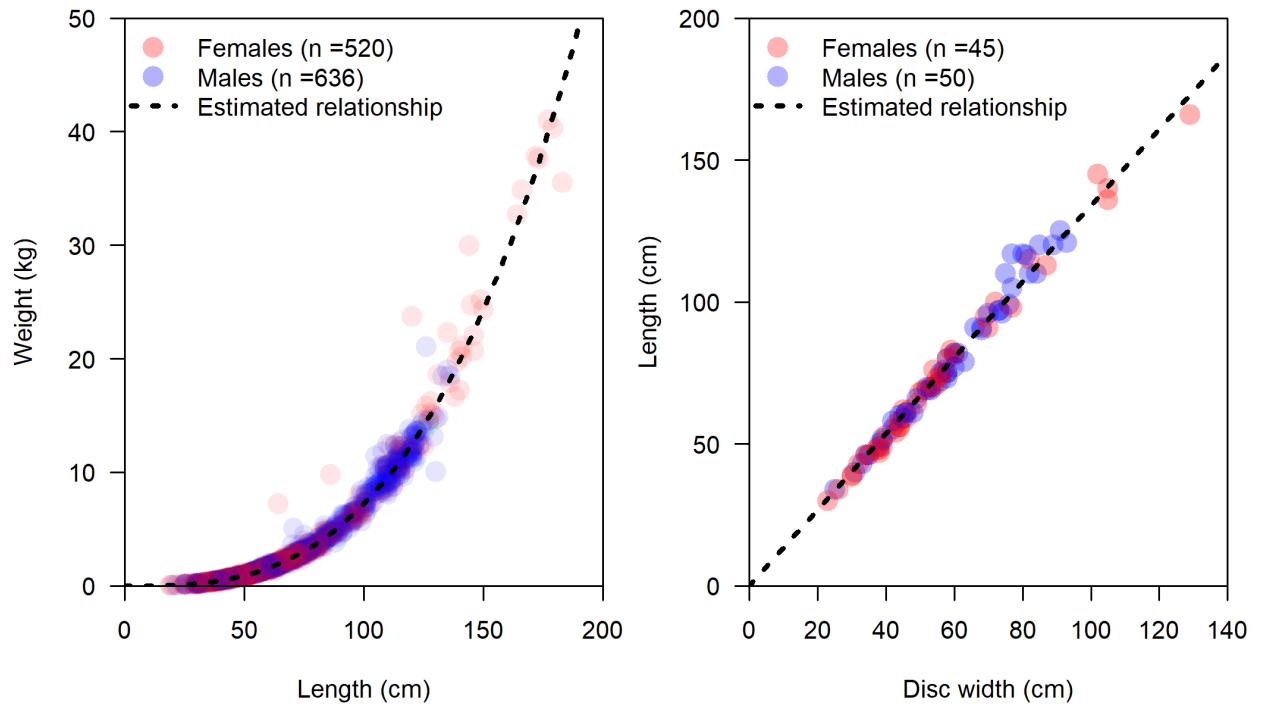


Figure 14: Estimated relationship between length and weight (left) and disc-width and length (right) for Big Skate. Colored points show observed values and the black line indicates the estimated relationship $W = 0.0000074924L^{2.9925}$.

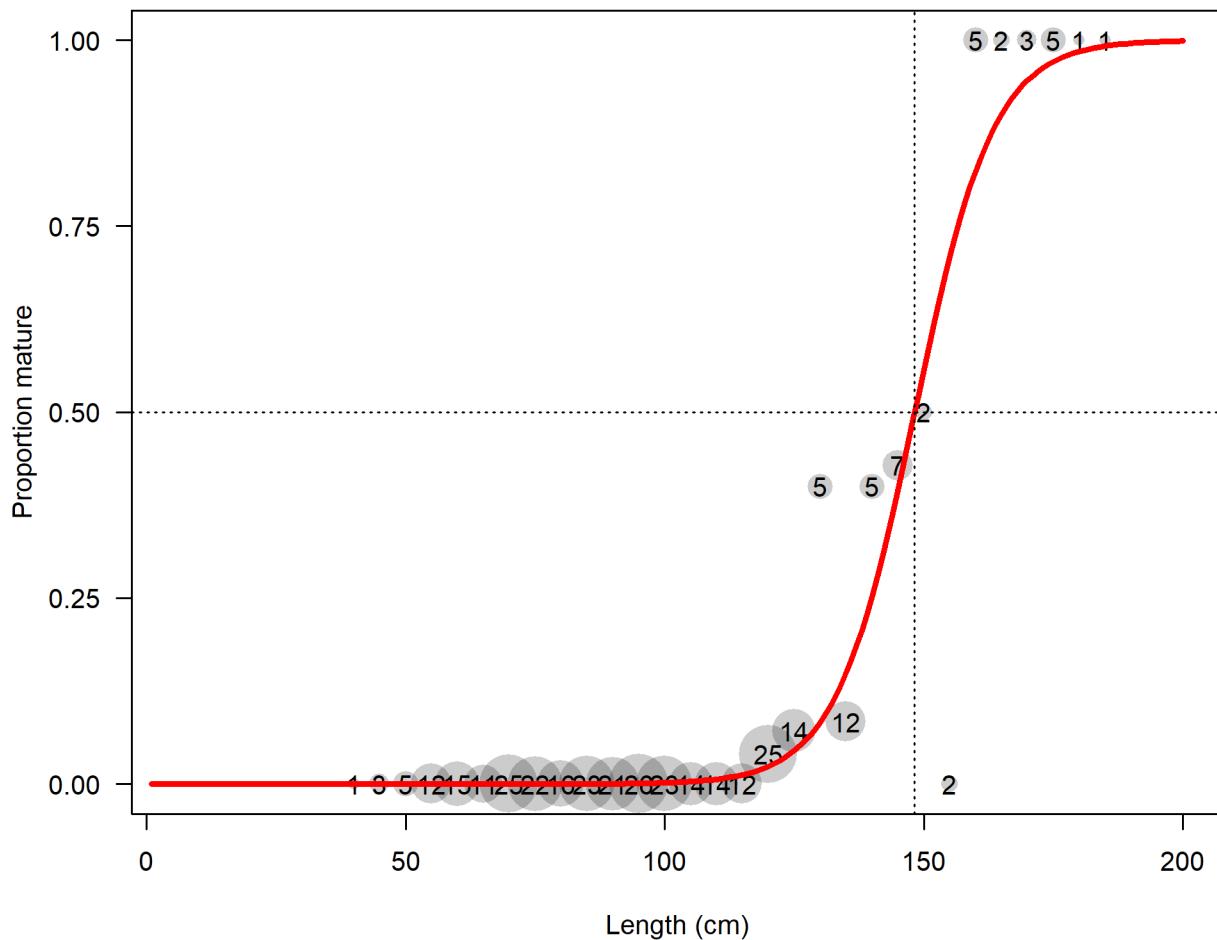


Figure 15: Estimated maturity relationship for female Big Skate. Gray points indicate average observed functional maturity within each length bin with point size proportional to the number of samples (indicated by text within each point).

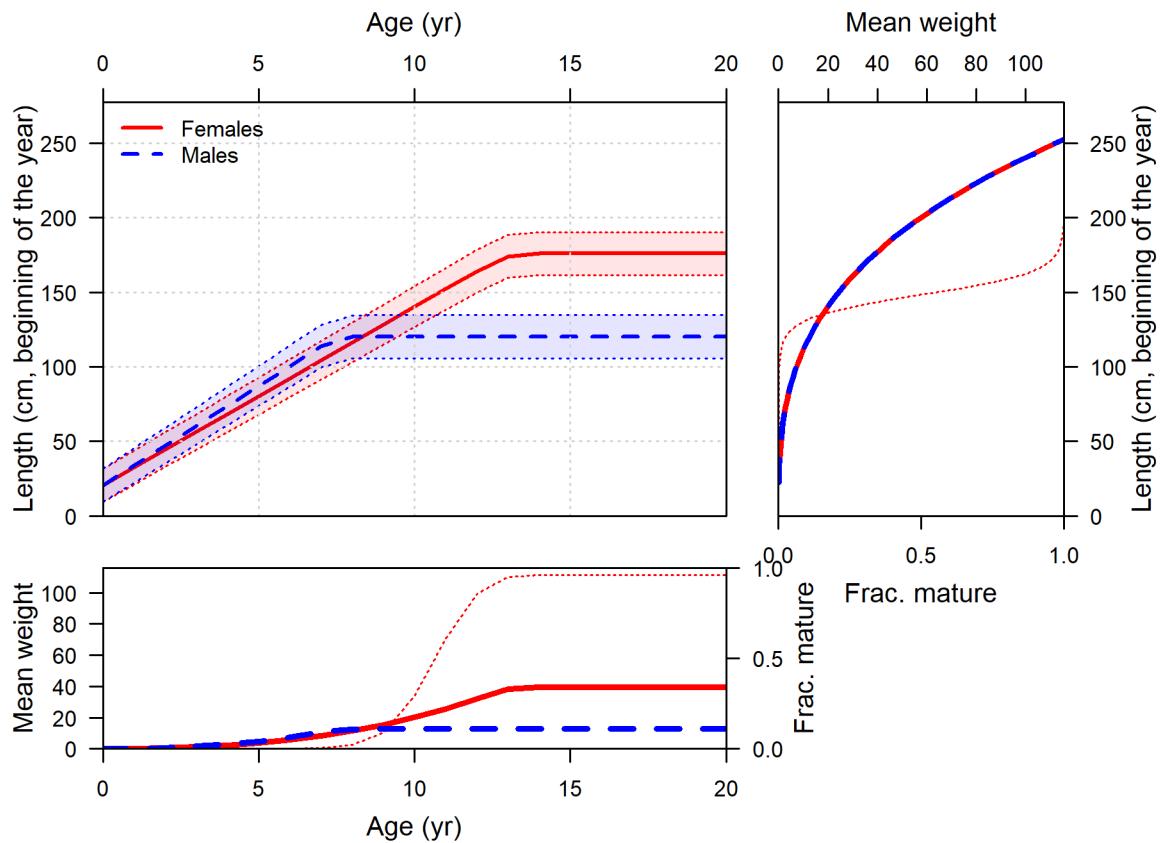


Figure 16: Estimated length-at-age for female and male Big Skate (top left panel). Shaded areas indicate 95% intervals for distribution of lengths at each age. Values represent beginning-of-year growth. Weight (thick line) and maturity (thin line) are shown in the top-right and lower-left panels as a function of length and age, respectively, where the values-at-age are calculated by mapping the length-based relationships through the estimated distribution of length at each age.

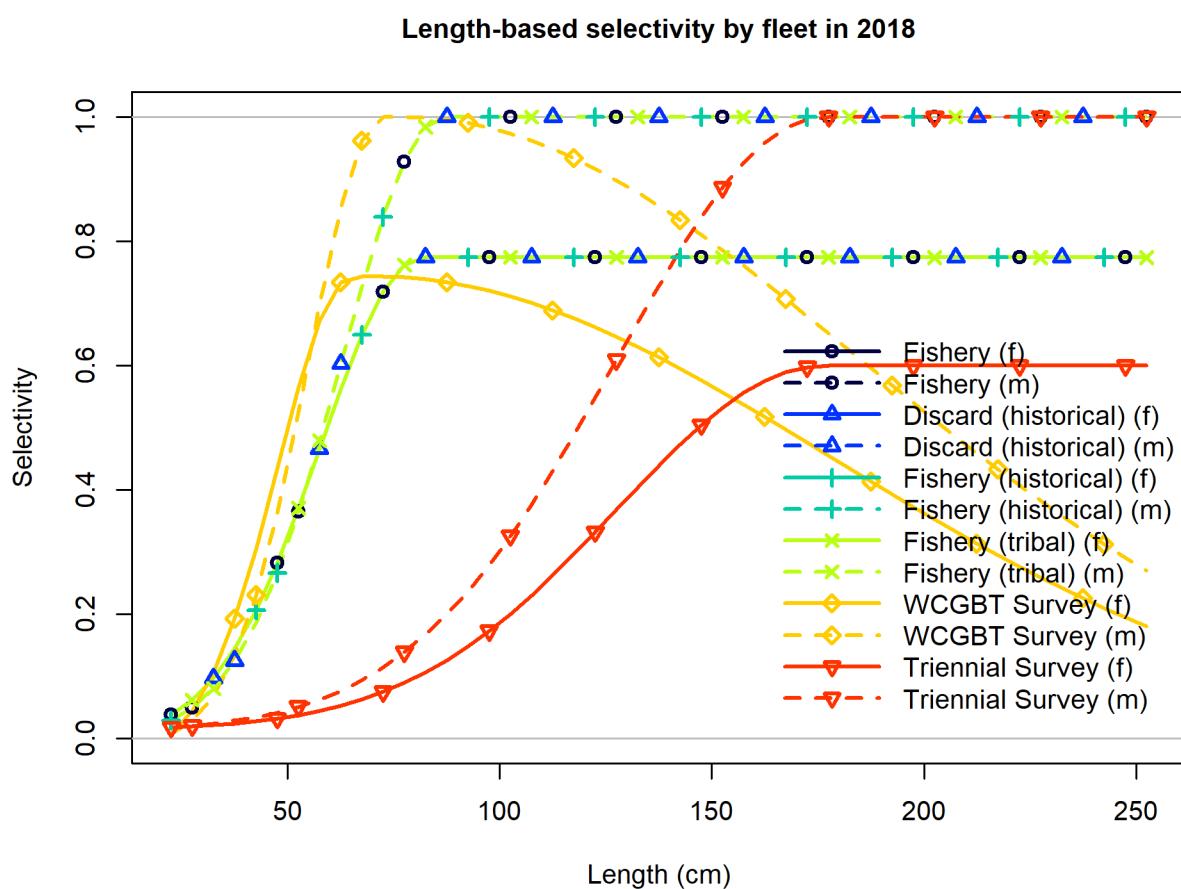


Figure 17: Selectivity at length for all of the fleets in the base model.

