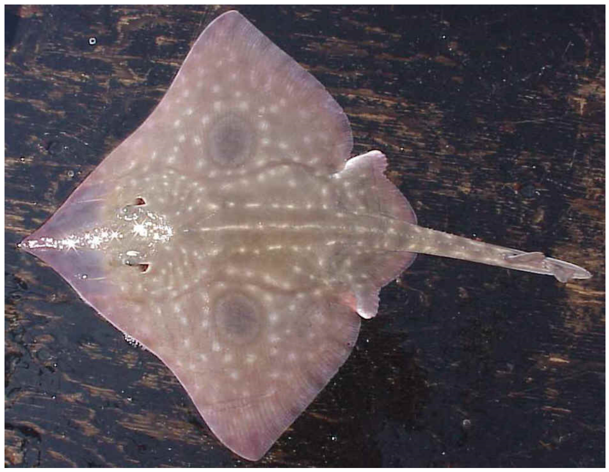
# Status of Big Skate (*Beringraja binoculata*) Off the U.S. Pacific Coast in 2019



Ian G. Taylor[1]
Vladlena Gertseva[1]
Joseph Bizzarro[2]
Andi Stephens[3]

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

[2]Southwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, California 95060

[3]Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2032 S.E. OSU Drive Newport, Oregon 97365

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

## Contents

# Executive Summary

## 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

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.

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)

| 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 |

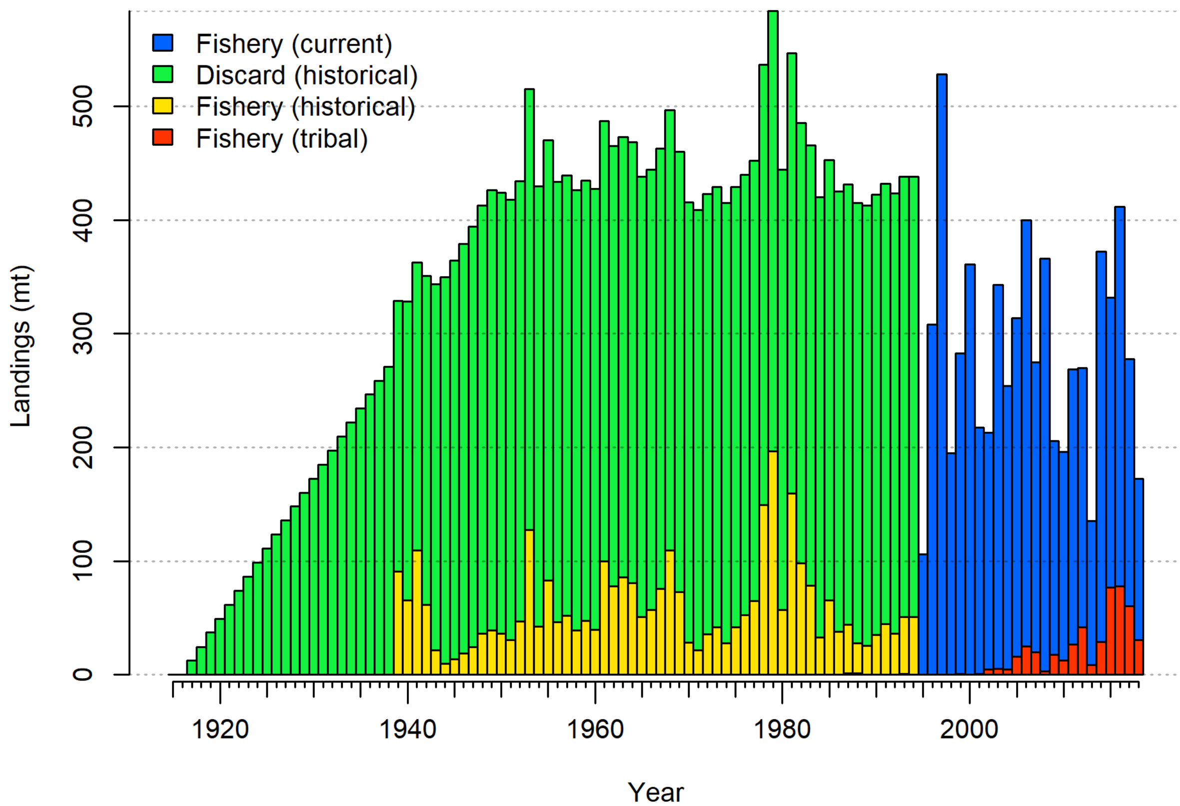



Figure a: Catch history of Big Skate in the model.

# 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.

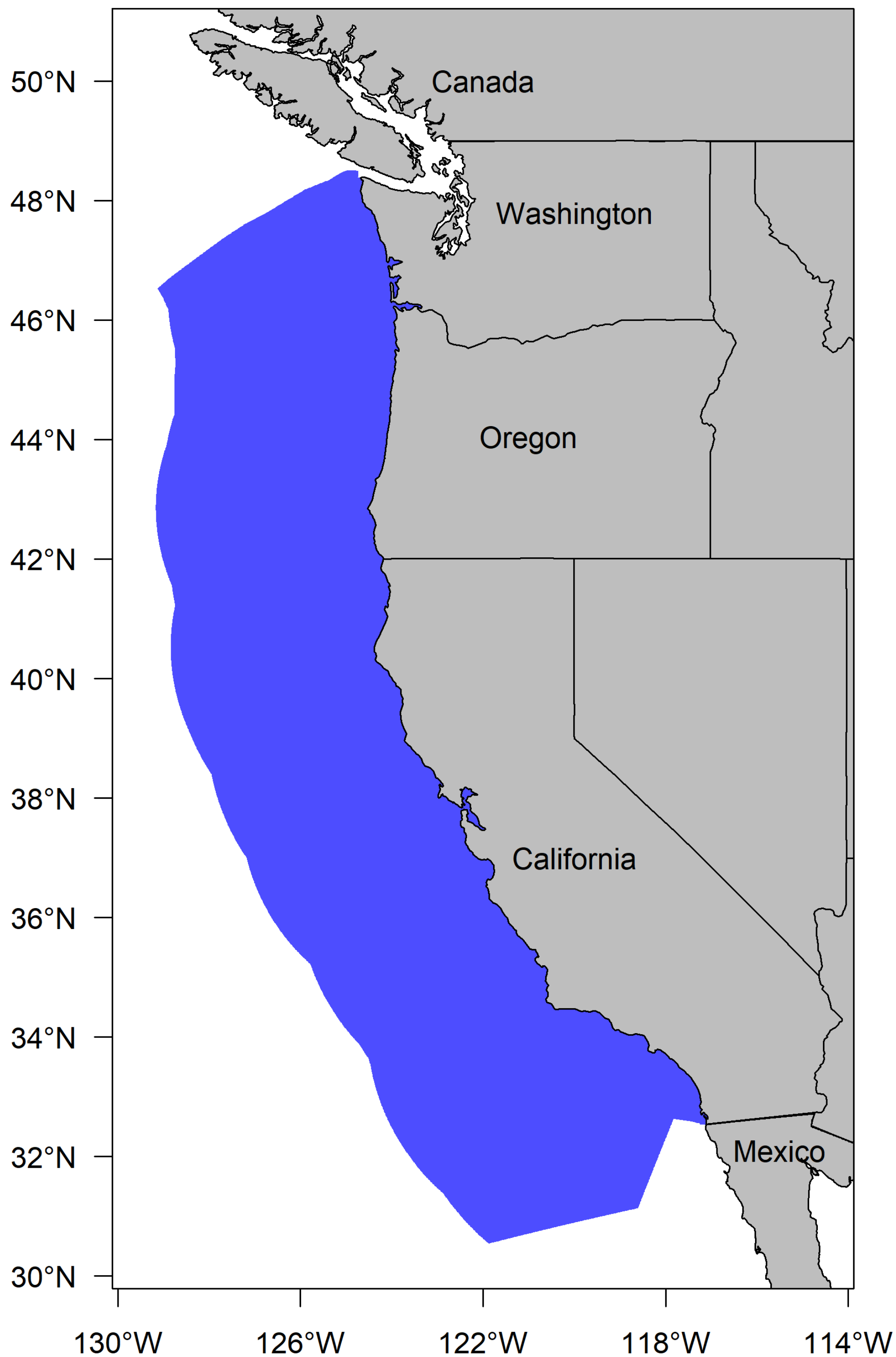



Figure b: This is a map depicting the distribution of Big Skate out to 600 ft. The data for this stock assessment are from Pt. Conception in the South to the U.S./Canada border in the north, as very few Big Skate are encountered south of Pt. Conception.

## Stock Biomass

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.

| 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) |

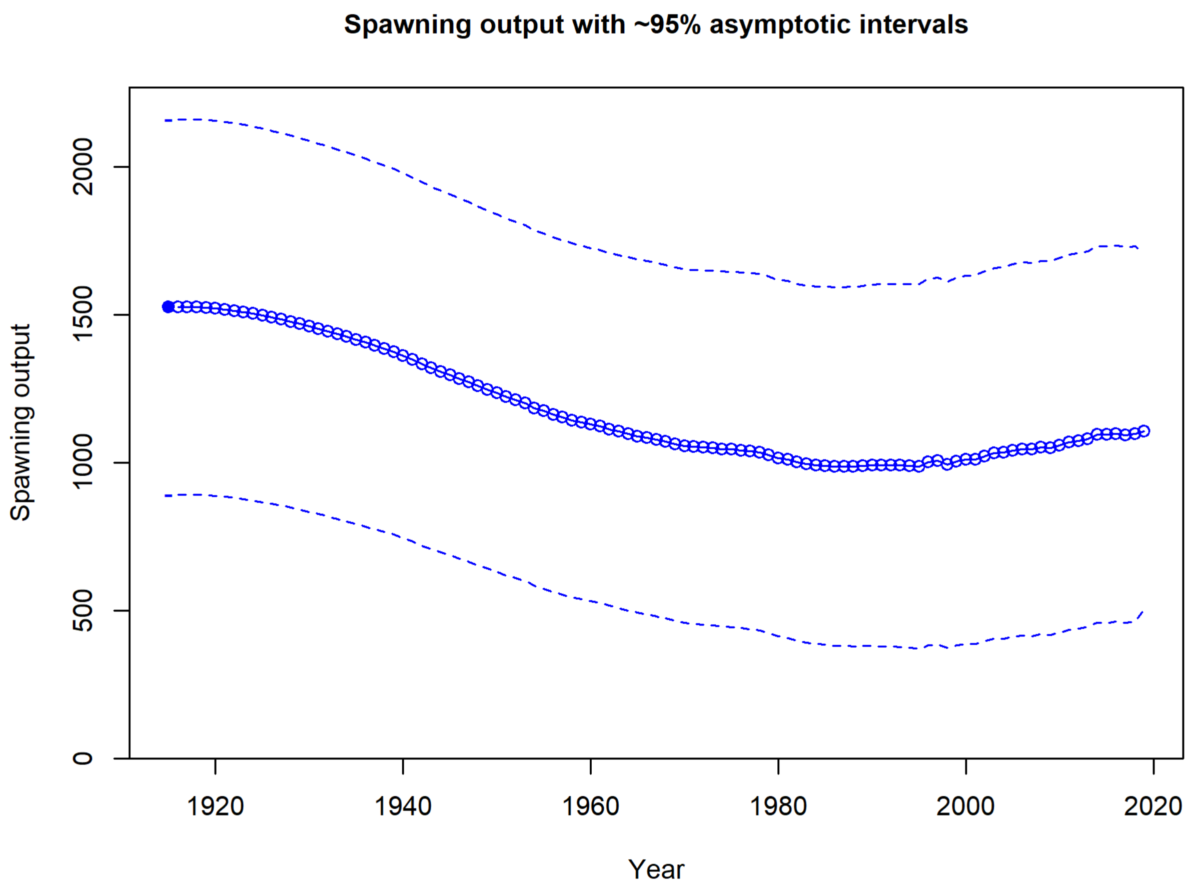



Figure c: Time series of spawning biomass trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base case assessment model.

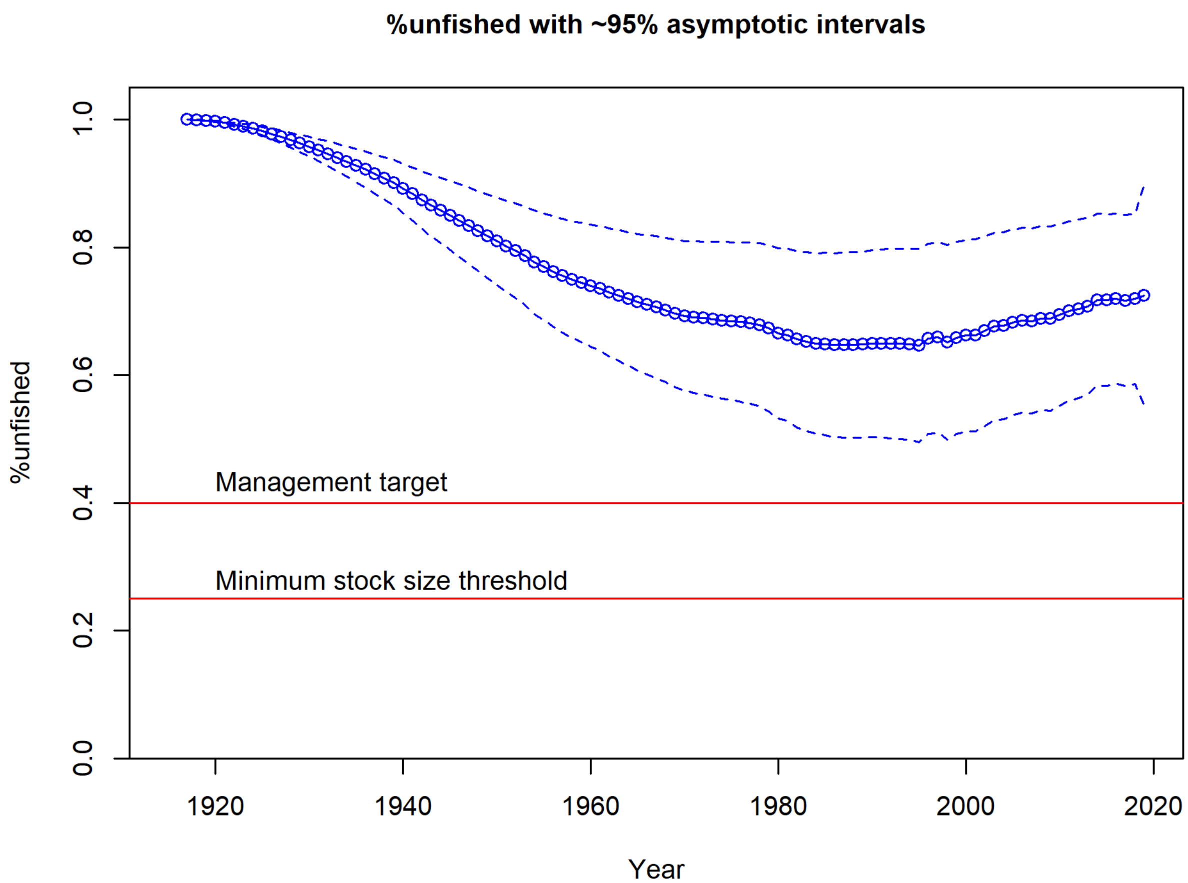



Figure d: Estimated relative depletion with approximate 95% asymptotic confidence intervals (dashed lines) for the base case assessment model.

