Agenda Item H.5
Attachment 14
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# Stock Assessment Update: Status of Widow Rockfish (*Sebastes entomelas*) Along the U.S. West Coast in 2019

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# Executive Summary

## Stock

This is an update assessment of Widow Rockfish (*Sebastes entomelas*) that reside in the waters off California, Oregon, and Washington from the U.S.-Canadian border in the north to the U.S.-Mexico border in the south. This is an update of the 2015 benchmark assessment (Hicks and Wetzel, 2015). Widow Rockfish inhabit water depths of 25–370 m from northern Baja California, Mexico to Southeastern Alaska. Although catches north of the U.S.-Canada border and south of the U.S.-Mexico border were not included in this assessment, it is not certain if those populations contribute to the biomass of Widow Rockfish off of the U.S. West Coast, possibly through adult migration and/or larval dispersion.

There is little evidence of genetically separate stocks along the U.S. coast and the previous benchmark assessment used a single area, coastwide model with multiple fisheries (Hicks and Wetzel, 2015). There is some evidence of biological differences between areas. For example, Widow Rockfish collected off California tend to mature at a smaller length than do Widow Rockfish collected off of Oregon (Barss and Echeverria 1987). This may be due to environmental or anthropogenic effects rather than genetic differences. The 2015 benchmark assessment decided to continue with a single area model for this assessment rather than lose prediction power by splitting the model and data into two separate areas.

## Landings

The historical reconstruction of landings for Widow Rockfish suggests that hook-and-line and bottom trawl fisheries have caught Widow Rockfish since the turn of the 20th century. Landings in the trawl fishery are estimated to have increased into the 1940s and remained relatively constant and small (below 1,000 mt per year) throughout the 1950s and into the 1960s before the foreign trawl fleet increased catches into the 1970s, with a peak at almost 5,000 mt in 1967. In the late 1970s a midwater trawl fishery developed for Widow Rockfish and catches increased rapidly with the discovery of large aggregations that form at night.

Total landings of Widow Rockfish peaked in the early 1980s, increasing from approximately 1,000 metric tons (mt) in 1978 to over 25,000 mt in 1981. After this sudden increase in catch, Widow Rockfish were given their own market category and often identified to species in the landings. However, species composition sampling of market categories occurred before the mid-1980s when Widow Rockfish was not specifically identified. The uncertainty in species composition is greater in past years, thus landings of Widow Rockfish are not well known further back in history.

The large landings in the early 1980s were curtailed with trip limits beginning in 1982, which resulted in a decline in landings throughout the 1980s and 1990s following sequential reductions in the trip limits. From 2000 to 2003, landings of Widow Rockfish dropped from over 4,000 mt to about 40 mt and have been slowly increasing in recent years as the population has rebuilt from early exploitation, with a more rapid relative increase after 2015 to above 10,000 mt in 2018. Midwater trawl gears in groundfish and Pacific Whiting (hake) fisheries account for the majority of the recent catch.

Widow Rockfish are a desirable market species and it is believed that discarding was low historically. However, management restrictions (e.g., trip limits) resulted in a substantial amount of discarding beginning in 1982. Trawl rationalization was introduced in 2011, and since then very little discarding of Widow Rockfish has occurred. Discards were estimated in the model with the assistance of data from the West Coast Observer Program (WCGOP), and total catches (discards plus landings) are reported in addition to landings.

**Table a: Recent landings for the bottom trawl, midwater trawl, at-sea hake, net, and hook-and-line fisheries and the total landings across fisheries and the total mortality (discards + landings) (mt).**

| Year | Trawl | Midwater Trawl | At-Sea Hake | Net | Hook-and-line | Total Landings | Total Mortality |
|---|---|---|---|---|---|---|---|
| 2009 | 8.06 | 42.16 | 135.35 | 0.21 | 0.43 | 176.6 | 186.21 |
| 2010 | 9.1 | 63.23 | 106.35 | 0 | 0.16 | 165.9 | 178.84 |
| 2011 | 18.53 | 44.32 | 149.65 | 0 | 0.13 | 212.0 | 212.63 |
| 2012 | 41.65 | 47.84 | 181.43 | 0 | 0.35 | 270.4 | 271.27 |
| 2013 | 51.79 | 243.53 | 176.41 | 0 | 1.03 | 469.8 | 472.75 |
| 2014 | 72 | 309.72 | 342.16 | 0.03 | 1.86 | 721.9 | 725.77 |
| 2015 | 12.3 | 484.04 | 386.2 | 0 | 2.25 | 879.6 | 884.79 |
| 2016 | 9.72 | 593.94 | 440.8 | 0 | 0.92 | 1039.2 | 1,045.38 |
| 2017 | 36.29 | 4,901.11 | 1,455.20 | 0 | 2.8 | 6345.9 | 6,395.41 |
| 2018 | 36.29 | 9,468.99 | 1,081.30 | 0 | 1.55 | 10496.0 | 10,588.14 |

