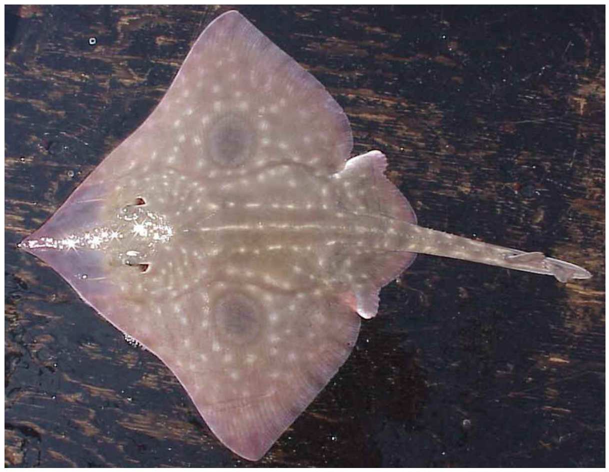
Status of Big Skate (*Beringraja binoculata*) Off the U.S. Pacific Coast in 2019



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

Contents

Executive Summary

executive-summary

Stock

stock

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

Catches

catches

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

(Table a).

(Figures **??**-**??**)
(Figure a)

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

Table a: Recent Big Skate landings (mt)

tab:Exec_catch

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

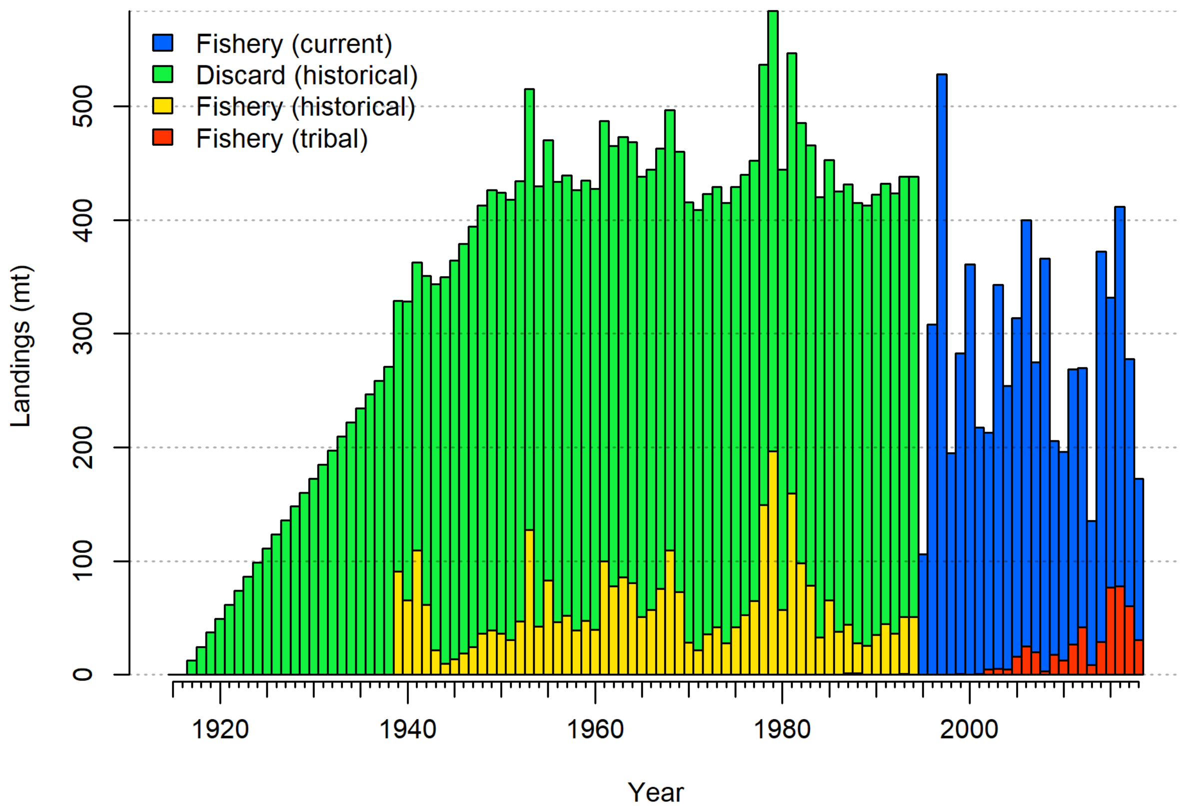


Figure a: Catch history of Big Skate in the model. fig:r4ss_catches

Data and Assessment

data-and-assessment

This the first full assessment for Big Skate, which was last assessed as part of the “Other Species” complex. This assessment uses the newest version of Stock Synthesis (3.30.13). The model begins in 1916, and assumes the stock was at an unfished equilibrium that year.

(Figure b).

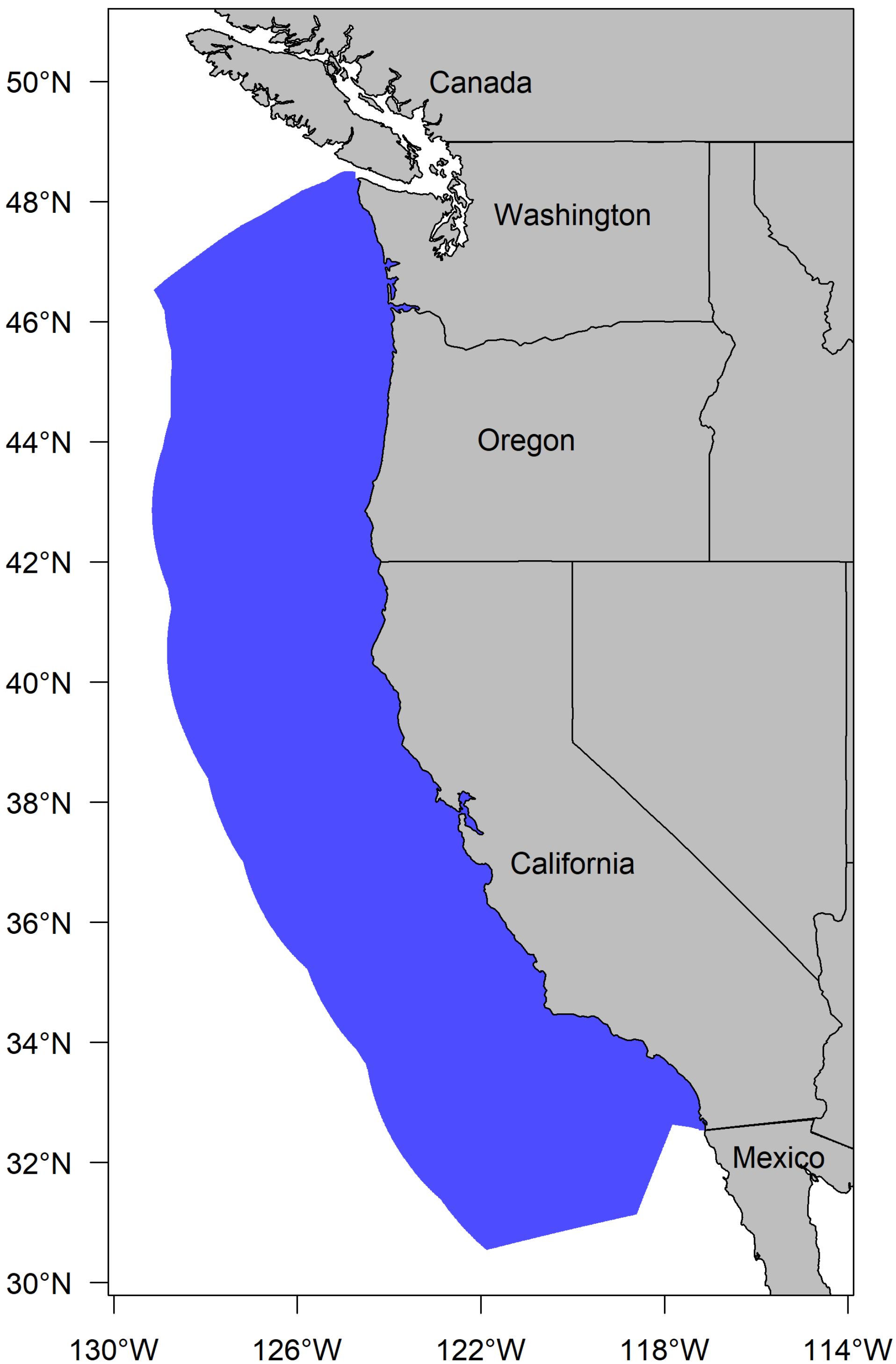


Figure b: This is NOT the map depicting the distribution of Big Skate out to 600 ft. The stock assessment is bounded at Pt. Conception in the South to the U.S./Canada border in the north. fig:assess_region_map

Stock Biomass

stock-biomass

(Figure c and Table b).

The 2018 estimated spawning biomass relative to unfished equilibrium spawning biomass is above the target of 40% of unfished spawning biomass at 72.5% (95% asymptotic interval: ± 55.2%-89.7%) (Figure d). Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning biomass is high.

Table b: Recent trend in beginning of the year spawning output and depletion for the model for Big Skate.

tab:SpawningDeplete_mod1

Year	Spawning Output (million eggs)	~ 95% confidence interval	Estimated depletion	~ 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)

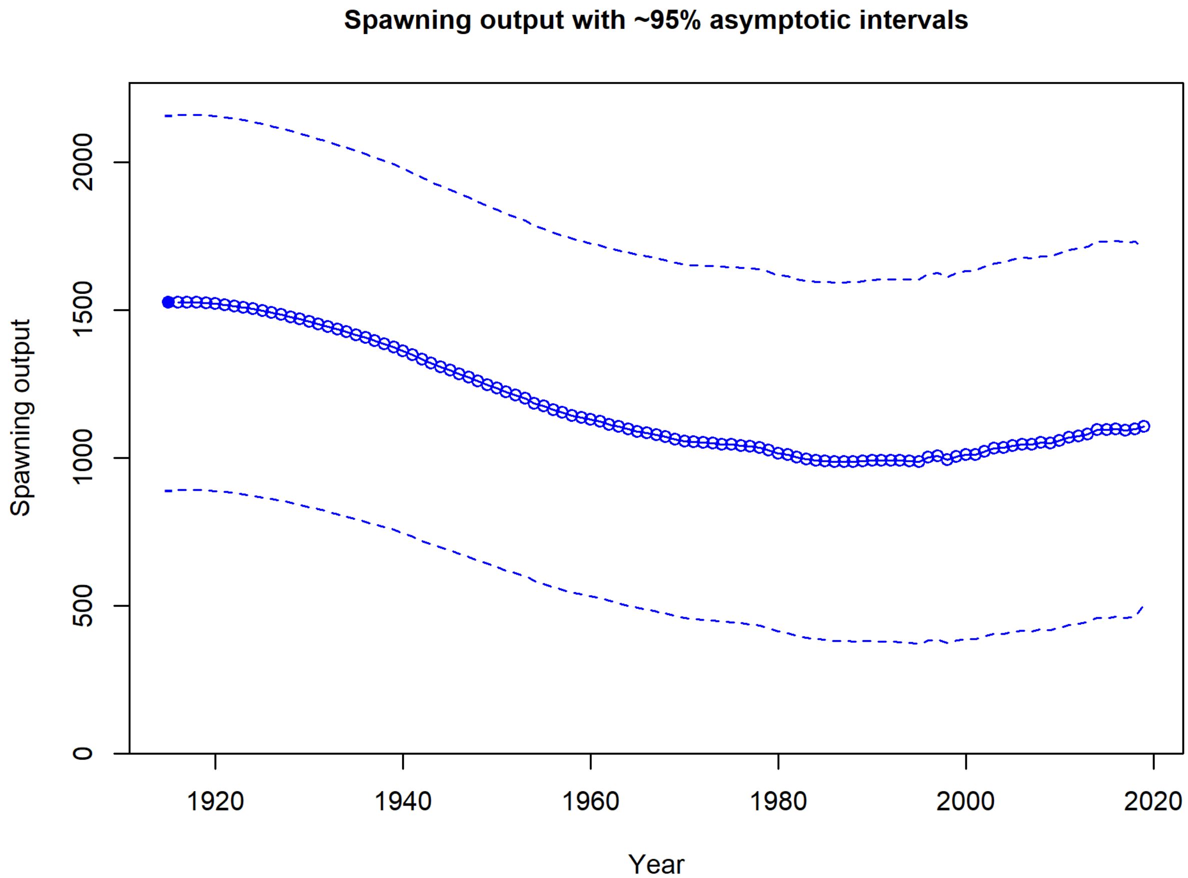


Figure c: Time series of spawning biomass trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base case assessment model. fig:Spawnbio_all

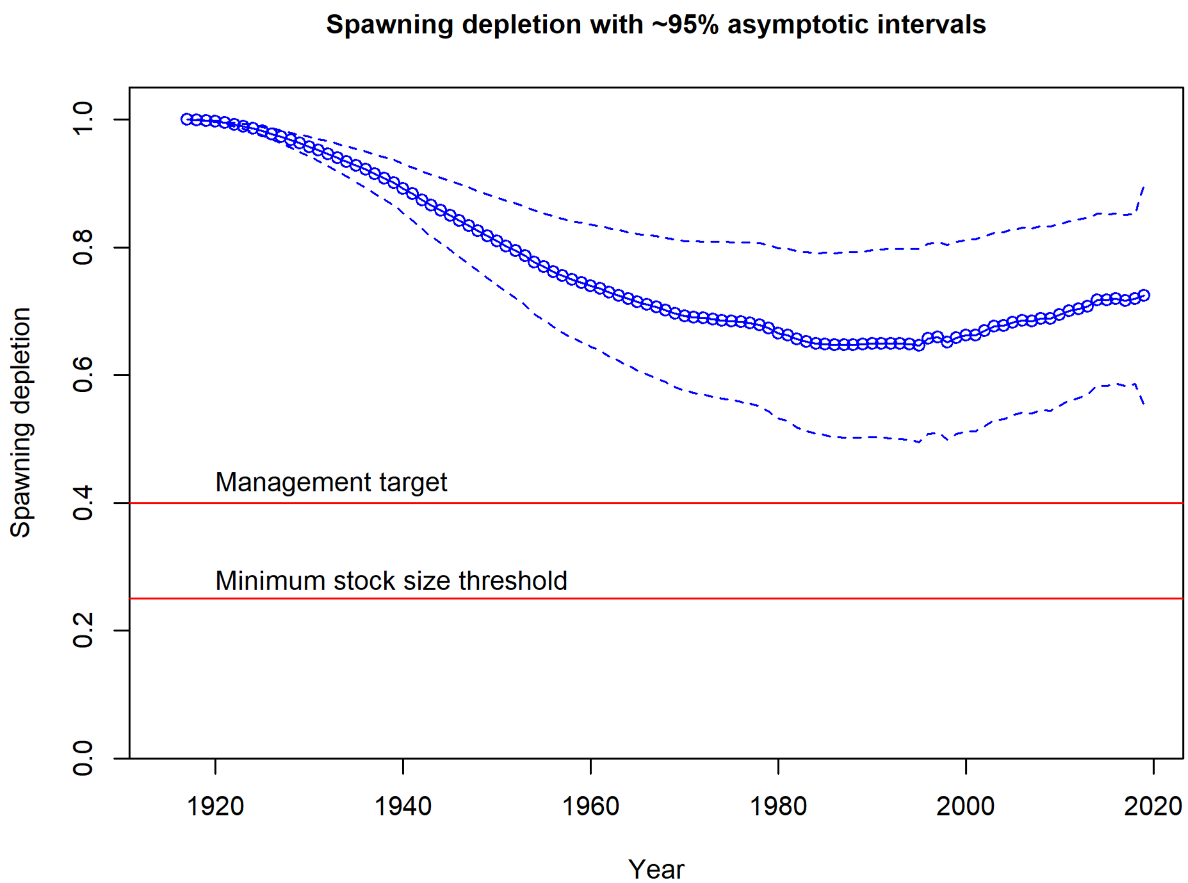


Figure d: Estimated relative depletion with approximate 95% asymptotic confidence intervals (dashed lines) for the base case assessment model. fig:RelDeplete_all

Recruitment

recruitment

Recruitment deviations were estimated from 1916-2018 (Figure e and Table c).