# Recruitment

Recruitment deviations were estimated from 1916-2018 (Figure e 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) |

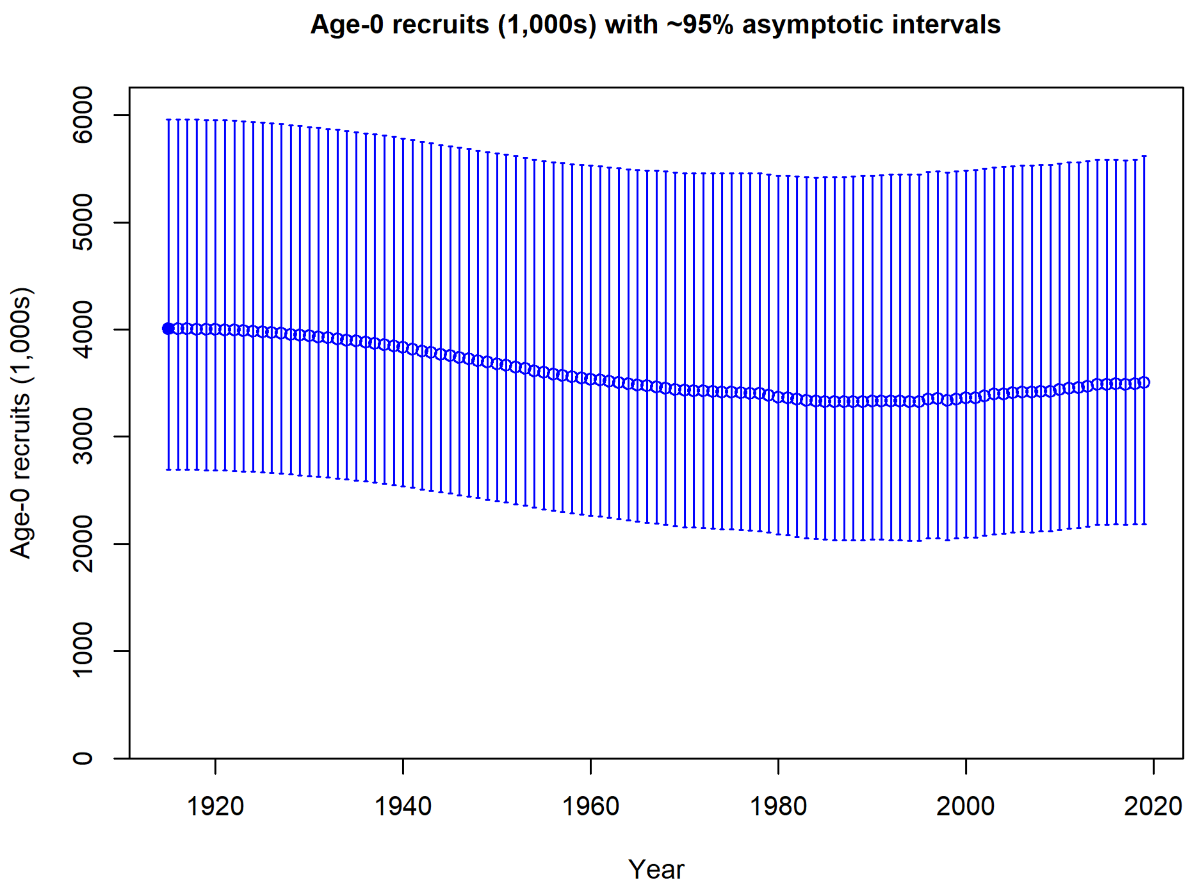



Figure e: Time series of estimated Big Skate recruitments for the base-case model with 95% confidence or credibility intervals.

# 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 $F_{SPR}$.

| 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) |

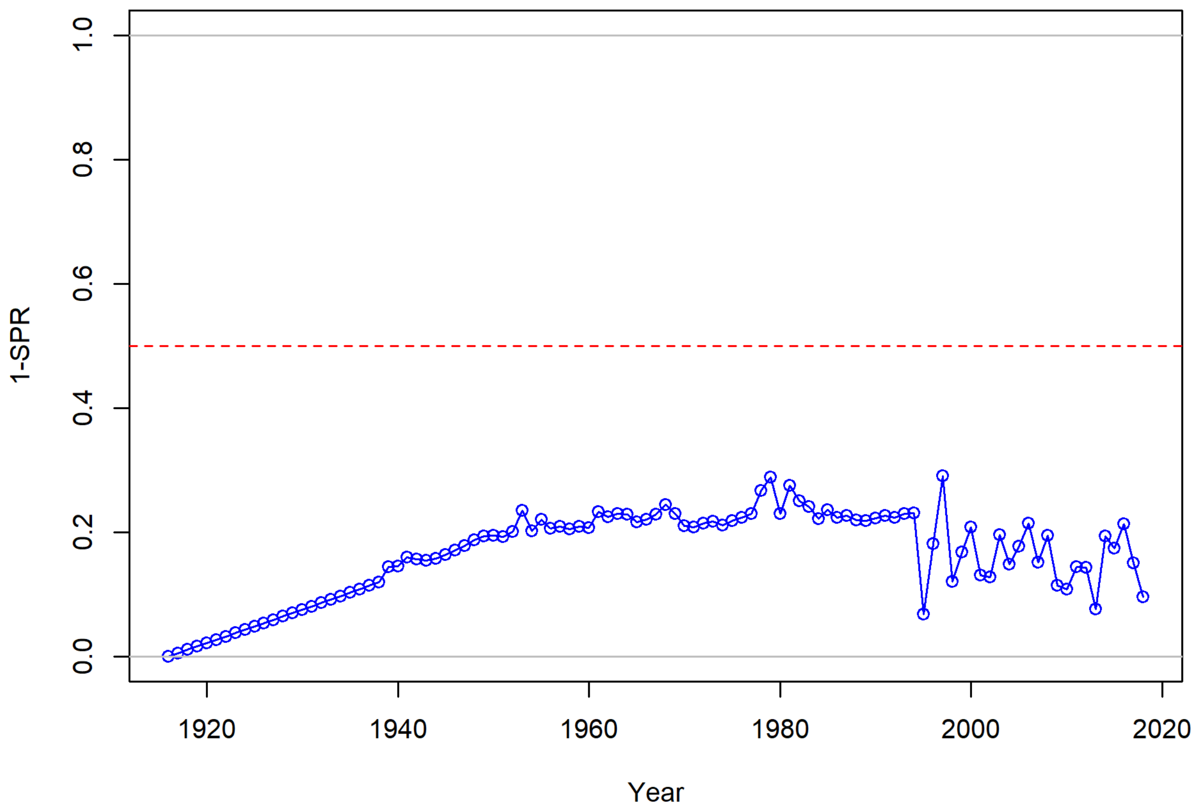



Figure f: Estimated spawning potential ratio (SPR) for the base-case model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing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

# 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

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: ± 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.

| **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

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 | |

# Unresolved Problems and Major Uncertainties

# Decision Table

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

| 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 |

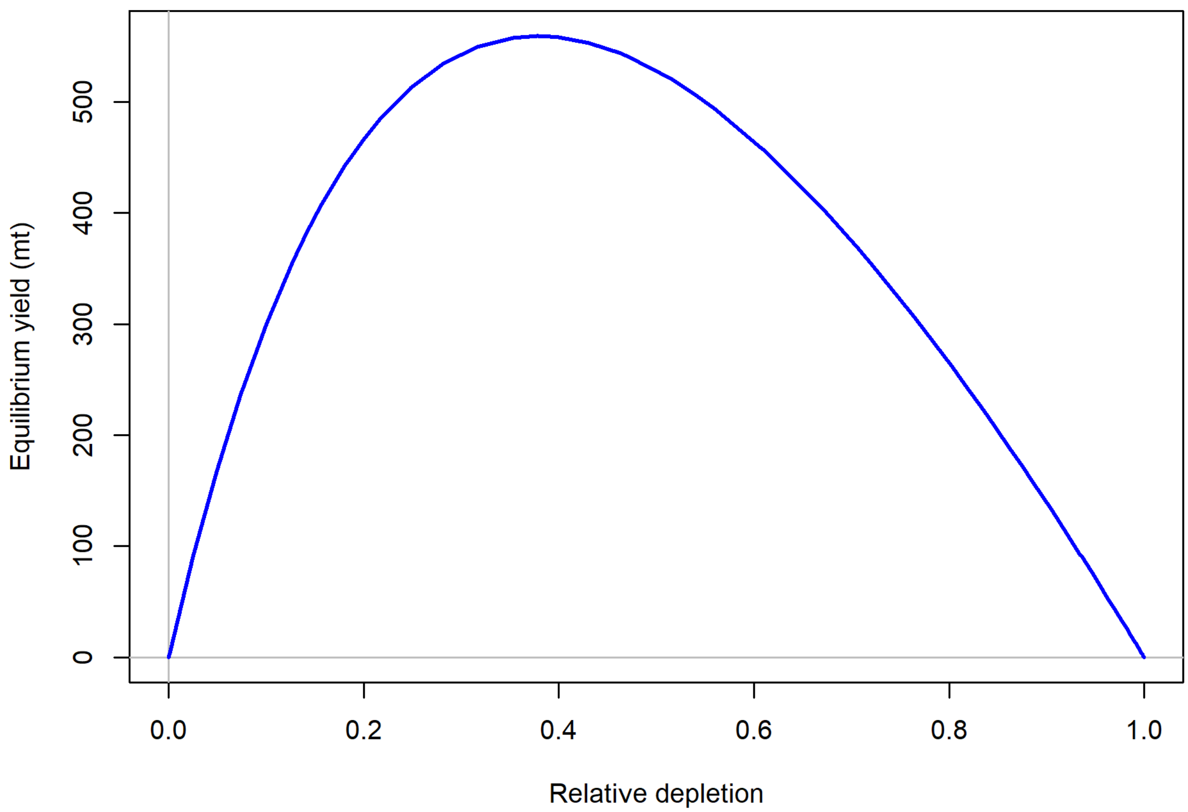



Figure g: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.718.

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

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

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

# 1 Introduction

## 1.1 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 (Bizzarro et al. (2007)); 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

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 (1993) 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 (McFarlane GA and King JR 2006); 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; Zeiner, S.J. and P. Wolf. (1993)) 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 (Gburski, C.M. and Gaichas, S.K. and Kimura, D.K. (2007), Ebert et al. (2008)). Generation length estimates range from 11.5 (Zeiner, S.J. and P. Wolf. 1993) to 17 years (McFarlane GA and King JR 2006).

Table 1: Regional comparison of life history parameter estimates.

| Region | Sex | 1st Maturity (TL cm) | 50% Maturity (TL cm) | Max Age (year) | 1st Maturity (year) | 50% Maturity (year) |
|---|---|---|---|---|---|---|
| California | Male | 100 | None | 11 | 10 | None |
| British Columbia | Female | 60 | 90 | 26 | 6 | 8 |
| British Columbia | Male | 50 | 72 | 25 | 5 | 10 |
| Gulf of Alaska | Female | 126 | 149 | 14 | 7 | 10 |
| Gulf of Alaska | Male | 124 | 119 | 15 | 9 | 7 |

## 1.3 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

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

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 (Lippert 2019).

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 (Lippert 2019); 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 (Calavan 2019).

## 1.6 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 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.

## Mexico

No information is available on any fishery for Big Skate in Mexican waters, however to the extent that they do occur, which is rarely, they may be taken in the artisanal fishery.

# 2 Fishery Data

## 2.1 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 Fishery Landings and discards

Catch 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 the landings of all skates as well as an analysis of discards of Longnose Skate. The estimated landings for each state and the tribal fishery are are provided in Table 2 and shown in Figure 3.

### 2.2.1 Washington Commercial Skate Landings Reconstruction

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

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

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

### 2.2.2 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.).

### 2.2.3 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. However, since Washington and Oregon did not have catch estimates for this year period, the California estimates of catch prior to 1938 were not used as they were subsumed into an estimated of the total catch across all states increasing linearly from 1916 to 1950.

### 2.2.4 Tribal Catch in Washington

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

### 2.2.5 Fishery Discards

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

Both what discard rate information is available and anecdotal information from those involved in the fishery for both skate species indicate 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. Therefore, the discard rate for Longnose Skate was used as a proxy for the discards of Big Skate in order to estimate Big Skate discards.

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

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

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

### 2.2.6 Fishery Length and Age Data

Fishery length composition data was available from PacFIN were available for the years 1995–2018 (with the exception of 2000) as shown in Table 4. Ages were available from only 2004, 2008-2012, and 2018. These were all represented as conditioned on length in order to provide more detailed information about the relationship between age and length, to reduce any influence of size-based selectivity on the age composition, and to ensure independence from the length samples.

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

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

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

# 3 Fishery-Independent Data Sources

## 3.1 Indices of abundance

### 3.1.1 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.

### 3.1.2 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 "WCGBT Survey" or "WCGBTS", is conducted annually. 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).

### 3.1.3 Index Standardization

The index standardization methods for the two bottom trawl surveys matched that used for Longnose Skate and additional detail is provided in (Gertseva, V. 2019). The data from both surveys 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 for the WCGBT Survey but not the Triennial 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).

Spatial patterns in the survey estimates show Big Skate widely distributed along the coast, with higher densities in the central and more northern areas and closer to shore 7.

### 3.1.4 Survey length composition data

Lengths of Big Skate were only collected form the Triennial survey in 1998, 2001, and 2004, but 1998 had only 3 samples and were excluded from this analysis. Length compositions were available for all years of the WCGBT Survey. Sample sizes for both surveys are provided in Table 5

### 3.1.5 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 (**???**), and Spiny Dogfish (**???**). 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.

### 3.1.6 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 9. 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 $L_\infty$ 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 10).

#### 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 11).

#### 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

### 3.1.7 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.

# 4 Assessment

## 4.1 Previous Assessments

### 4.1.1 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).

### 4.1.2 yyyy Assessment Recommendations

**Recommendation 1:**

STAT response: xxxxx

**Recommendation 2:**

STAT response: xxxxx

**Recommendation 3:**

STAT response: xxxx

## 4.2 Model Description

### 4.2.1 Transition to the Current Stock Assessment

### 4.2.2 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

### 4.2.3 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.

### 4.2.4 Data Weighting

### 4.2.5 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.

### 4.2.6 Estimated and Fixed Parameters

A full list of all estimated and fixed parameters is provided in Tables 7.

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 7.

*Growth.*

*Natural Mortality.*

*Selectivity.*

*Other Estimated Parameters.*

*Other Fixed Parameters.*

## 4.3 Model Selection and Evaluation

### 4.3.1 Key Assumptions and Structural Choices

### 4.3.2 Alternate Models Considered

### 4.3.3 Convergence

## 4.4 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

## 4.5 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 7 and the likelihood components are in Table 8. 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 9.

### 4.5.1 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 13 ).

The stock-recruit curve . . . Figure 14 with estimated recruitments also shown.

### 4.5.2 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.

### 4.5.3 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/

#### 4.5.4 Retrospective Analysis

#### 4.5.5 Likelihood Profiles

#### 4.5.6 Reference Points

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 18

The 2018 spawning biomass relative to unfished equilibrium spawning biomass is above/below the target of 40% of unfished levels (Figure 19). 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 20 shows the equilibrium curve based on a steepness value xxx.