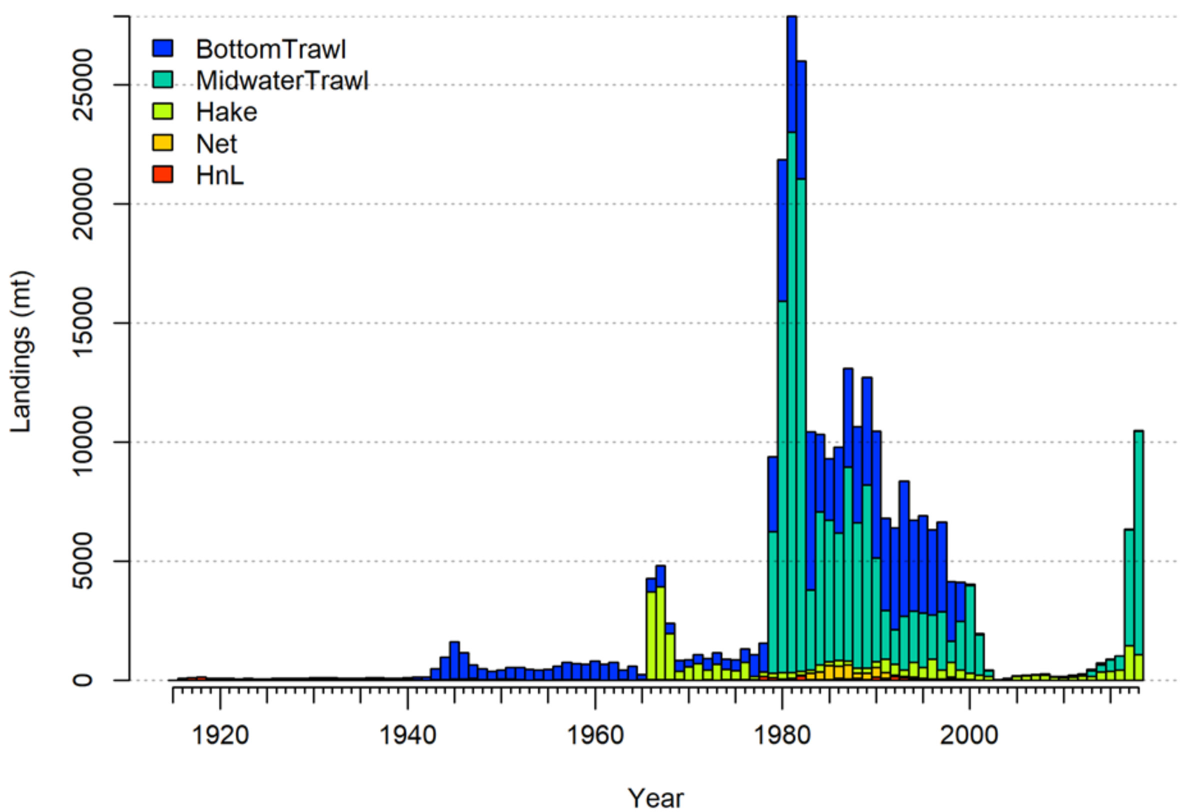


**Figure a: Landings of Widow Rockfish from 1916 to 2018 for bottom trawl, midwater trawl, net, and hook-and-line fisheries, and catches of Widow Rockfish for the foreign (1966–1976) and Pacific Whiting (hake) fisheries (green).**

## Data and assessment

This is an update assessment of the 2015 full assessment of Widow Rockfish (Hicks and Wetzel, 2015). In this assessment, aspects of the model including catches, data, and modelling assumptions were generally consistent with the 2015 assessment. However, the assessment used the updated version of the length- and age-structured modeling software Stock Synthesis (version 3.30.13), while the benchmark assessment used version 3.24U. The coastwide population was modeled assuming separate growth and mortality parameters for each sex (a two-sex model) from 1916 to 2019, and forecasted beyond 2019.

The definitions of fishing fleets have not been changed from those in the 2015 assessment. Five fishing fleets were specified within the model: 1) a shorebased bottom trawl fleet with coastwide catches from 1916–2018, 2) a shorebased midwater trawl fleet with coastwide catches from 1979–2018, 3) a mostly midwater trawl fleet that targets Pacific Hake/Whiting (*Merluccius productus*) and includes a foreign and at-sea fleet with catches from 1975–2018, a domestic shorebased fleet that targeted Pacific Hake with catches from 1991–2018, and foreign vessels that targeted Pacific Hake and rockfish between 1966–1976, 4) a net fishery consisting of catches mostly from California from 1981–2018, and 5) a hook-and-line fishery (predominantly longline) with coastwide catches from 1916–2018.

Data from three fishery-independent surveys were also included in the model: 1) the National Marine Fisheries Service (NMFS) Southwest Fisheries Science Center (SWFSC) and Northwest Fisheries Science Center (NWFSC)/Pacific Whiting Conservation Cooperative (PWCC) Midwater Trawl Survey that provides pre-recruit indices of abundance, 2) the NMFS Triennial Shelf Survey which was conducted from 1977–2004 in depths less than 500 meters, and 3) the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) which has been surveying the entire U.S. West Coast in depths between 55 and 1,280 meters since 2003.

The data used in the assessment model consisted of survey abundance indices, length compositions, discard data, and age compositions. Model-based biomass indices and length compositions were determined for the NMFS Triennial Shelf and NWFSC West Coast Groundfish Bottom Trawl Surveys. Length and age compositions were also available from the five fisheries. Age data for all years of the WCGBTS were input as age-at-length. Discard data for the bottom trawl, midwater trawl, and hook-and-line fisheries were available in various years in the form of discarded biomass and length compositions. A small amount of data was available to inform discarding practices of Widow Rockfish prior to 2002. The variances and sample sizes on all of the data were tuned to the expected variability in the model predictions.

The base model estimated parameters for length-based selectivity for all fleets and surveys, retention curves based on length for the bottom trawl, midwater trawl, and hook-and-line fishing fleets, a length-at-age relationship, natural mortality, and recruitment deviations starting in 1900. A Beverton-Holt stock-recruitment function was used to model productivity and the steepness parameter was fixed at 0.72 based on a steepness meta-analysis for west coast rockfishes.

Uncertainty for the parameter estimates and derived quantities was determined in three ways. First, estimation uncertainty in the base model was determined using approximate asymptotic 95% confidence intervals based on maximum likelihood theory. Second, model uncertainty was investigated with various sensitivity runs where alternative model structures were implemented. Finally, the major axis of uncertainty was determined to define a range of states of nature and results are presented in a decision table.

Although there are many types of data available for Widow Rockfish since the late 1970s, which were used in this assessment, there is little information about steepness and natural mortality, and recent recruitment. Estimates of steepness are uncertain partly because of variable recruitment. Uncertainty in natural mortality is common in many fish stock assessments even when length and age data are available. Finally, there is little information about the strength of recent recruitment because the young fish are seen with a lower probability in the fisheries and surveys. These uncertainties were characterized as best as possible in the predictions and projections from this assessment.

## Stock biomass

The predicted spawning biomass from the base model generally showed a slight decline over the time series until 1966 when the foreign fleet began. A short, but sharp decline occurred, followed by a steep increase due to strong recruitment. The spawning biomass declined rapidly with the developing domestic midwater fishery in the late 1970s and early 1980s. The stock continued to decline until 2000, when a combination of strong recruitment and low catches resulted in a steady increase. The 2019 spawning biomass relative to unfished equilibrium spawning biomass is 91.9%, well above the target of 40% of unfished spawning biomass and the minimum value of 36.3%, which occurred in 1998, 2000, and 2001.

Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning biomass is high, especially in the early years. Spawning biomass is estimated to be at 80,910 mt in 2019, with an asymptotic 95% confidence interval of 49,484–112,335.