Table c: Recent recruitment for the model.

tab:Recruit_mod1

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)

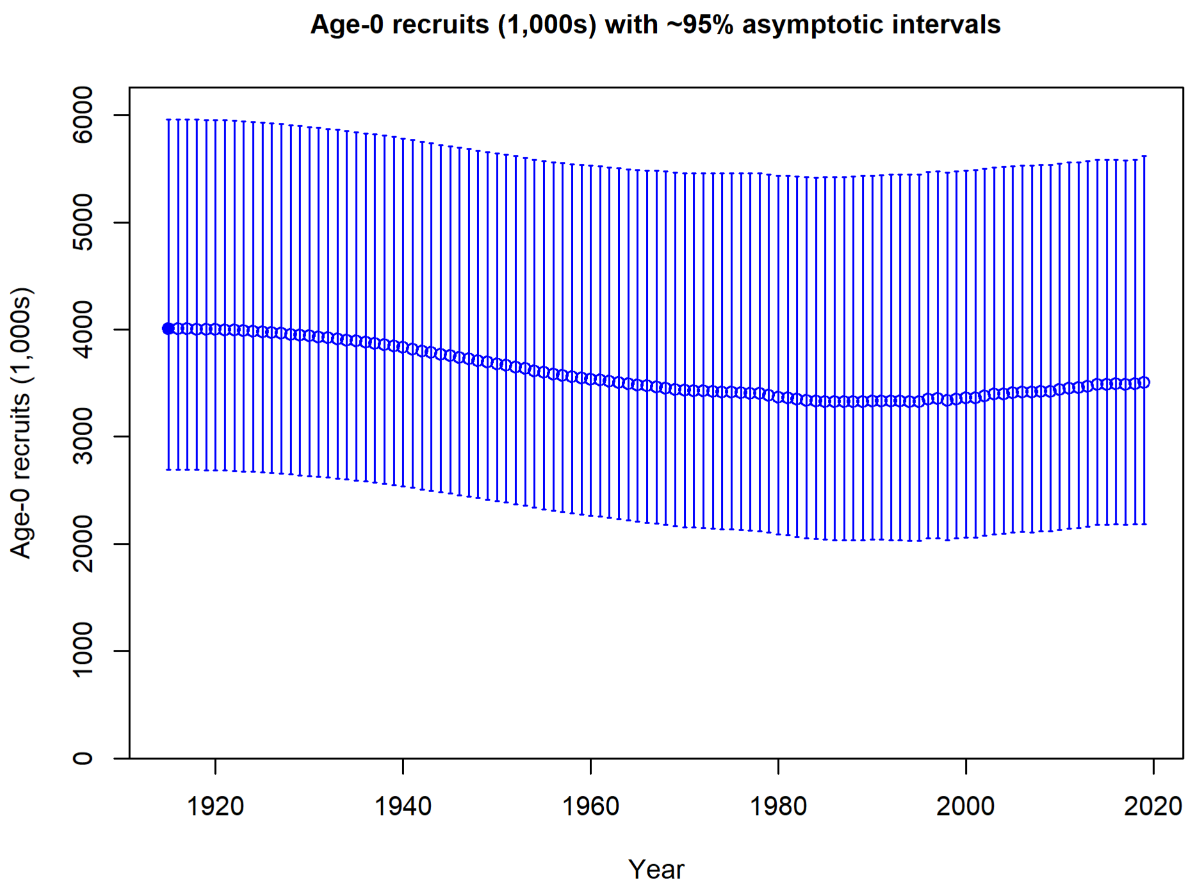


Figure e: Time series of estimated Big Skate recruitments for the base-case model with 95% confidence or credibility intervals. fig:Recruits_all

Exploitation status

exploitation-status

Harvest rates estimated by the base model. management target levels (Table d and Figure f).

Table d: Recent trend in spawning potential ratio and exploitation for Big Skate in the model. Fishing intensity is (1-SPR) divided by 50% (the SPR target) and exploitation is F divided by F_{SPR}.

tab:SPR_Exploit_mod1

Year	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)

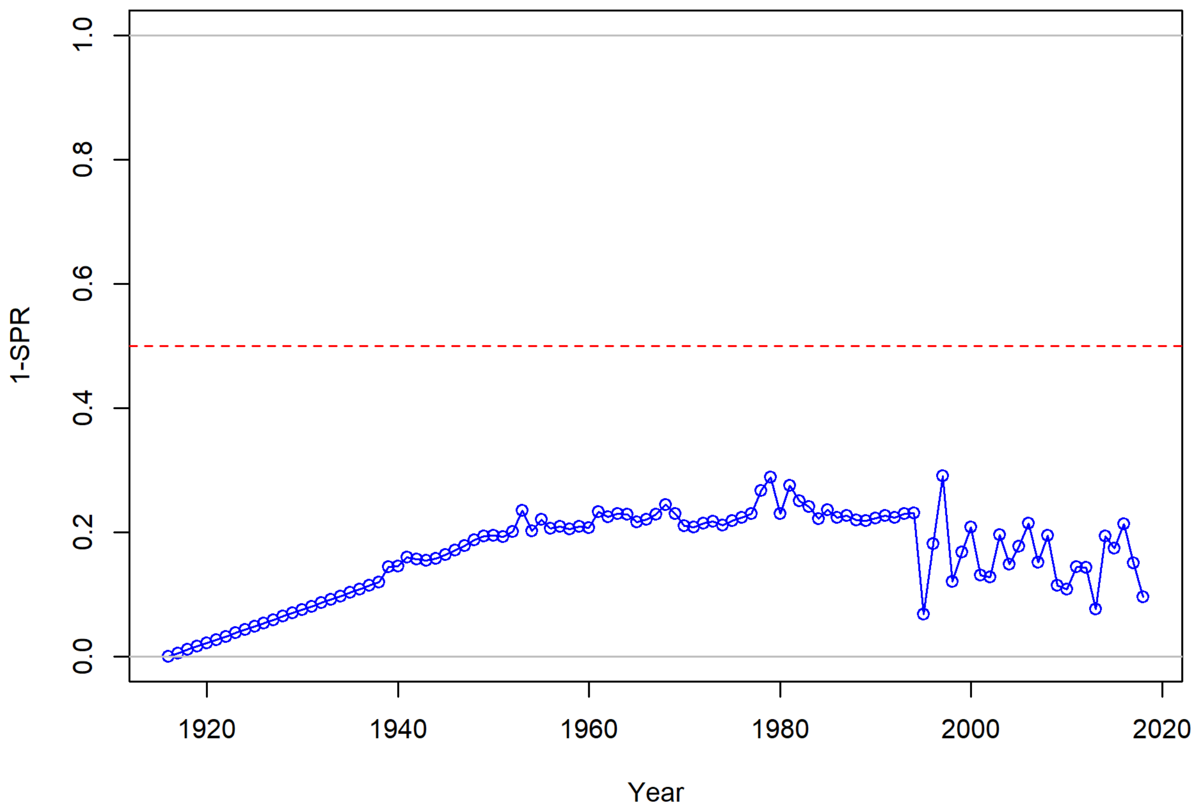


Figure f: Estimated spawning potential ratio (SPR) for the base-case model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing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

Ecosystem Considerations

`ecosystem-considerations`

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

Reference Points

`reference-points`

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

Table e: Summary of reference points and management quantities for the base case model.
tab:Ref_pts_mod1

Quantity	Estimate	Low 2.5% limit	High 2.5% limit
Unfished spawning output (million eggs)	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 million eggs)	1,097	462	1,732
Depletion (2018)	0.719	0.586	0.852
Reference points based on $\mathbf{SB_{40\%}}$			
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

Management Performance

management-performance

Table f

Unresolved Problems and Major Uncertainties

unresolved-problems-and-major-uncertainties

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.

tab:mnmgt_perform

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	

141 # Decision Table

decision-table

Table g: Projections of potential OFL (mt) for each model, using the base model forecast.

tab:OFL_projection

Year	OFL
2019	1274.29
2020	1211.22
2021	1159.12
2022	1117.47
2023	1083.86
2024	1055.15
2025	1029.12
2026	1004.39
2027	980.33
2028	956.75
2029	933.76
2030	911.62

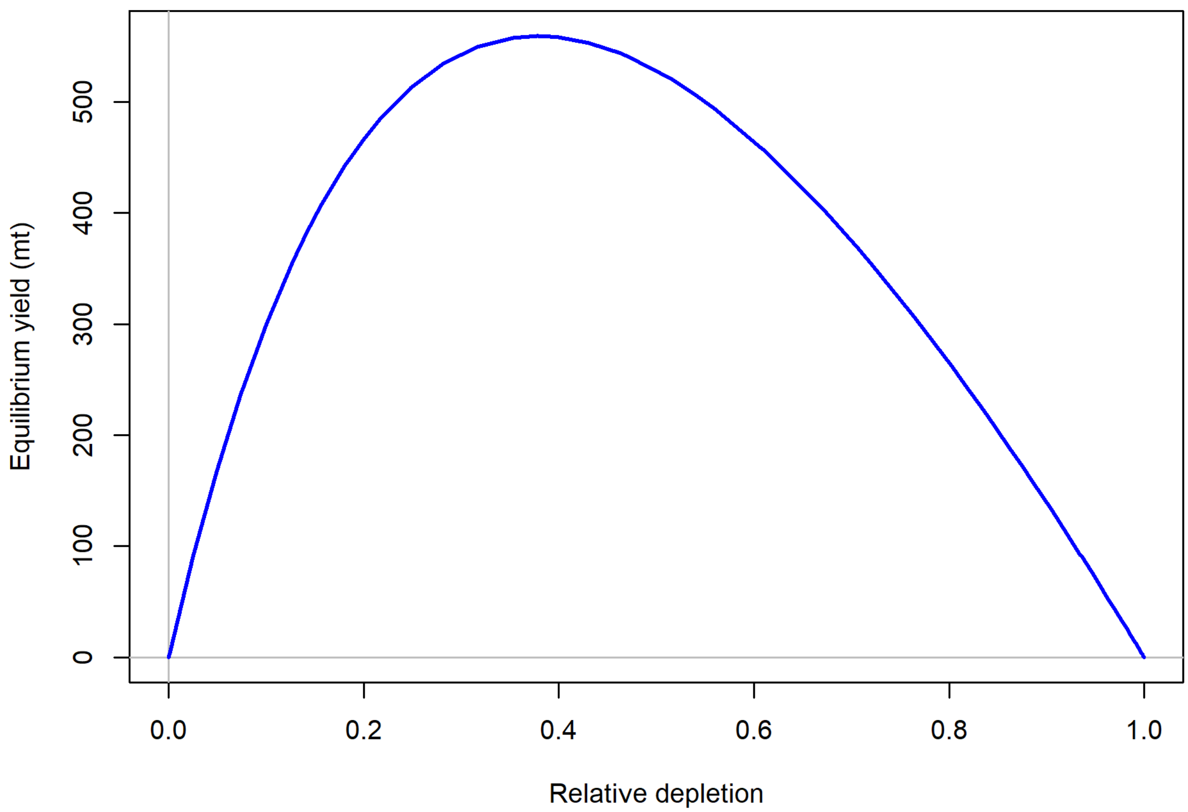


Figure g: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.718. fig:Yield_all

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.

tab:Decision_table_mod1

			States of nature					
			Low M 0.05		Base M 0.07		High M 0.09	
	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
40-10 Rule, Low M	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
40-10 Rule	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
40-10 Rule, High M	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
Average Catch	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-

Table i: Base case results summary.

tab:base_summary

Quantity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Landings (mt)										
Total Est. Catch (mt)										
OFL (mt)										
ACL (mt)										
(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)

Research and Data Needs

research-and-data-needs

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

1. **xxxx**:
2. **xxxx**:
3. **xxxx**:
4. **xxxx**:
5. **xxxx**:

1 Introduction

introduction

1.1 Distribution and Life History

distribution-and-life-history

Skates are the largest and most widely distributed group of batoid fish with approximately 245 species ascribed to two families (Ebert and Compagno (2007), McEachran and Miyake (1990)). Skates are benthic fish that are found in all coastal waters but are most common in cold temperatures and polar waters (Ebert and Compagno 2007).

There are eleven species of skates in three genera (Amblyraja, Bathyraja, and Raja) present in the Northeast Pacific Ocean off California, Oregon and Washington (Ebert 2003). Of that number, just three species (Longnose Skate, *Raja rhina*; Big Skate, *Raja binoculata*; and Sandpaper Skate, *Bathyraja interrupta*) make up over 95 percent of West Coast Groundfish Bottom Trawl Survey (WCGBTS) catches in terms of biomass and numbers, with the Longnose Skate leading in both categories (with 62 percent of biomass and 56 percent of numbers).

Big Skate (*Raja binoculata*) is the largest of the skate species in North America with a documented maximum length of 244 cm total length and a maximum weight of 91 kg (Eschmeyer and Herald 1983). The species name "binoculata" (two-eyed) refers to the prominent ocellus at the base of each pectoral fin. Big Skates are usually seen buried in sediment with only their eyes showing.

The Big Skate is most common in soft-sediment habitats in coastal waters of the continental shelf (Bizzarro, JJ and Broms, KM and Logsdon, MG and Ebert, DA and Yoklavich, MM and Kuhnz, LA and Summers, AP (2014), Farrugia et al. (2016)). Use of mixed substrate (e.g., mud with boulders) increases with ontogeny but hard substrates are largely avoided (Bizzarro (2015)). In the GOA, the Big Skate is the most commonly encountered skate species in continental shelf waters at 100–200 m depth, and is most abundant in the central and western areas of the GOA (Stevenson, DE and Orr, JW and Hoff, GR and McEachran, JD (2008); Bizzarro, JJ and Broms, KM and Logsdon, MG and Ebert, DA and Yoklavich, MM and Kuhnz, LA and Summers, AP (2014)). Off the U.S. Pacific Coast, the Big Skate is most densely distributed on the inner continental shelf ($<$ 100 m; Bizzarro, JJ and Broms, KM and Logsdon, MG and Ebert, DA and Yoklavich, MM and Kuhnz, LA and Summers, AP (2014)). Eggs are mainly deposited between 70–90 m on sand or mud substrates (Hitz (1964); NMFS-NWFSC-FRAM, unpub. data). Juveniles typically occur in shallower waters than adults (Bizzarro (2015)). Core habitat regions of Big Skate off the U.S. Pacific Coast and in the Gulf of Alaska are spatially segregated from those of other species (Bizzarro, JJ and Broms, KM and Logsdon, MG and Ebert, DA and Yoklavich, MM and Kuhnz, LA and Summers, AP (2014)).

Big Skates are highly mobile and capable of long range ($>$ 2000 km) movements (KingandMcF2010; Farrugia et al. (2016)). For example, in British Columbia, a study revealed that ~75% of tagged individuals were recaptured within 21 km of the tagging locations, but 15 of the tagged individuals (0.1%) moved over 1,000 km (max = 2340 km; King, JR and McFarlane, GA (2010)). In the Gulf of Alaska, a year of satellite tag data showed that six of twelve tagged individuals moved over 100 km, with one skate moving > 2,000 km (Farrugia et al. 2016). Although primarily benthic, Big Skates utilize the entire water column including surface waters (Farrugia et al. (2016)). They have broad thermal tolerances 2–19º C that enable their occurrence from boreal to subtropical latitudes (Love, Milton S (2011); Farrugia et al. (2016)).