724 file:

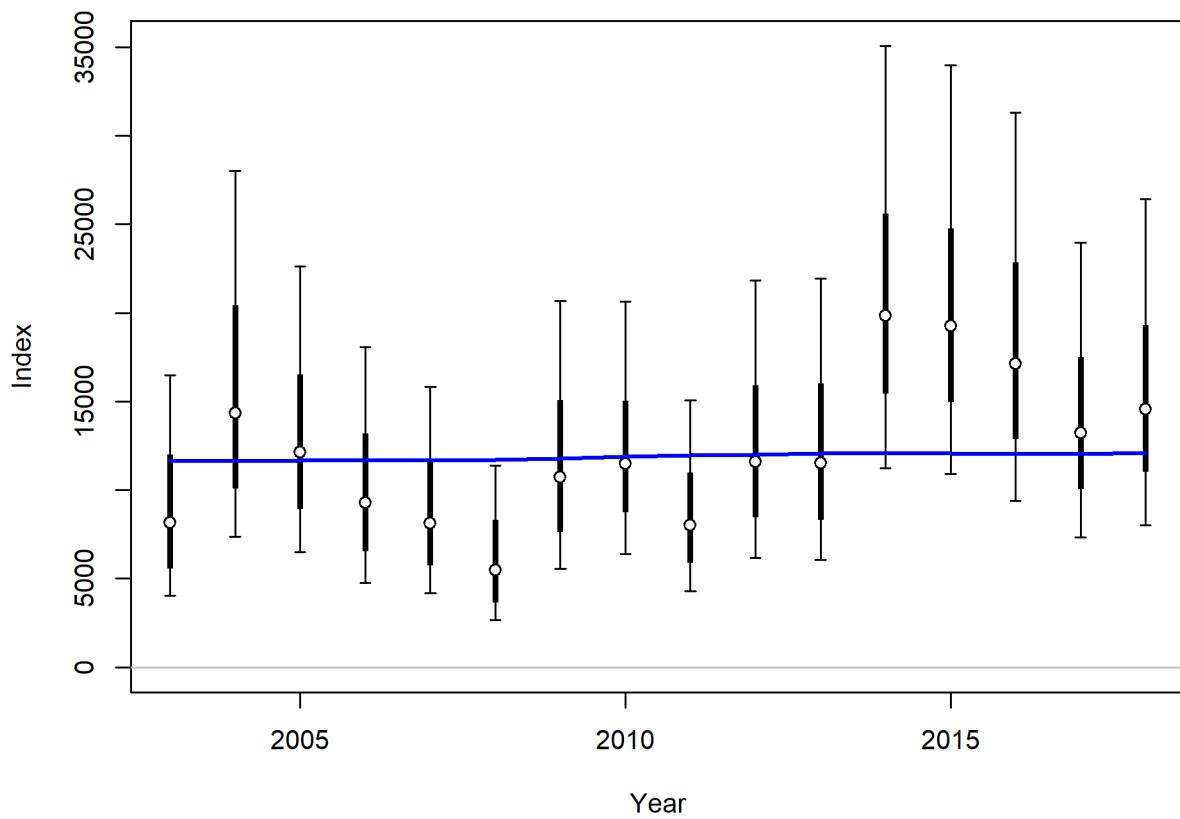


Figure 18: Fit to index data for WCGBT Survey. Lines indicate 95% uncertainty interval around index values. Thicker lines indicate input uncertainty before addition of estimated additional uncertainty parameter. The blue line indicates the model estimate.

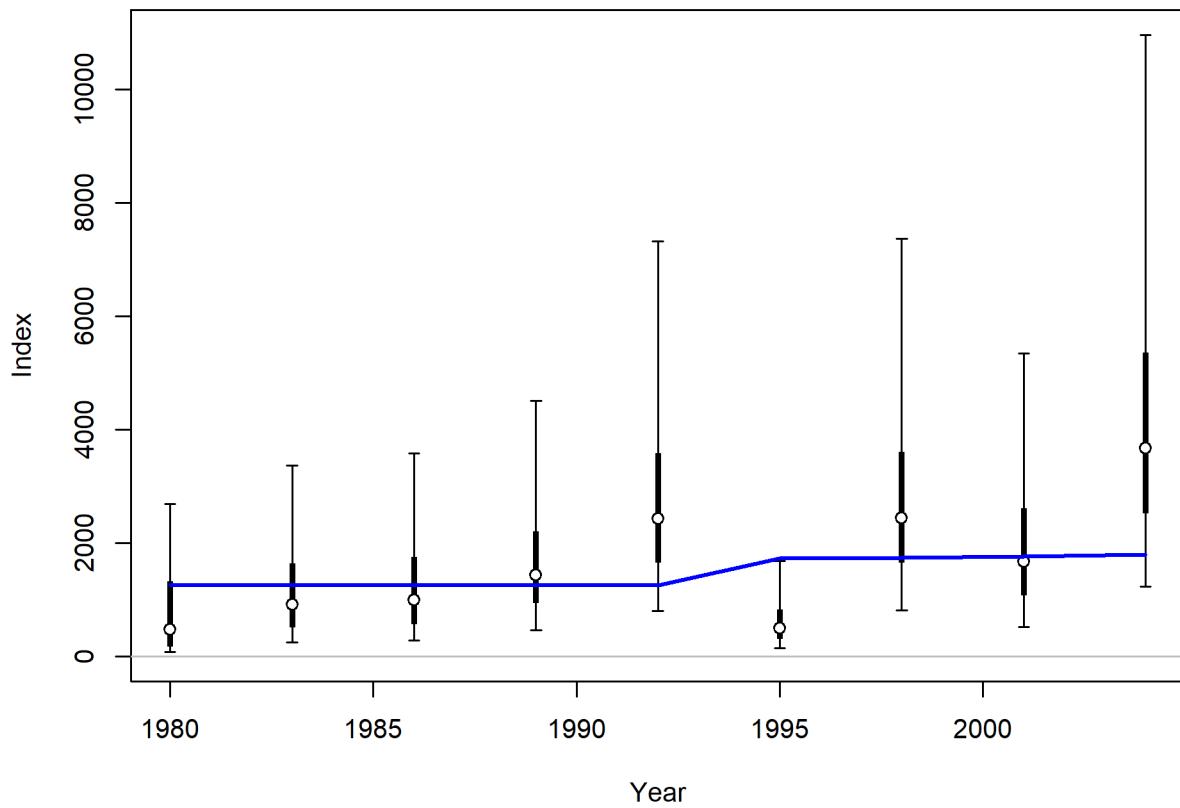


Figure 19: Fit to index data for Triennial Survey. Lines indicate 95% uncertainty interval around index values. Thicker lines indicate input uncertainty before addition of estimated additional uncertainty parameter. The blue line indicates the model estimate with a change between 1992 and 1995 associated with the estimated change in catchability.

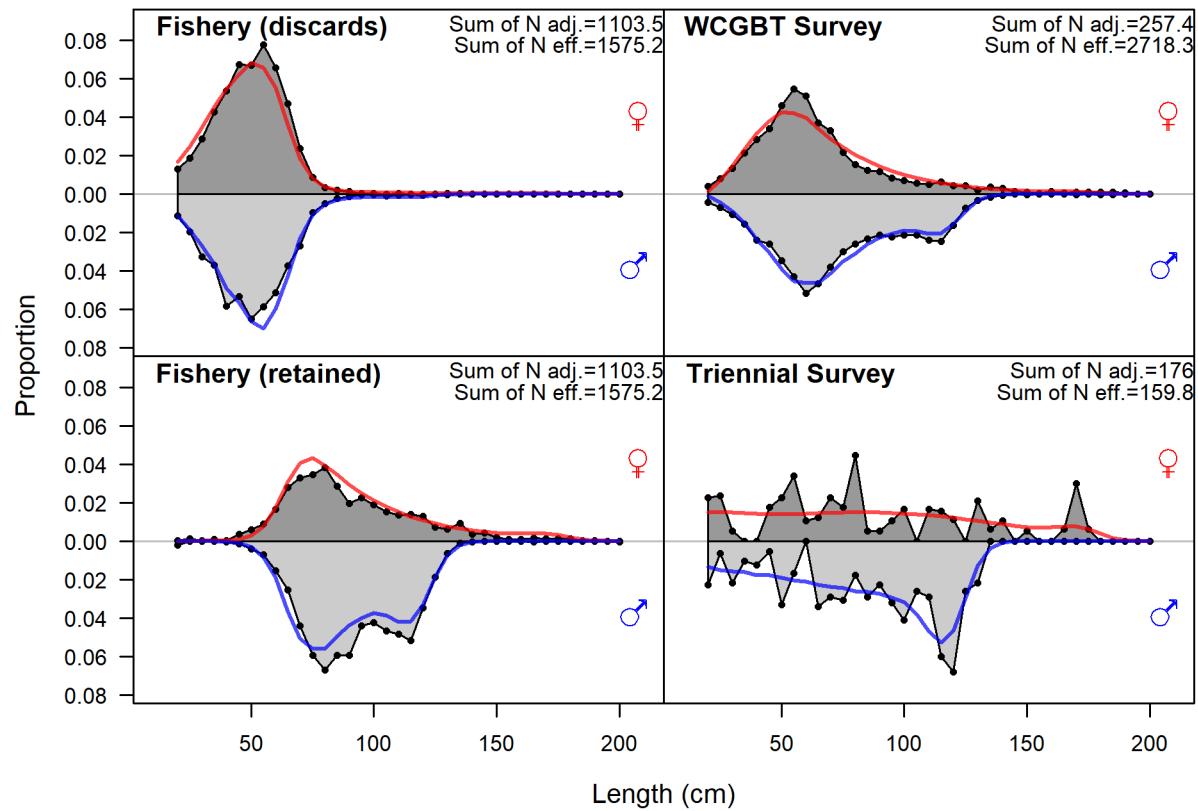


Figure 20: Fits to length comp data, aggregated across time by fleet.

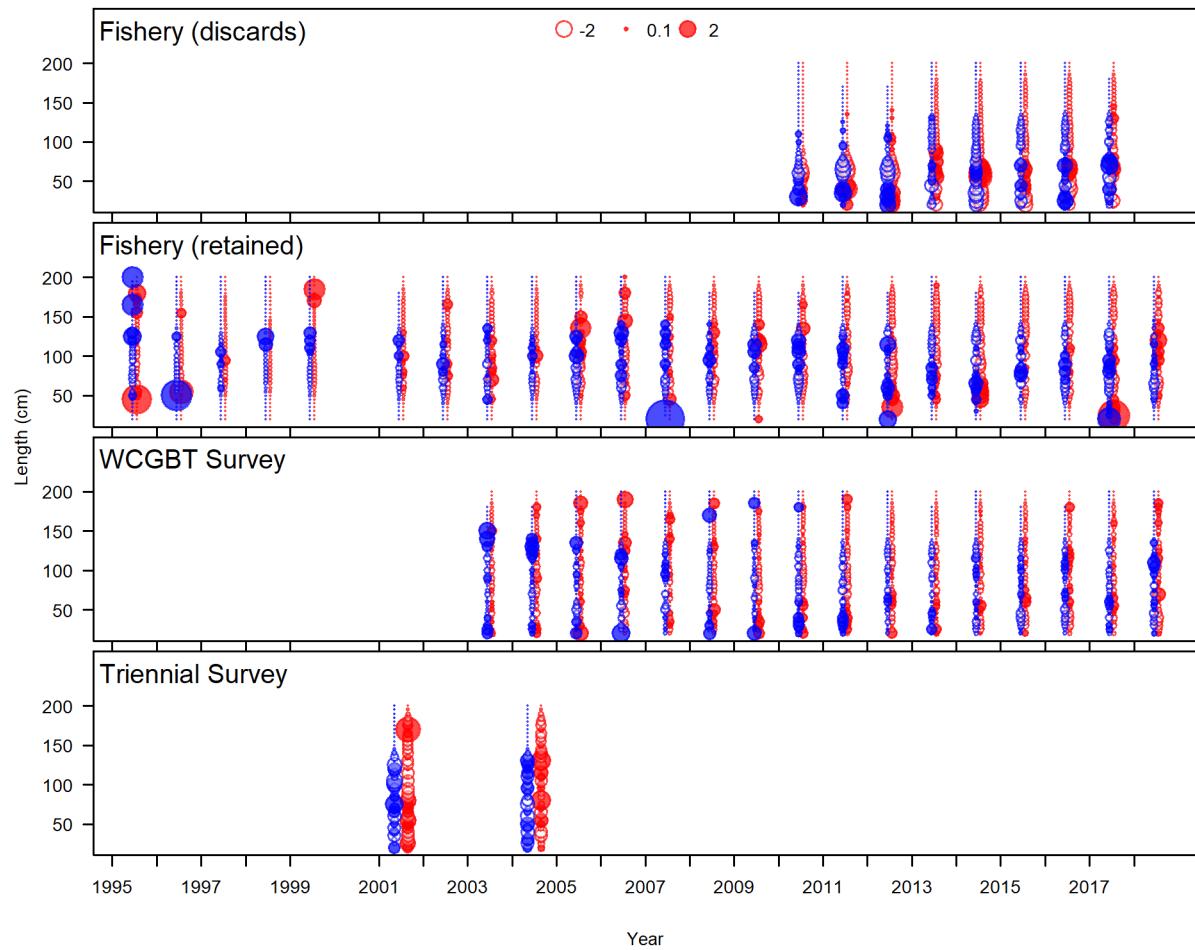


Figure 21: Pearson residuals for length comp data for all years and fleets, with females in red and males in blue.