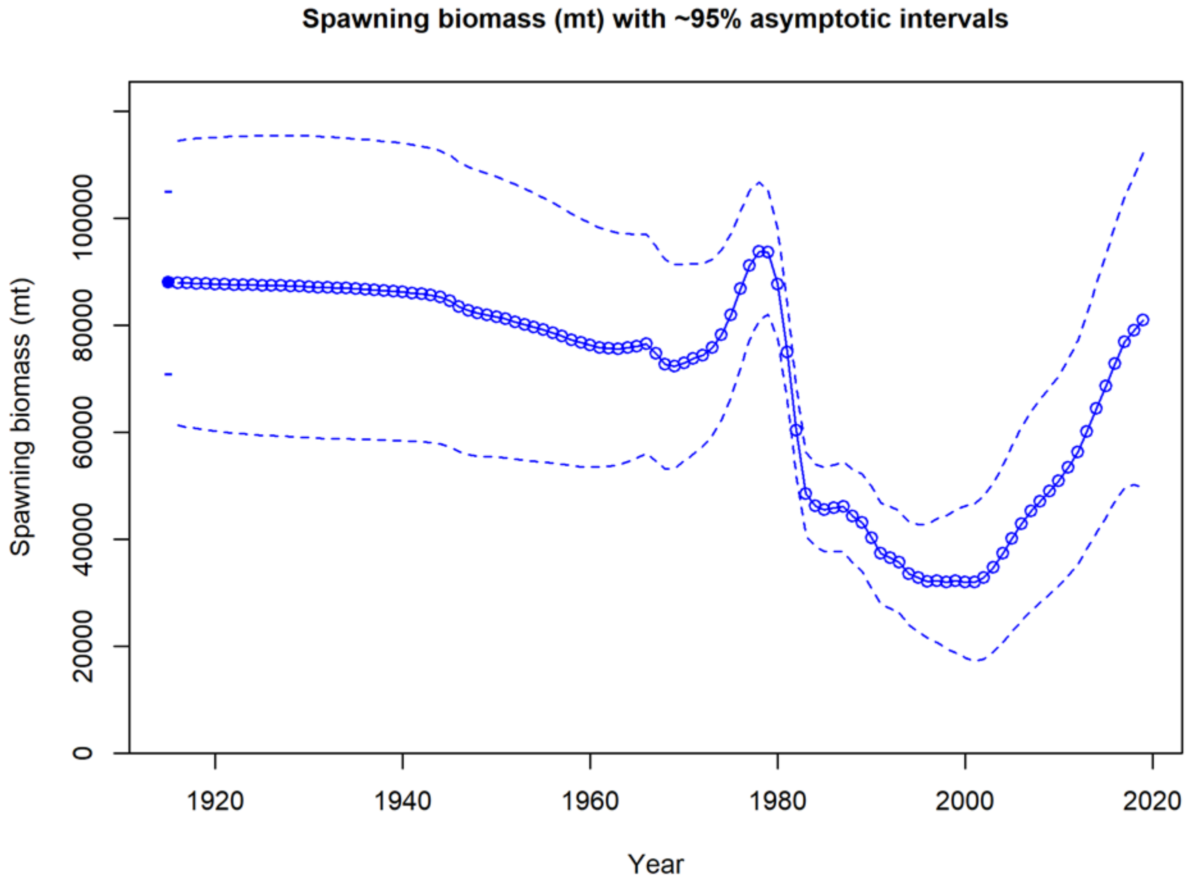


**Figure b: Estimated female spawning biomass time-series from the base model (solid line) with an approximate asymptotic 95% confidence interval (dashed lines).**

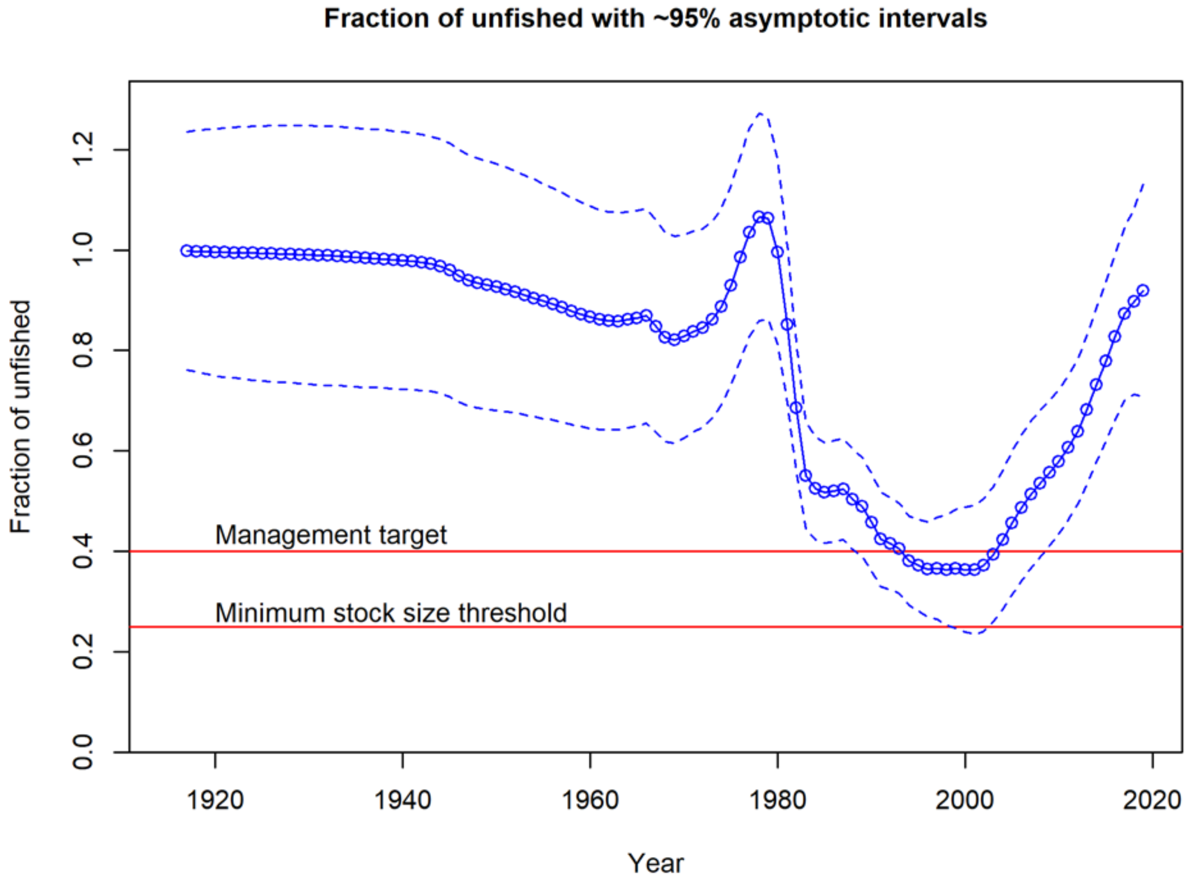


**Figure c. Estimated relative spawning biomass (depletion) with approximate 95% asymptotic confidence intervals (dashed lines) for the base case assessment model.**

**Table b: Recent trend in estimated female spawning biomass (mt) and relative spawning biomass (depletion).**

| Year | Spawning Biomass | ~95% Confidence Interval | Estimated Depletion (%) | ~95% Confidence Interval |
|---|---|---|---|---|
| 2010 | 50,864 | 31,199–70,529 | 57.8 | 43.4–72.2 |
| 2011 | 53,403 | 33,186–73,620 | 60.7 | 46.3–75.1 |
| 2012 | 56,192 | 35,332–77,051 | 63.9 | 49.4–78.3 |
| 2013 | 60,047 | 38,128–81,965 | 68.2 | 53.4–83.0 |
| 2014 | 64,421 | 41,214–87,627 | 73.2 | 57.9–88.5 |
| 2015 | 68,547 | 44,090–93,003 | 77.9 | 62.0–93.8 |
| 2016 | 72,782 | 46,970–98,594 | 82.7 | 66.2–99.2 |
| 2017 | 76,824 | 49,668–103,979 | 87.3 | 70.1–104.5 |
| 2018 | 79,032 | 50,137–107,927 | 89.8 | 71.2–108.4 |
| 2019 | 80,910 | 49,484–112,335 | 91.9 | 70.8–113.1 |

## Recruitment

Recruitment deviations were estimated for the entire time series modeled. There is little information regarding recruitment prior to 1965, and the uncertainty in these estimates is expressed in the model. There are very large, but uncertain, estimates of recruitment in 2013, 1970, 2008, and 1971. Other large recruitment events (in descending order of magnitude) occurred in 1978, 2014, 1981, 2010, and 1991. The five lowest recruitments (in ascending order) occurred in 2012, 2011, 1976, 2007, and 1973. Estimates of recruitment appear to be episodic and characterized by periods of low recruitment. Two of the four largest estimated recruitments happened in the last 11 years.