# 5 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.

# 6 Regional Management Considerations

# 7 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. **Data!**:
2. **xxxx**:
3. **xxxx**:
4. **xxxx**:
5. **xxxx**:

# 8 Acknowledgments

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

# 9 Tables

## 9.1 Data Tables

Table 2: 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 2: 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 2: 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 3: 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 4: 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 5: Samples from the surveys.

| | 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 | | |

## 9.2 Model Results Tables

Table 6: 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 7: 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 7: 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_WCGBTS(5) | -0.144 | 1 | (-2, 2) | OK | 0.187 | Normal (-0.188, 0.187) |
| 79 | Q_extraSD_WCGBTS(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 7: 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_WCGBTS(5) | 72.392 | 4 | (50, 150) | OK | 5.639 | None |
| 103 | Size_DblN_top_logit_WCGBTS(5) | -15.000 | -5 | (-15, 4) | | | None |
| 104 | Size_DblN_ascend_se_WCGBTS(5) | 6.440 | 4 | (-1, 9) | OK | 0.371 | None |
| 105 | Size_DblN_descend_se_WCGBTS(5) | 10.061 | 5 | (-1, 20) | OK | 1.621 | None |
| 106 | Size_DblN_start_logit_WCGBTS(5) | -5.000 | -4 | (-999, 9) | | | None |
| 107 | Size_DblN_end_logit_WCGBTS(5) | -999.000 | -5 | (-999, 9) | | | None |
| 108 | SzSel_Fem_Peak_WCGBTS(5) | -7.134 | 4 | (-50, 50) | OK | 3.982 | None |
| 109 | SzSel_Fem_Ascend_WCGBTS(5) | 0.000 | -4 | (-5, 5) | | | None |
| 110 | SzSel_Fem_Descend_WCGBTS(5) | 0.000 | -4 | (-5, 5) | | | None |
| 111 | SzSel_Fem_Final_WCGBTS(5) | 0.000 | -4 | (-5, 5) | | | None |
| 112 | SzSel_Fem_Scale_WCGBTS(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 |

Continued on next page

Table 7: 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 8: 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 |
| Parmeter soft bounds | 0.01 |

Table 9: 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 9: 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 9: 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 10: 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 11: 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 12: Sensitivity of the base model to assumptions about biology and misc.

| Label | Base.model | Bio.separate.M.by.sex | Bio.M.prior | Bio.von.bertalanffy.growth | Bio.Richards.growth | Misc.McAllister.Ianelli.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 13: Summary of the biomass/abundance time series used in the stock assessment.

| Fleet | Years | Name | Fishery ind. | Filtering | Method | Endorsed |
|---|---|---|---|---|---|---|
| 4 | 2004-2016 | Recreational PR dockside CPUE | No | trip, area, regulations, Stephens-MacCall | delta-GLM (bin-lognormal) | SSC |
| 5 | 1980-2016 | CPFV logbook CPUE | No | trip, gear, effort, species, depth, sample size | negative binomial | SSC |
| 6 | 2002-2016 | Onboard observer discard catch CPUE | No | habitat ,regulations, effort, boats | delta-GLM (bin-lognormal) | SSC |
| 7 | 1970-2016 | Sanitation district CPUE | Yes | sample size, depth, tow times | delta-GLM (bin-lognormal) | SSC |
| 8 | 2003-2016 | NWFSC trawl survey CPUE | Yes | depth, area | VAST | SSC |
| 9 | 1995-2008 | CSUN/VRG Gillnet survey CPUE | Yes | gear, site, month | delta-GLM (bin-lognormal) | SSC |
| 11 | 1994; 1998; 2003; 2008; 2013 | Southern California Bight trawl survey CPUE | Yes | depth, area | delta-GLM (bin-lognormal) | SSC |
| 12 | 2002-2016 | Onboard observer retained catch CPUE | No | habitat, regulations, effort, boats | delta-GLM (bin-lognormal) | SSC |

Table 14: 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 |
| Equililibrium 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 15: Summaries of key assessment outputs and likelihood values from selected likelihood profile runs on virgin recruitment (lnR0) 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 16: 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 17: 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 |

# 10 Figures

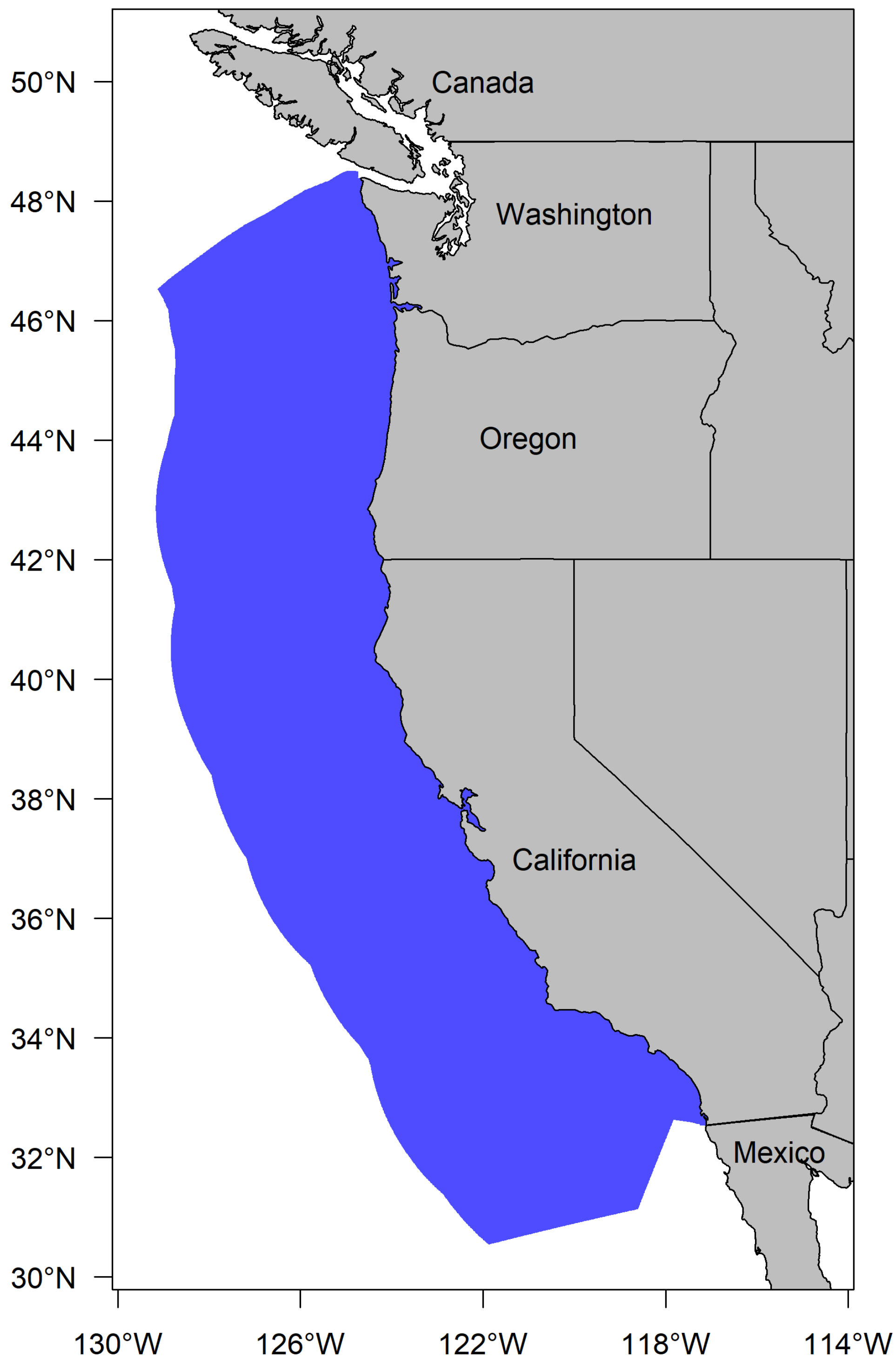



Figure 1: Map showing the U.S. Exclusive Economic Zone covered by this stock assessment.

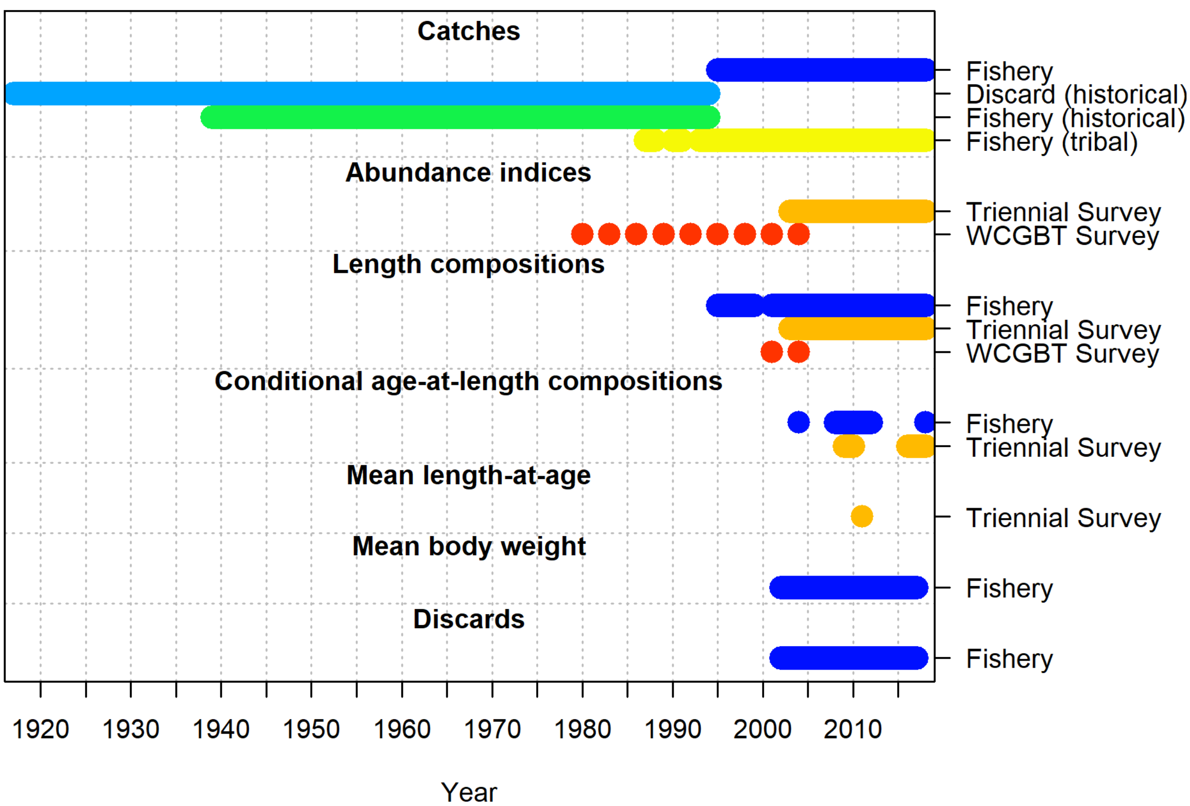



Figure 2: Summary of data sources used in the model.

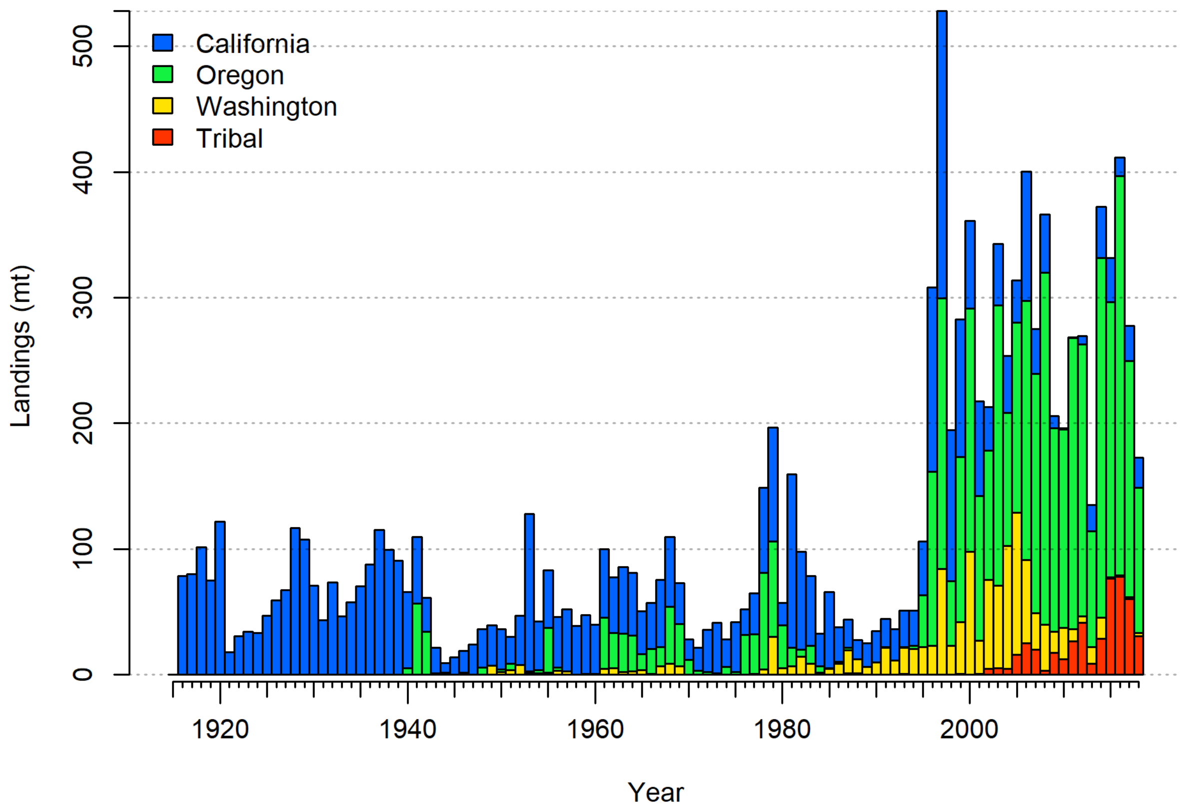



Figure 3: Catch by area. Tribal catch was all landed in Washington State.