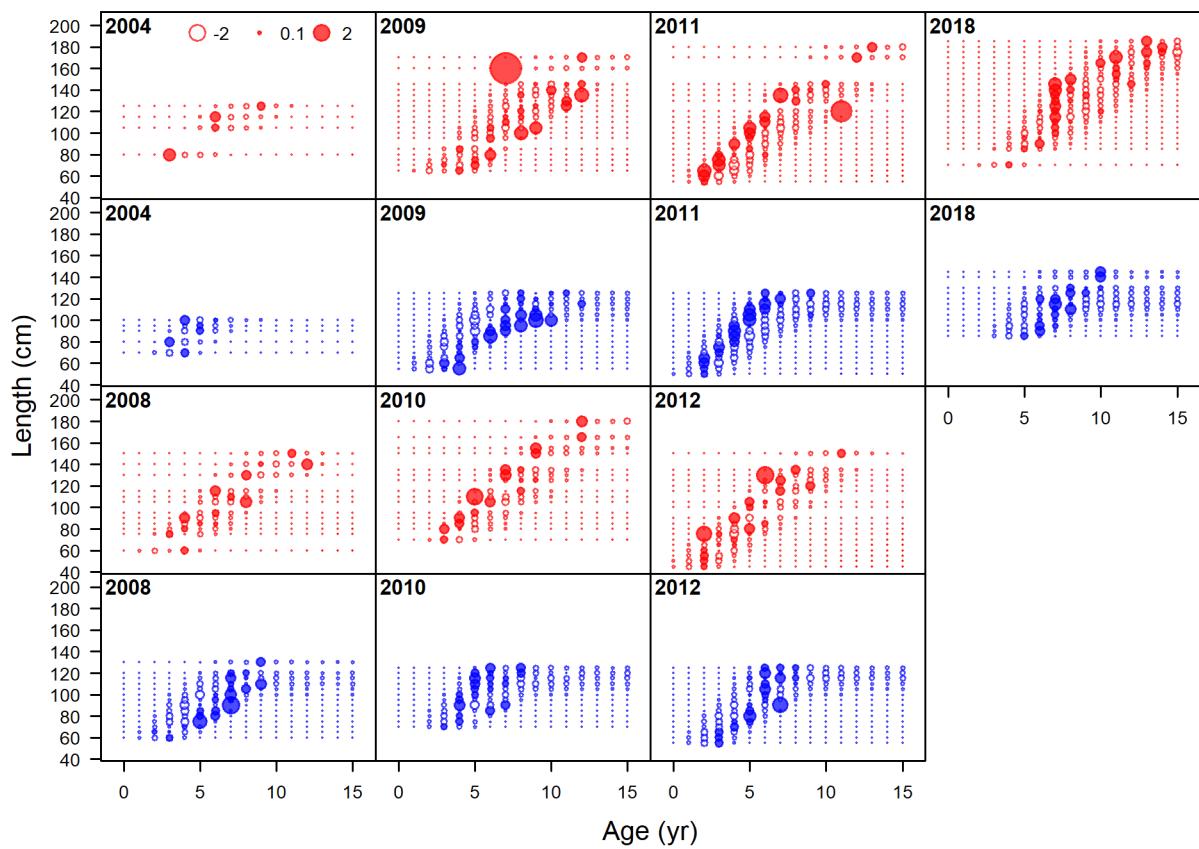


Figure 22: Pearson residuals for the fit to conditional age-at-length data from the fishery.

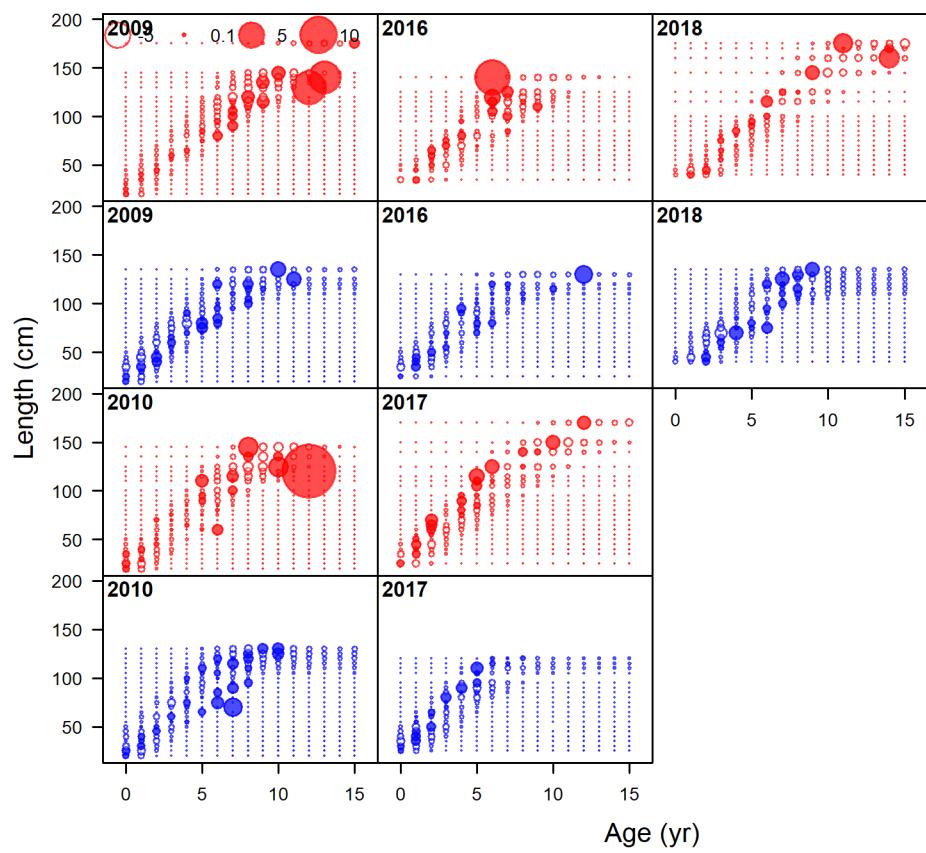


Figure 23: Pearson residuals for the fit to conditional age-at-length data from the WCGBT Survey.

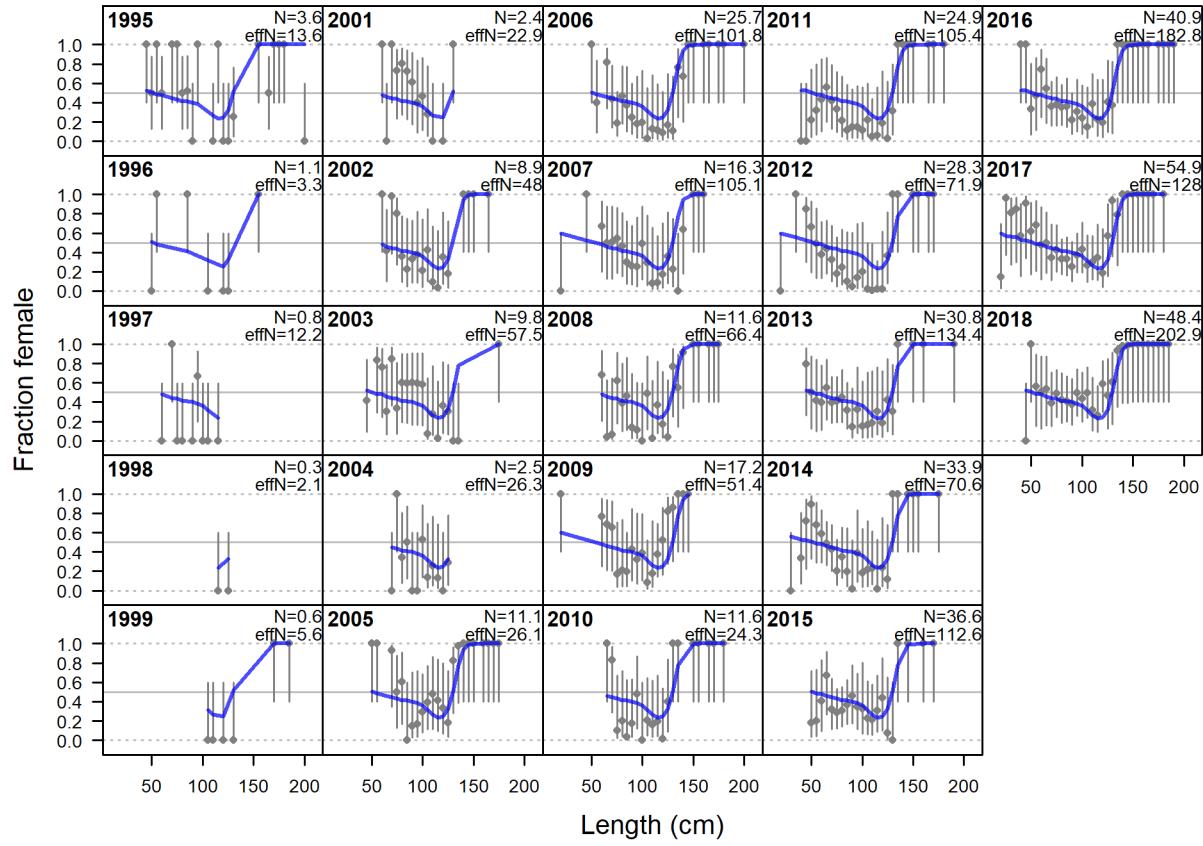


Figure 24: Observed sex ratios (points) from the fishery length comp data with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the blue line.

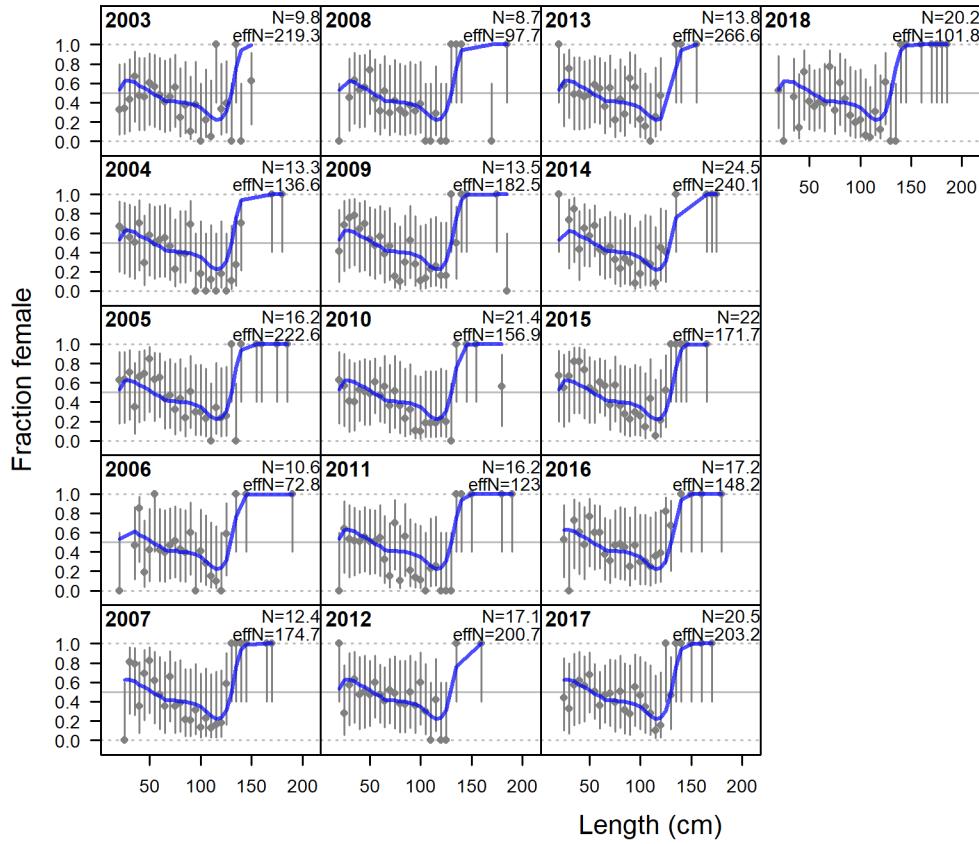


Figure 25: Observed sex ratios (points) from the WCGBT Survey length comp data with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the blue line.

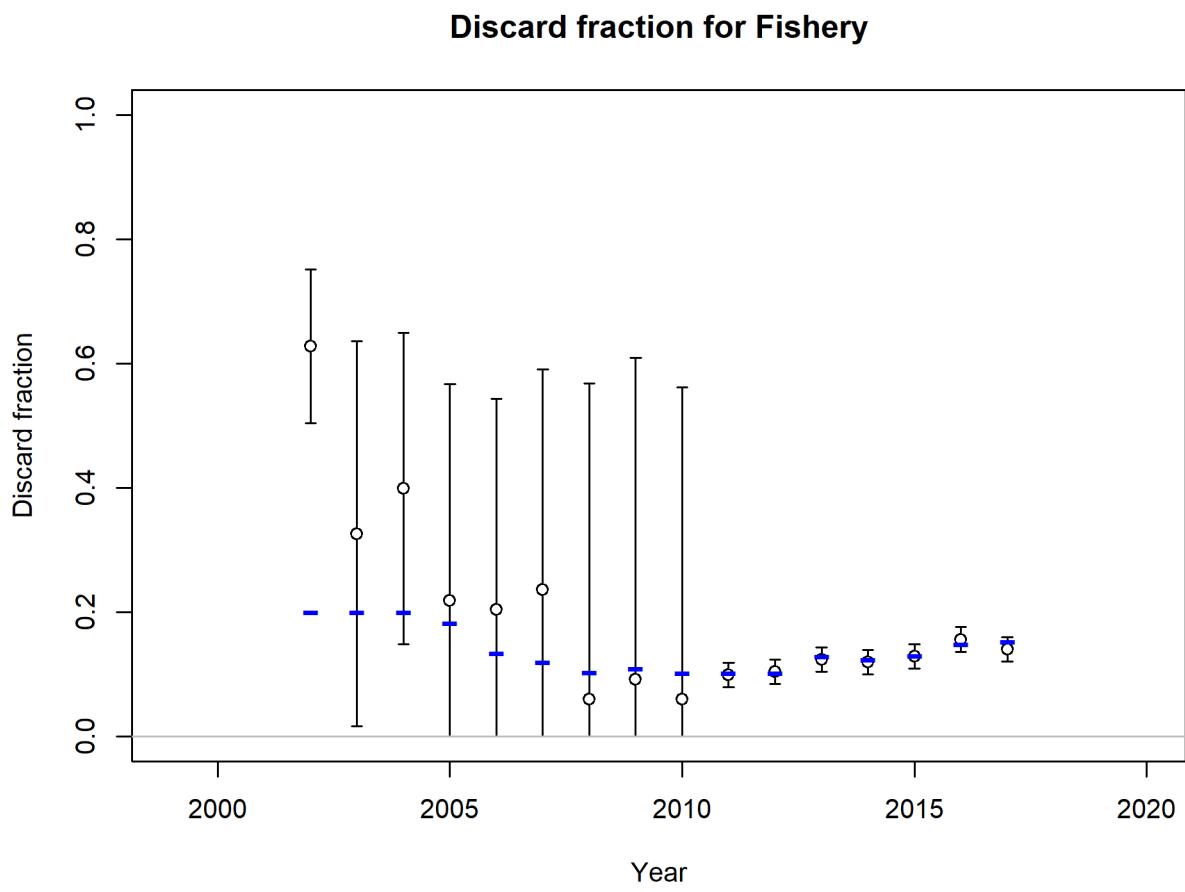


Figure 26: Fit to the discard fraction estimates. Points are model estimates with 95% uncertainty intervals. The model estimate is shown in the blue lines.