**Figure d: Time-series of estimated recruitments (medians as open circles) for the base case model with approximate asymptotic 95% confidence interval (vertical bars). Estimated mean unfished equilibrium recruitment ($R_0$) is shown as the closed circle with a 95% confidence interval at the beginning of the time series.**

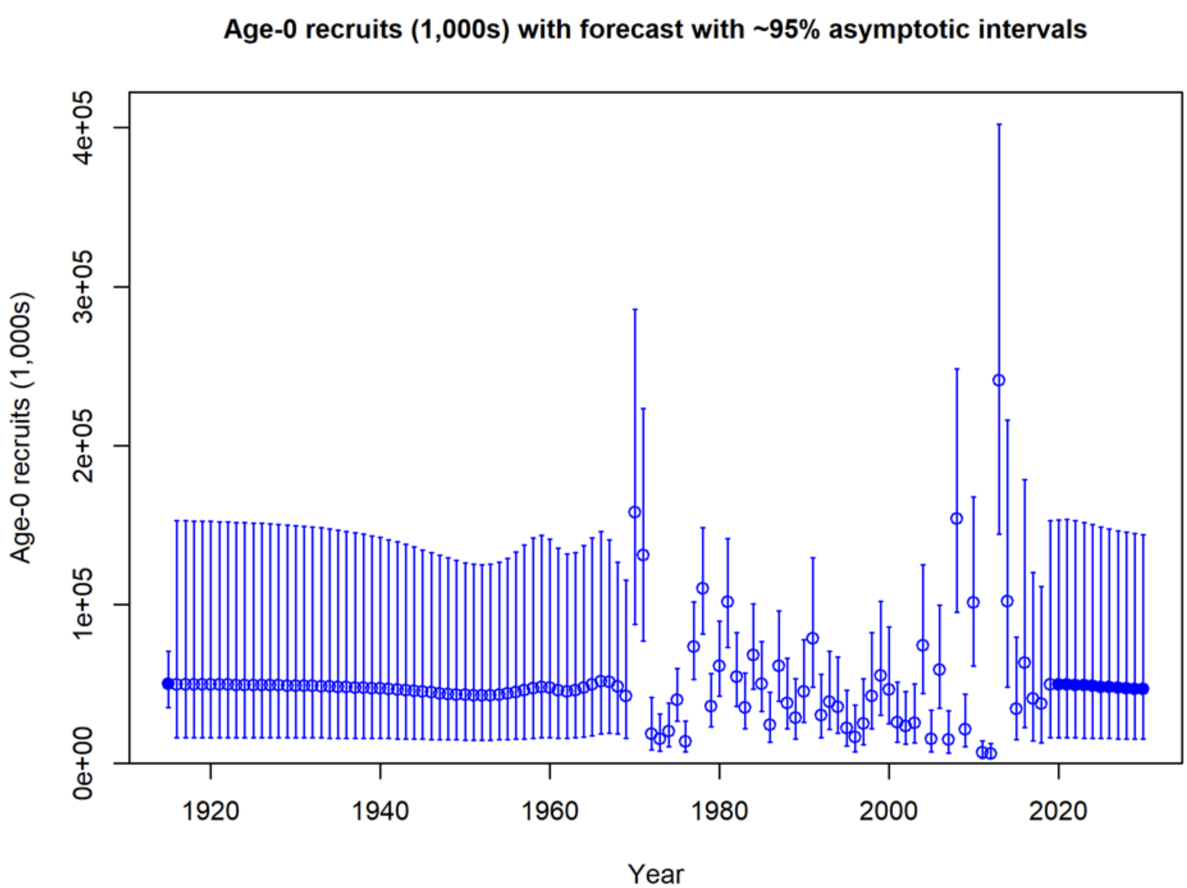

**Table c: Recent estimated trend in Widow Rockfish recruitment with approximate 95% confidence intervals determined from the base model. Recruitment deviations were fixed at zero in 2019 in the base model.**

| Year | Estimated Recruitment (number in thousands) | ~95% Confidence Interval | Estimated Recruitment Deviation | ~95% Confidence Interval |
|---|---|---|---|---|
| 2010 | 101,007 | 60,929–167,448 | 0.931 | 0.630–1.232 |
| 2011 | 6,740 | 3,220–14,107 | -1.783 | -2.424–-1.143 |
| 2012 | 6,074 | 3,040–12,134 | -1.895 | -2.493–-1.297 |
| 2013 | 240,825 | 144,209–402,171 | 1.776 | 1.418–2.133 |
| 2014 | 101,692 | 47,924–215,784 | 0.904 | 0.243–1.566 |
| 2015 | 34,200 | 14,729–79,408 | -0.244 | -1.047–0.559 |
| 2016 | 63,177 | 22,368–178,435 | 0.312 | -0.739–1.362 |
| 2017 | 40,750 | 13,832–120,048 | -0.184 | -1.288–0.920 |
| 2018 | 37,521 | 12,654–111,256 | -0.27 | -1.382–0.843 |
| 2019 | 49,257 | 15,883–152,756 | 0 | – |

## Exploitation status

The spawning biomass of Widow Rockfish reached a low in 2001 before increasing due to low catch levels. The lower 95% confidence interval of the estimated depletion dipped below the overfished threshold in the very late 1990s and early 2000s, but has remained above that level otherwise, and currently the depletion estimate is significantly greater than the spawning biomass target. Throughout the 1980s and 1990s the exploitation rate and (1-*SPR*) were mostly above target levels. Recent exploitation rates on Widow Rockfish are estimated to have been substantially below target levels.

**Table d. Recent trend in spawning potential ratio and summary exploitation rate.**

| Year | Estimated (1-SPR)/(1-SPR$_{50\%}$) | ~95% confidence interval | Harvest rate (proportion) | ~95% confidence interval |
|---|---|---|---|---|
| 2009 | 3.83 | 2.02-5.64 | 0.002 | 0.001-0.003 |
| 2010 | 3.53 | 1.90-5.15 | 0.002 | 0.001-0.002 |
| 2011 | 3.99 | 2.20-5.79 | 0.002 | 0.001-0.003 |
| 2012 | 4.9 | 2.75-7.04 | 0.002 | 0.001-0.003 |
| 2013 | 7.67 | 4.46-10.88 | 0.004 | 0.002-0.005 |
| 2014 | 10.8 | 6.41-15.19 | 0.005 | 0.003-0.007 |
| 2015 | 11.83 | 7.12-16.54 | 0.006 | 0.004-0.008 |
| 2016 | 13.04 | 7.93-18.14 | 0.007 | 0.005-0.010 |
| 2017 | 60.67 | 42.03-79.31 | 0.037 | 0.024-0.051 |
| 2018 | 85.46 | 62.27-108.65 | 0.058 | 0.036-0.080 |