Big Skates are opportunistic, generalist mesopredators with highly variable spatio-temporal trophic roles (Ebert and Compagno (2007); Bizzarro (2015)). Off central California, diet of Big Skates is composed mainly of fishes, shrimps, and crabs (in descending order), with larger skates incorporating more fishes ((**???**)); however, in the Gulf of Alaska, Big Skate diet consists mainly of crabs (esp. Tanner Crabs) throughout ontogeny, with relatively small portions of fishes and shrimps (Bizzarro (2015)). Correspondingly, trophic level and general diet composition estimates differ significantly between California and Gulf of Alaska Big Skate populations (Bizzarro (2015)).

Big Skates and their egg cases are preyed upon by a variety of vertebrates and invertebrates. Snails and other molluscs bore holes in egg cases to feed on developing embryos and especially their protein rich yolk-sacs (Bizzarro, pers. obs; Hoff, GR (2009)). Sevengill Sharks, Brown Rockfish, and Stellar Sea Lions are known predators of juvenile and adult Big Skates (Ebert (2003), Love, Milton S (2011)). Northern Sea Lions consume free-living Big Skates and their egg cases (Ebert (2003), Love, Milton S (2011)).

In 2012, the Big Skate was moved from genus *Raja* to the new genus *Beringraja* together with the Mottled Skate (*B. pulchra*) (Ishihara et al. 2012). These are the only two skates with multiple embryos per egg case, and they are very similar mophologically and genetically (Bizzarro, J. 2019).

1.2 Biology

biology

The Big Skate is broadly distributed, occurring from the southeastern Bering Sea (Mecklenburg, CW and Mecklenburg, TA and Thorsteinson, LK 2002) to southern Baja California (22.90º N, 110.03º W; (Castro-Aguirre et al. 1993)) and the Gulf of California (Castro-Aguirre and Pérez 1996). It has been reported at depths of 2–501 m (min: Miller et al. (1980); max: Farrugia et al. (2016)) but is most common on the inner continental shelf (< 100 m; (Love, Milton S 2011); (Bizzarro 2015)). Big Skates are highly mobile and capable of long range (> 2000 km) movements ((King and McFarlane 2009); (Farrugia et al. 2016)).

Big Skate is oviparious, and is one of two skate species that have multiple embryos per egg case (Ebert et al. 2008). From 1–8 embryos can be contained in a single, large egg capsule, but most have 3–4 (DeLacy and Chapman 1935, Hitz 1964, Ford 1971). Eggs are deposited year-round on sand or mud substrates at depths of ~50–150 m (Hitz 1964, Ebert and Compagno 2007). Embryos hatch from eggs after 6–20 months, with shorter developmental periods associated with warmer temperatures (Hoff, GR 2009). In captivity, Big Skate females may produce > 350 eggs/year (average of 2 embryos/egg case; Chiquillo, Kelcie L and Ebert, David A and Slager, Christina J and Crow, Karen D (2014)) from long-term sperm storage (**???**). Size at birth is 18–23 cm TL (Ebert 2003). Maximum size is 244 cm TL [Eschmeyer and Herald (1983), with females growing to larger sizes.

Size at maturity has been variably estimated for Big Skate populations off California, British Columbia, and Alaska. Off central California, Zeiner and Wolf (**???**) reported sizes at first maturity of ~129 cm TL (females) and ~100 cm TL (males). A similar size at maturity was estimated for females from the Gulf of Alaska (first = 126 cm TL, 50% = 149 cm TL), but male estimates were considerably greater (first = 124 cm TL, 50% = 119 cm TL; Ebert et al. (2008)). Much smaller sizes at first (female = 60 cm TL, male = 50 cm TL) and 50% (female = 90 cm TL, male = 72 cm TL) maturity were generated for the Longnose Skate populations off British Columbia (**???**); however, maturity evaluation criteria were flawed (subadults were considered to be mature), and these results are therefore not considered valid.

Age and growth parameters have been established from California, British Columbia, and the Gulf of Alaska. Maximum ages off central California (females = 12, males = 11; (**???**)) and in the Gulf of Alaska (females = 14, males = 15; Gburski et al. 2007) were similar, but estimates off British Columbia were much greater (females = 26, males = 25; McFarlane and King 2006). It is important to note that age estimates are based on an unvalidated method and geographic differences in size or age may reflect differences in sampling or ageing criteria. In the Gulf of Alaska, Big Skates reach 50% maturity at 10 years and 7 years for females and males, respectively ((**???**), Ebert et al. (2008)). Generation length estimates range from 11.5 (**???**) to 17 years (**???**).

1.3 Map

map

A map showing the scope of the assessment and depicting boundaries for fisheries or data collection strata is provided in Figure 1.

1.4 Ecosystem Considerations

ecosystem-considerations-1

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

1.5 Fishery Information

fishery-information

Big Skate are caught in commercial and recreational fisheries on the West Coast using line and trawl gears. There is a limited market for pectoral fins (skate wings).

The history of Big Skate is not well documented. They were used as a food source by the native Coastal and Salish Tribes (Batdorf, C 1990) long before Europeans settled in the Pacific Northwest and then as fertilizer by the settlers (Bowers, G. M. 1909). No directed fishery for Big Skate has been documented; rather, they were taken along with other skates and rays as "scrap fish" and used for fertilizer, fish meal and oil (**???**).

Skates have been regarded as a predator on desirable market species such as Dungeness crab, and were thought of as nuisance fish with no appeal as a food item save for small local markets. They had been discarded or harvested at a minimal level until their livers became valued along with those of other cartilaginous fishes for the extraction of vitamin A in the 1940s. Chapman (Chapman, W.M. 1944) recorded that "At present they are being fished heavily, in common with the other elasmobranchs of the coast, forthe vitamins in their livers. The carcasses are either thrown away at sea or made into fish meal. Little use is made of the excellent meat of the wings".

Little information is available about the historic Washington fishery for Big Skate. In records before 2000, they are lumped together with other skates or in market categories (**???**); this necessitates considerable attention to reconstructing the fishery by observing the composition of skate catches in the modern fishery and applying those to the recently reconstructed historical records.

Very little information is known about the Big Skate historical fishery in Oregon. The information we do have is mainly from historical landing data and species composition samples starting in the mid-nineties. The bulk of the catch is from the bottom trawl and longline fisheries, with smaller amounts as by-catch in mid-water trawl and the shrimp trawl fishery. Big Skate was lumped into the nominal “Skate” category until 2015 when it was separated into its own market category. Species composition data have been vitally important in reconstructing the pre-2015 historical catch (**???**).

1.6 Stock Status and Management History

`stock-status-and-management-history`

Big Skate were managed in the “Other Fish” complex until 2015 when they were designated an Ecosystem Component (EC) species. Catches of Big Skate are estimated to have averaged 95 mt from 2007–2011, along with large landings of “Unspecified Skate”. Analysis of Oregon port-sampling data indicates that about 98 percent of the recent Unspecified Skate landings in Oregon were comprised of Big Skate. Such large landings indicates targeting of Big Skate has occurred and an EC designation was not warranted. Based on this evidence, Big Skate was redesignated as an actively-managed species in the fishery. Big skate have been managed with stock-specific harvest specifications since 2017.

The recent OFL of 541 mt was calculated by applying approximate MSY harvest rates toestimates of stock biomass from the Northwest Fisheries Science Center (NWFSC) West Coast Groundfish Bottom Trawl Survey. This survey-based biomass estimate is likely underestimated since Big Skate are distributed all the way to the shoreline and no West Coast trawl surveys have been conducted in water shallower than 55 meters. This introduces an extra source of uncertainty to management and suggests that increased precaution is needed to reduce the risk of overfishing the stock.

There has been consideration for managing Big Skate in a complex with Longnose Skate, the other actively-managed West Coast skate species, but the two species have disparate distributions and fishery interactions (Longnose Skate is much more deeply distributed than Big Skate) and that option was not endorsed. The Pacific Fishery Management Council has chosen to set the Annual Catch Limit (ACL) equal to the Allowable Biological Catch (ABC) with a buffer for management uncertainty (P*) of 0.45.

1.7 Management Performance

`management-performance-1`

Table f

1.8 Fisheries Off Alaska, Canada and Mexico

`fisheries-off-alaska-canada-and-mexico`

** Alaska **

In Alaska, skates were primarily taken as bycatch in both longline and trawl fisheries until 2003, when a directed skate fishery developed in the Gulf of Alaska, where Longnose and Big skates comprise the majority of the skate biomass.

The Gulf of Alaska (GOA) skate complex is managed as three units. Big skates and Longnose Skates each have separate harvest specifications, with acceptable biological catches (ABCs) specified for each GOA regulatory area (western, central, and eastern). A single gulfwide overfishing level (OFL) is specified for each stock. All remaining skate species are managed as an "Other Skates" group with gulfwide harvest specifications. All GOA skates are managed as Tier 5 stocks, where OFL and ABC are based on survey biomass estimates and natural mortality rate (Alaska Fisheries Science Center 2018).

In the Bering Sea and Aleutian Islands, skates are assessed as a group rather than as separate species.

** Canada **

In Canada historic information regarding skate catches goes back to the 1950's. Prior to 1990's skates were taken mostly as bycatch and landings were reported as part of a skate complex (not by species). As with the West Coast, the trawl fishery is responsible for the largest amount of bycatch. Skate catches off British Columbia accelerated in the early 1990's, partly due to emerging Asian markets. Since 1996, longnose skate has been targeted by the B.C. trawl fishery and, as a result, catches have been more accurately reported.

Assessments of Longnose Skate and Big Skate were conducted by Canada's Division of Fisheries and Oceans in 2015(King, J.R., Surry, A.M., Garcia, S., and P.J. Starr 2015). For Big Skate, a Bayesian surplus production model failed to provide plausible results, and two data-limited approaches were investigated: Depletion-Corrected Average Catch Analysis (DCAC), and a Catch-MSY (maximum sustainable yield) Approach.

DCAC produced a range of potential yield estimates that were above the long-term average catch, with an upper bound that was three orders of magnitude larger than the long-term average catch. The Catch-MSY approach was found to be quite sensitive to assumptions and was not recommended as the sole basis of advice to managers.

The recommendation for managment for both skate species was that they should be managed with harvest yeilds based on mean historic catch, with consideration given to survey trends and to the ranges of maximum sustainable yield estimates identified by the Catch-MSY Approach. However, the analysis found no significant trends in abundance indices for Big Skate, and mean historical catches were below the maximum MSY estimate from the catch-MSY results.

2 Fishery Data

fishery-data

2.1 Data

data

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

2.2 Commercial Fishery Landings

commercial-fishery-landings

2.2.1 Catch reconstructions for WA, OR, and CA

catch-reconstructions-for-wa-or-and-ca

Washington Commercial Skate Landings Reconstruction

Information for Big Skate is very limited, in part because the requirement to sort landings of Big Skate in the shore-based Individual Fishing Quota fishery from landings in the "Unidentified Skate" category was not implemented until June 2015. The historical catch of Big Skate therefore relies on the historical reconstruction of Longnose Skate.

For the 2019 assessment, a new approach has been developed for estimating the catch history for Longnose Skate based on a linear regression model that predicts the catch of Longnose Skate from the catch of Dover sole, for which historical catch estimates are available (Gertseva, V. 2019). The dependent variable for the linear regression model was the West Coast Groundfish Observer Program (WCGOP) annual estimates of the coastwide total catch (landings plus discards) of Longnose Skate for the period 2009 to 2017 and the independent variable was the corresponding WCGOP annual estimates of coastwide total catch (landings plus discards) of Dover sole. The regression model has good predictive power ($R^2 = 95.7\%$) over the range of the Dover sole catches (6,500 to 12,500 mt).

The discard component of the catch reconstruction for Big Skate may be based either on the catch reconstruction for Longnose Skate and the assumption that the two species experience similar discard rates (discard / total catch) or on a similar analysis with links to species that co-occur with big skate. Data from the Pikitch discard study (1985-1987) and from WCGOP (2015-2017) support the idea that discard rates for the two species are very similar. Also, market demand for skates does not seem to distinguish between the two species. There are insufficient years of data from the WCGOP to develop a regression model for Big Skate as was done for Longnose Skate.

Oregon Commercial Skate Landings Reconstruction

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

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

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

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

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

California Catch Reconstruction

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

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

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

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

As no spatial information on catch is available from 1916-1930, and the block summary data were very sparse in the first few years of the CDFW fish ticket program (1931–1934), spatial information from the late 1930's was used to hindcast to the 1916–1935 time period.

2.2.2 Tribal Catch in Washington

tribal-catch-in-washington

2.2.3 Commercial Discards

commercial-discards

Commercial discards of Big Skate are highly uncertain. The method used to estimate discards for Longnose Skate was based on a strong correlation between total mortality of that species, and total mortality of Dover Sole for the years 2009–2017 during which Longnose were landed separately from other skates. In contrast, the sorting requirement for Big Skate occurred too recently to provide an adequate range of years for this type of correlation. Furthermore, there is greater uncertainty in the total mortality for the shallow-water species with which Big Skate most often co-occurs, such as Sand Sole and Starry Flounder, than there is for Dover Sole, which has been the subject of recurring stock assessments.

However, those involved in the fishery for both skate species report that discarding for Big Skate and Longnose Skate in the years prior to 1995 were driven by the same market forced and the discard rates were similar. primarily lack of margets or fish processors accepting only skate wings that had been separated at-sea, as well as the quantitative have more uncertainty in their own catch estimates have no stock assessment and more uncertain mortality estimated total mortality and Dover Sole for which a correlation between relationship (Gertseva, V. 2019),

2.2.4 Commercial Fishery Length and Age Data

`commercial-fishery-length-and-age-data`

The input sample sizes were calculated via the Stewart Method (Ian Stewart, personal communication, IPHC):

$$\text{Input effN} = N_{\text{trips}} + 0.138 * N_{\text{fish}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is} < 44$$

$$\text{Input effN} = 7.06 * N_{\text{trips}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is} \geq 44$$

2.2.5 Sport Fishery Removals and Discards

`sport-fishery-removals-and-discards`

Biological samples from the recreational fleets are described in the sections below.

2.2.6 Fishery-Dependent Indices of Abundance

`fishery-dependent-indices-of-abundance`

Data Source 1

Data Source 1 Index Standardization

Data Source 1 Length Composition

Data Source 2

Data Source 3

2.2.7 Fishery-Independent Data Sources

`fishery-independent-data-sources`

Alaska Fisheries Science Center (AFSC) Triennial Shelf Survey

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

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

An index of abundance was estimated based on the VAST delta-GLMM model as described for the NWFSC Combo Index above. In this case as well, Q-Q plots indicated slightly better performance of the gamma over lognormal models for positive tows (Figure **??**).

Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey

In 2003, the NWFSC took over an ongoing slope survey the AFSC had been conducting, and expanded it spatially to include the continental shelf. This survey, referred to in this document as the **NWFSC Combo Survey**, has been conducted annually since. It uses a random-grid design covering the coastal waters from a depth of 55 m to 1,280 m from late-May to early-October (Bradburn, M.J. and Keller, A.A and Horness, B.H. 2011 , Keller, A.A. and Wallace, J.R. and Methot, R.D. 2017). Four chartered industry vessels are used each year (with the exception of 2013 when the U.S. federal-government shutdown curtailed the survey). Yellowtail catches in the NWFSC Combo Survey are shown in **??**.

The data from the NWFSC Combo survey was analyzed using a spatio-temporal delta-model (Thorson, J. T. and Shelton, A. O. and Ward, E. J. and Skaug, H. J. 2015), implemented as an R package VAST (Thorson, 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 in both encounter probability and positive catch rates, a logit-link for encounter probability, and a log-link for positive catch rates. Vessel-year effects were included for each unique combination of vessel and year in the database.