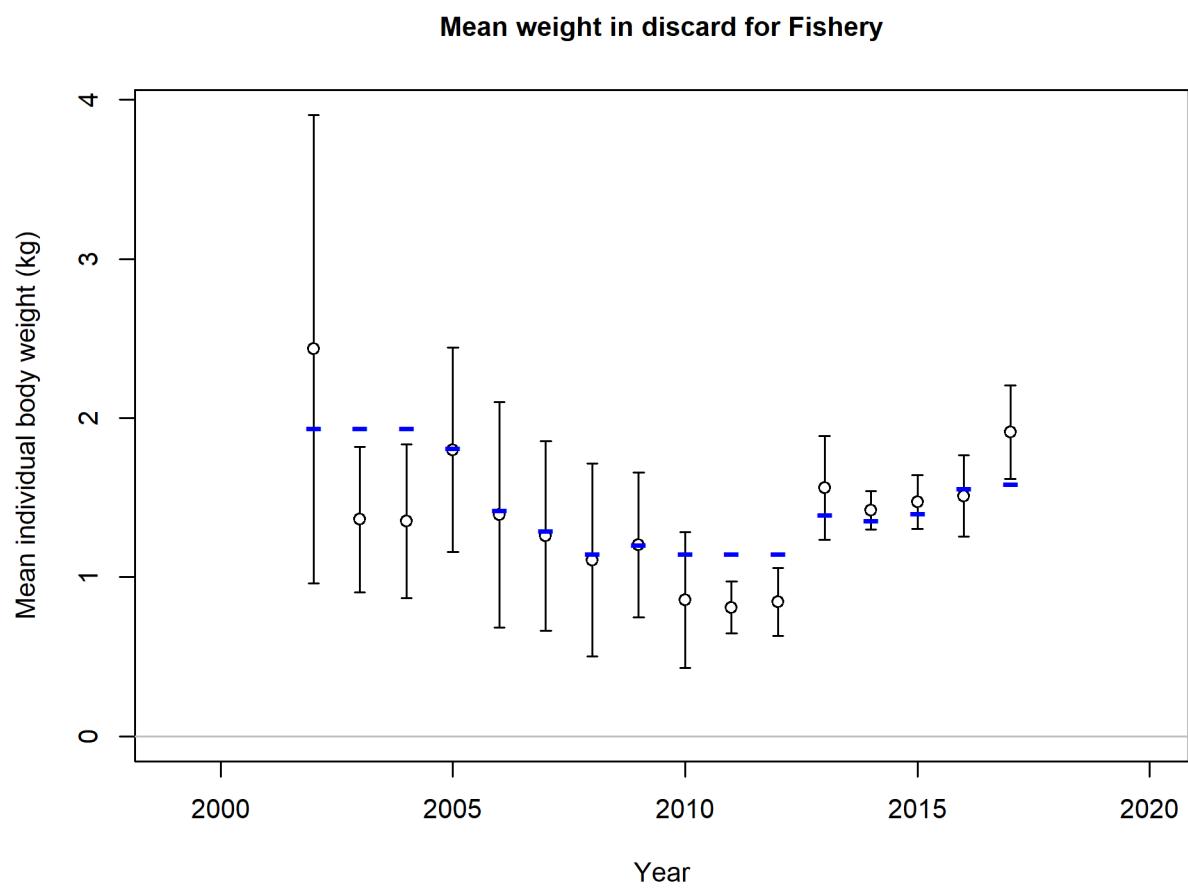


Figure 27: Fit to the mean weight of the discards. Points are model estimates with 95% uncertainty intervals. The model estimate is shown in the blue lines.

⁷²⁵ 9.0.1 Sensitivity analyses for model

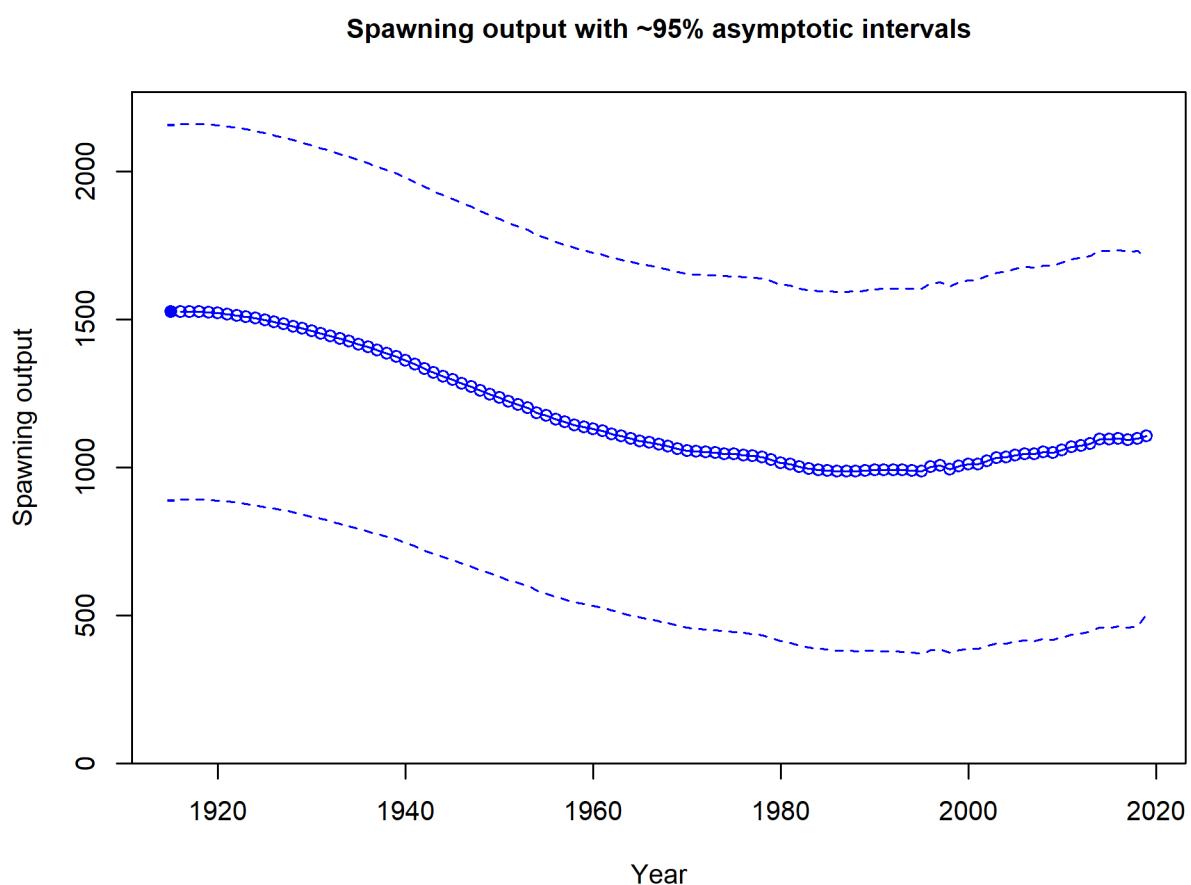


Figure 28: Estimated spawning biomass (mt) with approximate 95% asymptotic intervals.

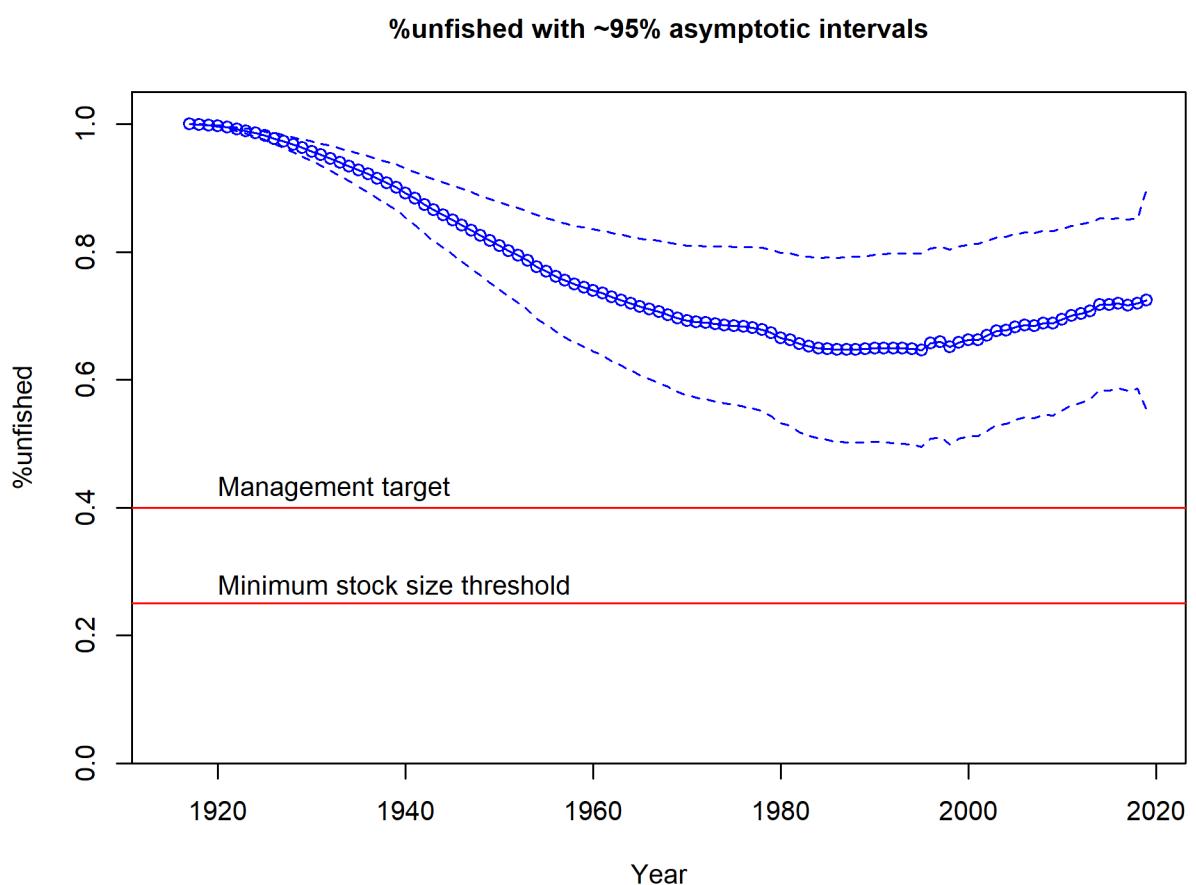


Figure 29: Estimated spawning depletion with approximate 95% asymptotic intervals.



Figure 30: Estimated time-series of recruitment for Big Skate.

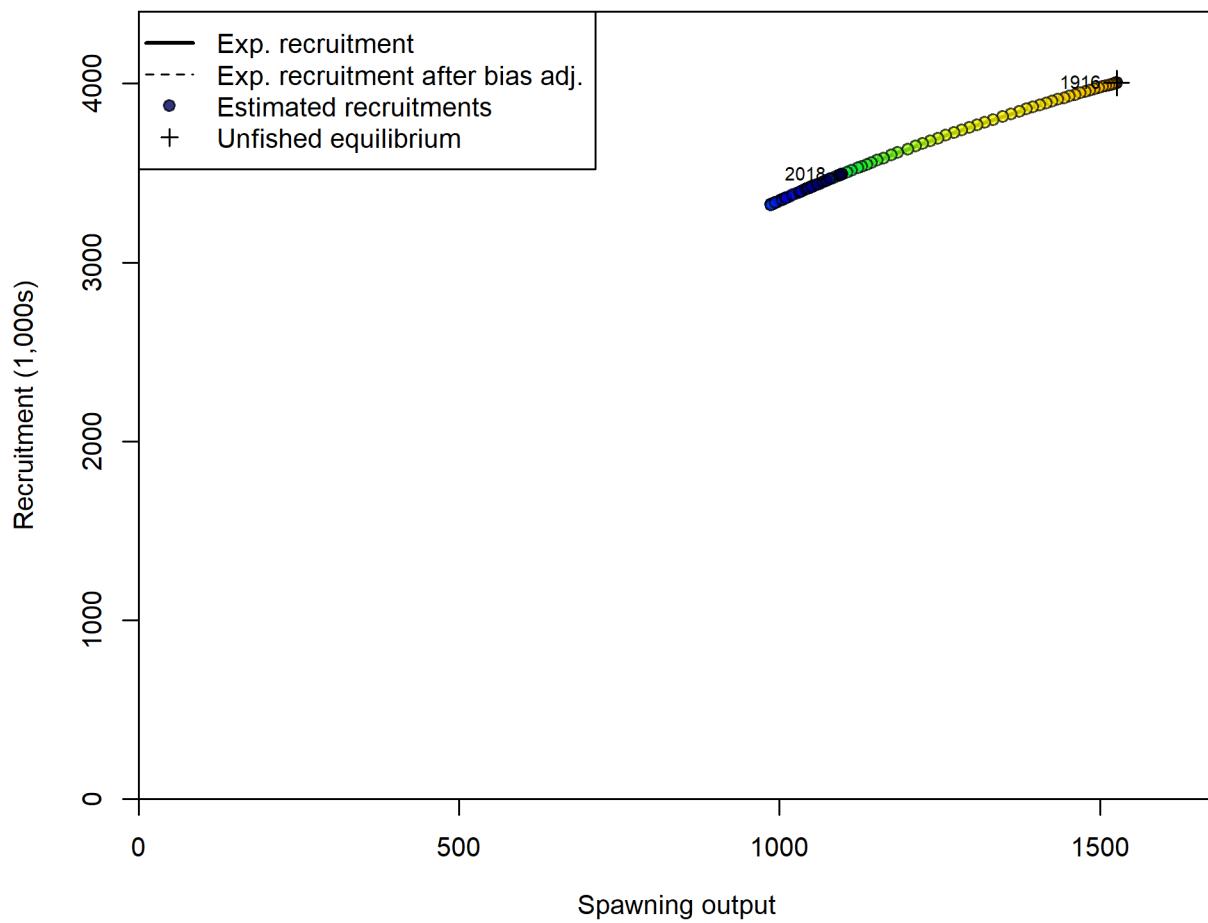


Figure 31: Estimated recruitment and the assumed stock-recruit relationship.