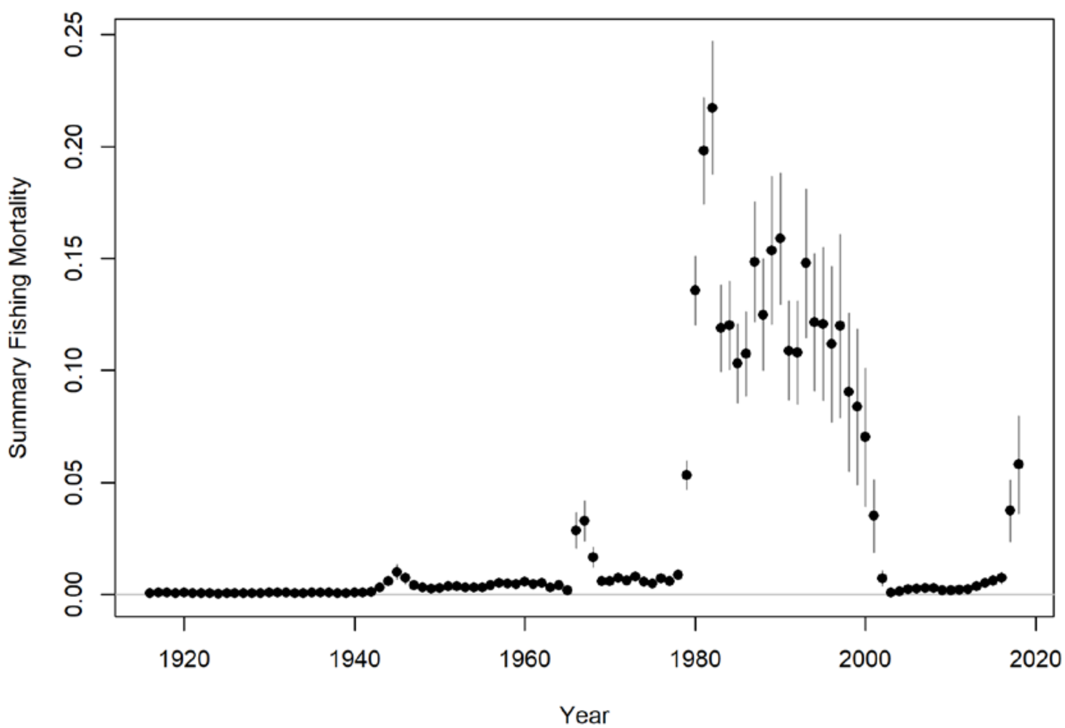

**Figure e. Time-series of estimated summary harvest rate (catch divided by age 4+ biomass) for the base case model (round points) with approximate 95% asymptotic confidence intervals (gray lines).**

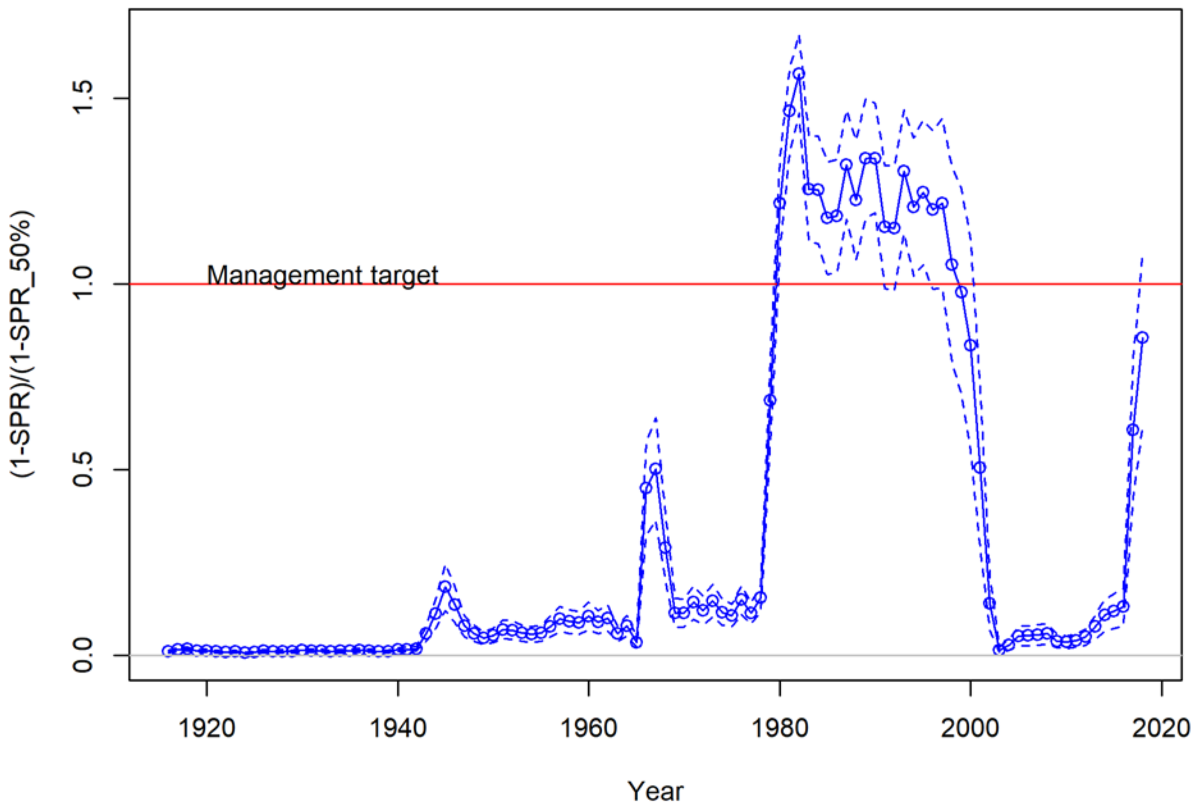


**Figure f. Trend in estimated fishing intensity (relative to the SPR management target) through 2018 with 95% asymptotic confidence intervals. One minus SPR is used so that higher exploitation rates occur on the upper portion of the y-axis. The relative management target is plotted as a horizontal line and values above this reflect harvests in excess of the overfishing proxy based on $SPR_{50\%}$.**