Data Source 1 Index Standardization VAST

Data Source 1 Length Composition

Triennial Survey *Data Source 2 Index Standardization* VAST

Internation Pacific Halibut Commission Longline Survey

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

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

In most years, bycatch of non-halibut species has been recorded during this survey on the first 20 hooks of each 100-hook group, although in 2003 only 10% of the hooks were observed for bycatch, and starting in 2012, some stations had 100% of the hooks observed for bycatch. Combining these observation pattern with the number of hooks deployed each year, resulted in most stations having 80, 100, 120, 140, or 160 hooks observed, with a mean of 144 hooks and a maximum of 800 hooks observed. The depth range of the 84 stations considered was 42—530 m, thus extending beyond the range of Big Skate, but 74% of the stations were shallower than 200 m. Big Skate have been observed at 51 of the 84 the standard stations that were retained for this analysis, but no station had Big Skates observed in more than 12 out of the 19 years of survey data, and only 10% of the station/year combinations had at least one observed Big Skate (Figure X). Of those station/year combinations with at least one Big Skate observed, the Big Skates were observed on an average of 1.3% of the hooks observed. The highest proportion was 10 Big Skates out of 81 hooks observed at one station.

The IPHC longline survey catch data were standardized using a Generalized Linear Model (GLM) with binomial error structure. Catch-per-hook was modeled, rather than catch per station due to the variability in the number of hooks deployed and observed each year. The binomial error structure was considered logical, given the binary nature of capturing (or not) a Longnose Skate on each longline hook. The modeling approach is identical to that which has been applied in the past for Yelloweye Rockfish (*Stewart et al. 2009*), and Spiny Dogfish (*Gertseva et al., 2011*). MCMC sampling of the GLM parameters was used to estimate the variability around each index estimate. The median index estimates themselves were approximately equal to the observed mean catch rate in each year (Figure Y). In recent years, the IPHC standardization of the index of halibut abundance has included an adjustment to account for missing baits on hooks returned empty in an effort to account for reduced catchability of the gear that may result from the lost bait. This adjustment was not included in the analysis for Big Skate although it could be considered in future years.

2.2.8 Biological Parameters and Data

`biological-parameters-and-data`

Measurement Details and Conversion Factors

Disc width to total length (estimated by Ian on Apr 15, similar to Ebert 2008 estimates for Alaska) L = 1.3399 * W estimated from 95 samples from WCGBTS where both measurements collected (R-squared = 0.9983). Little sex difference observed, so using single relationship for both sexes. Inter-spiracle width to total length from Downs & Cheng (2013): L = 12.111 + 9.761*ISW (females) L = 3.824 + 10.927*ISW (males)

Love et al. (1987)

Length and Age Compositions

Length comps (some based on widths)

WCGBTS Lengths from all years except 2006 and 2007 Widths in 2006 and 2007

Triennial Survey Sample sizes: 3 in 1998 (all widths), 84 in 2001 (3 widths, 81 lengths), 100 in 2004 (all lengths) Triennial survey About 90+ samples in each of 2001 and 2004 Only 3 unsexed fish from 1998

Commercial fisheries In process Discard comps from 2010-2015

Length compositions were provided from the following sources:

- Source 1 (*type, e.g., commercial dead fish, research, recreational*, yyyy-yyyy)
- Source 2 (*type*, yyyy-yyyy)
- Source 3 (*research*, yyyy, yyyy, yyyy, yyyy)

The length composition of all fisheries aggregated across time by fleet is in Figure 3. Descriptions and details of the length composition data are in the above section for each fleet or survey.

Age Structures

von Bertalanffy growth curve (von Bertalanffy, L 1938), $L_i = L_\infty e^{(-k[t-t_0])}$, where L_i is the length (cm) at age i, t is age in years, k is rate of increase in growth, t_0 is the intercept, and L_∞ is the asymptotic length.

Ages WCGBTS Currently only 333 ages from 2010 present in data warehouse as of Apr 15 Patrick submitting an 300 additional ages from 2016 and 2017 to Beth on Apr 2 and promised further additions during the week of Apr 15.

Triennial Survey No ages

Commercial fisheries 2009 samples from WA were stratified by length, so should be treated as conditionals

Aging Precision and Bias

Weight-Length

Estimated by Ian based on WCGBT samples (n = 1159) $Weight = 0.0000074924 * Length^2.9925$ (Figure 4).

Sex Ratio, Maturity, and Fecundity

The female maturity relationship was based on visual maturity estimates from port samplers (n = 278, of which 241 were from Oregon and 37 from Washington, with 24 mature specimens) as well as 55 samples from the WCGBTS (of which 4 were mature). The resulting relationship was $L_{50\%} = 148.2453$ with a slope parameter of $Beta = -0.13155$ in the relationship $M = (1 + Beta(L - L_{50\%}))^{-1}$ (Figure 5).

Natural Mortality

The Hamel prior for M is lognormal(ln(5.4/max age),.438), which based on 1 age-15 fish out of 1034 observed in the WCGBTS results in lognormal(-1.021651, 0.438)

If it needs to be fixed, it should be set to M = 5.4/max age = 5.4/15 = 0.36

2.2.9 Environmental or Ecosystem Data Included in the Assessment

`environmental-or-ecosystem-data-included-in-the-assessment`

In this assessment, neither environmental nor ecosystem considerations were explicitly included in the analysis. This is primarily due to a lack of relevant data and results of analyses (conducted elsewhere) that could contribute ecosystem-related quantitative information for the assessment.

3 Assessment

assessment

3.1 Previous Assessments

previous-assessments

3.1.1 History of Modeling Approaches Used for this Stock

history-of-modeling-approaches-used-for-this-stock

Deriving estimates of OFL for species in the "Other Fish" complex or potential alternative complexes

The current "Other Fish" complex and proposed alternatives include a number of species for which estimates of OFL contributions are not available from stock assessments or data-poor methods. Four of the species had OFL contributions for the 2013–2014 management cycle calculated by applying approximate MSY harvest rates to estimates of stock biomass from the NWFSC West Coast Bottom Trawl Survey (Bradburn et al., 2012). This approach is described in detail in Cope et al. (2012).

3.1.2 yyyy Assessment Recommendations

yyyy-assessment-recommendations

Recommendation 1:

STAT response: xxxxx

Recommendation 2:

STAT response: xxxxx

Recommendation 3:

STAT response: xxxx

3.2 Model Description

model-description

3.2.1 Transition to the Current Stock Assessment

transition-to-the-current-stock-assessment

3.2.2 Summary of Data for Fleets and Areas

summary-of-data-for-fleets-and-areas

There are xxx fleets in the base model. They include:

Commercial: The commercial fleets include …

Recreational: The recreational fleets include …

Research: There are xx sources of fishery-independent data available …

###Other Specifications

3.2.3 Modeling Software

`modeling-software`

The STAT team used Stock Synthesis 3 version 3.30.05.03 by Dr. Richard Methot at the NWFSC. This most recent version was used, since it included improvements and corrections to older versions. The r4SS package (GitHub release number v1.27.0) was used to post-processing output data from Stock Synthesis.

3.2.4 Data Weighting

`data-weighting`

3.2.5 Priors

`priors`

The log-normal prior for female natural mortality were based on a meta-analysis completed by Hamel (2015), as described under "Natural Mortality." Female natural mortality was fixed at the median of the prior, 0.xxx for an assumed maximum age of xx. An uninformative prior was used for the male offset natural mortality, which was estimated.

The prior for steepness (h) assumes a beta distribution with parameters based on an update for the Thorson-Dorn rockfish prior (Dorn, M. and Thorson, J., pers. comm.), which was endorsed by the Science and Statistical Committee in 2018. The prior is a beta distribution with mu=0.xxx and $sigma$=0.xxx. Steepness is fixed in the base model at the mean of the prior. The priors were applied in sensitivity analyses where these parameters were estimated.

3.2.6 Estimated and Fixed Parameters

`estimated-and-fixed-parameters`

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

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

- xxx,
- xxx

- xxx, and
- xxx selectivity parameters

The estimated parameters are described in greater detail below and a full list of all estimated and parameters is provided in Table **??**.

Growth.

Natural Mortality.

Selectivity.

Other Estimated Parameters.

Other Fixed Parameters.

3.3 Model Selection and Evaluation

`model-selection-and-evaluation`

3.3.1 Key Assumptions and Structural Choices

`key-assumptions-and-structural-choices`

3.3.2 Alternate Models Considered

`alternate-models-considered`

3.3.3 Convergence

`convergence`

3.4 Response to the Current STAR Panel Requests

`response-to-the-current-star-panel-requests`

Request No. 1:

Rationale: xxx

STAT Response: xxx

Request No. 2:

Rationale: xxx

STAT Response: xxx

Request No. 3:

Rationale: x.

STAT Response: xxx

Request No. 4:

Rationale: xxx

STAT Response: xxx

Request No. 5:

Rationale: xxx

STAT Response: xxx

3.5 Base Case Model Results

`base-case-model-results`

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

3.5.1 Parameter Estimates

`parameter-estimates`

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

(Figure 7).

The stock-recruit curve . . . Figure 8 with estimated recruitments also shown.

3.5.2 Fits to the Data

`fits-to-the-data`

Model fits to the indices of abundance, fishery length composition, survey length composition, and conditional age-at-length observations are all discussed below.

3.5.3 Uncertainty and Sensitivity Analyses

`uncertainty-and-sensitivity-analyses`

A number of sensitivity analyses were conducted, including:

1. Sensitivity 1
2. Sensitivity 2
3. Sensitivity 3
4. Sensitivity 4
5. Sensitivity 5, etc/

3.5.4 Retrospective Analysis

`retrospective-analysis`

3.5.5 Likelihood Profiles

`likelihood-profiles`

3.5.6 Reference Points

`reference-points-1`

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

(Figure 12

The 2018 spawning biomass relative to unfished equilibrium spawning biomass is above/below the target of 40% of unfished levels (Figure 13). The relative fishing intensity, $(1 - SPR)/(1 - SPR_{50\%})$, has been xxx the management target for the entire time series of the model.

Table e shows the full suite of estimated reference points for the base model and Figure 14 shows the equilibrium curve based on a steepness value xxx.

4 Harvest Projections and Decision Tables

`harvest-projections-and-decision-tables`

The forecasts of stock abundance and yield were developed using the final base model, with the forecasted projections of the OFL presented in Table g.

The forecasted projections of the OFL for each model are presented in Table h.

5 Regional Management Considerations

regional-management-considerations

6 Research Needs

research-needs

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

1. **xxxx**:
2. **xxxx**:
3. **xxxx**:
4. **xxxx**:
5. **xxxx**:

7 Acknowledgments

acknowledgments

8 Tables

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
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

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)
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
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

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)
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

tab:Reconstructed_Landings_byState

Table 2: Landings by source. Landings are reconstructed histories 1916-1995.
tab:index_inputs

	WCGBTS		Triennial		IPHC	
Year	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.

tab:PacFIN_Samples

	CA		OR		WA		All Landings		Discards	
Year	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.

tab:Survey_Samples

	Triennial		WCGBTS		IPHC	
NA.	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		

#Figures

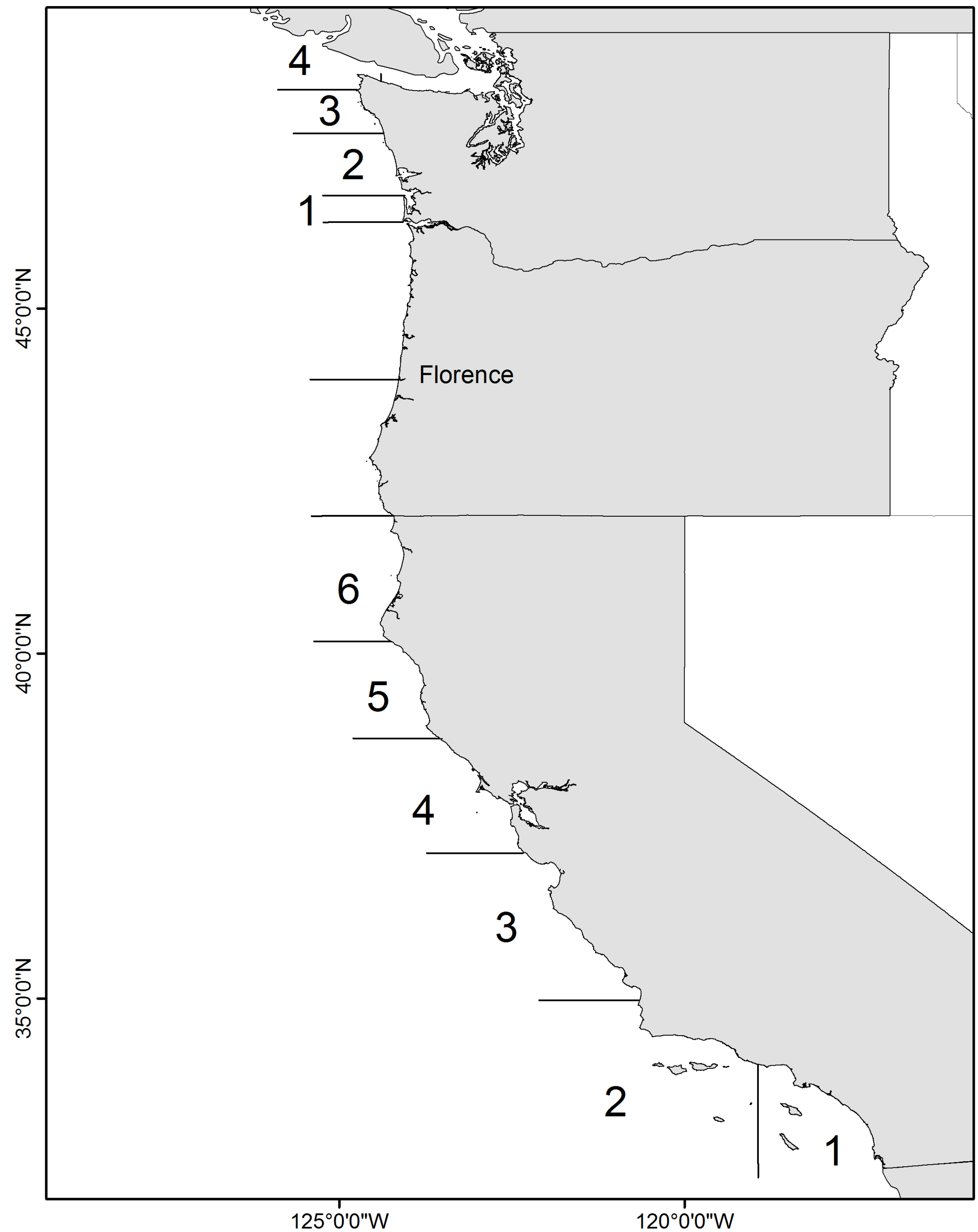


Figure 1: Map showing the state boundary lines for management of the recreational fishing fleets fig:boundary_map