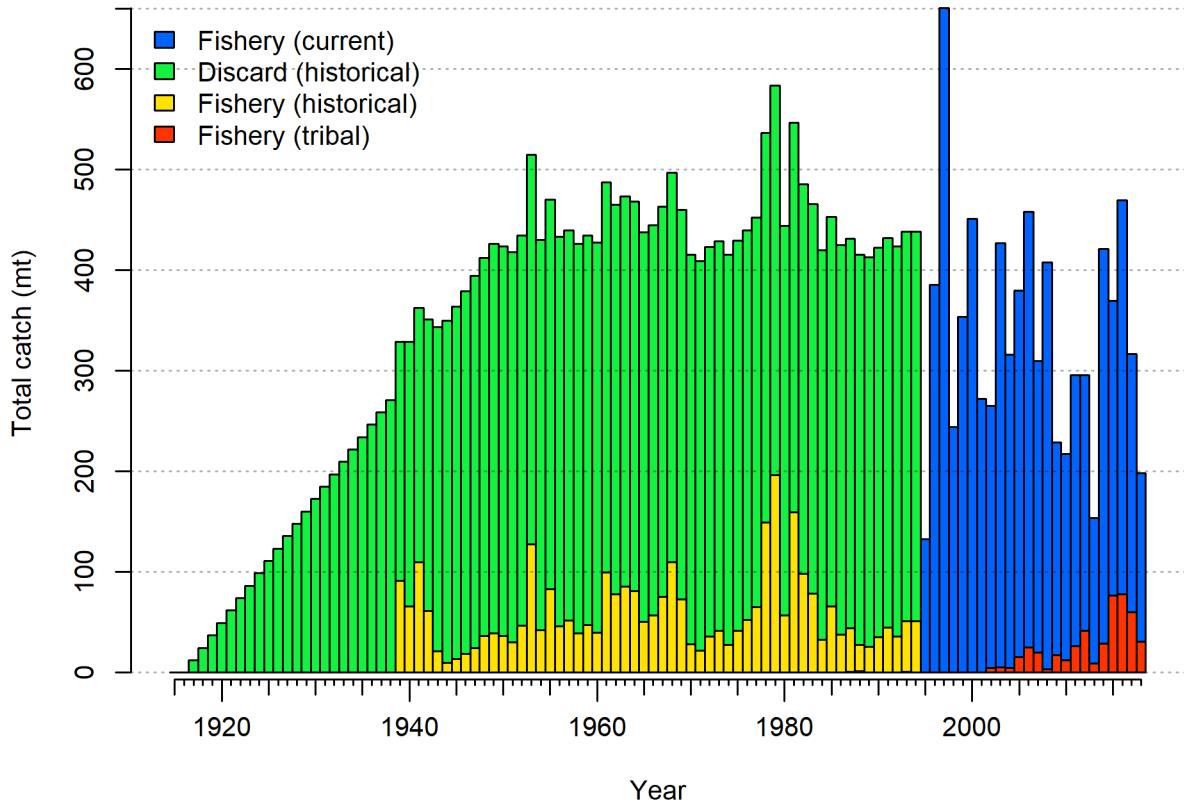


Figure 32: Estimated total catch including discards estimated within the model. The historical discards shown in green have been scaled to account for an assumed 50% discard mortality but the discards in the recent period show both live and dead discards.

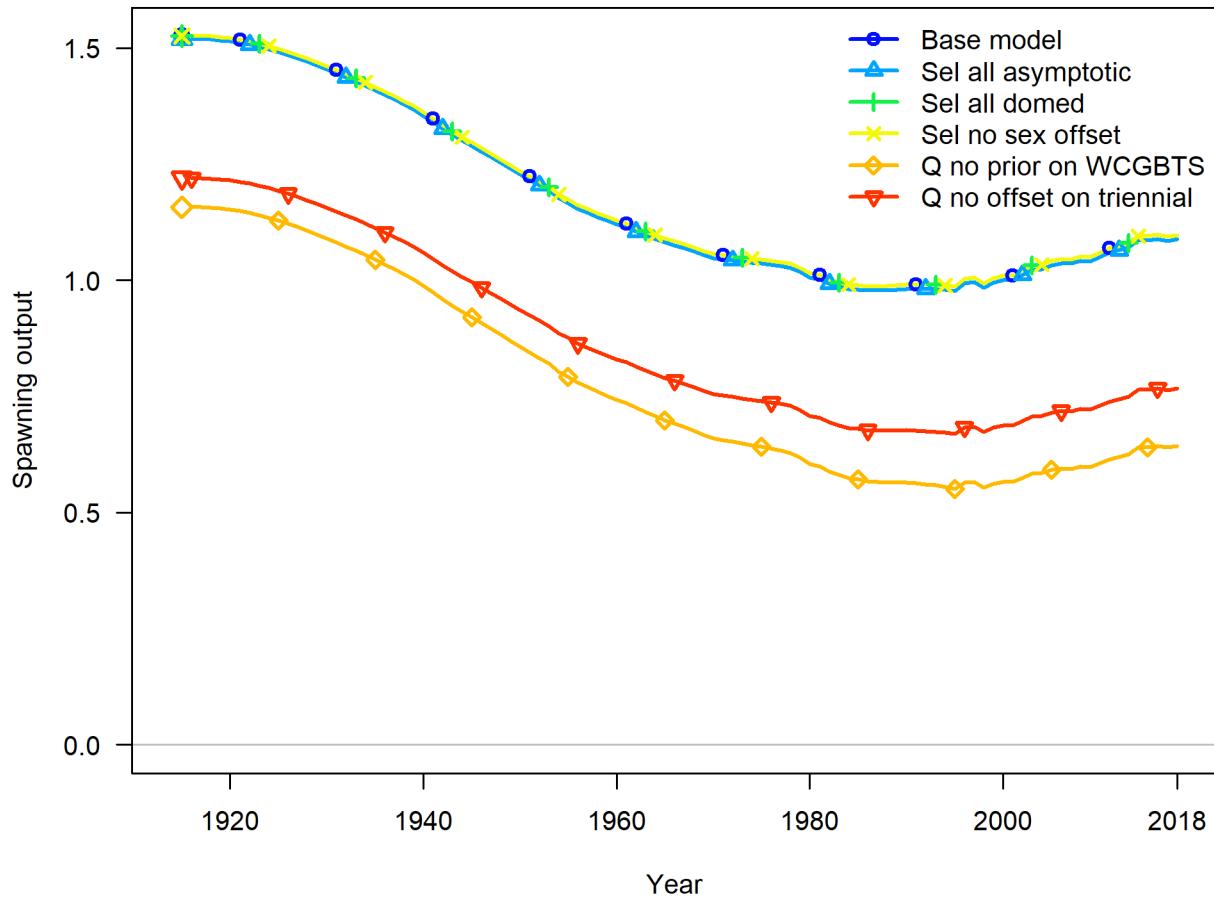


Figure 33: Time series of spawning output estimated in sensitivity analyses related to selectivity and catchability.

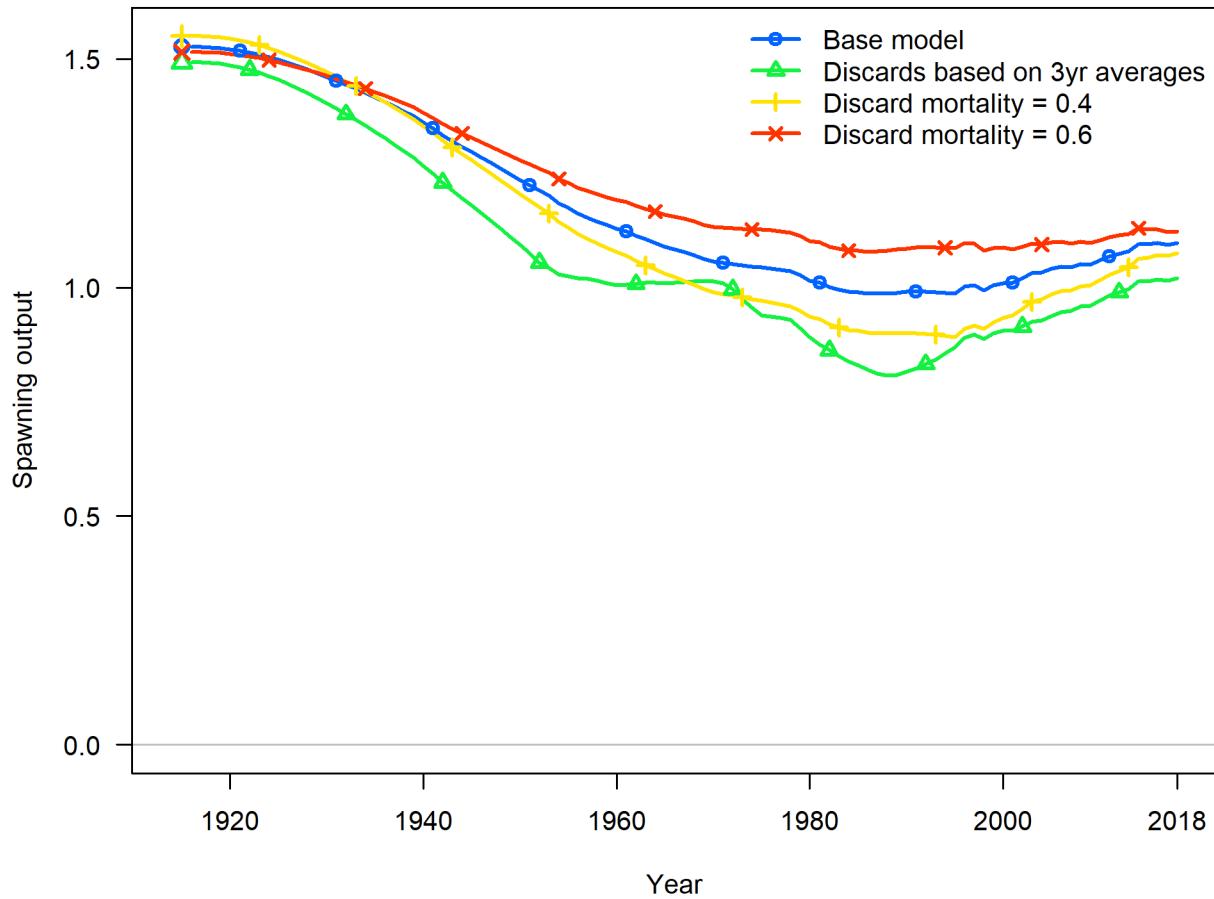


Figure 34: Time series of spawning output estimated in sensitivity analyses related to historic catch and discards.

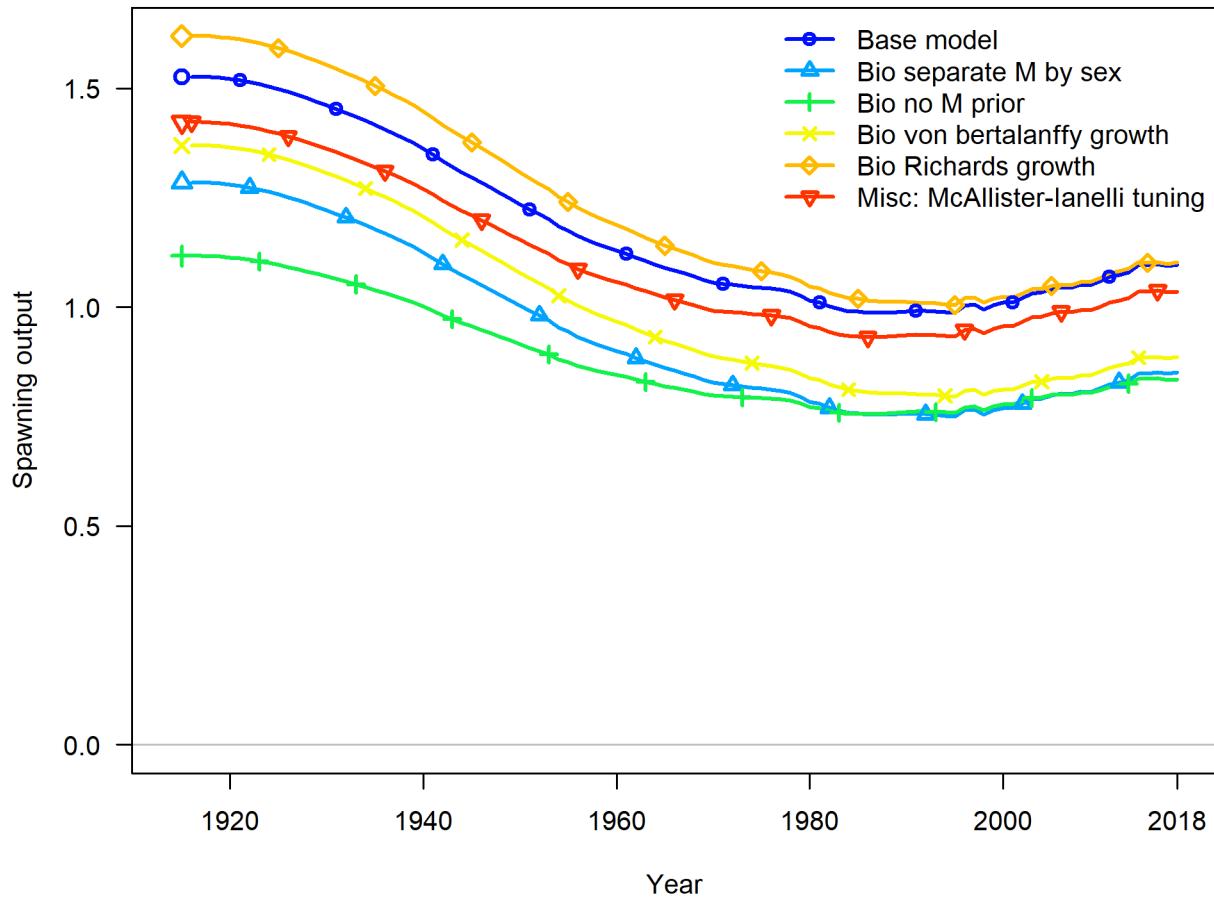


Figure 35: Time series of spawning output estimated in sensitivity analyses related to biology and other assumptions.