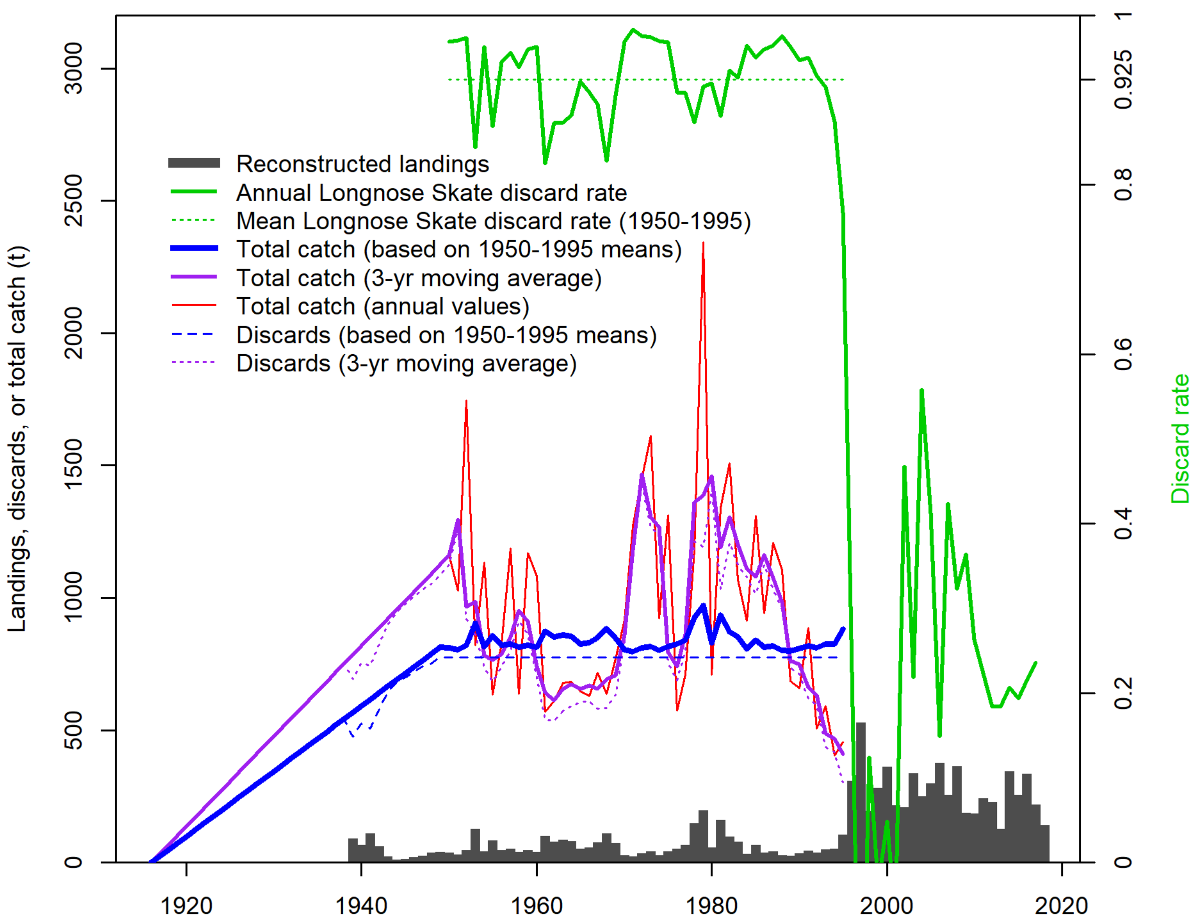



Figure 4: Estimated total catch using different assumptions for discards.

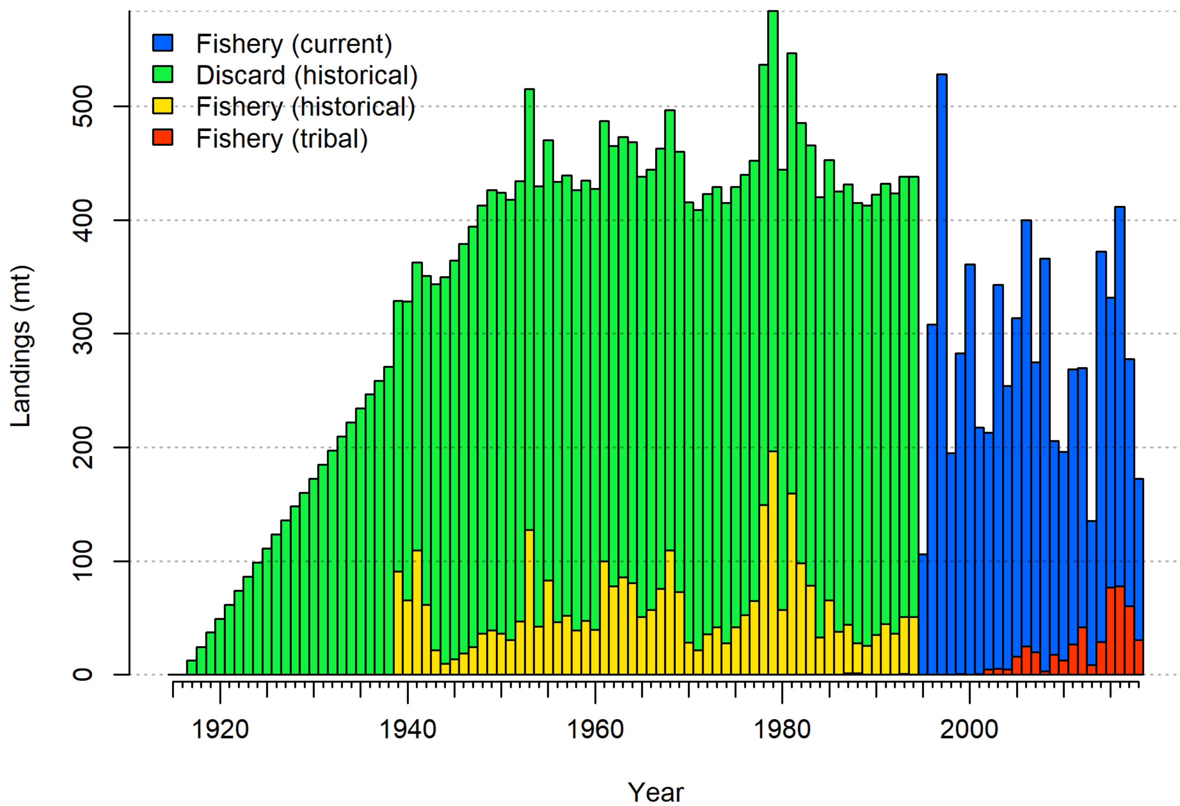



Figure 5: Catch data input to the model under assumed fleet structure. The historical discards shown in green have been scaled to account for an assumed 50% discard mortality. Discards during the period from 1995 onward are not represented here as they are estimated within the model.

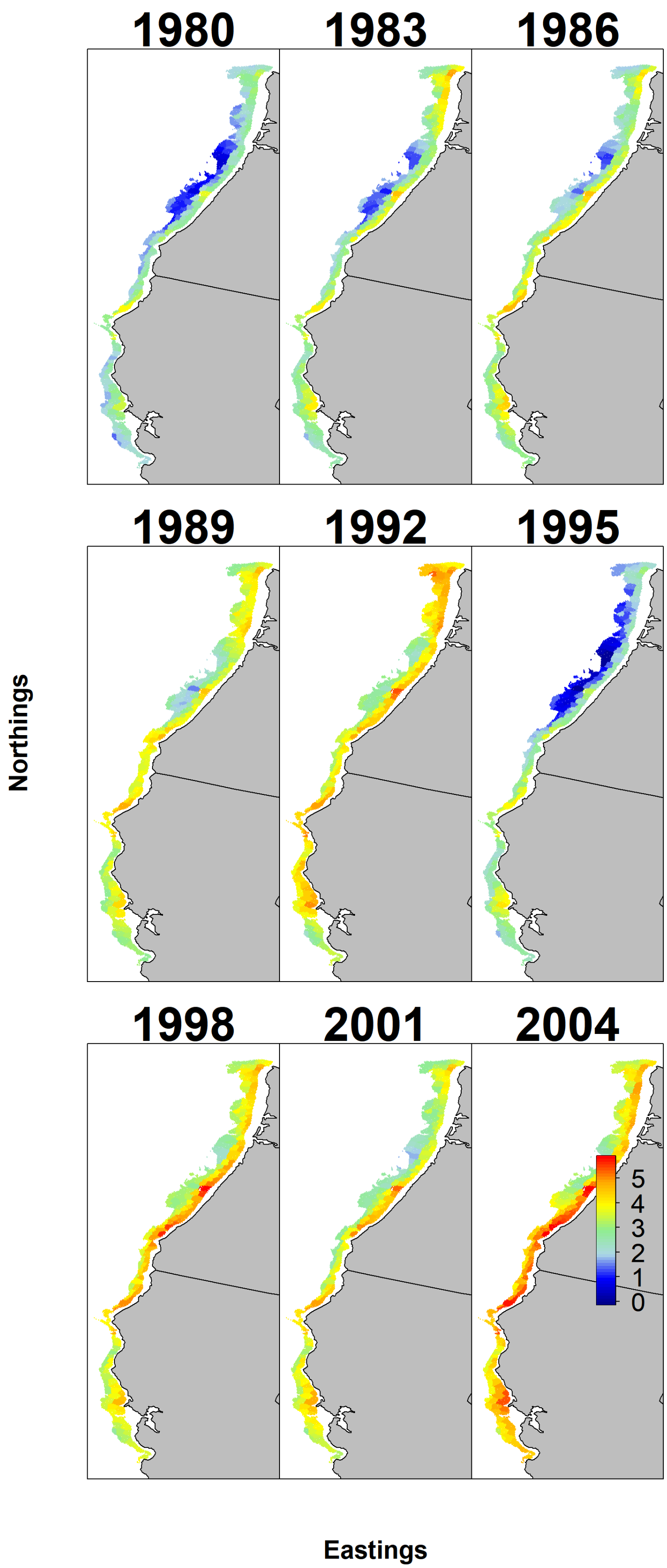



Figure 6: Map of estimated density by year for Big Skate in the Triennial survey.

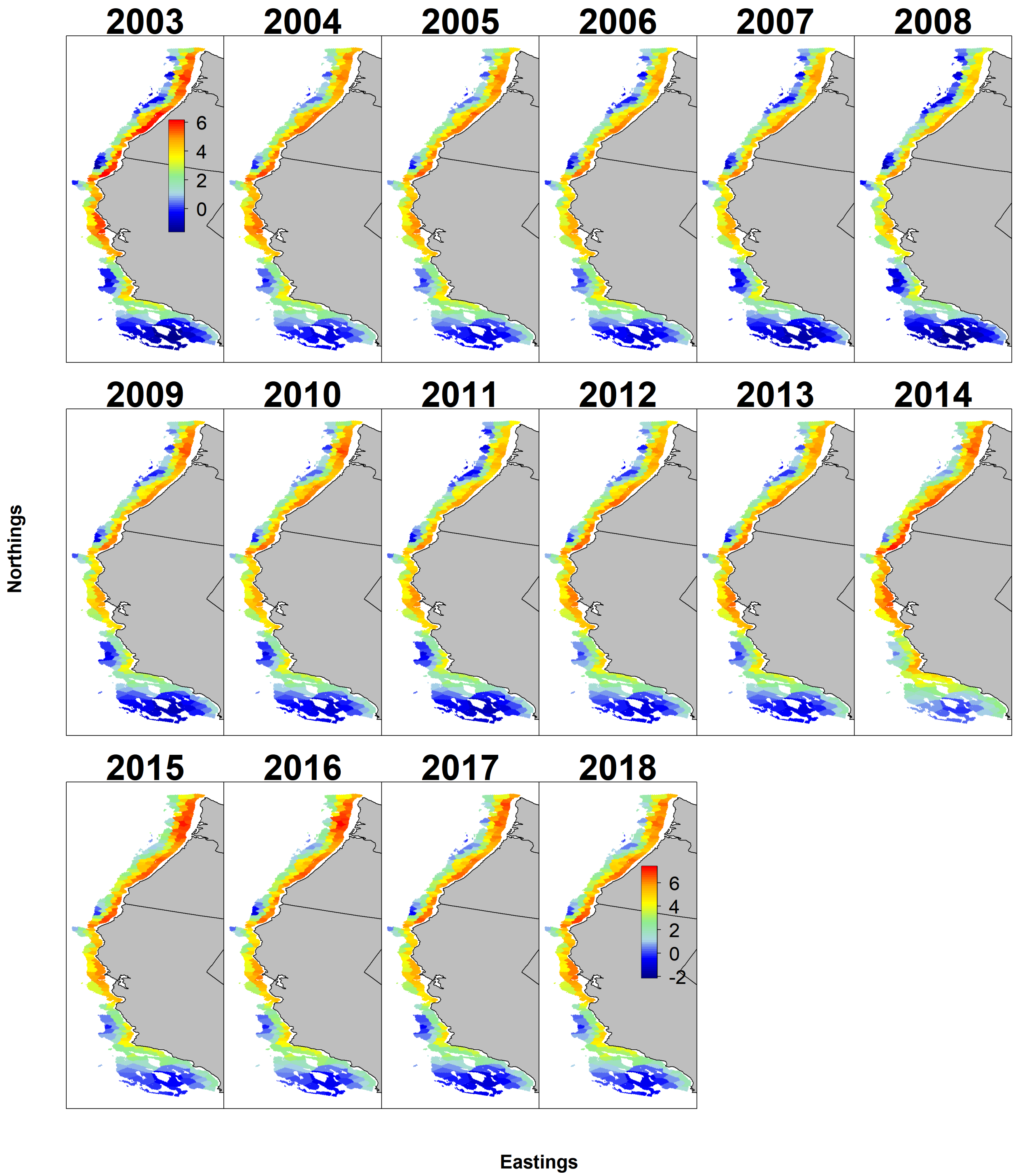



Figure 7: Map of estimated density by year for Big Skate in the WCGBT Survey.

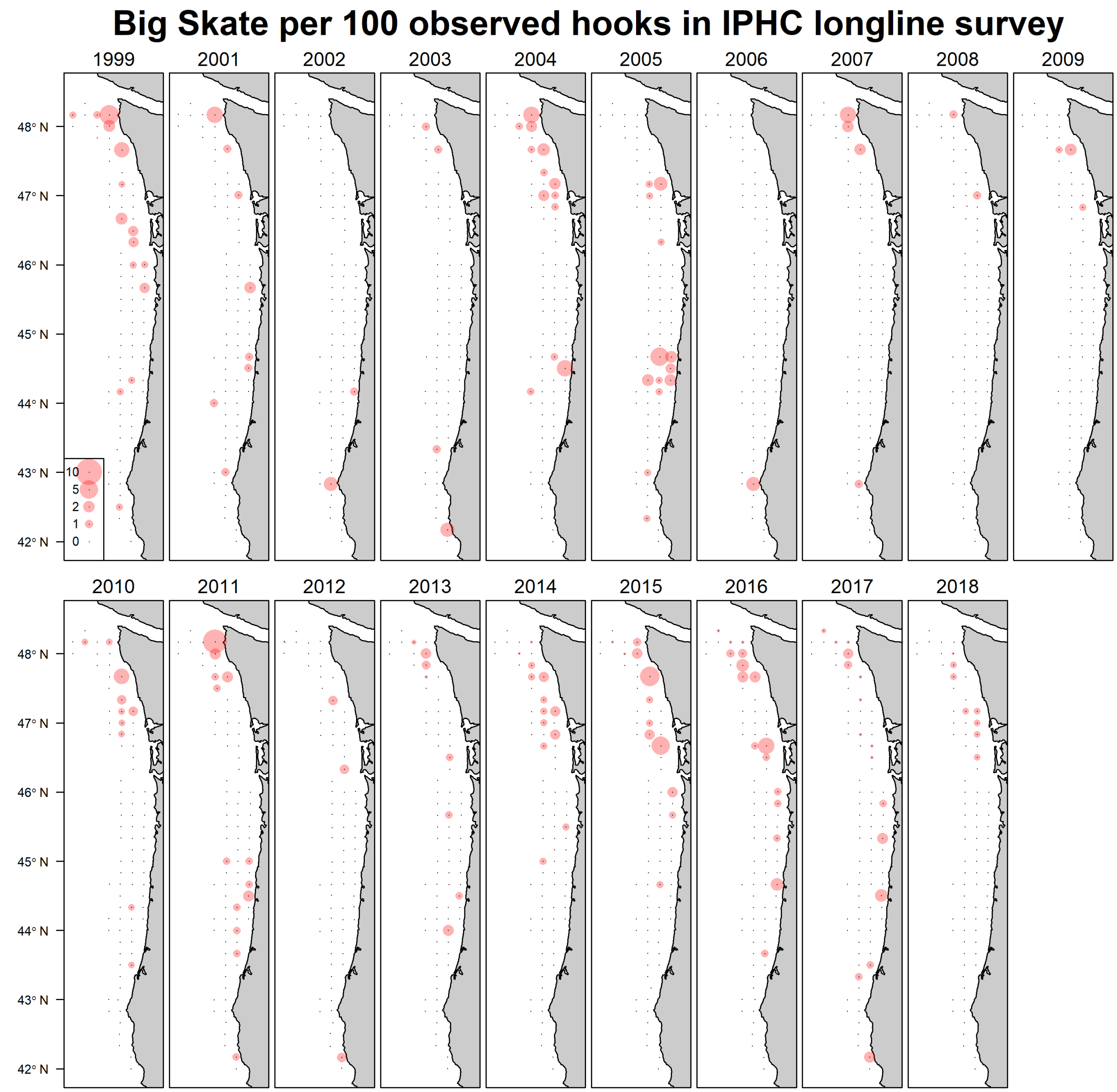



Figure 8: Map of catch rates by year for Big Skate in the International Pacific Halibut Commission longline survey.