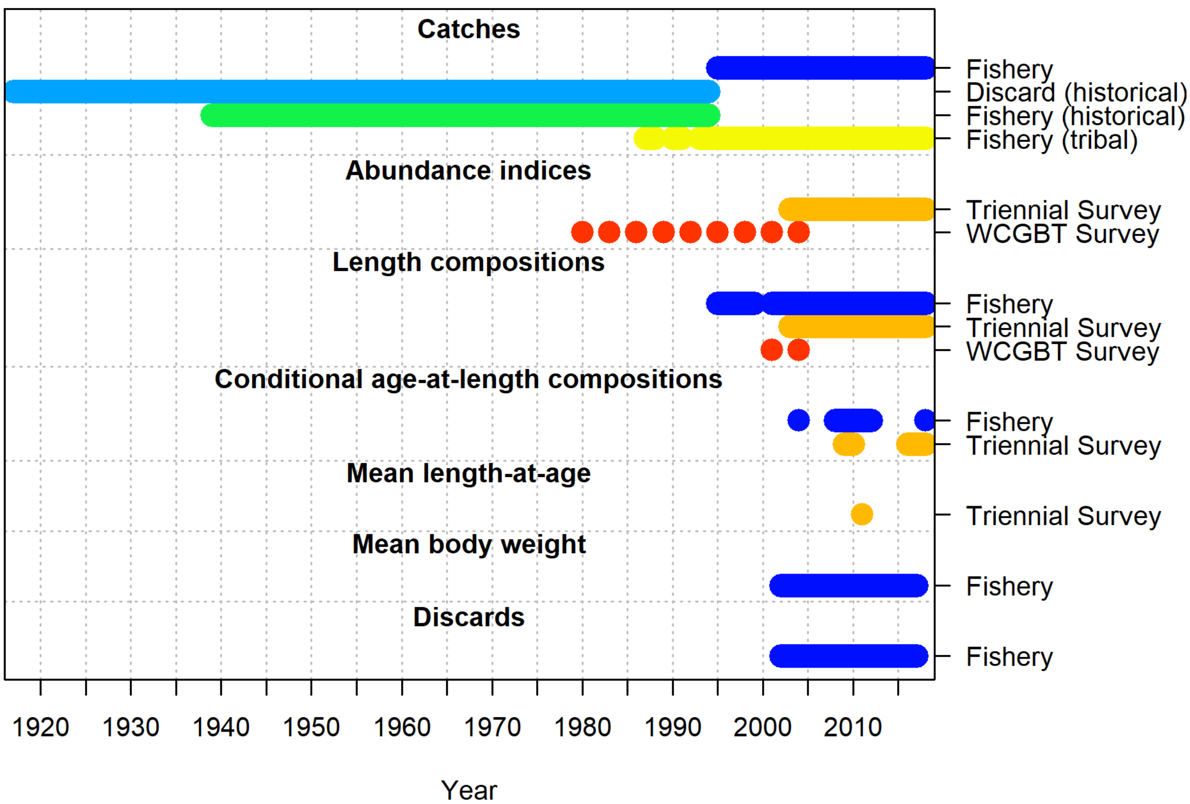


Figure 2: Summary of data sources used in the model. fig:data_plot

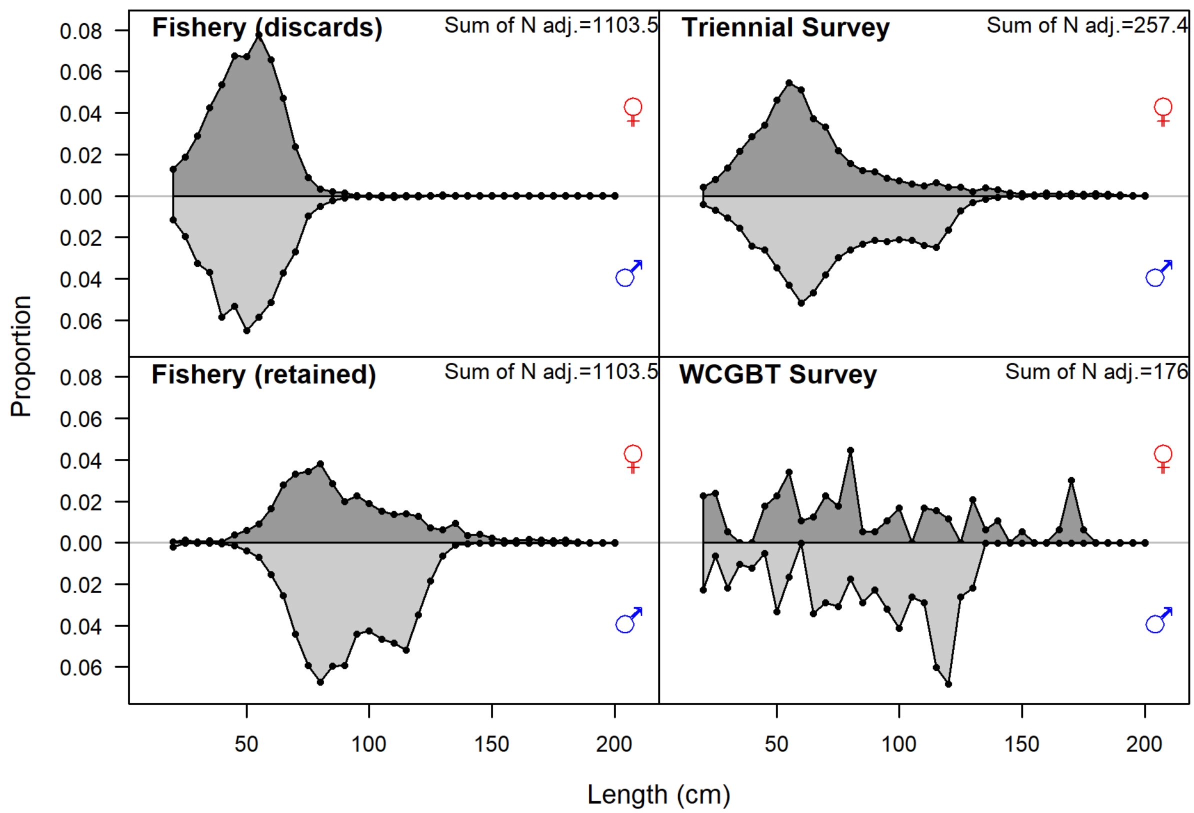


Figure 3: Length comp data, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch. fig:comp_lendat_aggregated_across_time

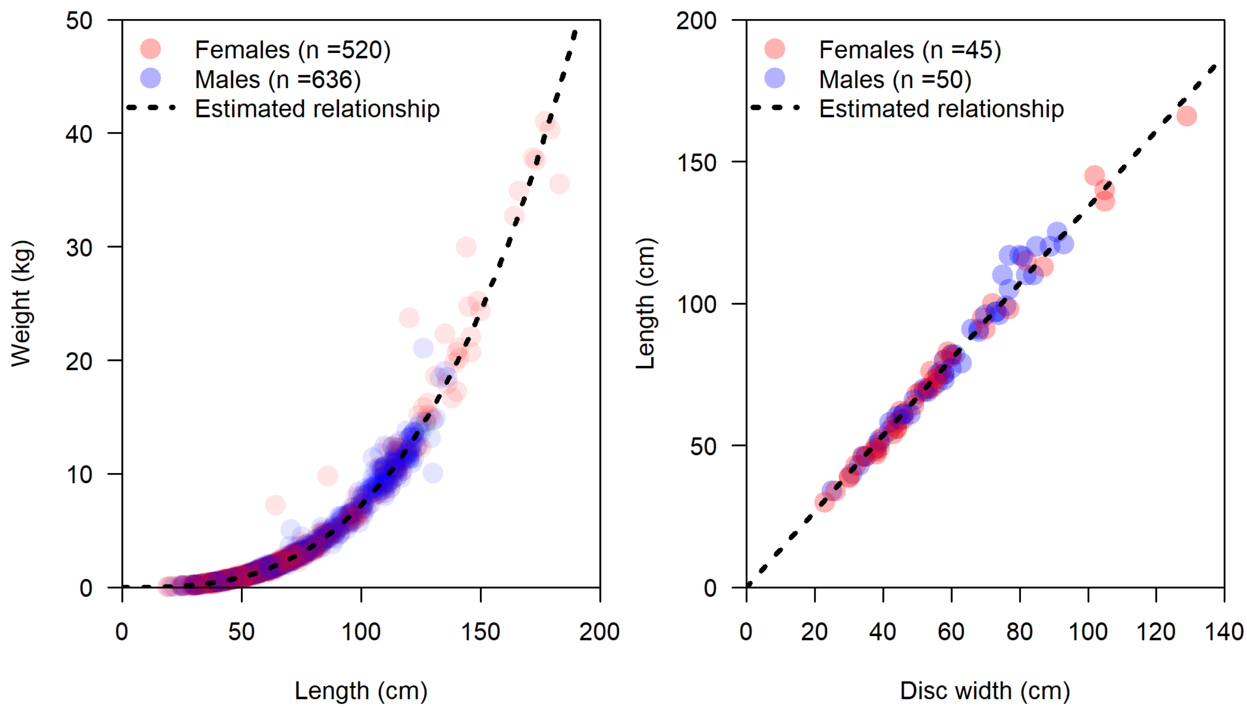


Figure 4: Estimated relationship between length and weight (left) and disc-width and length (right) for Big Skate. Colored points show observed values and the black line indicates the estimated relationship $W = 0.0000074924L^{2.9925}$. fig:weight-length

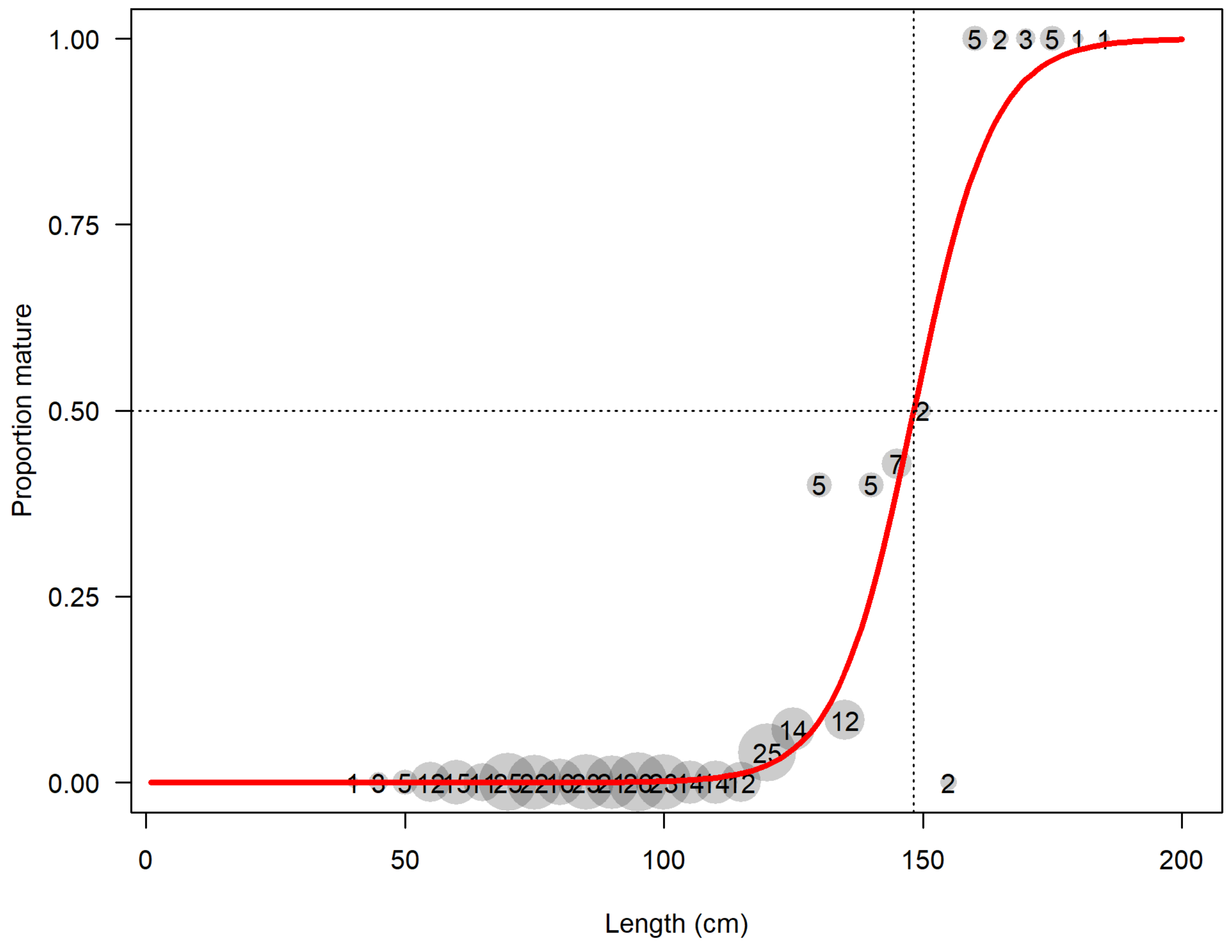


Figure 5: Estimated maturity relationship for female Big Skate. Gray points indicate average observed functional maturity within each length bin with point size proportional to the number of samples (indicated by text within each point). fig:maturity

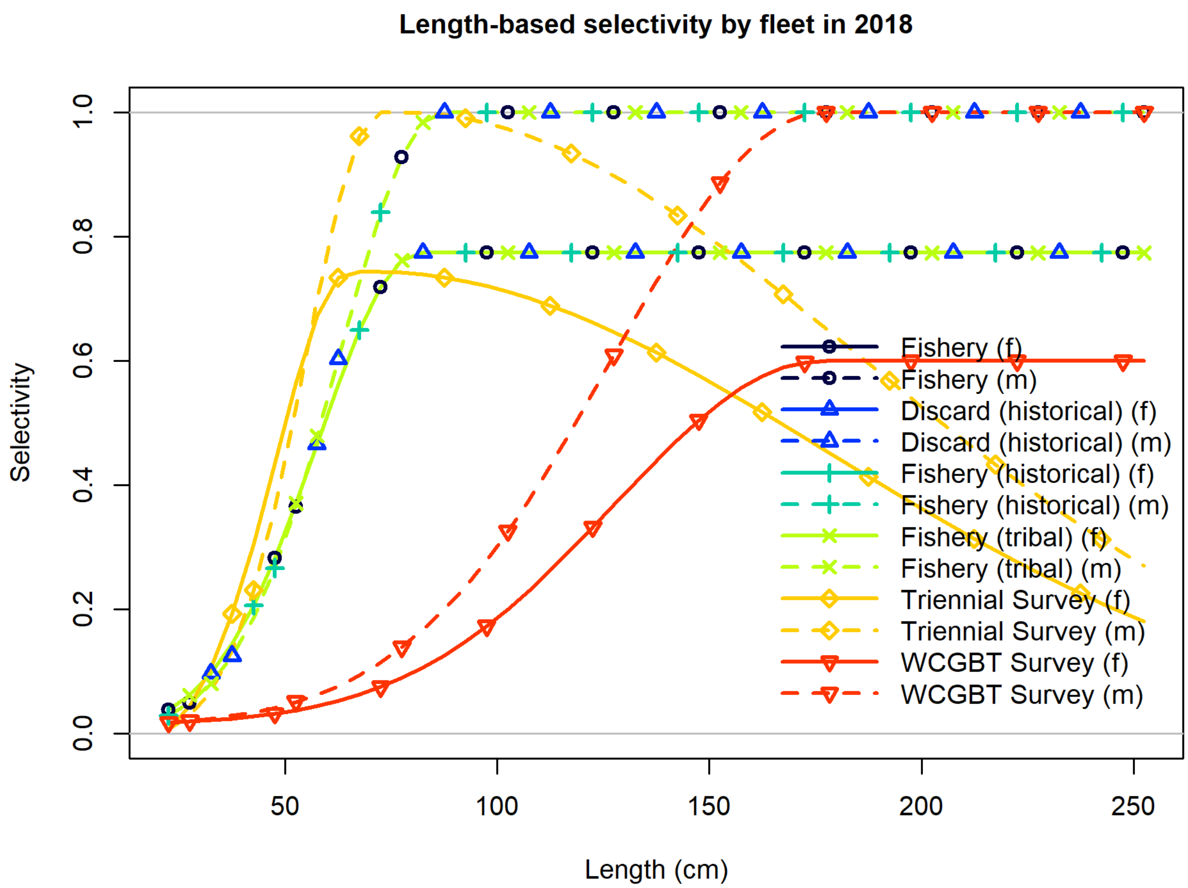


Figure 6: Selectivity at length for all of the fleets in the base model. fig:sel01_multiple_flee