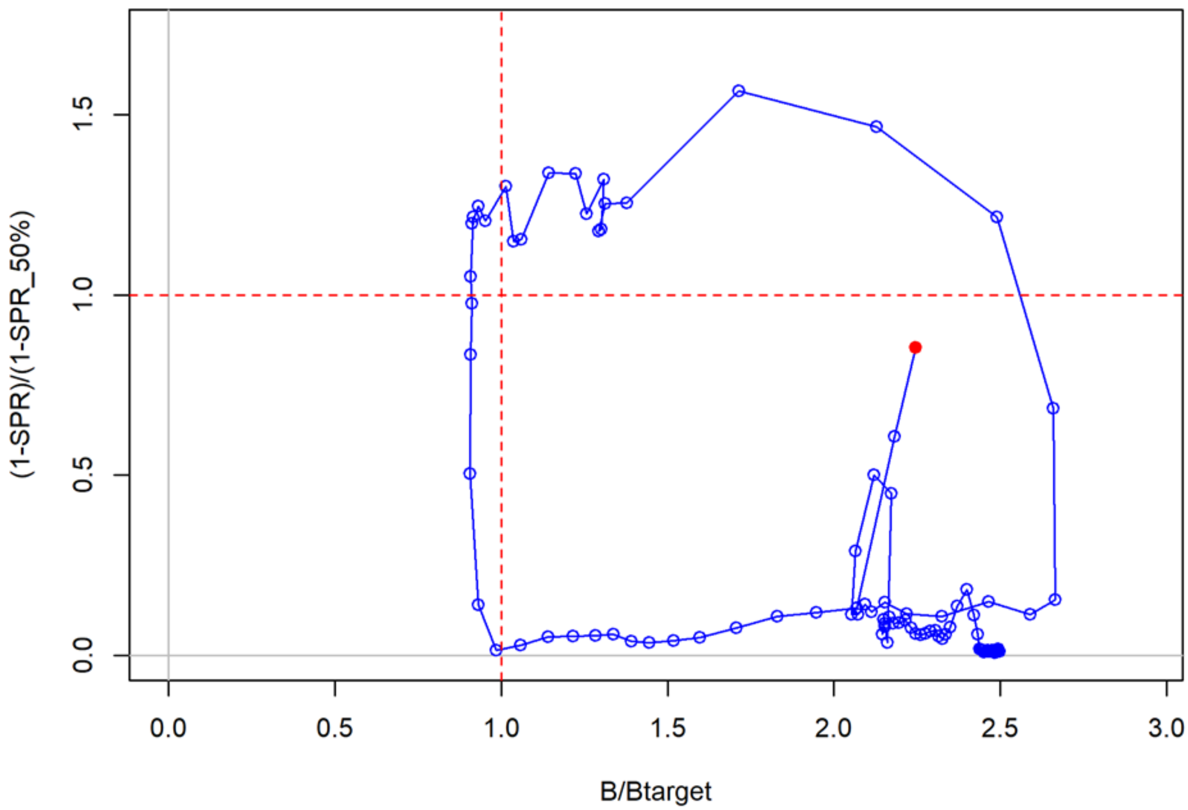


**Figure g. Phase plot of estimated relative (1-SPR) vs. relative biomass for the base case model. The relative (1-SPR) is (1-SPR) divided by 0.5 (one minus the SPR target). 2018 is noted a red circle.**

## Ecosystem considerations

Rockfish are an important component of the California Current ecosystem along the U.S. West Coast, with its more than sixty-five species filling various niches in both soft and hard bottom habitats from the nearshore to the continental slope, as well as near bottom and pelagic zones. Widow Rockfish frequently aggregate in the pelagic zone.

Recruitment is one mechanism by which the ecosystem may directly impact the population dynamics of Widow Rockfish. The specific pathways through which environmental conditions exert influence on Widow Rockfish dynamics are unclear; however, changes in water temperature and currents, distribution of prey and predators, and the amount and timing of upwelling are all possible linkages. Changes in the environment may also result in changes in age-at-maturity, fecundity, growth, and survival which can affect how the status of the stock and its susceptibility to fishing are determined. Unfortunately, there are few data available for Widow Rockfish that provide insights into these effects.

Fishing has effects on both the age structure of a population as well as the habitat with which the target species is associated. Fishing often targets larger, older fish, and years of fishing mortality results in a truncated age-structure when compared to unfished conditions. Rockfish are often associated with habitats containing living structure such as sponges and corals, and fishing may alter that habitat to a less desirable state. This assessment provides a look at the effects of fishing on age structure, and recent studies on essential fish habitat are beginning to characterize important locations for rockfish throughout their life history; however there is little current information available to evaluate the specific effects of fishing on the ecosystem issues specific to Widow Rockfish.

## Reference points

Reference points were calculated using the estimated selectivities and catch distribution among fleets in the most recent year of the model (2018). Sustainable total yields (landings plus discards) were 7,240 mt when using an $SPR_{50\%}$ reference harvest rate and with a 95% confidence interval of 5,447 to 9,033 mt based on estimates of uncertainty. The spawning biomass equivalent to 40% of the unfished spawning output ($SB_{40\%}$) was 35,198 mt. Prior to 2018, the most recent catches (landings plus discards) have been below the point estimate of potential long-term yields calculated using an $SPR_{50\%}$ reference point and the population has been increasing over the last decade. However, catches in 2018 were above the point estimate of potential long-term yields calculated using an $SPR_{50}$ reference point.

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

| Quantity | Estimate | ~95% Confidence Interval |
|---|---|---|
| Unfished Spawning Biomass (mt) | 87,995 | 70,867–105,123 |
| Unfished age 4+ biomass (mt) | 171,336 | 137,799–204,873 |
| Unfished recruitment ($R_0$) | 49,662 | 36,639-70,665 |
| Spawning Biomass (2019) | 80,910 | 49,484–112,335 |
| Depletion (2019) | 91.95 | 70.78–113.11 |
| ***Reference points based on SB40%*** | | |
| Spawning biomass ($SB_{40\%}$, mt) | 35,198 | 28,347–42,049 |
| SPR resulting in $B_{40\%}$ ($SPR_{B40\%}$) | 0.458 | 0.458–0.458 |
| Exploitation rate resulting in $B_{40\%}$ | 0.096 | 0.087–0.105 |
| Yield with $SPR_{B40\%}$ at $B_{40\%}$ (mt) | 7,606 | 5,717–9,494 |
| ***Reference points based on SPR proxy for MSY*** | | |
| Spawning Biomass ($SB_{SPR50\%}$, mt) | 39,259 | 31,618–46,901 |
| $SPR_{50\%}$ | 0.5 | NA |
| Exploitation rate corresponding to $SPR_{50\%}$ | 0.084 | 0.075–0.092 |
| Yield with $SPR_{50\%}$ at $SB_{SPR50\%}$ (mt) | 7,240 | 5,447–9,033 |
| ***Reference points based on estimated MSY values*** | | |
| Spawning biomass at *MSY* ($SB_{MSY}$, mt) | 23,063 | 18,611–27,516 |
| $SPR_{MSY}$ | 0.334 | 0.330–0.337 |
| Exploitation rate corresponding to $SPR_{MSY}$ | 0.145 | 0.130–0.159 |
| *MSY* (mt) | 8,169 | 6,123–10,215 |

## Management performance

Exploitation rates on Widow Rockfish exceeded *MSY* proxy target harvest rates during the 1980s and 1990s and spawning biomass is predicted to have fallen below the proxy management target of 40%. Exploitation rates decreased in the late 1990s due to management restrictions, and have increased in recent years. Predicted catches in the last decade have not exceeded the annual catch limit (ACL) set by management.