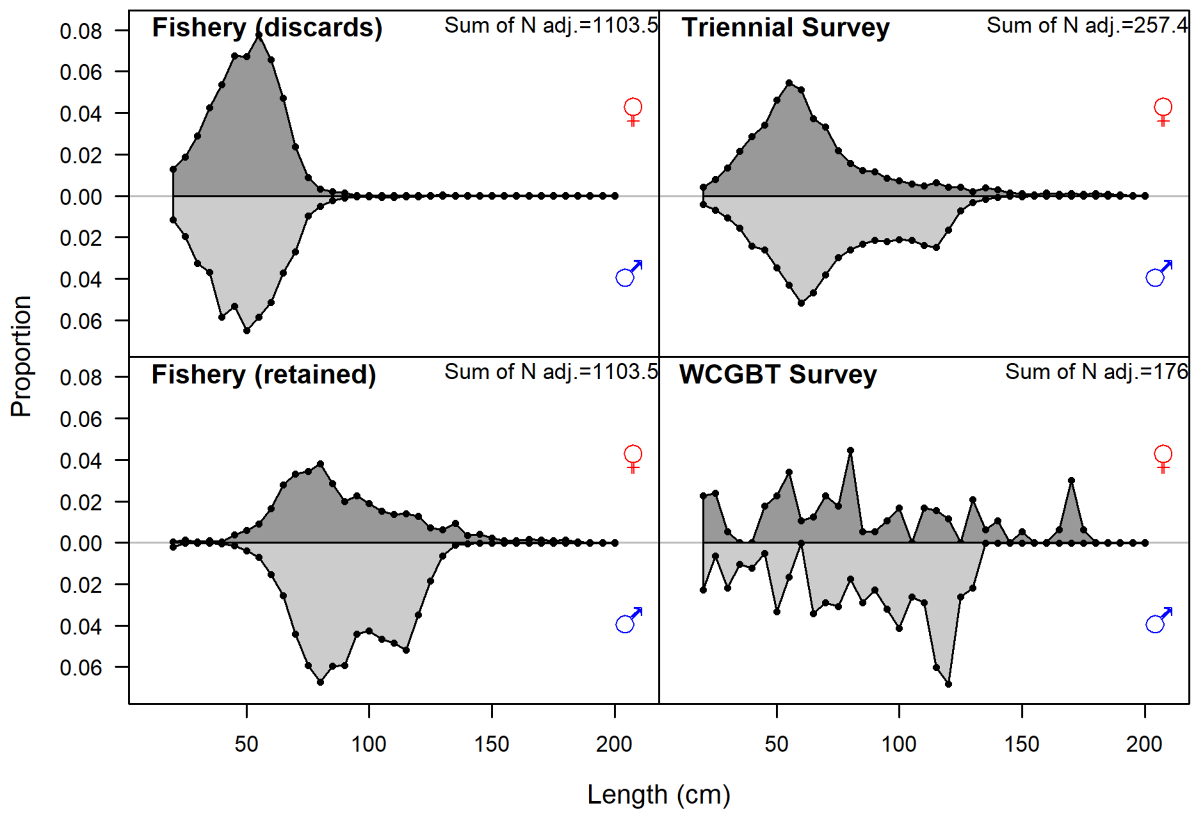



Figure 9: Length comp data, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch.

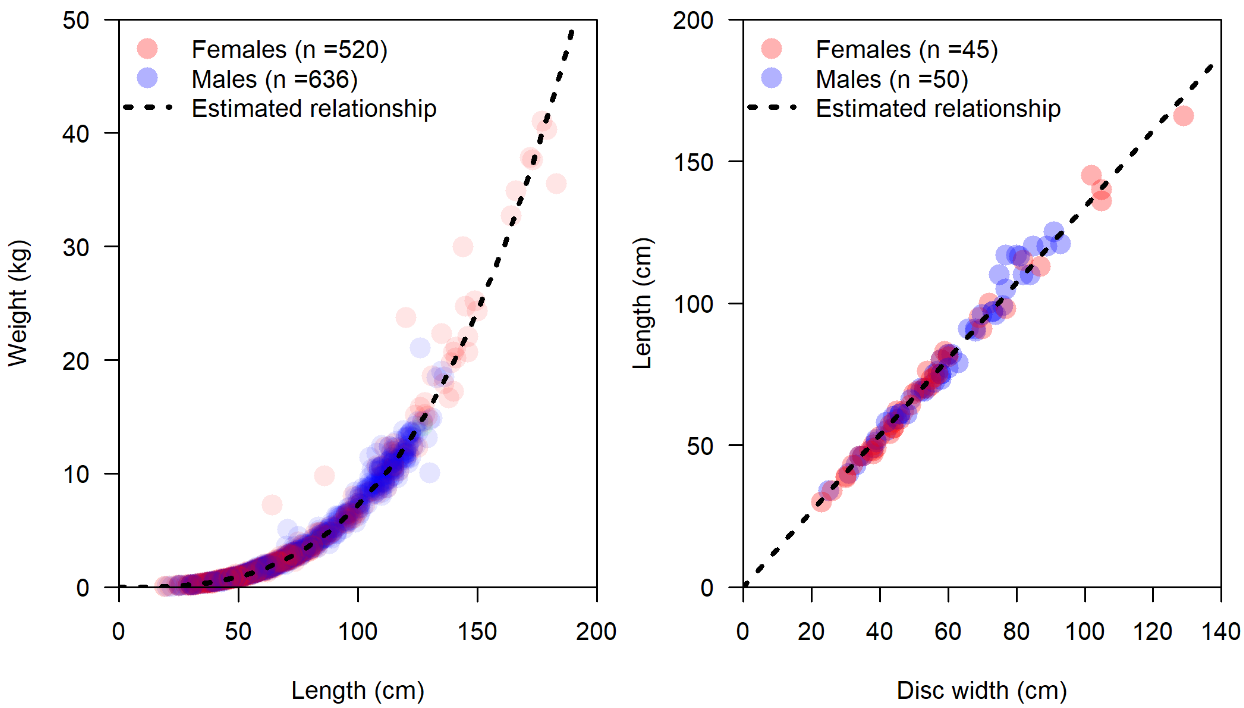



Figure 10: Estimated relationship between length and weight (left) and disc-width and length (right) for Big Skate. Colored points show observed values and the black line indicates the estimated relationship $W = 0.0000074924L^{2.9925}$.

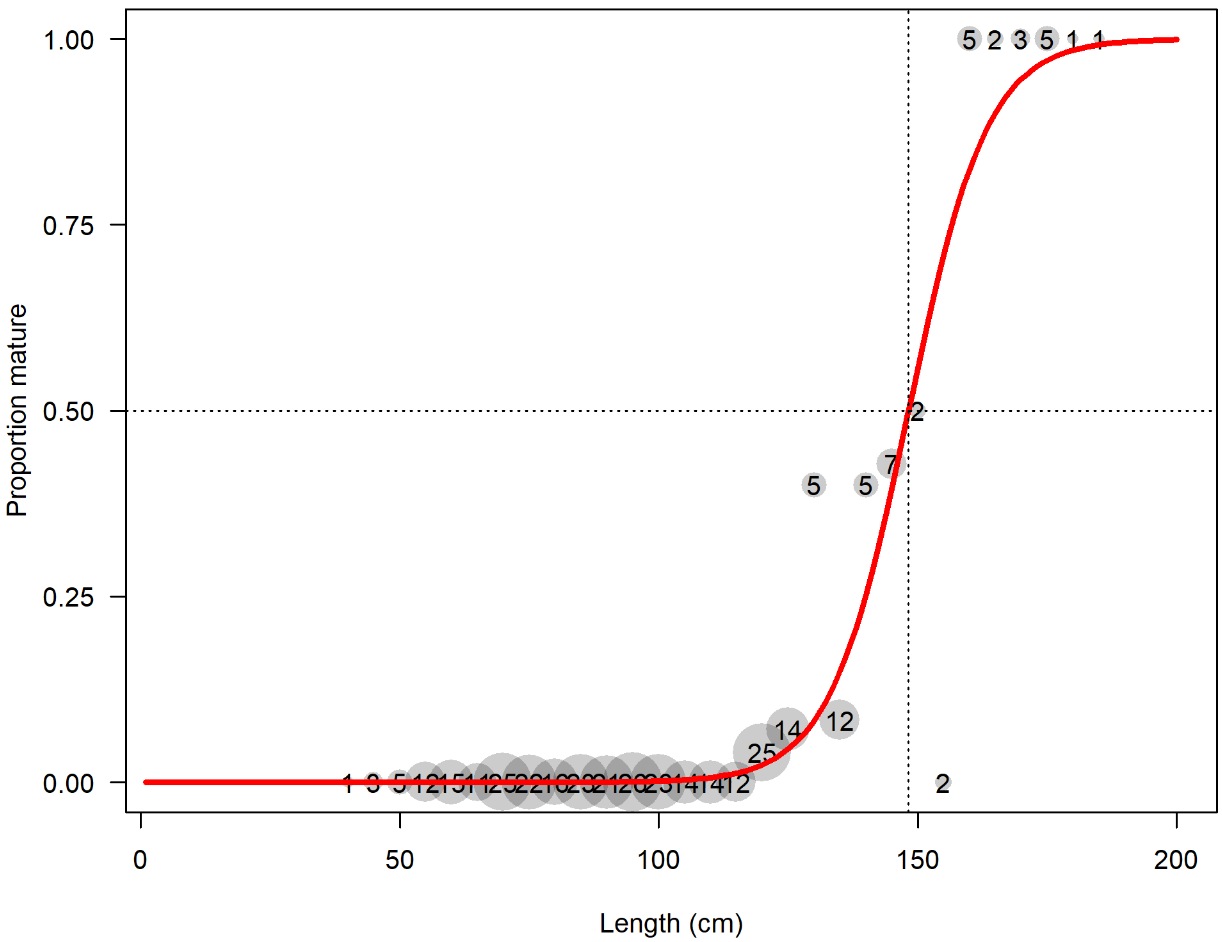



Figure 11: Estimated maturity relationship for female Big Skate. Gray points indicate average observed functional maturity within each length bin with point size proportional to the number of samples (indicated by text within each point).

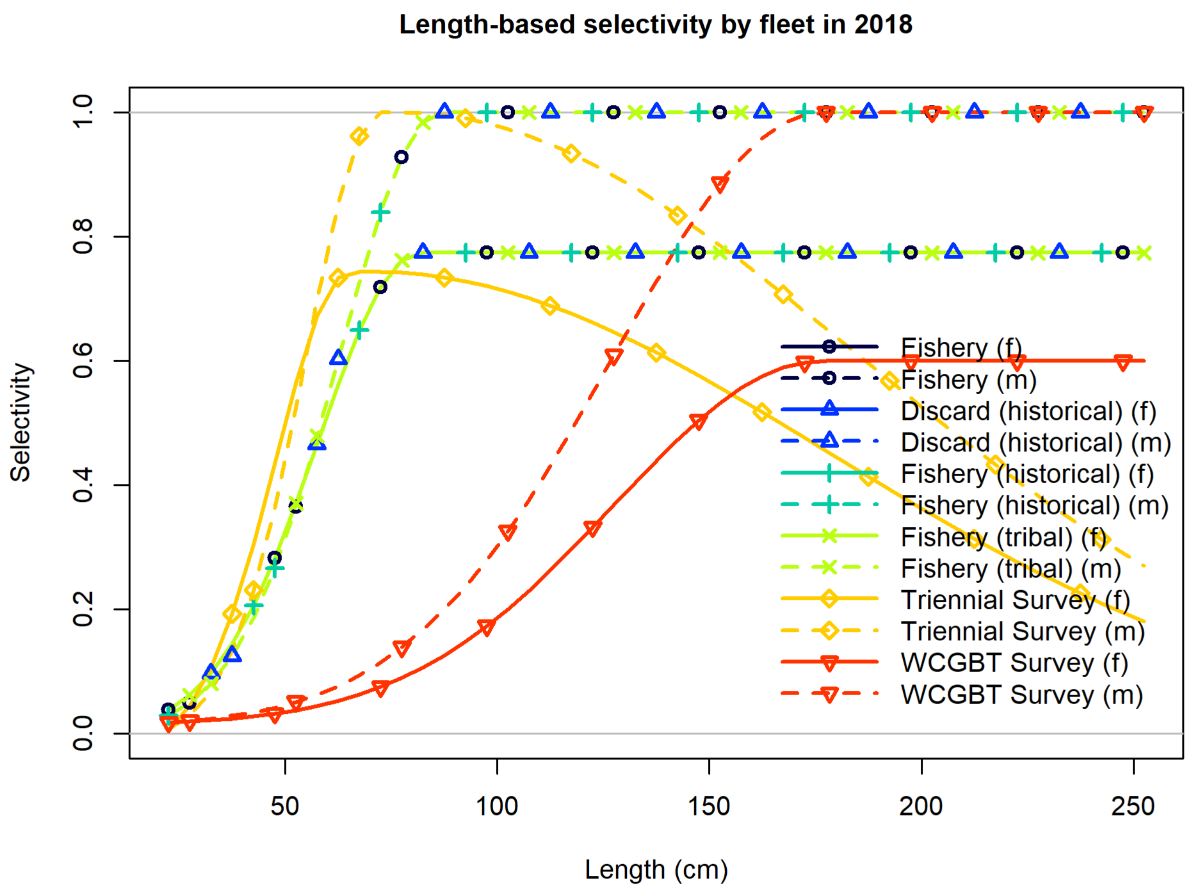



Figure 12: Selectivity at length for all of the fleets in the base model.