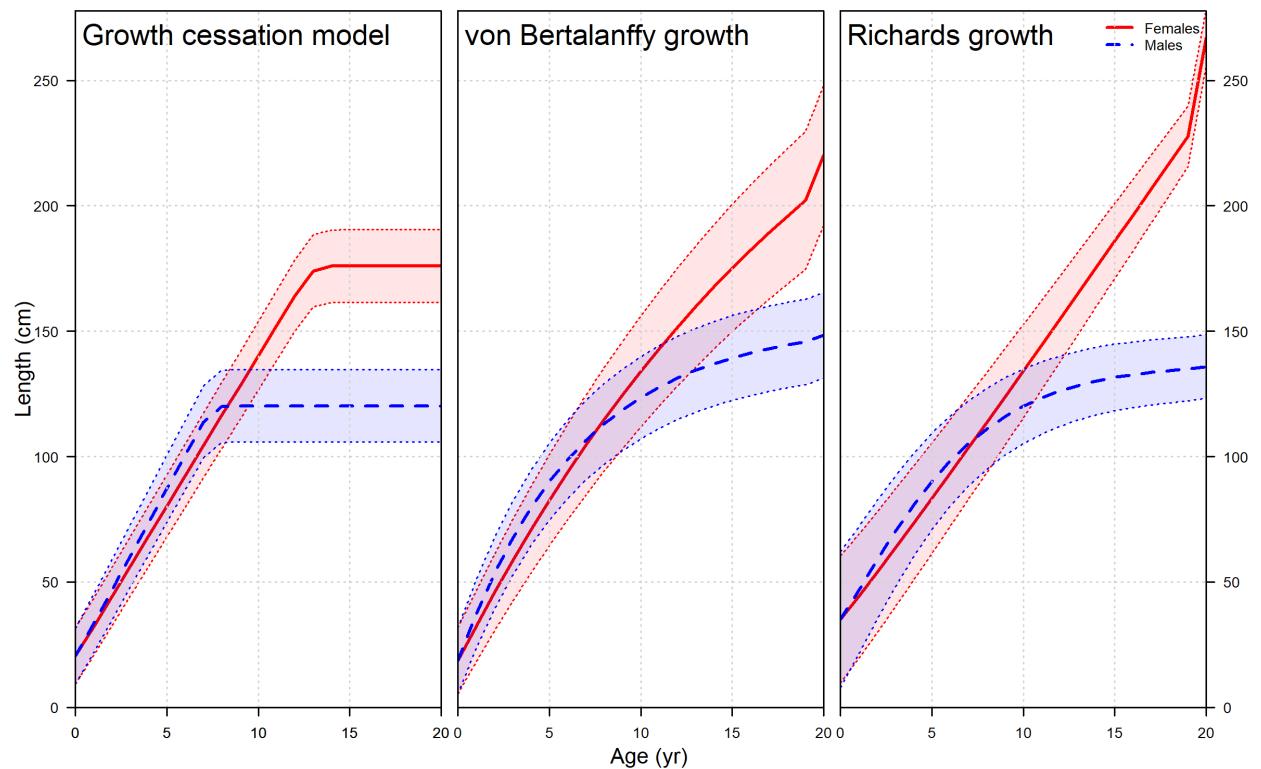


Figure 36: Comparison of the estimated growth curves from the sensitivities analyses.

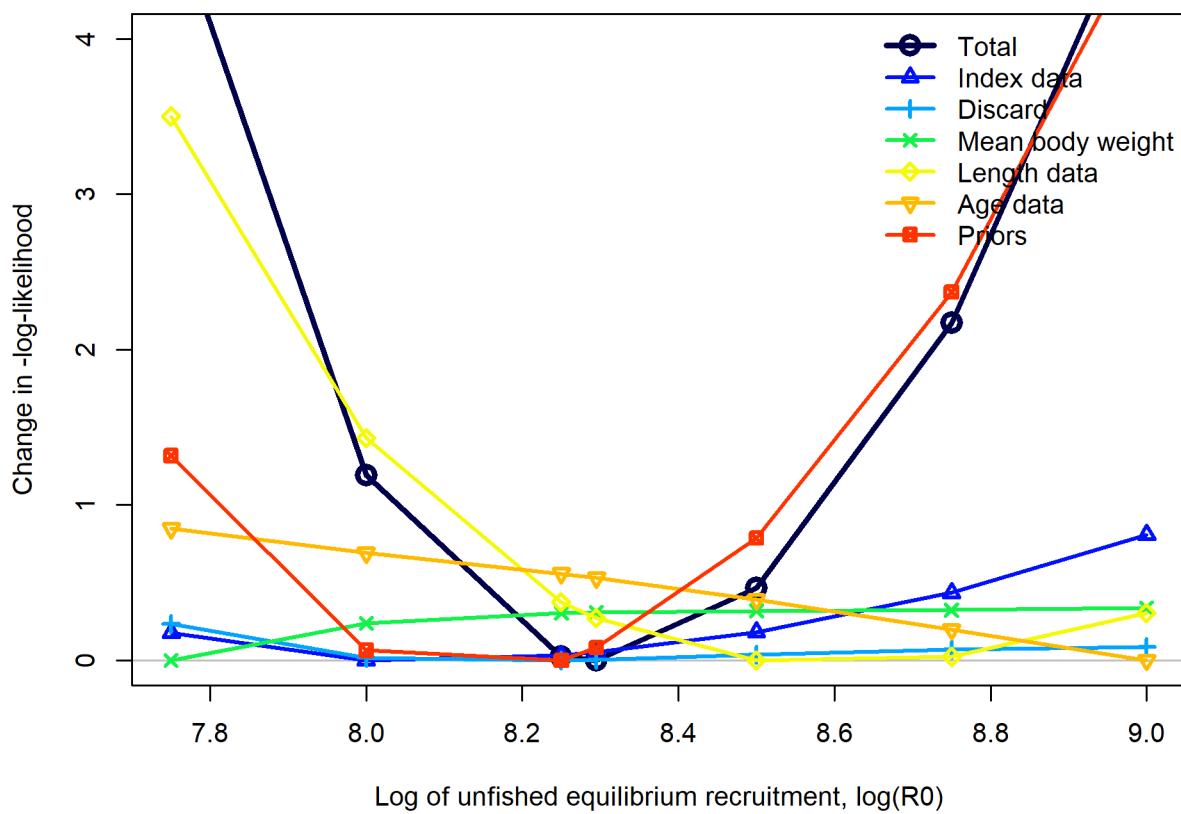


Figure 37: Likelihood profile over the log of equilibrium recruitment (R_0).

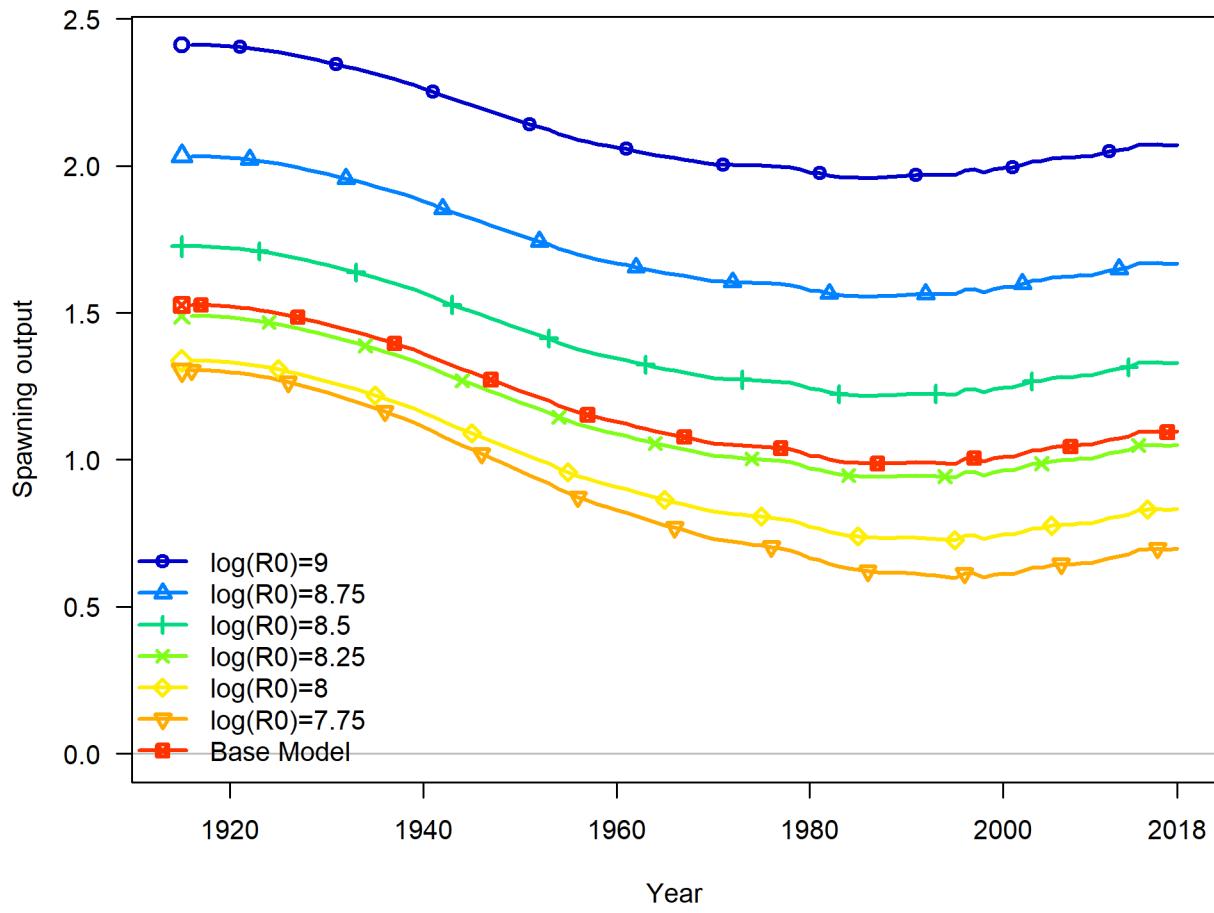


Figure 38: Time series of spawning output estimated for the models included in the profile over the log of equilibrium recruitment (R_0).

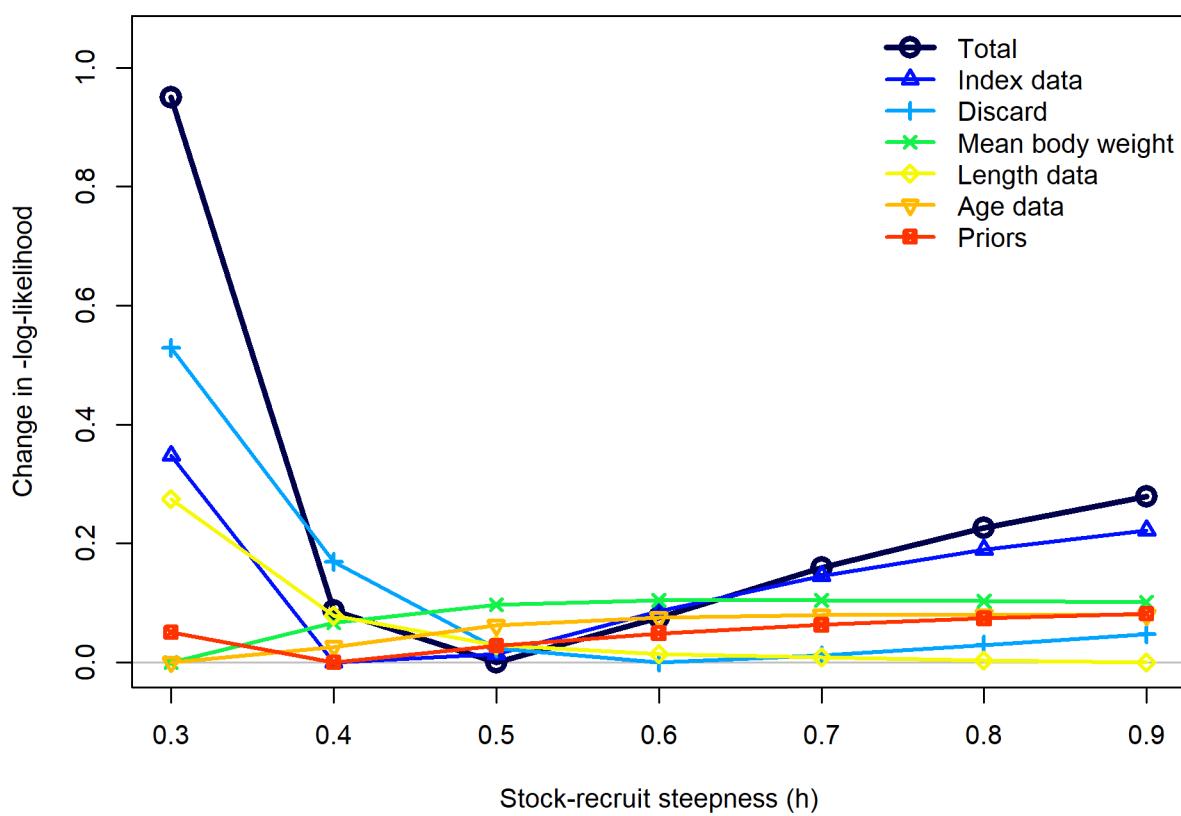


Figure 39: Likelihood profile over stock-recruit steepness (h).