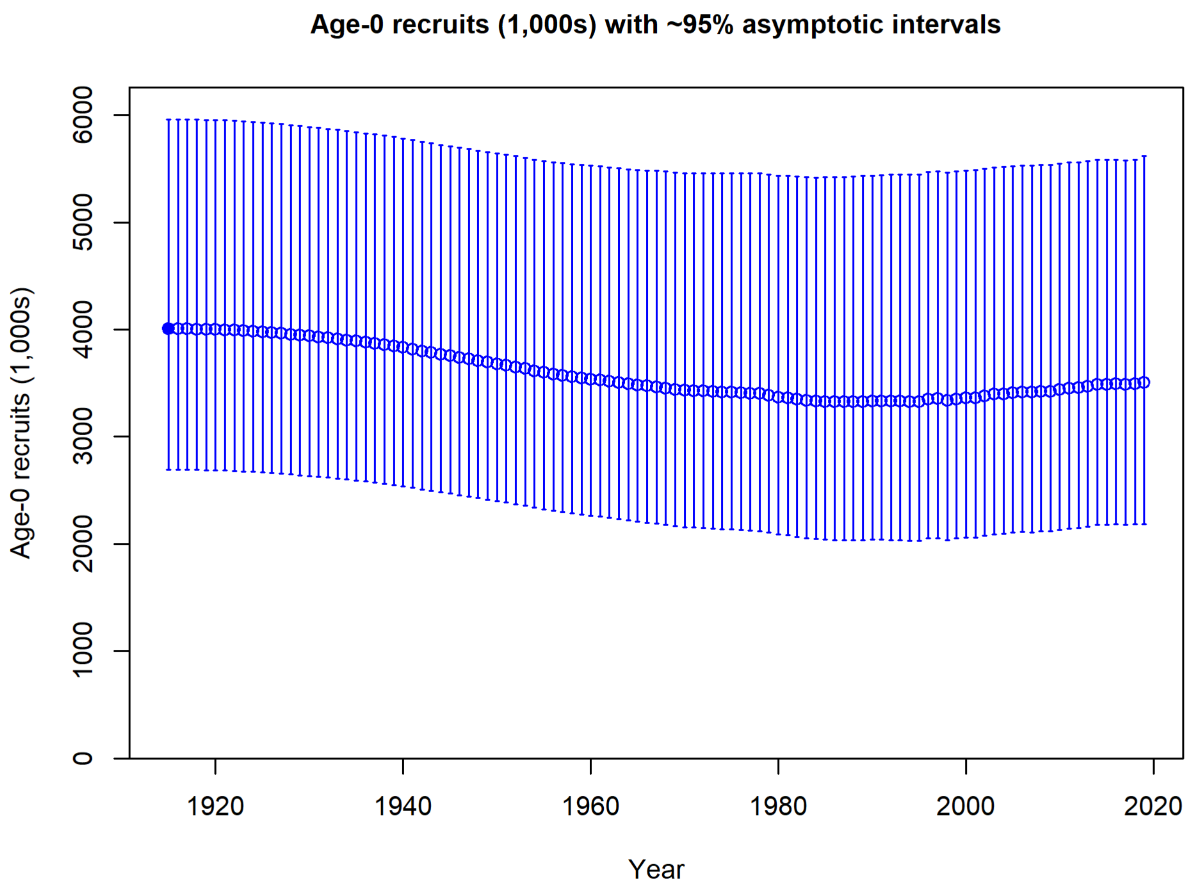


Figure 7: Estimated time-series of recruitment for Big Skate. fig:ts11_Age-0_recruits_(1

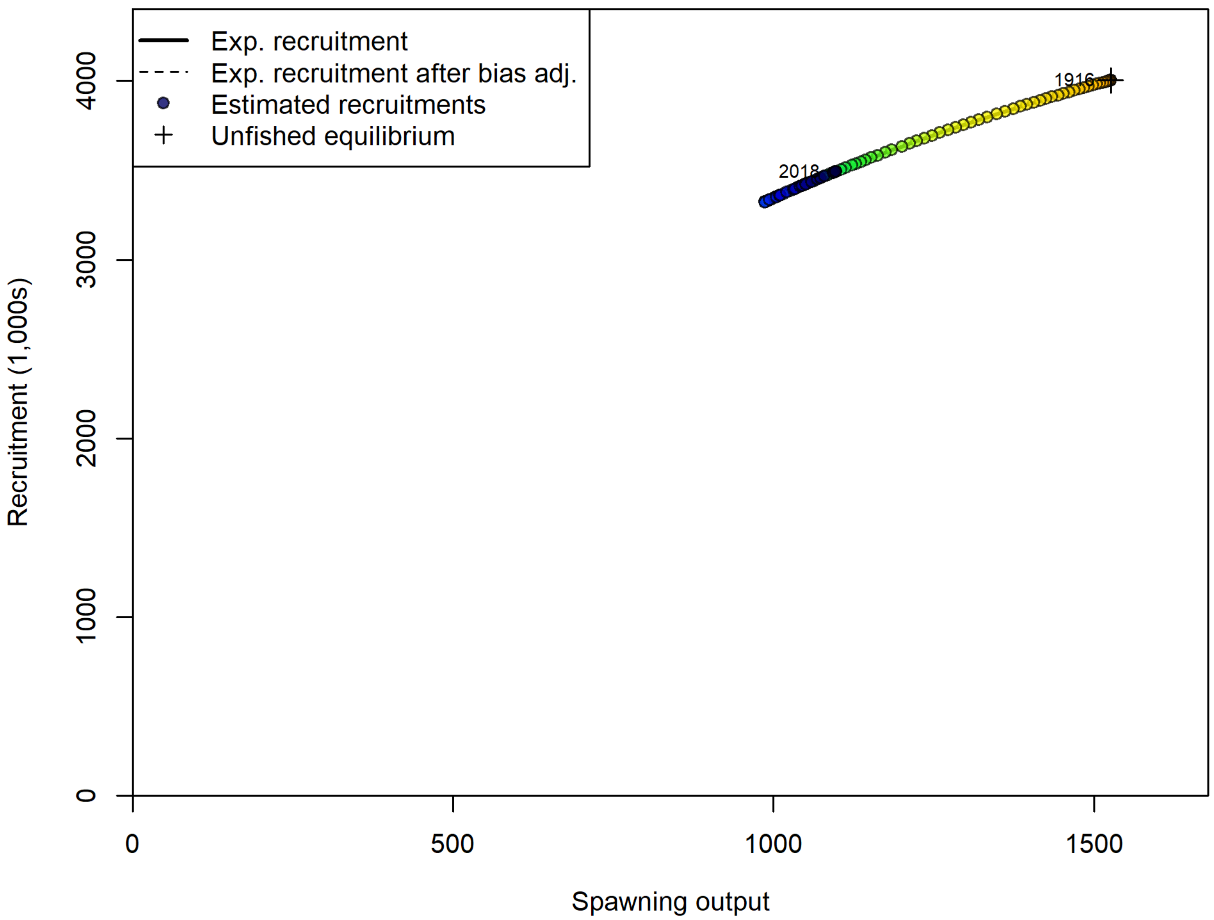
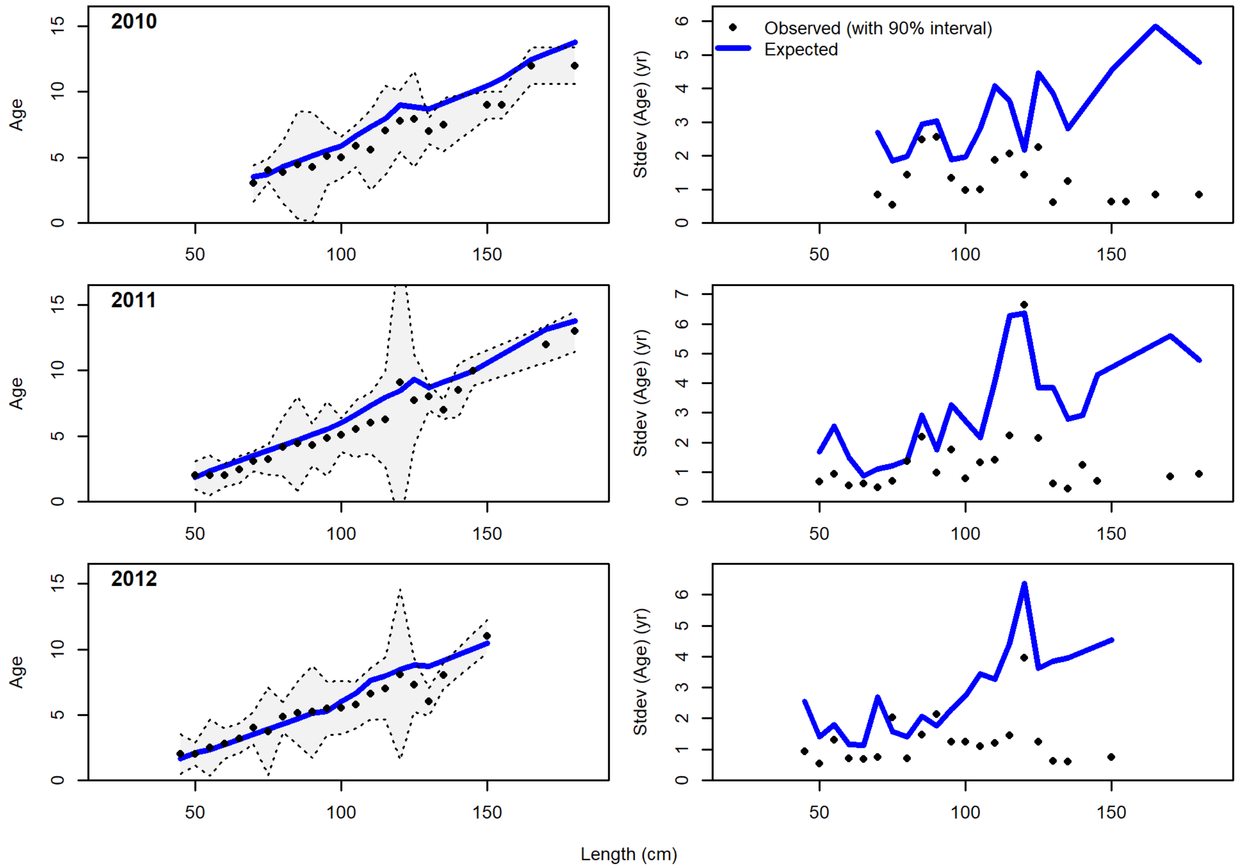


Figure 8: Estimated recruitment (red circles) and the assumed stock-recruit relationship (black line) for Big Skate. The green line shows the effect of the bias correction for the lognormal distribution. fig:SR_curve2



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737 Figure continued from previous page

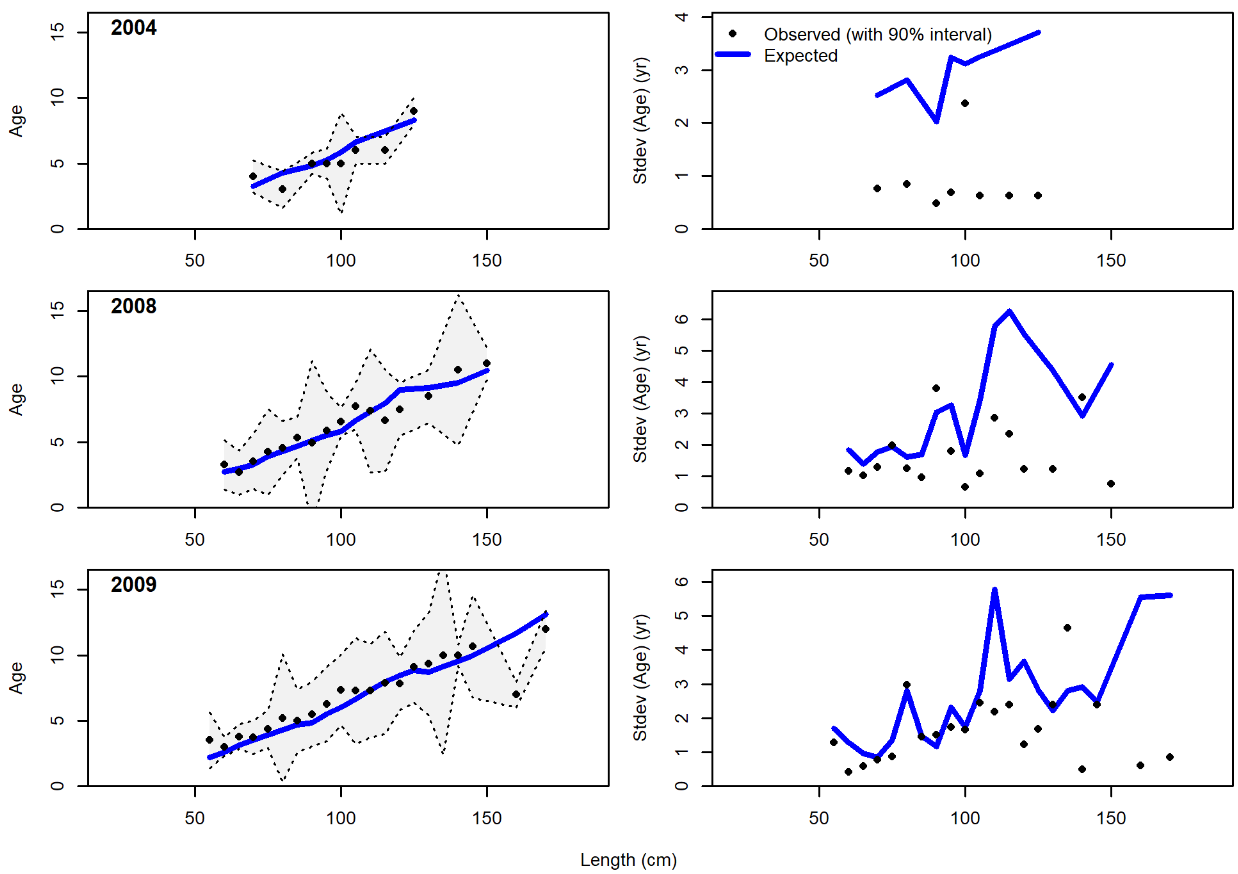
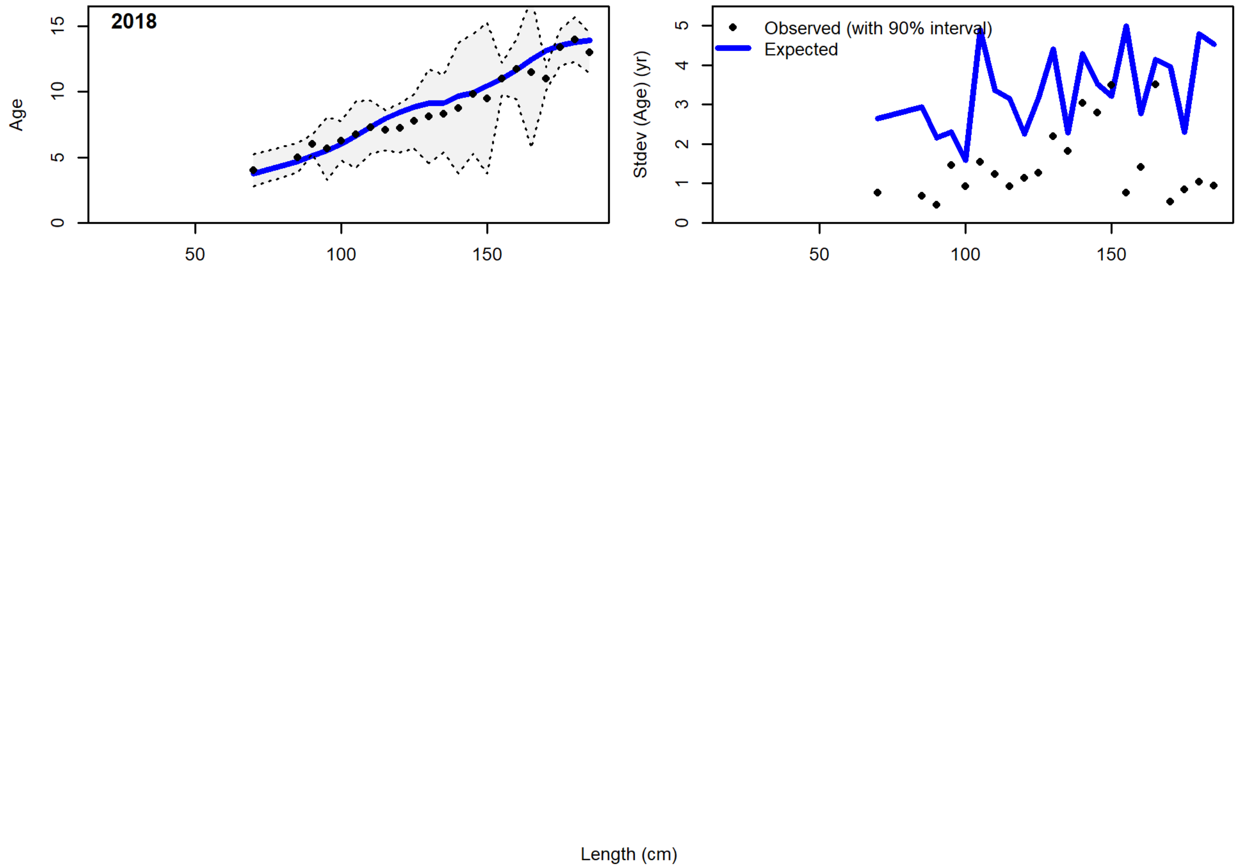