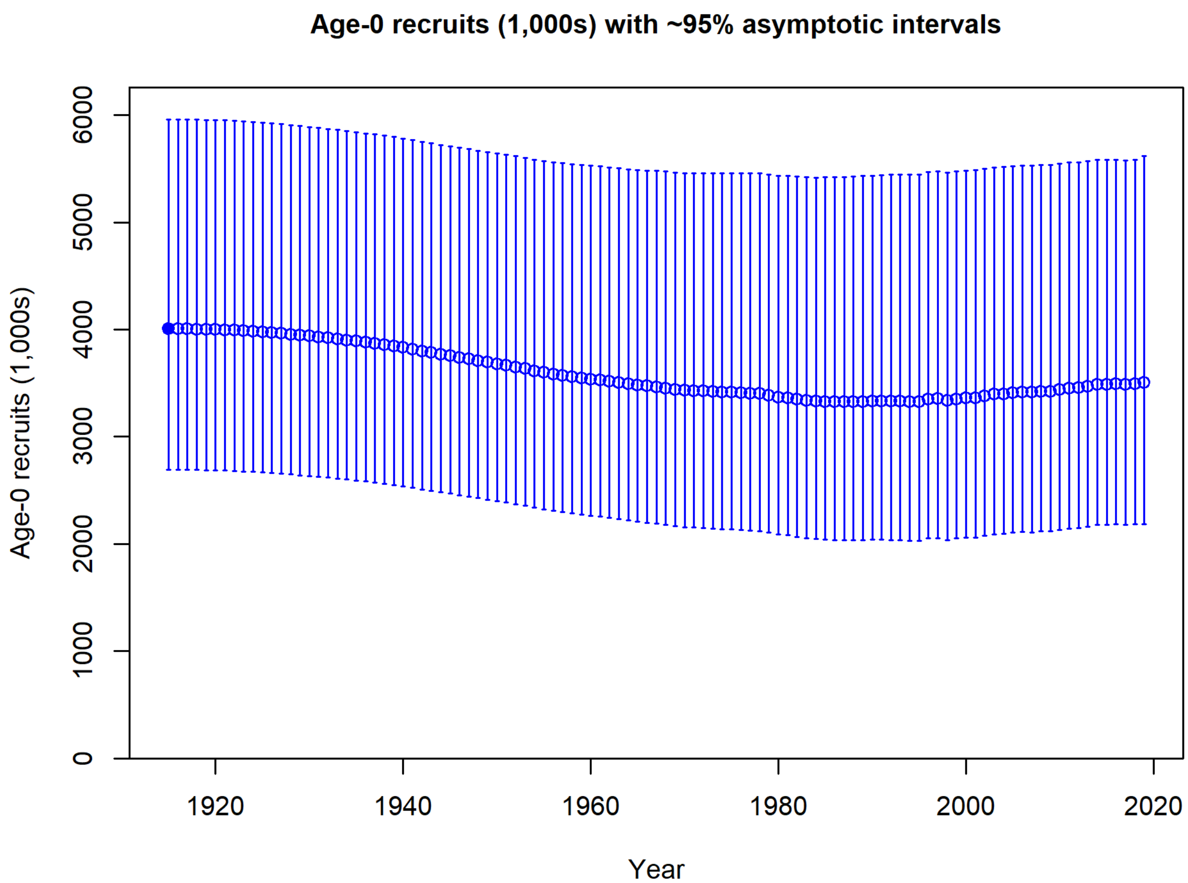



Figure 13: Estimated time-series of recruitment for Big Skate.

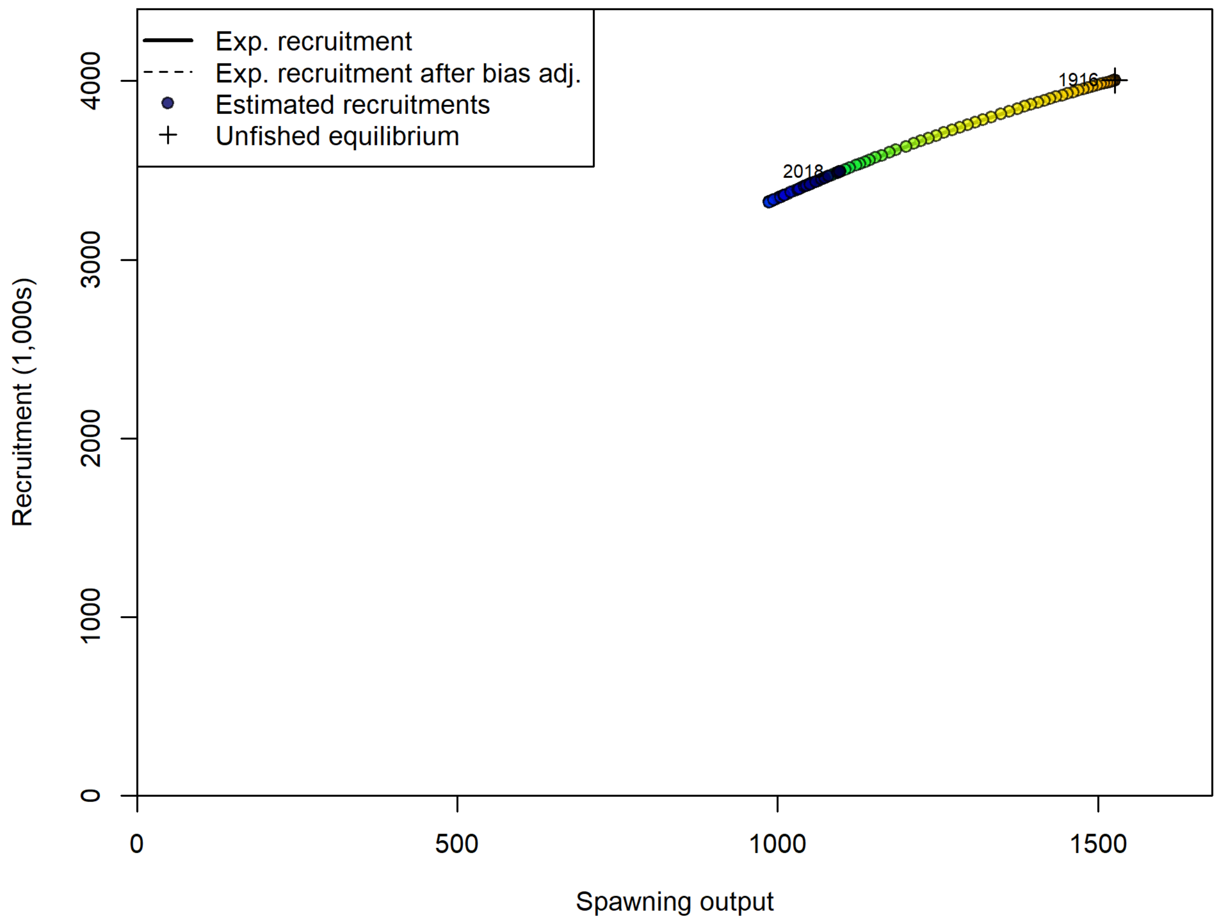
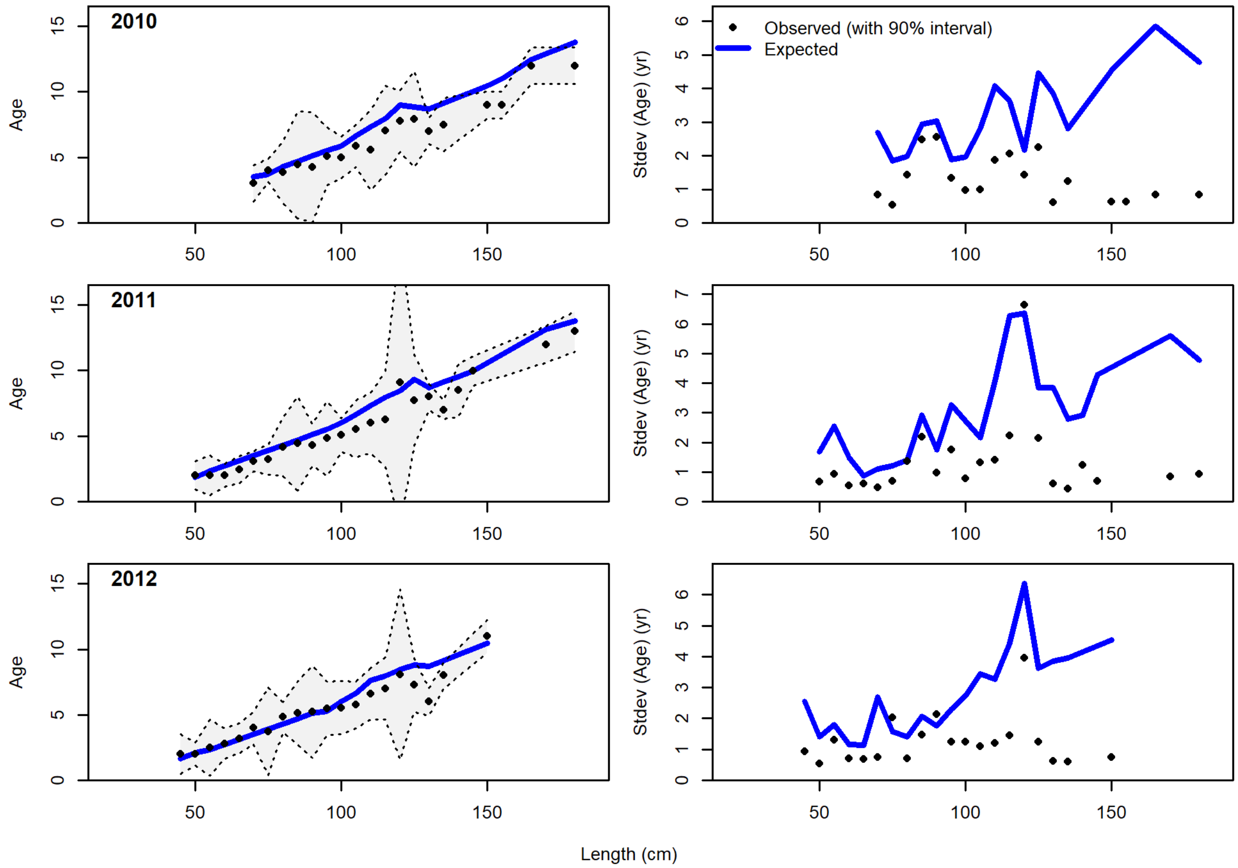



Figure 14: Estimated recruitment (red circles) and the assumed stock-recruit relationship (black line) for Big Skate. The green line shows the effect of the bias correction for the lognormal distribution.

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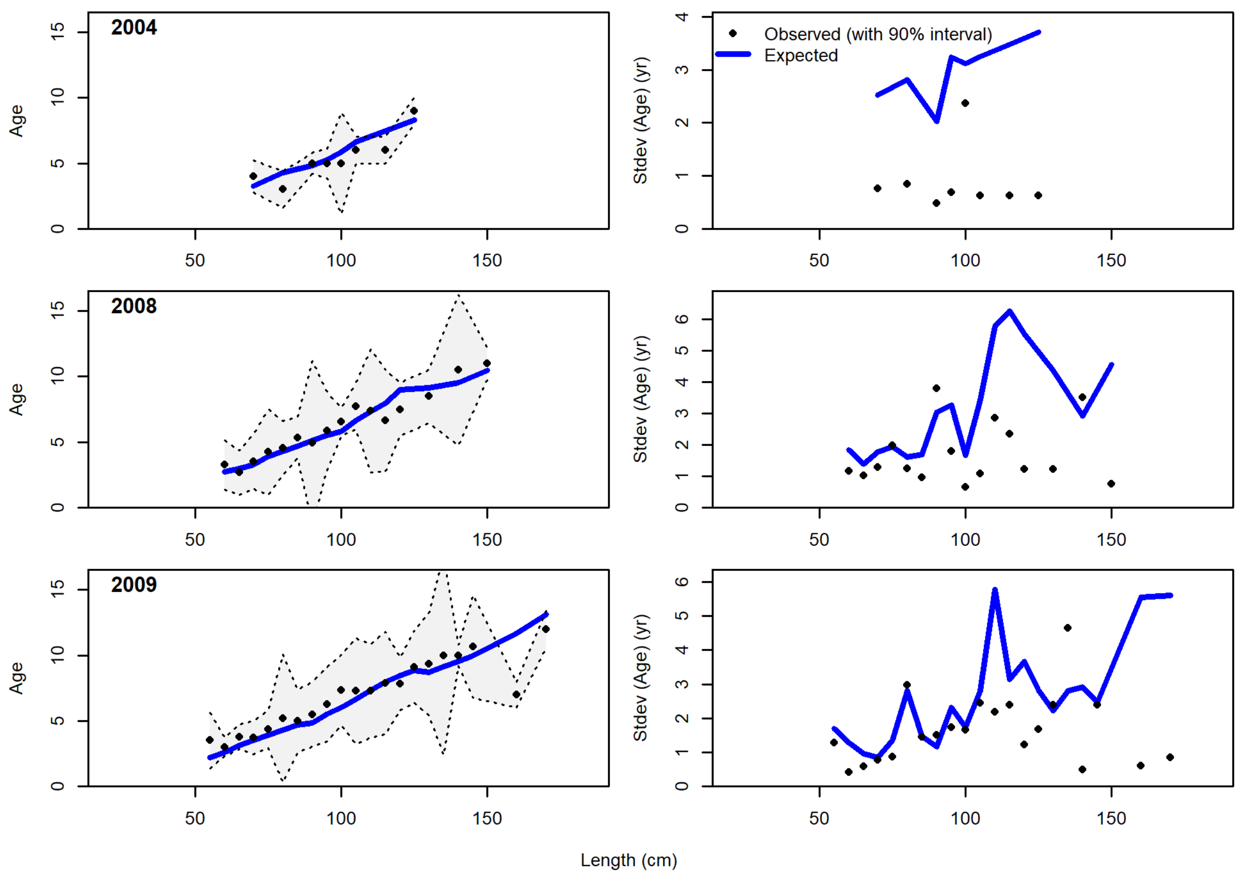
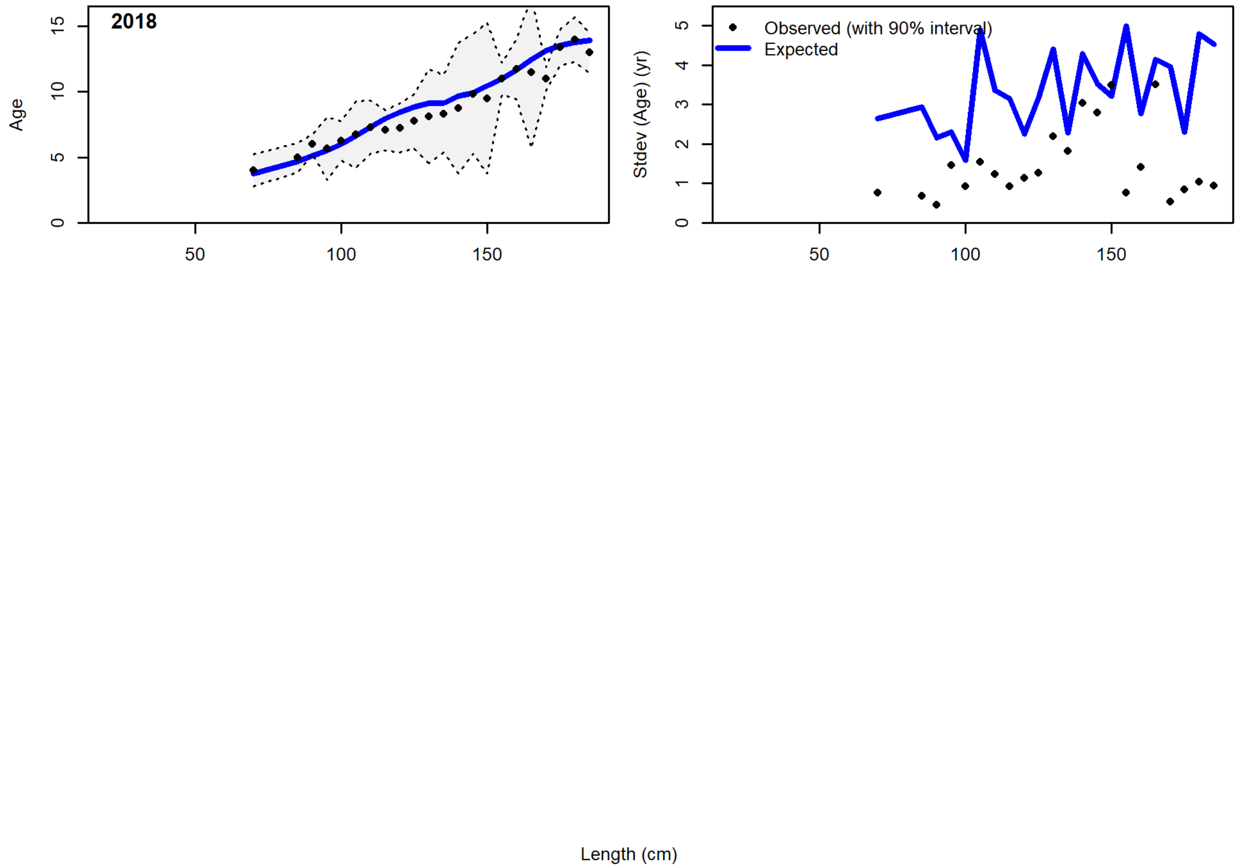



Figure 15: Conditional AAL plot, retained, Fishery (plot 1 of 3) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution.