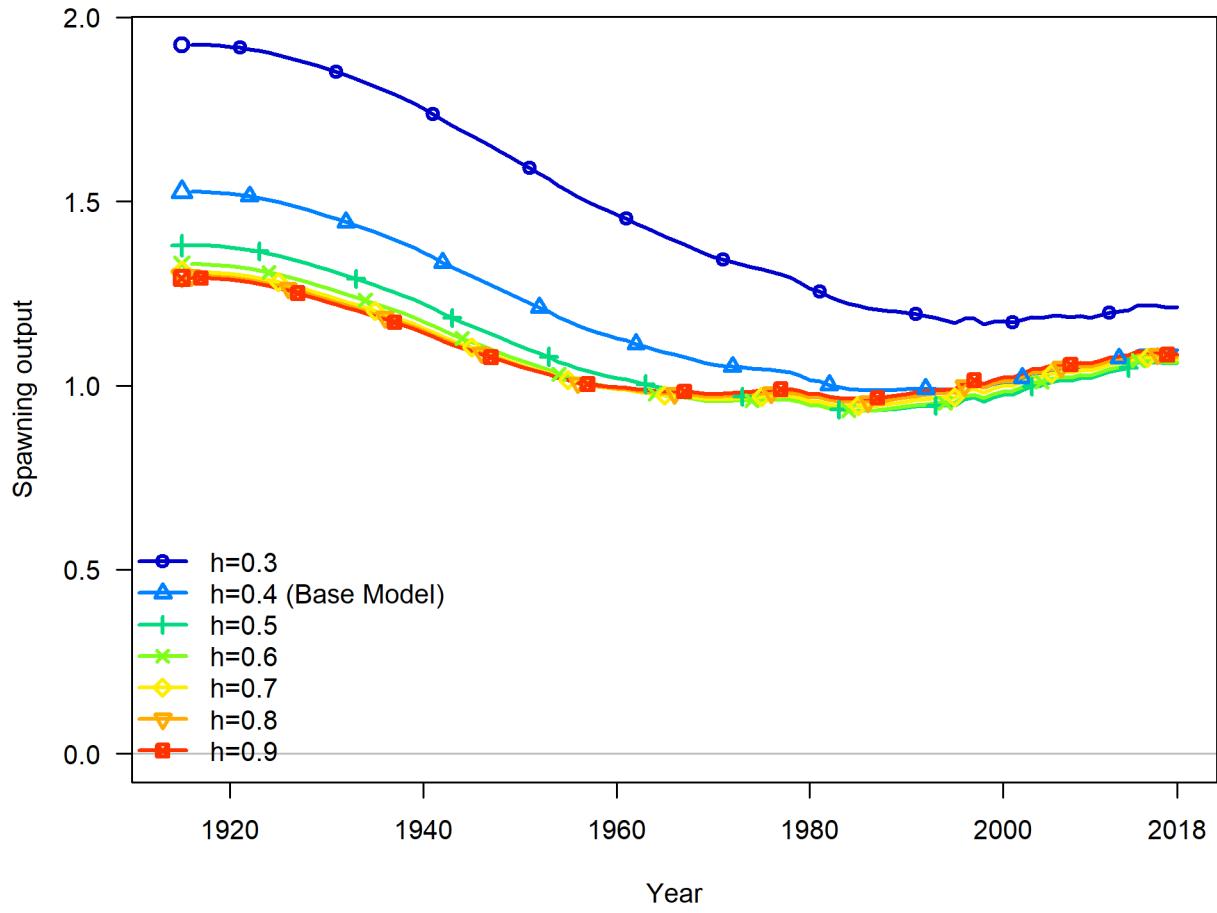


Figure 40: Time series of spawning output estimated for the models included in the profile over stock-recruit steepness (h).

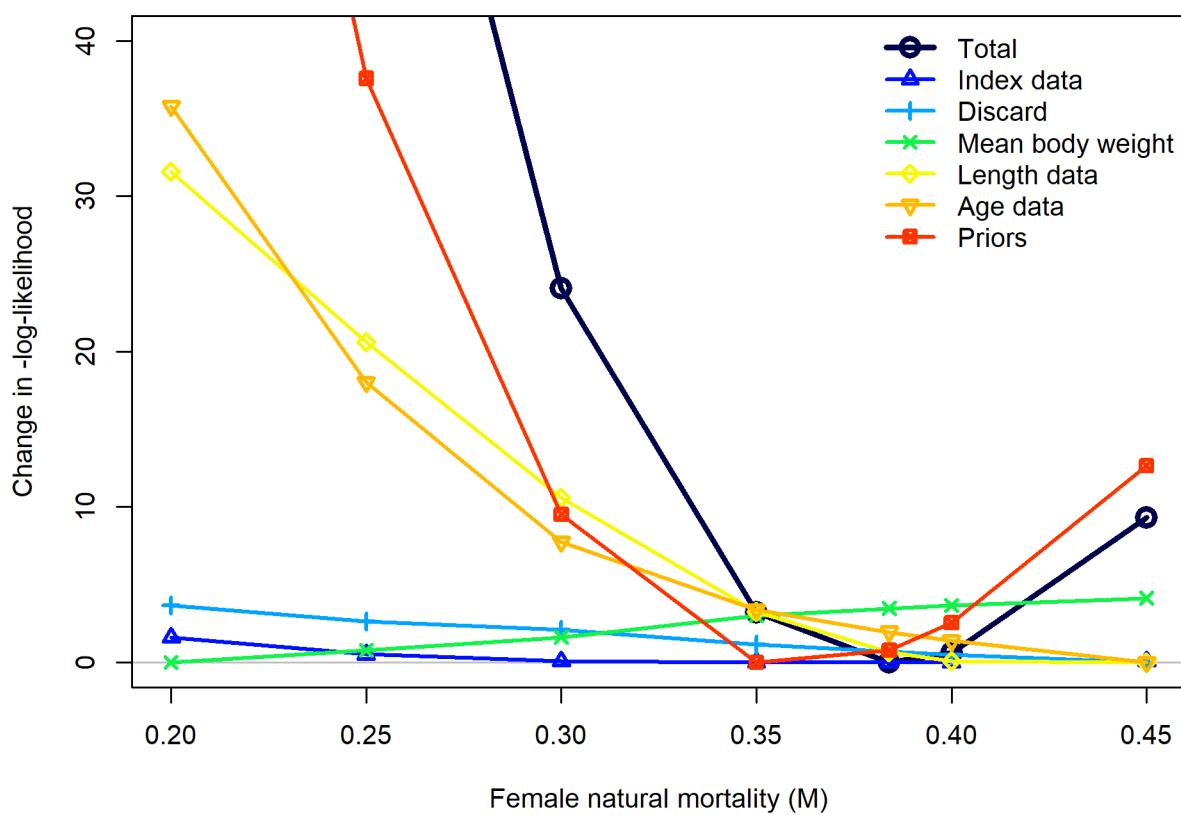


Figure 41: Likelihood profile over natural mortality (M).

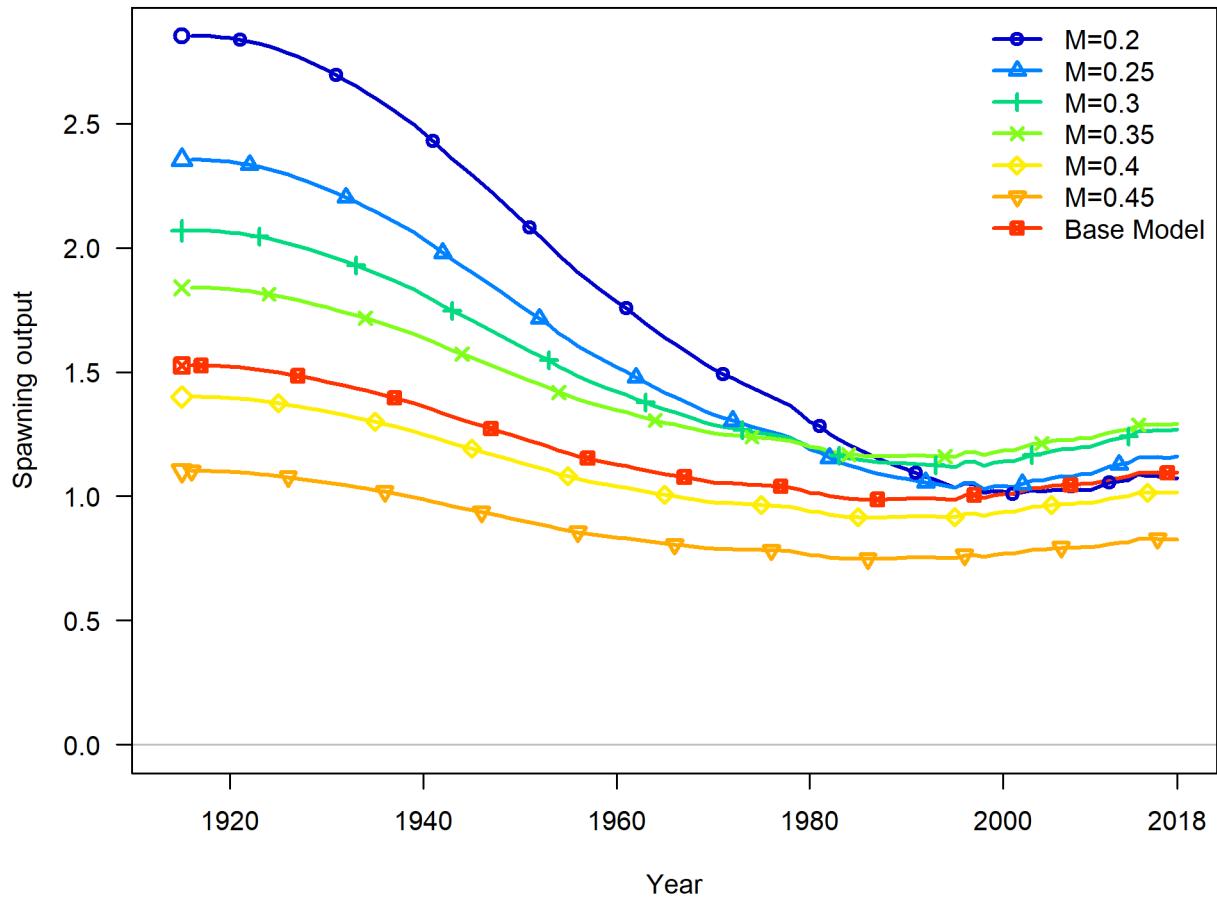


Figure 42: Time series of spawning output estimated for the models included in the profile over natural mortality (M).

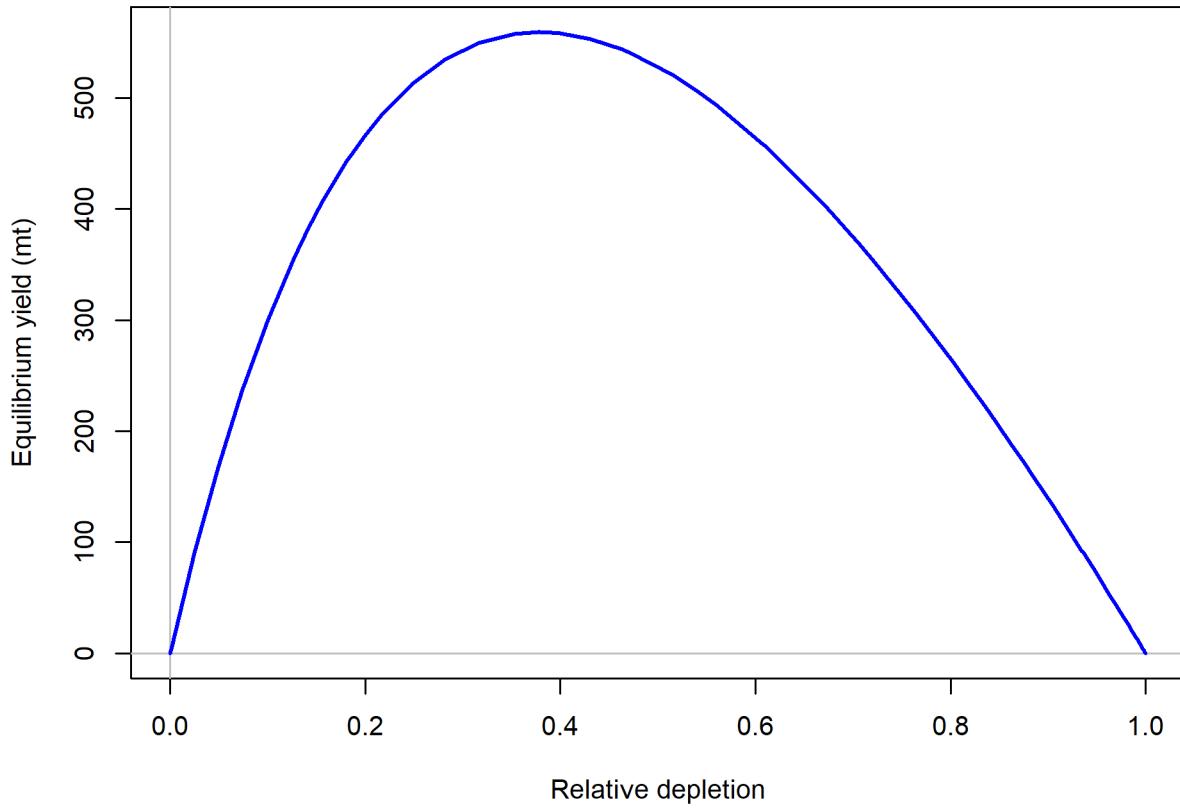


Figure 43: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.718.