Figure 9: Conditional AAL plot, retained, Fishery (plot 1 of 3) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:mod1_4_comp_cond



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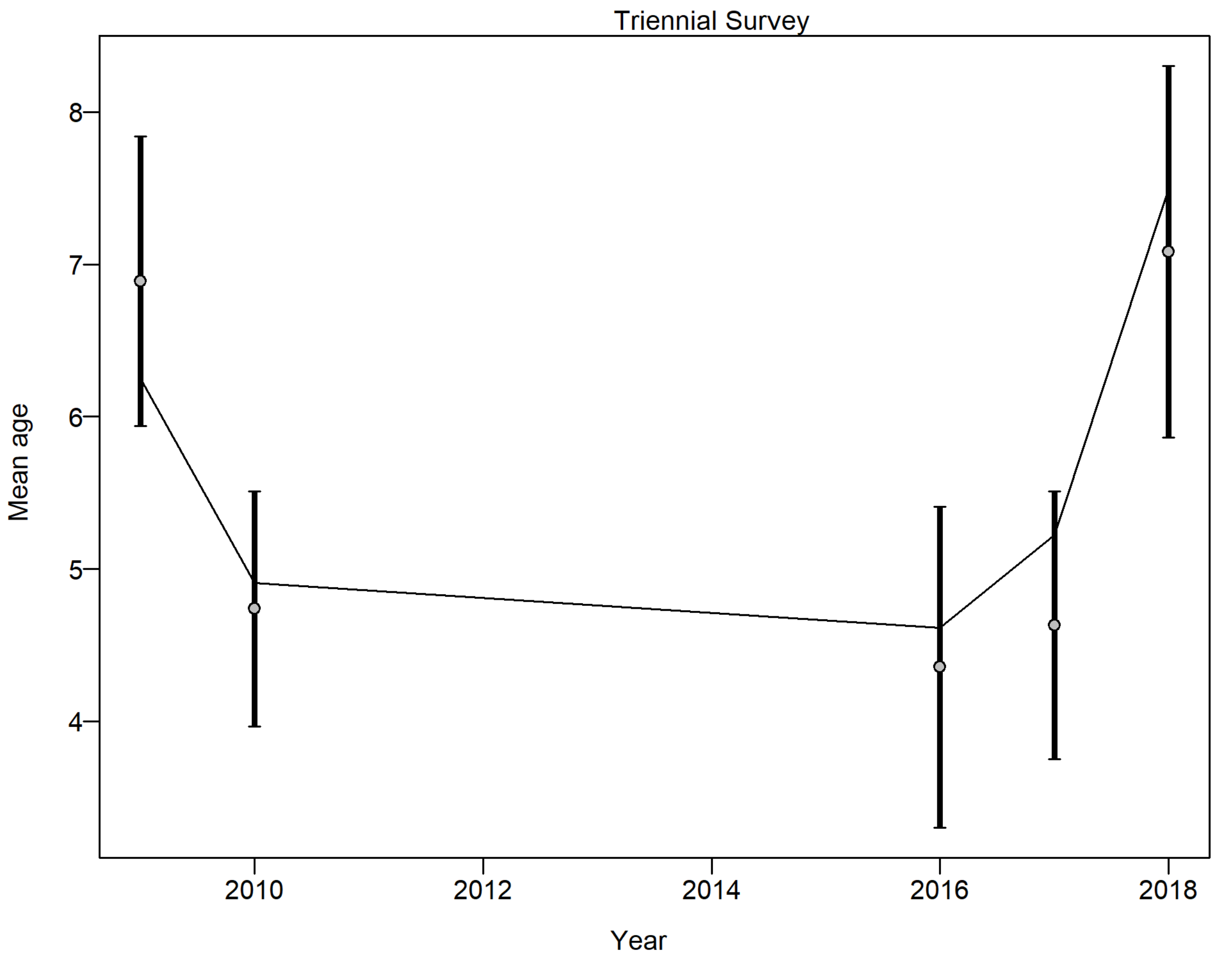


Figure 10: Mean age from conditional data (aggregated across length bins) for Triennial Survey with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age_at_length data from Triennial Survey: 1.0013 (0.5403_106.6286) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_7_comp_condAALfit_data_weighting_TA1.8_condAgeTriennial Survey

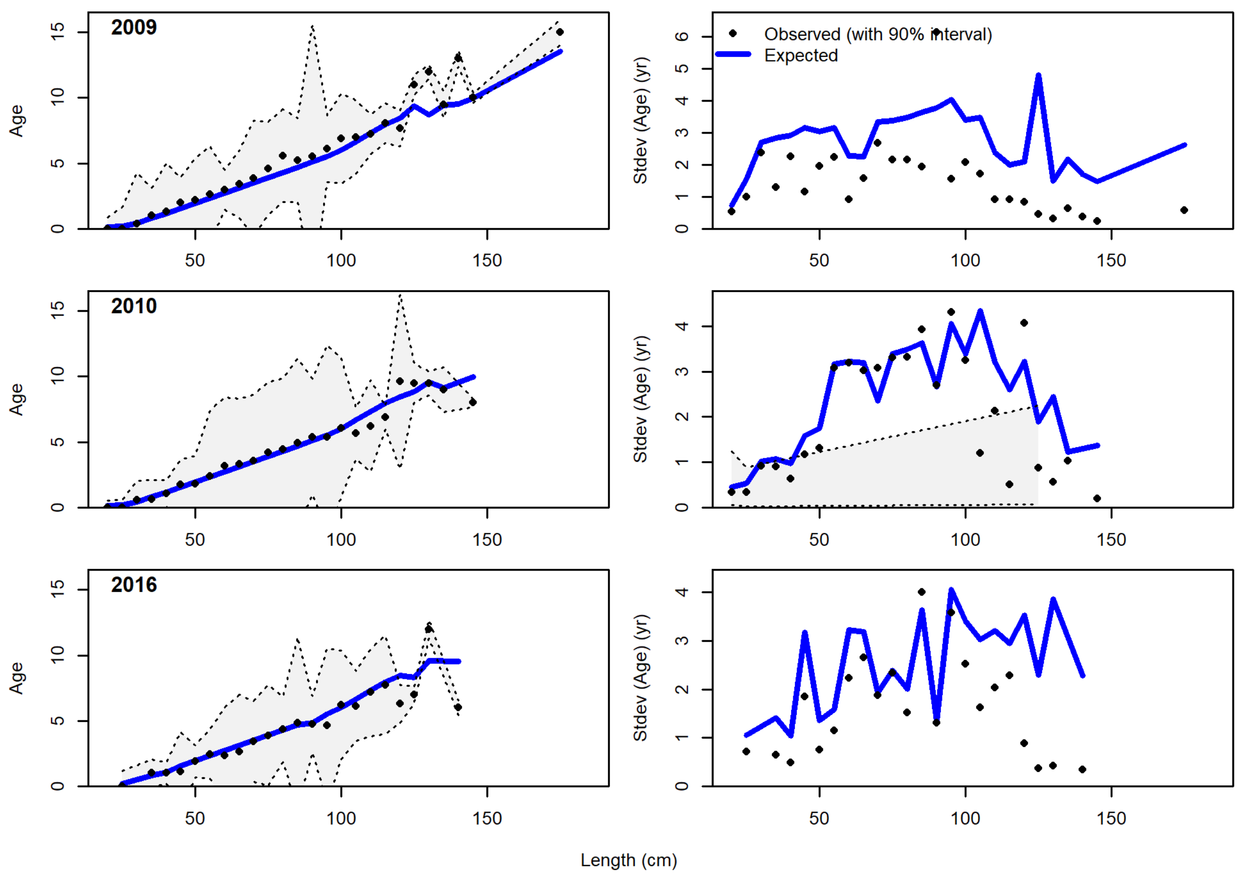
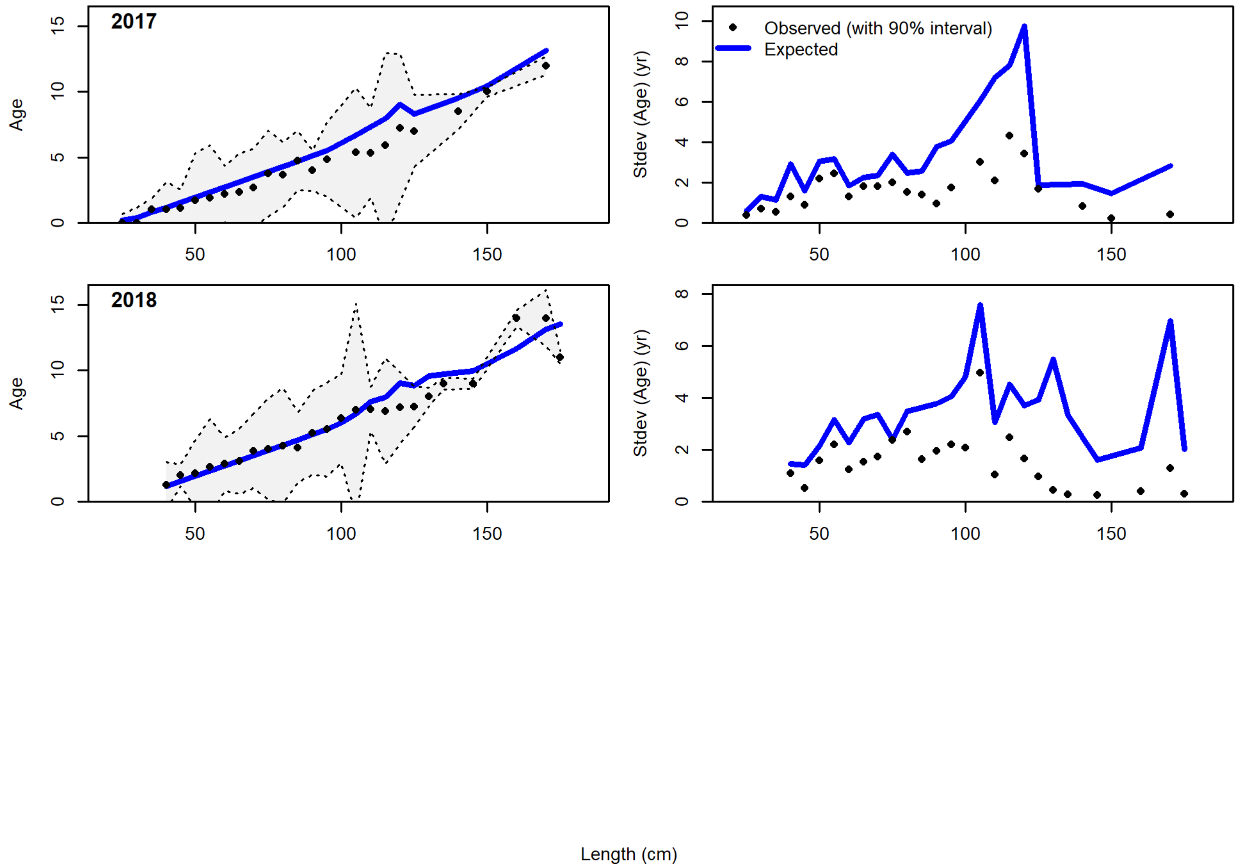


Figure 11: Conditional AAL plot, whole catch, Triennial Survey (plot 1 of 2) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:mod1_8_comp_condAALfit_Andre_plotsflt5mkt0_page1



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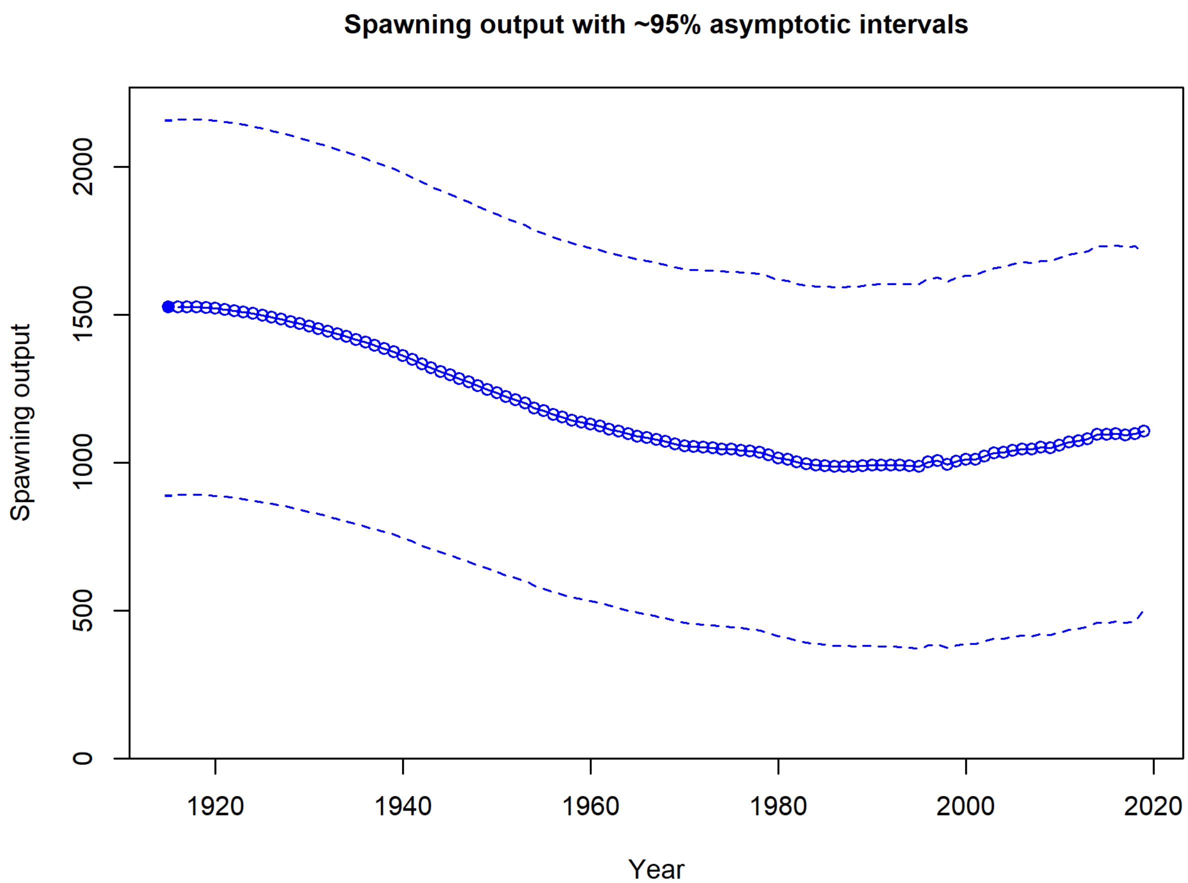