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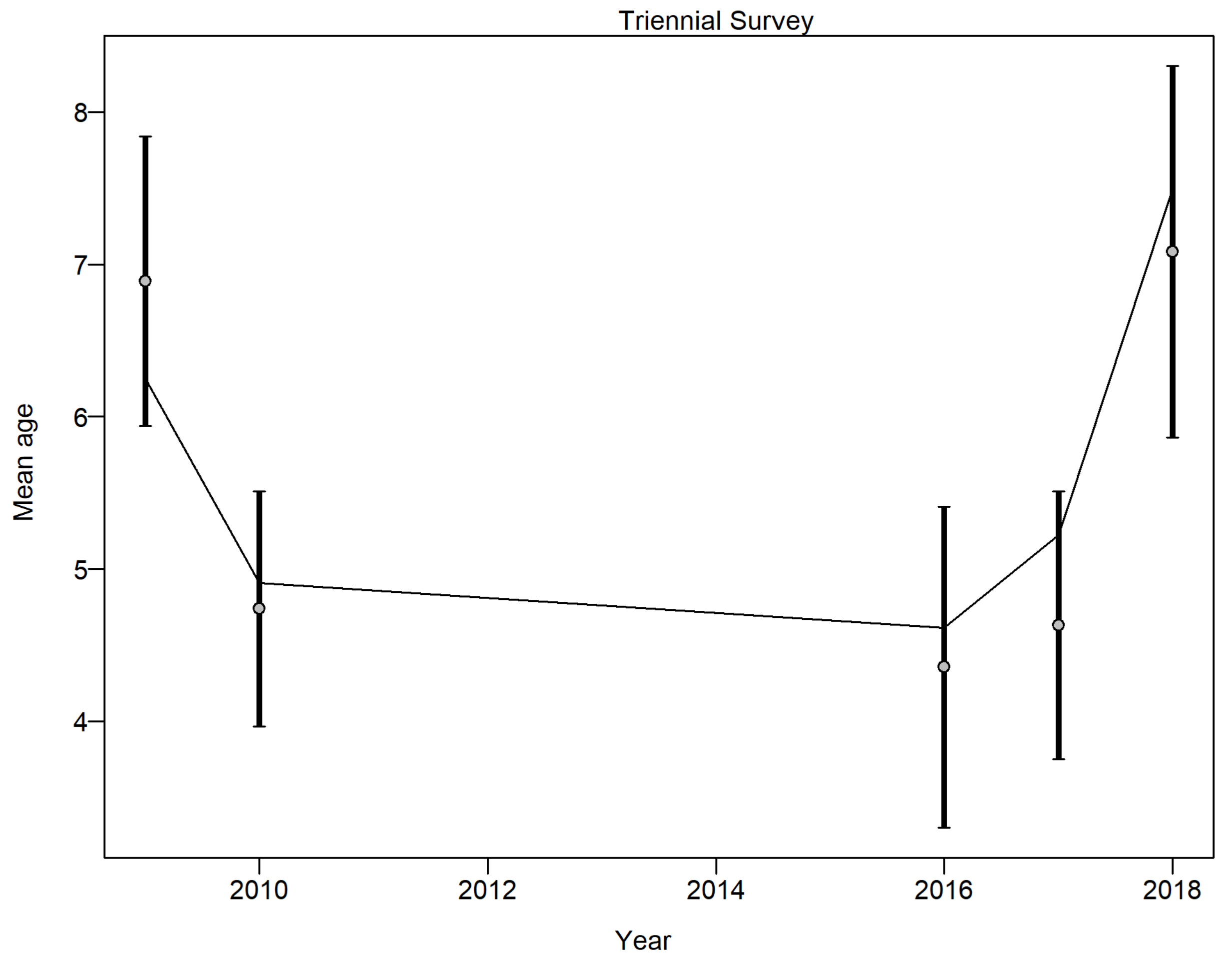



Figure 16: Mean age from conditional data (aggregated across length bins) for Triennial Survey with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (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.

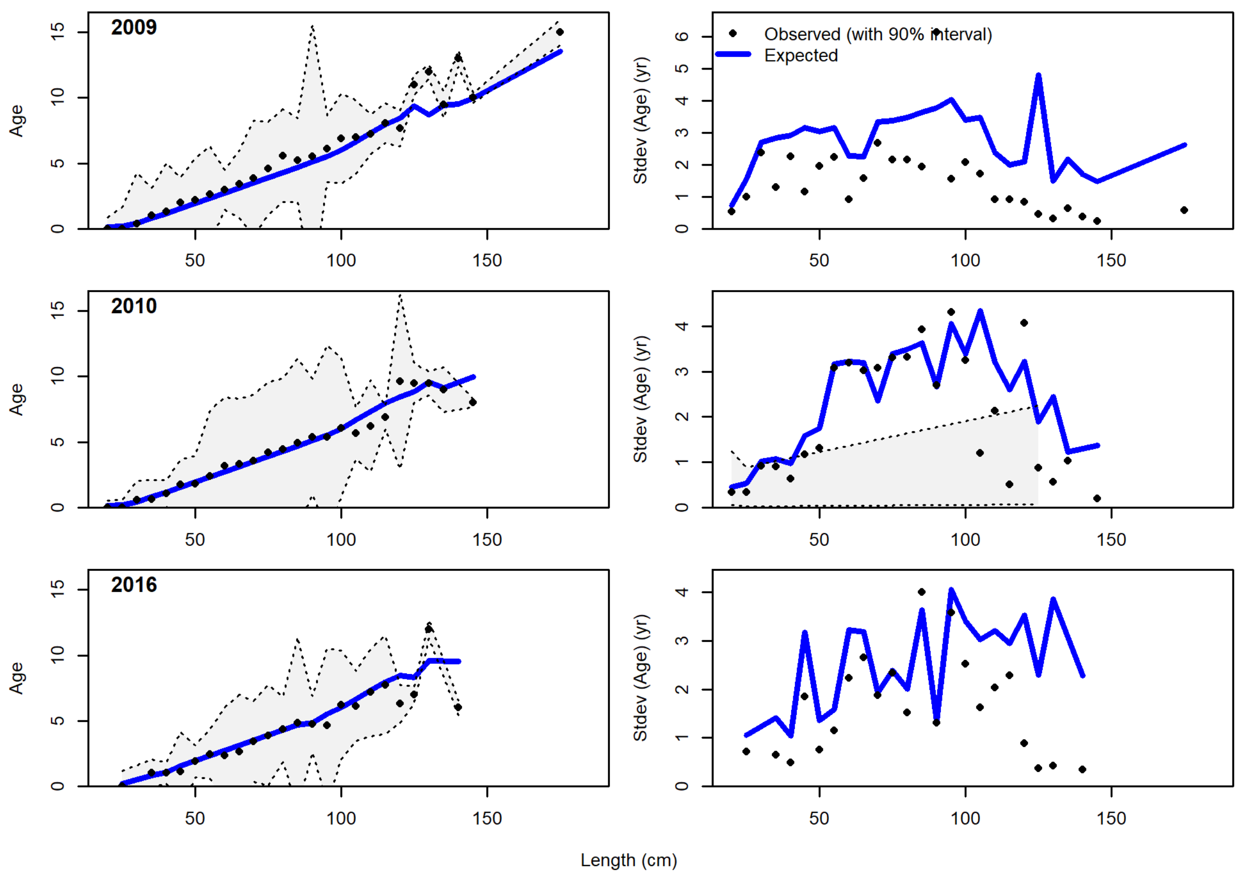
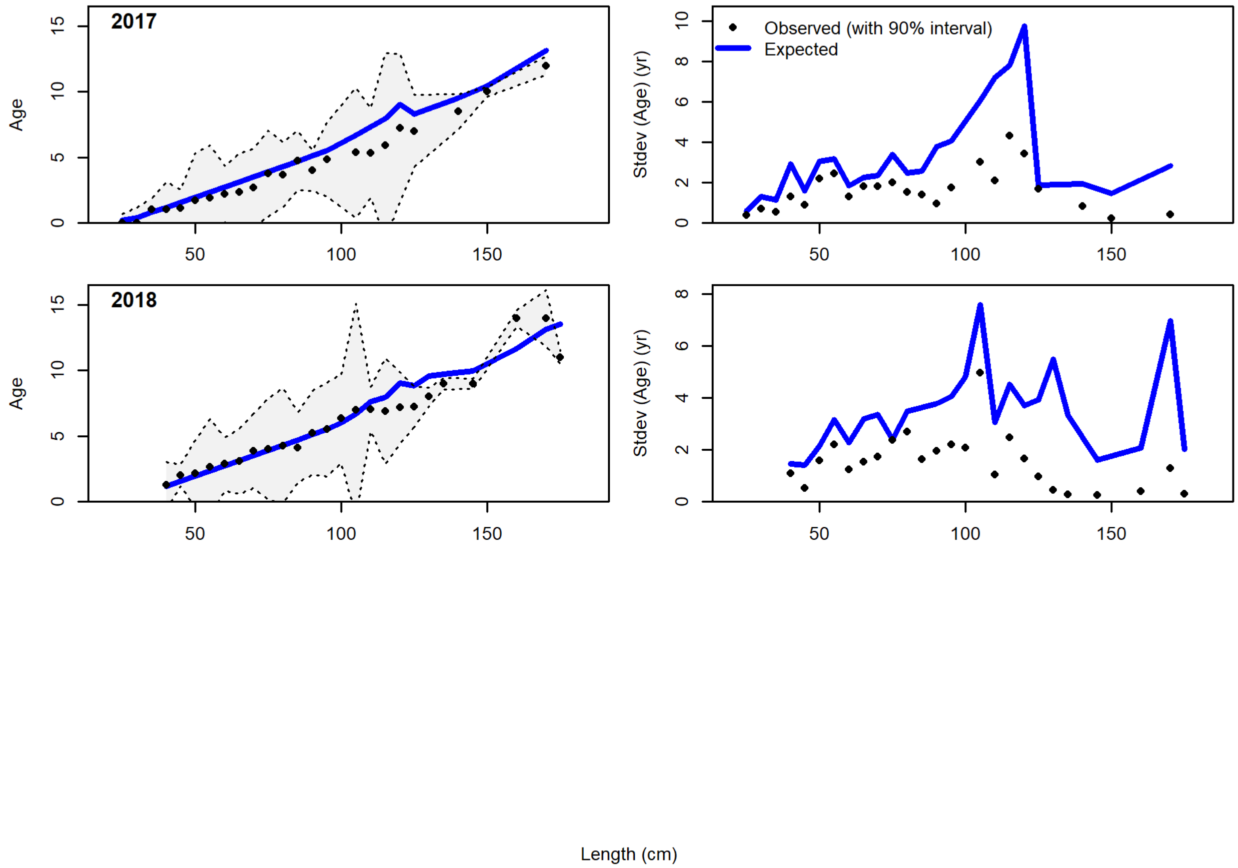



Figure 17: Conditional AAL plot, whole catch, Triennial Survey (plot 1 of 2) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution.

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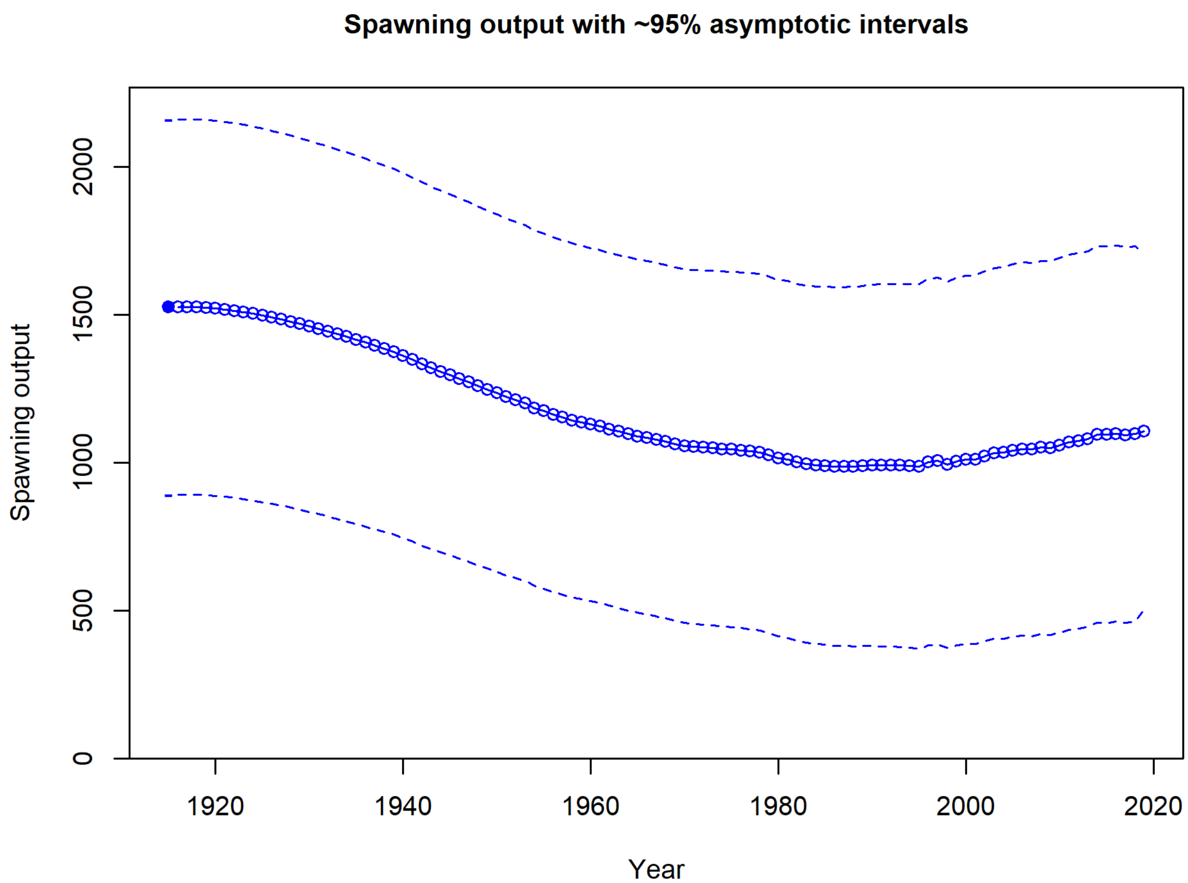


Figure 18: Estimated spawning biomass (mt) with approximate 95% asymptotic intervals.