⁷²⁶ Appendix A. Detailed fits to length composition data

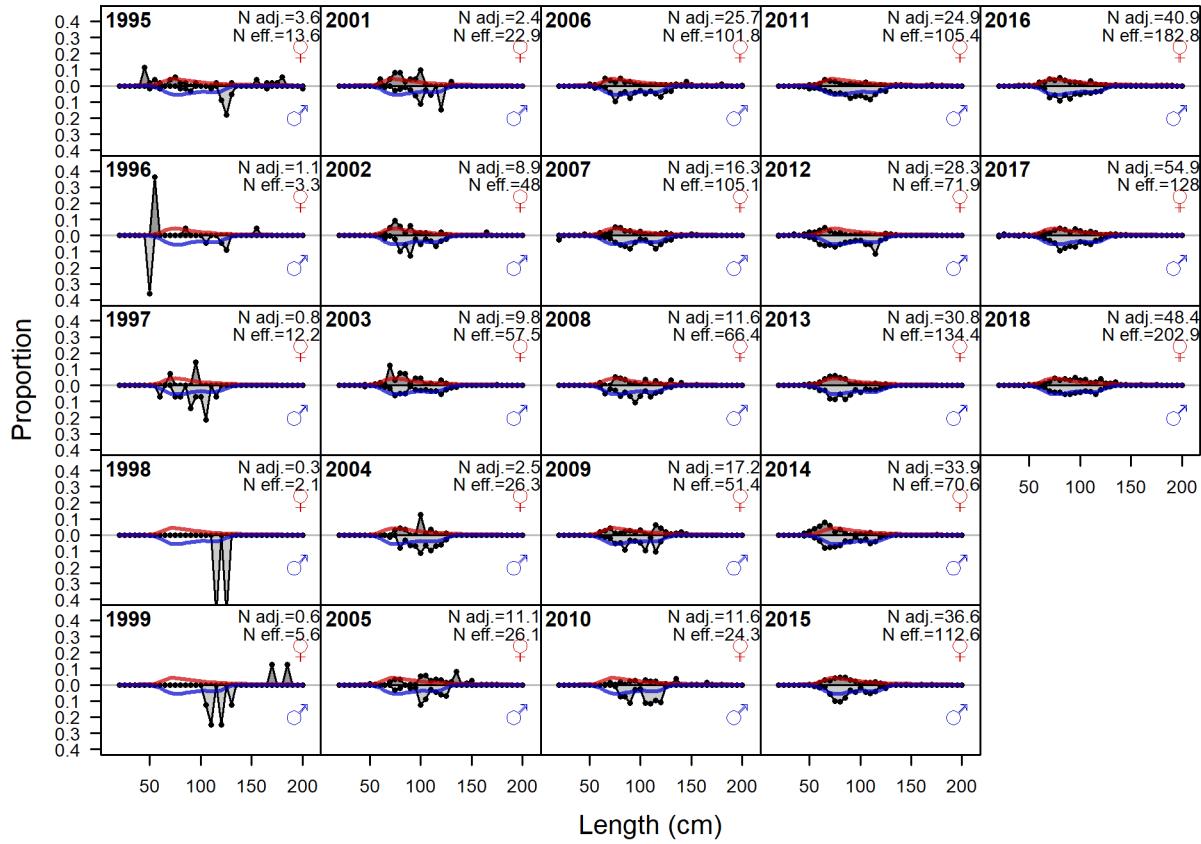


Figure A44: Length comps, retained, Fishery. ‘N adj.’ is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAlister_Iannelli tuning method.

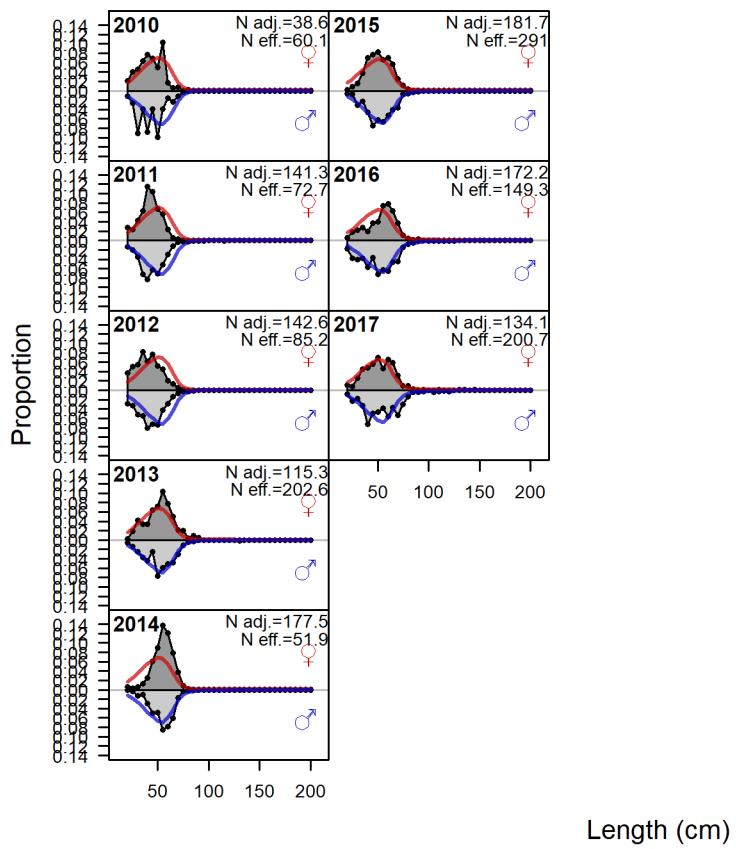


Figure A45: Length comps, discard, Fishery. ‘N adj.’ is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAlister_Iannelli tuning method.

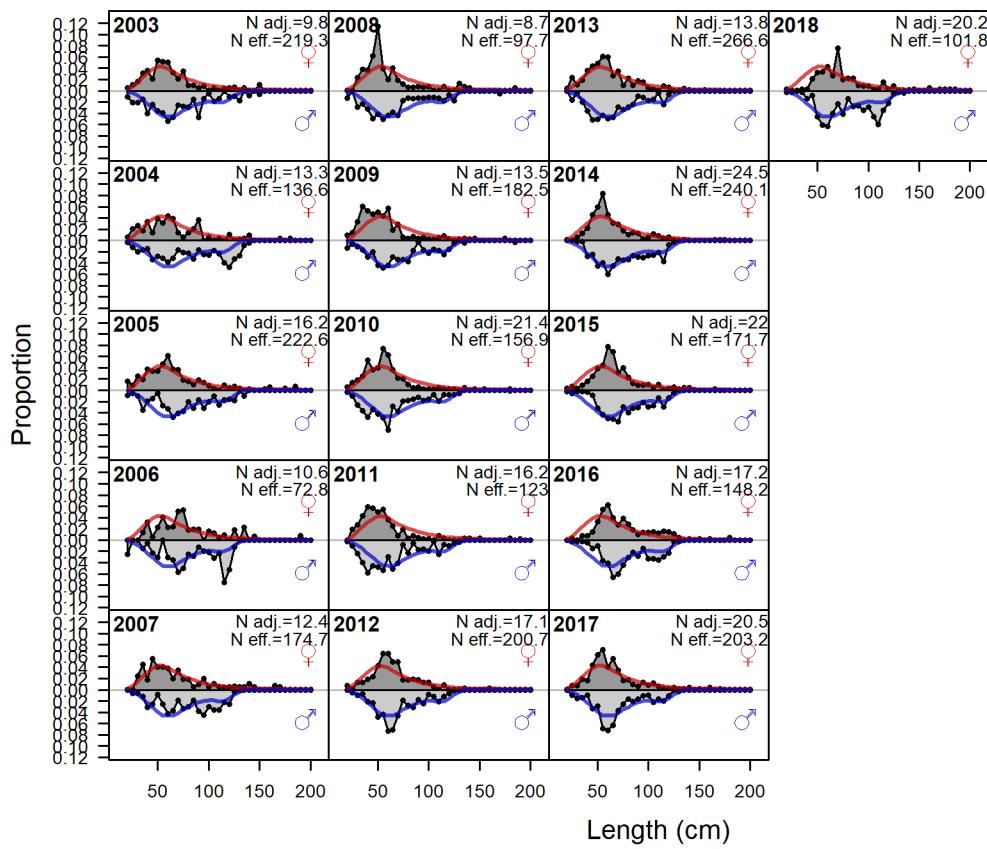


Figure A46: Length comps, whole catch, WCGBT Survey. ‘N adj.’ is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

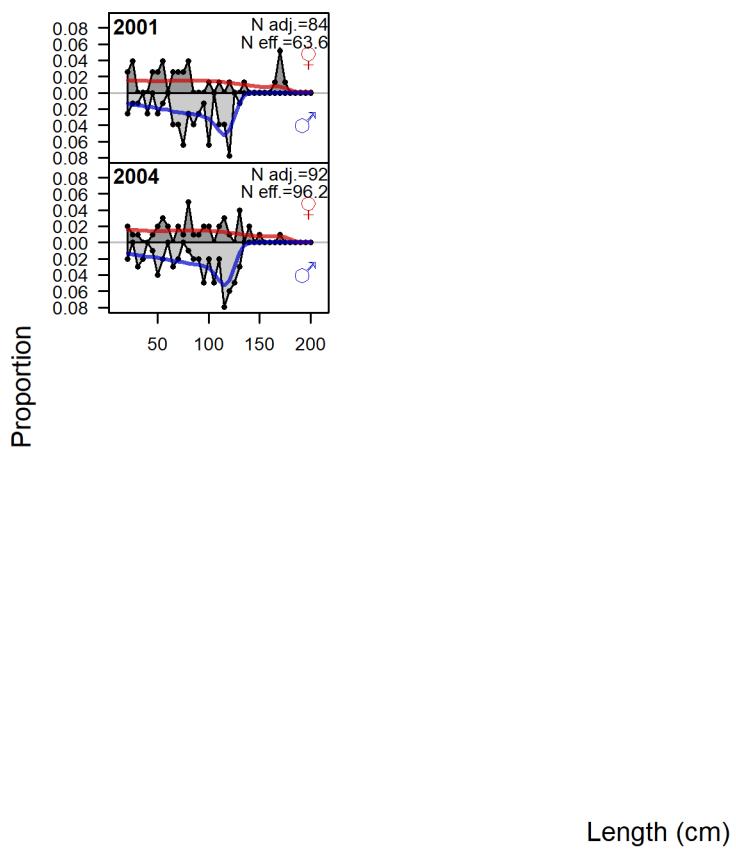


Figure A47: Length comps, whole catch, Triennial Survey. ‘N adj.’ is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

727 **References**

- 728 Bizzarro, J. 2019. Manuscript in preparation.
- 729 Bradburn, M.J. and Keller, A.A and Horness, B.H. 2011. The 2003 to 2008 US West
730 Coast bottom trawl surveys of groundfish resources off Washington, Oregon, and Califor-
731 nia: estimates of distribution, abundance, length, and age composition. NOAA Technical
732 Memorandum NMFS NOAA-TM-NMFS-NWFSC-114: 323 pp.
- 733 Ebert, D.A., Smith, W.D., and Cailliet, G.M. 2008. Reproductive biology of two commer-
734 cially exploited skates, *r. binoculata* and *r. Rhina*, in the western gulf of alaska. Fisheries
735 Research **94**(1): 48–57. Elsevier.
- 736 Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Cana-
737 dian Journal of Fisheries and Aquatic Sciences **68**: 1124–1138.
- 738 Gertseva, V. 2019a. Manuscript in preparation.
- 739 Gertseva, V. 2019b. Manuscript in preparation.
- 740 Gunderson, Donald Raymond and Sample, Terrance M. 1980. Distribution and
741 abundance of rockfish off Washington, Oregon and California during 1977. North-
742 west and Alaska Fisheries Center, National Marine Fisheries Service. Available from
743 [{http://spo.nmfs.noaa.gov/mfr423-4/mfr423-42.pdf}](http://spo.nmfs.noaa.gov/mfr423-4/mfr423-42.pdf).
- 744 Hamel, Owen S. 2015. A method for calculating a meta-analytical prior for the natural
745 mortality rate using multiple life history correlates. ICES Journal of Marine Science: Journal
746 du Conseil **72**(1): 62–69. doi: [{10.1093/icesjms/fsu131}](https://doi.org/10.1093/icesjms/fsu131).
- 747 Keller, A.A. and Wallace, J.R. and Methot, R.D. 2017. The Northwest Fisheries Science
748 Center's West Coast Groundfish Bottom Trawl Survey: History, Design, and Description.
749 NOAA Technical Memorandum NMFS NOAA-TM-NMFS-NWFSC-136: 38 pp.
- 750 Maunder, M.N., Deriso, R.B., Schaefer, K.M., Fuller, D.W., Aires-da-Silva, A.M., Minte-
751 Vera, C.V., and Campana, S.E. 2018. The growth cessation model: A growth model for
752 species showing a near cessation in growth with application to bigeye tuna (*thunnus obesus*).
753 Marine biology **165**(4): 76. Springer.
- 754 McFarlane GA and King JR. 2006. Age and growth of big skate (*Raja binoculata*) and
755 longnose skate (*Raja rhina*) in British Columbia waters. Fisheries Research **May 1 (2-3)**:
756 169–78.
- 757 Methot, Richard D. and Wetzel, Chantell R. 2013. Stock synthesis: A biological and statis-
758 tical framework for fish stock assessment and fishery management. Fisheries Research **142**:
759 86–99.

- 760 Taylor, I.G., Stewart, I.J., Hicks, A.C., Garrison, T.M., Punt, A.E., Wallace, J.R., Wetzel,
761 C.R., Thorson, J.T., Takeuchi, Y., Ono, K., Monnahan, C.C., Stawitz, C.C., A'mar, Z.T.,
762 Whitten, A.R., Johnson, K.F., Emmet, R.L., Anderson, S.C., Lambert, G.I., Stachura,
763 M.M., Cooper, A.B., Stephens, A., Klaer, N.L., McGilliard, C.R., Iwasaki, W.M., Doering,
764 K., and Havron, A.M. 2019. R4ss: R code for stock synthesis. Available from <https://github.com/r4ss>.
- 765
- 766 Thorson, James T. and Barnett, Lewis A. K. 2017. Comparing estimates of abundance
767 trends and distribution shifts using single- and multispecies models of fishes and
768 biogenic habitat. ICES Journal of Marine Science: Journal du Conseil: fsw193. doi:
769 [{10.1093/icesjms/fsw193}](https://doi.org/10.1093/icesjms/fsw193).
- 770 Thorson, J. T. and Shelton, A. O. and Ward, E. J. and Skaug, H. J. 2015. Geostatistical
771 delta-generalized linear mixed models improve precision for estimated abundance indices
772 for West Coast groundfishes. ICES Journal of Marine Science **72**(5): 1297–1310. doi:
773 [{10.1093/icesjms/fsu243}](https://doi.org/10.1093/icesjms/fsu243).