Figure 12: Estimated spawning biomass (mt) with approximate 95% asymptotic intervals. fig:ts7_Spawn

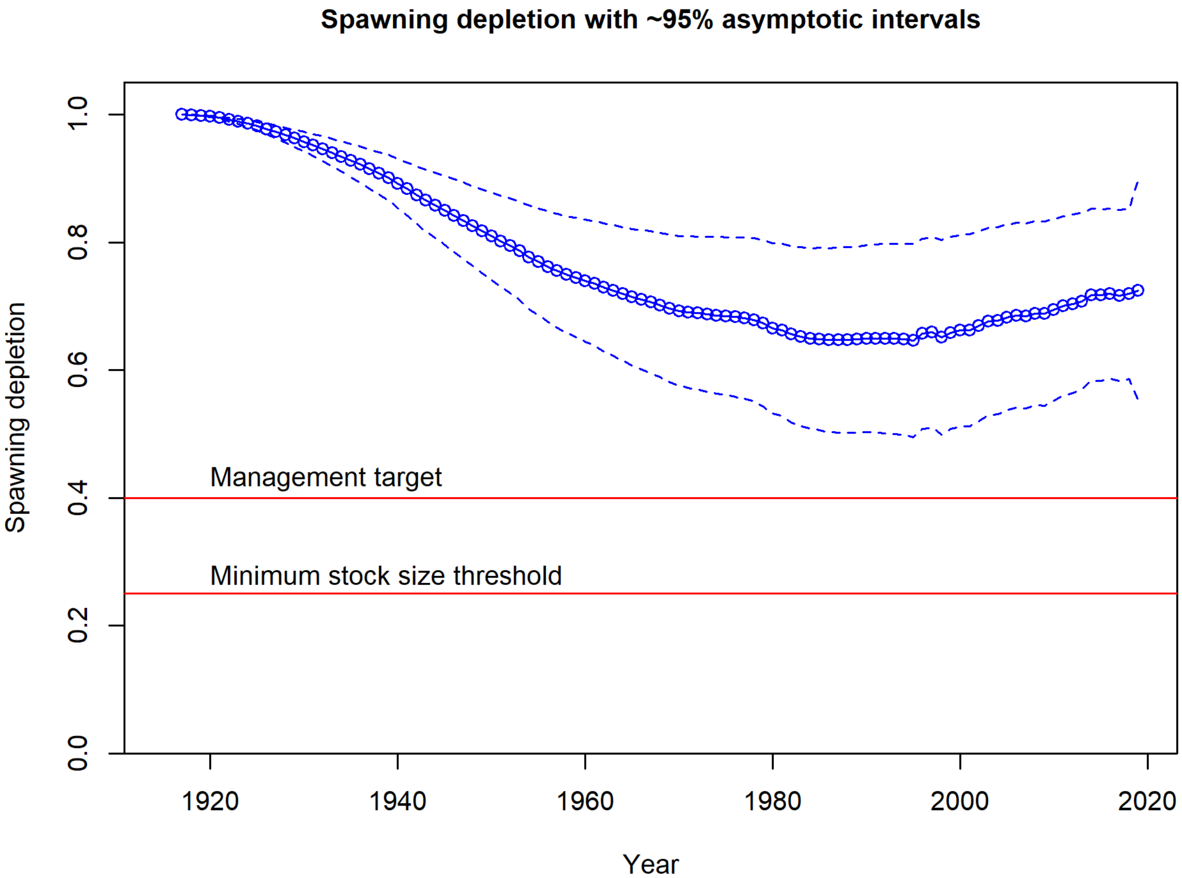

Figure 13: Estimated spawning depletion with approximate 95% asymptotic intervals. fig:ts9_Spawnin

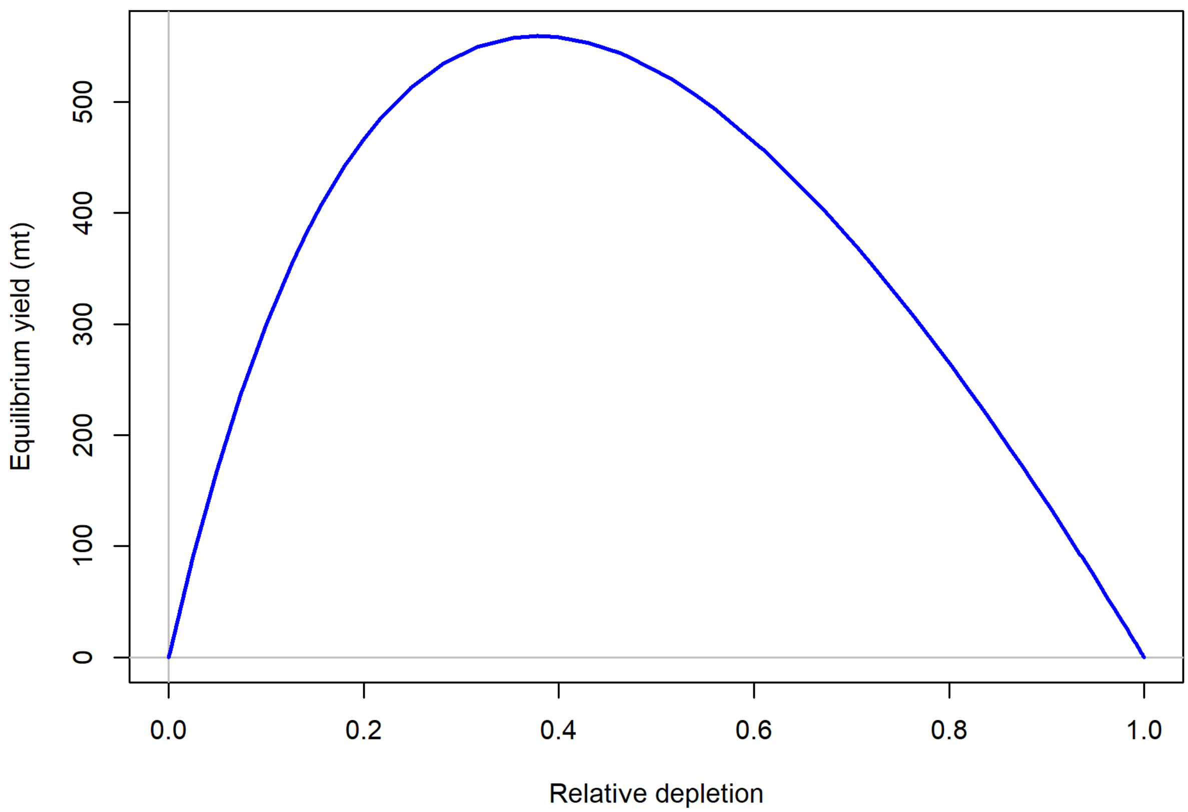

Figure 14: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.718. fig:yield1_yield_curve

#Appendix A. Detailed fits to length composition data {-}

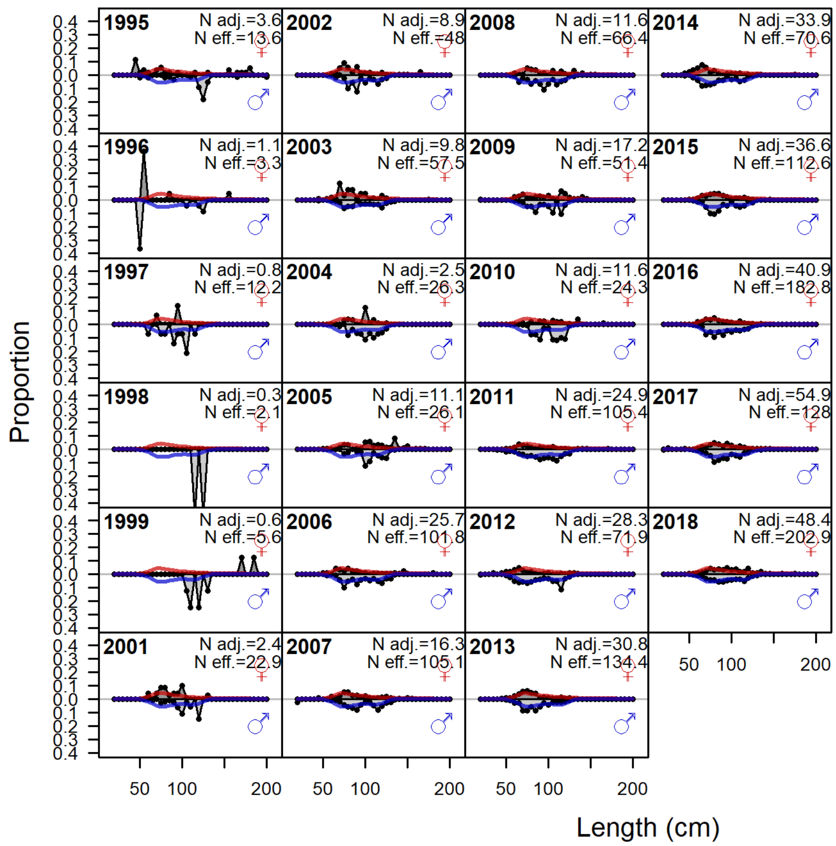

Figure A15: Length comps, retained, Fishery. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method. fig:mod1_1_comp_lenfit_flt1mkt2

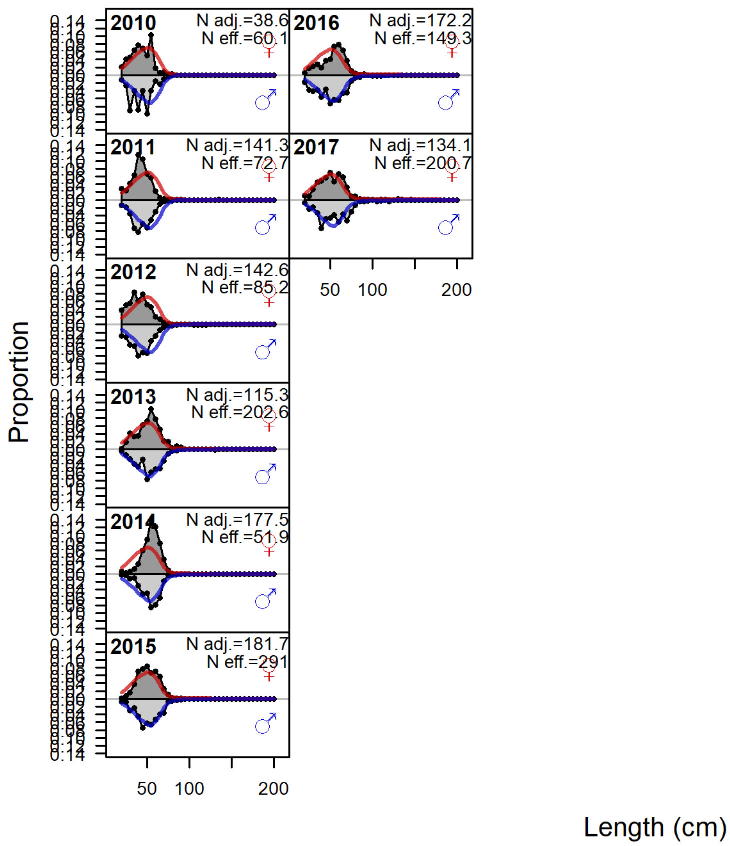

Figure A16: Length comps, discard, Fishery. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method. fig:mod1_2_comp_lenfit_flt1mkt1

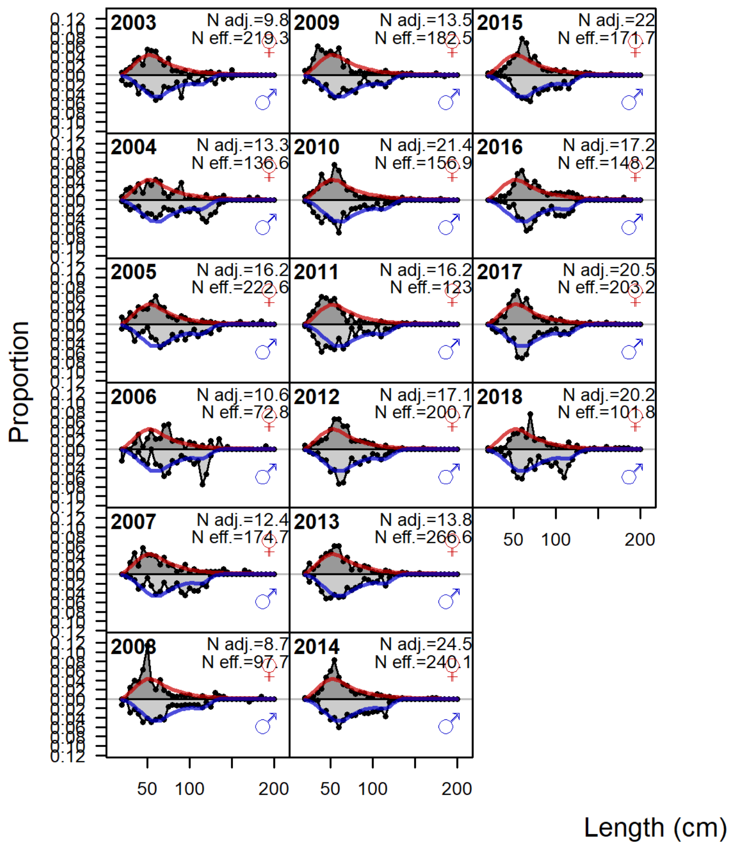

Figure A17: Length comps, whole catch, Triennial Survey. 'N adj.' is the input sample size after data_weighting adjustment. N_eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method. fig:mod1_3_comp_lenfit_flt5mkt0

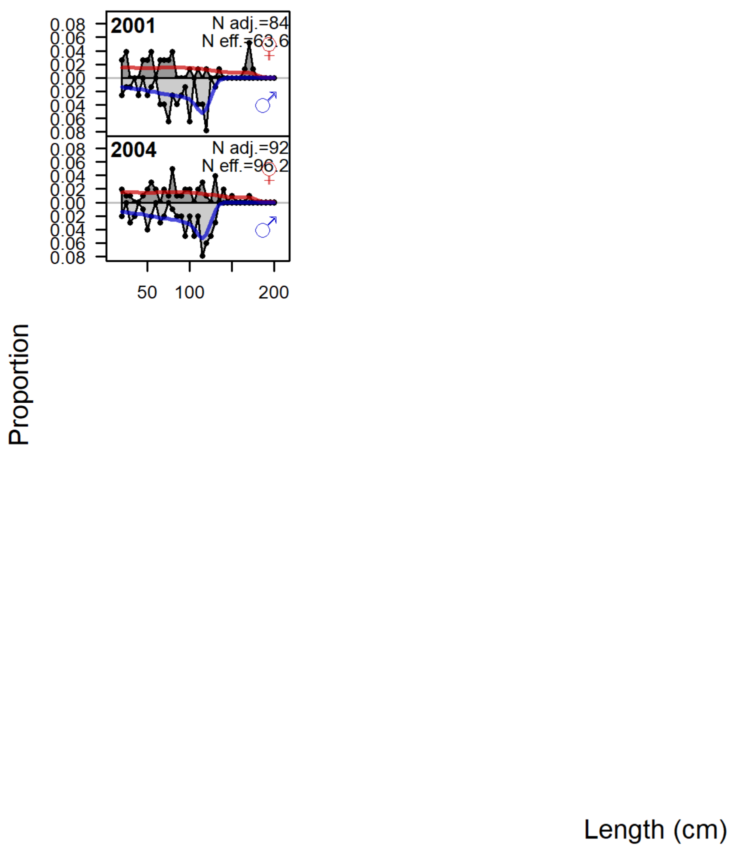

Figure A18: Length comps, whole catch, WCGBT Survey. ‘N adj.’ is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method. fig:mod1_4_comp_lenfit_flt6mkt0

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