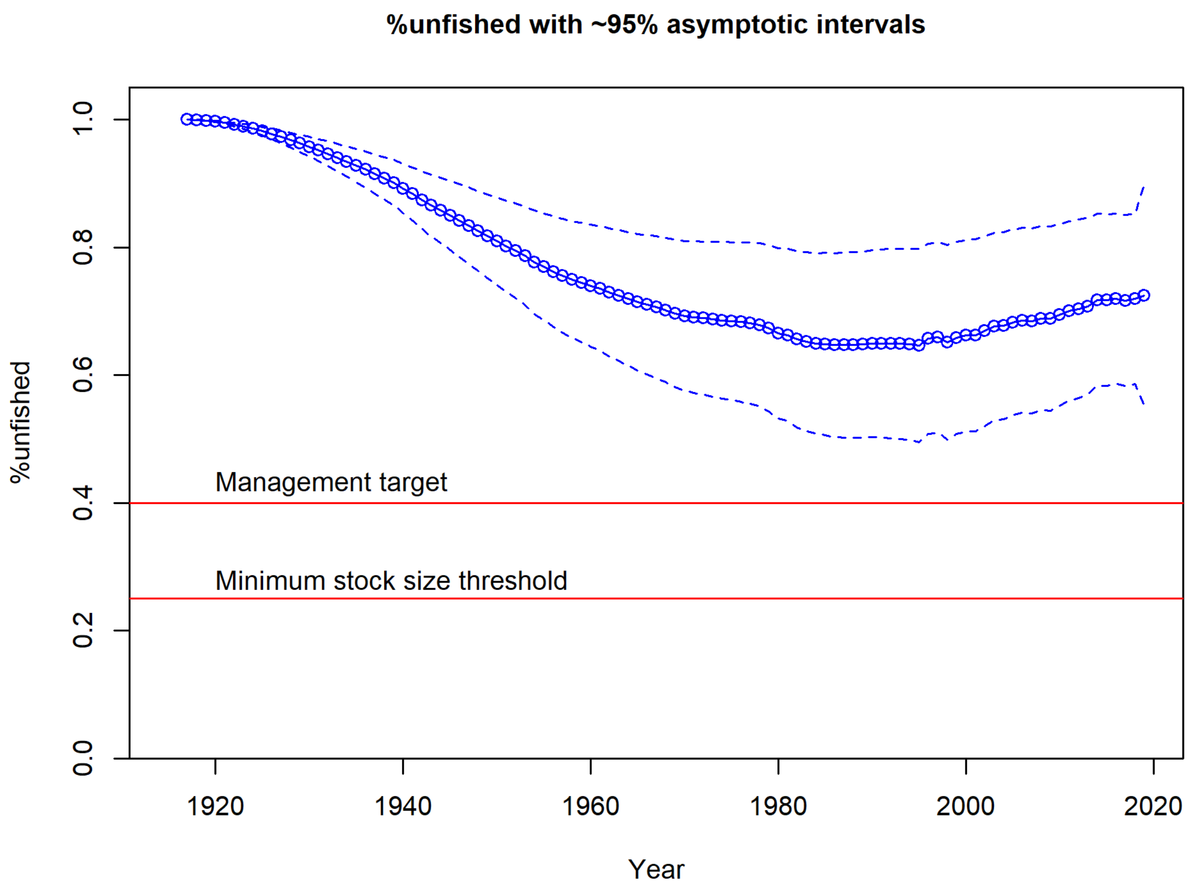


Figure 19: Estimated spawning depletion with approximate 95% asymptotic intervals.

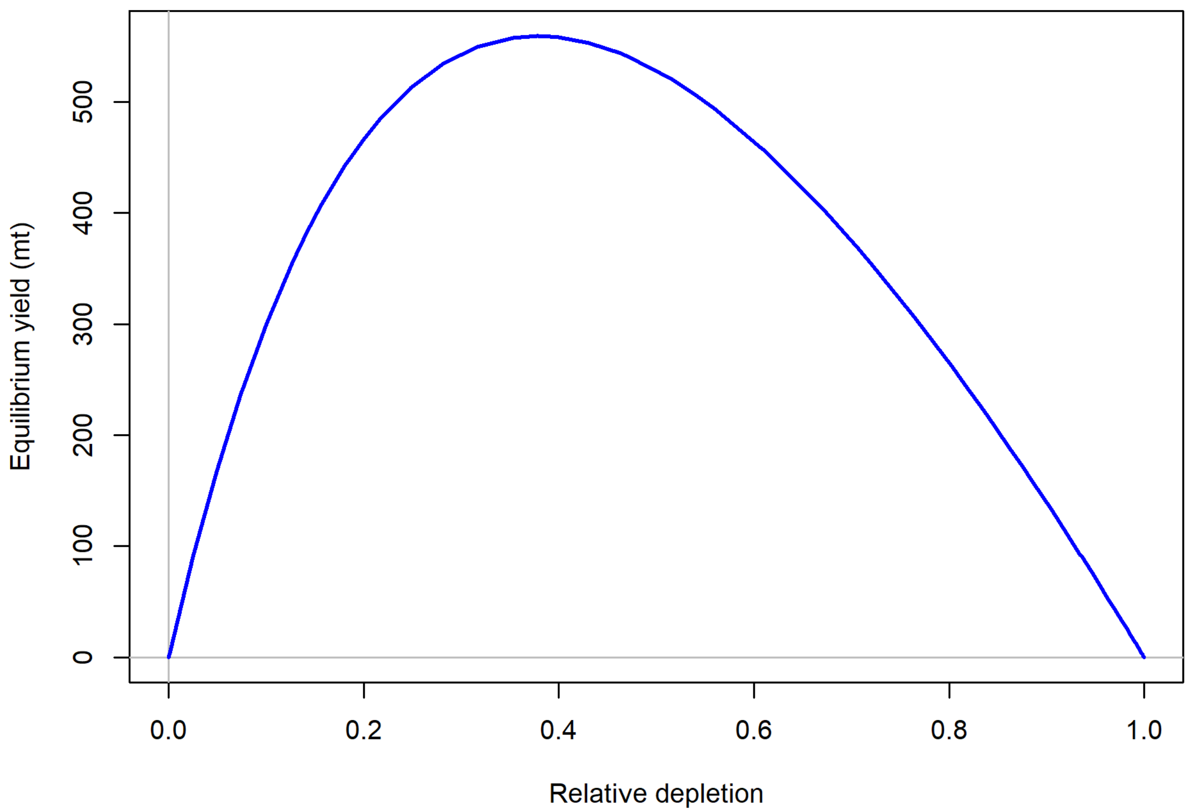


Figure 20: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.718.

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

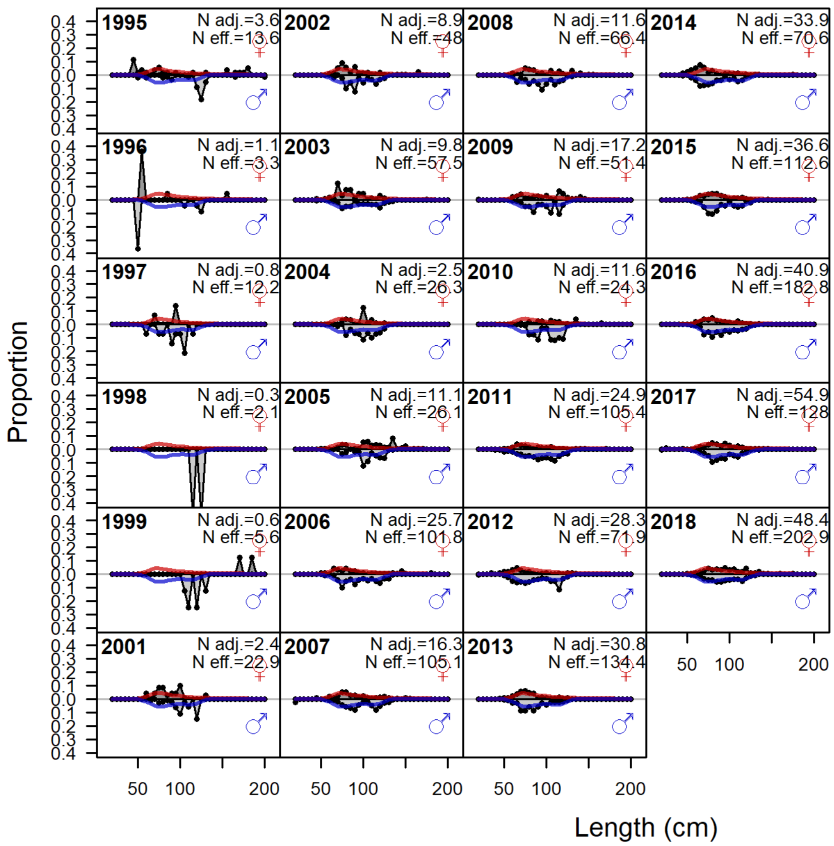


Figure A21: Length comps, retained, Fishery. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

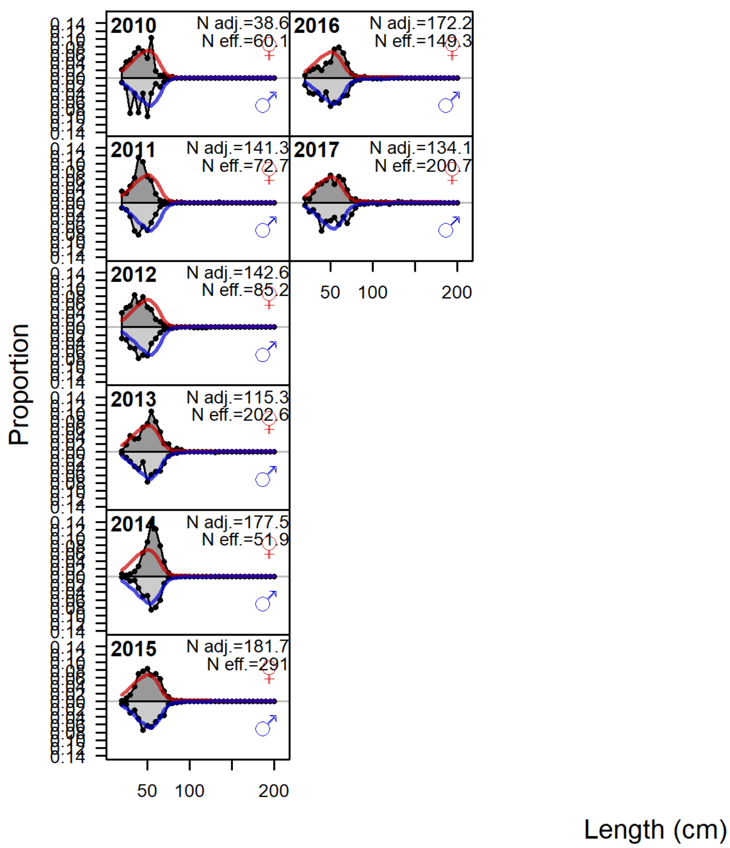


Figure A22: Length comps, discard, Fishery. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

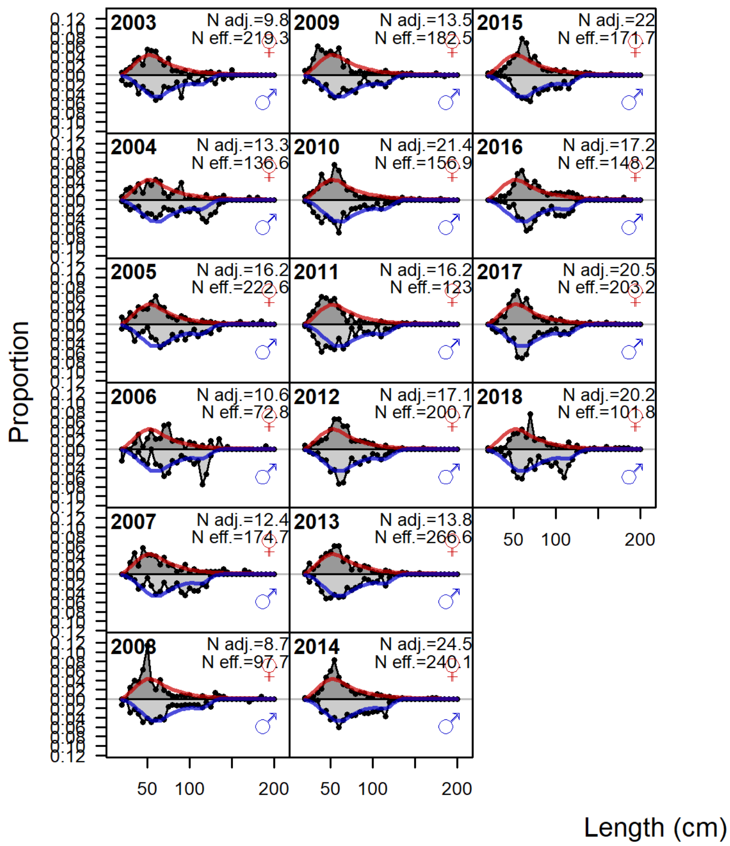


Figure A23: Length comps, whole catch, Triennial Survey. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

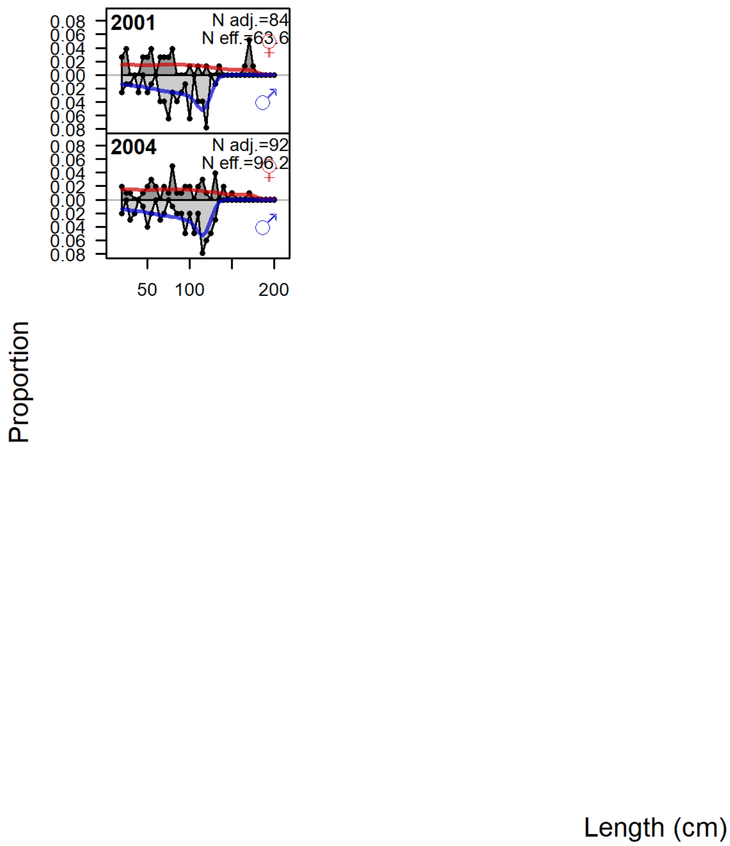


Figure A24: Length comps, whole catch, WCGBT Survey. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

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