**Table f. Recent trend in total catch and commercial landings (mt) relative to the management guidelines. Estimated total catch reflects the commercial landings plus the model estimated discarded biomass.**

| Year | OFL (mt) (termed ABC prior to 2011) | ABC (mt) | ACL (mt) (termed OY prior to 2011) | Estimated Total Catch (mt) |
|---|---|---|---|---|
| 2008 | 5,144 | NA | 368 | 272.16 |
| 2009 | 7,728 | NA | 522 | 186.21 |
| 2010 | 6,937 | NA | 509 | 178.84 |
| 2011 | 5,097 | 4,872 | 600 | 212.63 |
| 2012 | 4,923 | 4,705 | 600 | 271.27 |
| 2013 | 4,841 | 4,598 | 1,500 | 472.75 |
| 2014 | 4,435 | 4,212 | 1,500 | 725.77 |
| 2015 | 4,137 | 3,929 | 2,000 | 884.79 |
| 2016 | 3,990 | 3,790 | 2,000 | 1,045.38 |
| 2017 | 14,130 | 13,508 | 13,508 | 6,395.41 |
| 2018 | 13,237 | 12,655 | 12,655 | 10,588.14 |
| 2019 | 12,375 | 11,831 | 11,831 | NA |

## Unresolved problems and major uncertainties

This is a reconfiguration of a long line of stock assessments for Widow Rockfish on the U.S. West Coast and although scientifically credible advice is provided by synthesizing many sources of data, there remain data and structural assumptions that contribute to uncertainty in the estimates. Major sources of uncertainty include landings, discards, natural mortality, and recruitment, which are discussed below.

Discards of Widow Rockfish are even more uncertain than landings, but because Widow Rockfish is a marketable species, historical discard rates were likely lower than less desirable or smaller species. In this assessment, we assumed that discarding was nearly negligible before management restrictions began in 1982. Once trip limits were introduced, discarding tended to be an all or none event, and detecting large, but rare, discard events with far less than 100% observer coverage has a low probability. For the years 2002–2010, the WCGOP has provided data on discards from vessels that were randomly selected for observer coverage, thus some uncertainty is present in the total amount discarded. The implementation of trawl rationalization in 2011 resulted in almost 100% observer coverage for the trawl fleet and very little incentive to discard Widow Rockfish. However, the open access fixed-gear fleet is not monitored by the full observer coverage required under trawl rationalization and data show that discarding of Widow Rockfish has occurred on fixed gear vessels in recent years (limited entry vessel fishing with fixed gear are subject to 100% observer coverage). Uncertainty in recent discards is greatly reduced because of observer coverage, but it is unknown what historical discarding may have been. The model assumes a discard rate of 1% pre-1982, which is arbitrary, but reasonable.

Widow Rockfish is a relatively long-lived fish, and natural mortality is likely to be lower than many species of fish, such as gadoids. Ages above 50 years have been observed and it is expected that natural mortality could be less than 0.10 $yr^{-1}$. However, even with length and age data available back to the late 1970s, natural mortality was estimated above 0.14 $yr^{-1}$ with a small amount of uncertainty (7% coefficient of variation). This assessment attempts to capture that uncertainty by estimating natural mortality (*M*) and integrating that uncertainty into the derived biomass estimates, as well as additional uncertainty by including levels outside of the predicted interval in a decision table.

Model sensitivities and profiles over *M* showed that current stock status was highly sensitive to the assumption about natural mortality. The estimates of *M* varied slightly depending on the weight given to age and length data, or removing recent years of data, but *M* was always estimated above 0.123 $yr^{-1}$. Profiles over natural mortality provide support for values above 0.14 $yr^{-1}$.

Steepness was fixed at 0.720 in the base model, but a likelihood profile showed that it would be estimated at a value less than that. Estimates of *M* increased with lower steepness, while unfished equilibrium spawning biomass increased and current spawning biomass decreased. Equilibrium yield ranged from approximately 3,600 to 7,500 mt depending on the value of steepness.

## Decision table

Model uncertainty has been described by the estimated uncertainty within the base model and by the sensitivities to different model structure. The estimated parameter that resulted in the most variability of predicted status and yield advice was natural mortality (*M*), which was estimated with much more certainty than the prior distribution implied. In fact, the 95% confidence interval for estimated *M* was entirely greater than and did not include the point estimate from the prior distribution. There is the possibility that the base model and the approximate uncertainty intervals based on maximum likelihood theory may not entirely convey the actual uncertainty of this assessment

Three categories of parameters that greatly contribute to uncertainty in the results were natural mortality (an important estimated parameter), steepness (not estimated in the model), and the strength of recent year classes (influential on projections). A combination of these three factors was used as the axis of uncertainty to define low and high states of nature. The 12.5% and 87.5% quantiles for female and male natural mortality (independently) were chosen as low and high values (0.133 $yr^{-1}$ and 0.155 $yr^{-1}$ for females; 0.144 $yr^{-1}$ and 0.166 $yr^{-1}$ for males). The 12.5% and 87.5% quantile of the 2013 recruitment deviation were also used (1.5781 and 1.9985). Steepness is probably the most important factor since it was fixed in the base model and is not incorporated in the estimation uncertainty. The 12.5% and 87.5% quantiles from the steepness prior (without Widow Rockfish data) were used to define the low and high values of steepness (0.536 and 0.904). The low combination of these three factors defined the low state of nature and the high combination of these three factors defined the high state of nature. The predictions of spawning biomass in 2019 from the low and high states of nature are close to the 12.5% and 87.5% lognormal quantiles from the base model.

This assessment synthesizes many sources of data and estimates recruitment variability, thus it is classified as a Category 1 stock assessment. Therefore, the sigma for P* to determine the catch reduction to account for scientific uncertainty is 0.50.

**Table g. Projection of potential OFL, landings, and catch, summary biomass (age-4 and older), spawning biomass, and depletion for the base case model projected with total catch equal to the predicted ABC. The predicted OFL is the calculated total catch determined by $F_{SPR=50\%}$.**

| Year | Predicted OFL (mt) | Projected ABC/ Catch (mt) | Age 4+ Biomass (mt) | Spawning Biomass (mt) | Depletion (%) |
|---|---|---|---|---|---|
| 2019 | 12,375* | 10,868 | 180,855 | 80,910 | 92% |
| 2020 | 11,714* | 10,868 | 179,750 | 83,054 | 94% |
| 2021 | 15,749 | 14,725 | 173,890 | 83,673 | 95% |
| 2022 | 14,826 | 13,788 | 161,799 | 80,275 | 91% |
| 2023 | 13,633 | 12,625 | 151,136 | 75,720 | 86% |
| 2024 | 12,453 | 11,481 | 141,680 | 70,914 | 81% |
| 2025 | 11,487 | 10,533 | 133,763 | 66,509 | 76% |
| 2026 | 10,769 | 9,832 | 127,304 | 62,790 | 71% |
| 2027 | 10,240 | 9,308 | 122,045 | 59,739 | 68% |
| 2028 | 9,842 | 8,897 | 117,739 | 57,242 | 65% |
| 2029 | 9,534 | 8,580 | 114,196 | 55,185 | 63% |
| 2030 | 9,288 | 8,322 | 111,249 | 53,473 | 61% |

* Value determined prior to the 2019 assessment as part of the harvest specifications

Table h. Summary table of 12-year projections beginning in 2021 for alternate states of nature based on the axis of uncertainty (a combination of *M*, *h*, and 2013 recruitment strength). Columns range over low, mid, and high state of nature, and rows range over different assumptions of total catch levels (discards + retained). Catches in 2019 and 2020 are allocated using the percentage of landings for each fleet in 2018.

| | | | | **State of nature** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Low | | Base case | | High | |
| **Relative probability of ln(SB_2013)** | | | | 0.25 | | 0.5 | | 0.25 | |
| **Management decision** | Year | OFL | Catch (mt) | Spawning biomass (mt) | Depletion (%) | Spawning biomass (mt) | Depletion (%) | Spawning biomass (mt) | Depletion (%) |
| 9,000 K | 2021 | 15,749 | 9,000 | 60,785 | 66% | 83,673 | 95% | 95,098 | 107% |
| | 2022 | 15,378 | 9,000 | 60,237 | 66% | 83,145 | 94% | 94,188 | 106% |
| | 2023 | 14,608 | 9,000 | 58,583 | 64% | 80,975 | 92% | 91,415 | 103% |
| | 2024 | 13,686 | 9,000 | 56,291 | 61% | 77,825 | 88% | 87,555 | 99% |
| | 2025 | 12,828 | 9,000 | 53,815 | 59% | 74,318 | 84% | 83,321 | 94% |
| | 2026 | 12,106 | 9,000 | 51,443 | 56% | 70,866 | 81% | 79,179 | 89% |
| | 2027 | 11,505 | 9,000 | 49,264 | 54% | 67,638 | 77% | 75,325 | 85% |
| | 2028 | 10,995 | 9,000 | 47,262 | 51% | 64,664 | 73% | 71,805 | 81% |
| | 2029 | 10,553 | 9,000 | 45,397 | 49% | 61,935 | 70% | 68,615 | 77% |
| | 2030 | 10,164 | 9,000 | 43,636 | 48% | 59,432 | 68% | 65,737 | 74% |
| ACL (p* = 0.45 sigma = 0.50) | 2021 | 15,749 | 14,725 | 60,785 | 66% | 83,673 | 95% | 95,098 | 107% |
| | 2022 | 14,826 | 13,788 | 57,355 | 62% | 80,275 | 91% | 91,324 | 103% |
| | 2023 | 13,633 | 12,625 | 53,270 | 58% | 75,720 | 86% | 86,203 | 97% |
| | 2024 | 12,453 | 11,481 | 49,250 | 54% | 70,914 | 81% | 80,742 | 91% |
| | 2025 | 11,487 | 10,533 | 45,784 | 50% | 66,509 | 76% | 75,676 | 85% |
| | 2026 | 10,769 | 9,832 | 43,043 | 47% | 62,790 | 71% | 71,336 | 81% |
| | 2027 | 10,240 | 9,308 | 40,927 | 45% | 59,739 | 68% | 67,731 | 76% |
| | 2028 | 9,842 | 8,897 | 39,262 | 43% | 57,242 | 65% | 64,757 | 73% |
| | 2029 | 9,534 | 8,580 | 37,905 | 41% | 55,185 | 63% | 62,310 | 70% |
| | 2030 | 9,288 | 8,322 | 36,744 | 40% | 53,473 | 61% | 60,294 | 68% |
| ACL (p* = 0.25 sigma = 0.50) | 2021 | 15,749 | 10,961 | 60,785 | 66% | 83,673 | 95% | 95,098 | 107% |
| | 2022 | 15,188 | 10,313 | 59,254 | 65% | 82,166 | 93% | 93,211 | 105% |
| | 2023 | 14,304 | 9,470 | 56,935 | 62% | 79,347 | 90% | 89,801 | 101% |
| | 2024 | 13,364 | 8,620 | 54,445 | 59% | 76,020 | 86% | 85,781 | 97% |
| | 2025 | 12,575 | 7,910 | 52,246 | 57% | 72,813 | 83% | 81,863 | 92% |
| | 2026 | 11,984 | 7,346 | 50,530 | 55% | 70,035 | 80% | 78,406 | 88% |
| | 2027 | 11,553 | 6,908 | 49,278 | 54% | 67,743 | 77% | 75,492 | 85% |
| | 2028 | 11,235 | 6,550 | 48,381 | 53% | 65,875 | 75% | 73,073 | 82% |
| | 2029 | 10,998 | 6,247 | 47,742 | 52% | 64,362 | 73% | 71,084 | 80% |
| | 2030 | 10,819 | 5,994 | 47,288 | 52% | 63,143 | 72% | 69,463 | 78% |

## Research and data needs

There are many areas of research that could be improved to benefit the understanding and assessment of Widow Rockfish. Below, we specifically identify five topics that we believe are most important.

- **Historical landings and discards:** The historical landings and discards are uncertain for Widow Rockfish and improvements would increase the certainty that fishing removals are applied appropriately. Because landings are assumed to be known exactly in the assessment model, uncertainty in the predictions does not include uncertainty in the landings. A thorough look at historical landings, species compositions, and discarding practices would potentially account for and possibly reduce the uncertainty. More importantly, though, a measure of uncertainty on the estimated historical landings would allow for reasonable sensitivities to be investigated.

- **Natural mortality:** Uncertainty in natural mortality translates into uncertain estimates of status and sustainable fishing levels for Widow Rockfish. The collection of additional age data, re-reading of older age samples, reading old age samples that are unread, and improved understanding of the life-history of Widow Rockfish may reduce that uncertainty.

- **Maturity and fecundity:** There are few studies on the maturity of Widow Rockfish and even less recent information. There have been no studies that reported results of a histological analysis. Further research on the maturity and fecundity of Widow Rockfish, the potential differences between areas, the possibility of changes over time would greatly improve the assessment of these species.

- **Age data and error:** There is a considerable amount of error in the age data and potential for bias. Investigating the ageing error and bias would help to understand the influences that the age data have on this assessment.

- **Basin-wide understanding of stock structure, biology, connectivity, and distribution:** This is a stock assessment for Widow Rockfish off of the west coast of the U.S. and does not consider data from British Columbia or Alaska. Further investigating and comparing the data and predictions from British Columbia and Alaska to determine if there are similarities with the U.S. West Coast observations would help to define the connectivity between Widow Rockfish north and south of the U.S.-Canada border.

**Table i. Summary table of results for the assessment of Widow Rockfish.**

| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total catch (mt) | 188.93 | 212.09 | 270.41 | 472.3 | 722.04 | 885.19 | 1,038.85 | 6,347.48 | 10,517.80 | NA |
| OFL (mt) | 6,937 | 5,097 | 4,923 | 4,841 | 4,435 | 4,137 | 3,990 | 14,130 | 13,237 | 12,375 |
| ACL (mt) | 509 | 600 | 600 | 1,500 | 1,500 | 2,000 | 2,000 | 13,508 | 12,655 | 11,831 |
| (1-SPR)/(1-$SPR_{50\%}$) | 0.04 | 0.04 | 0.05 | 0.08 | 0.11 | 0.12 | 0.13 | 0.61 | 0.85 | NA |
| Exploitation rate (catch/ age 4+ biomass) | 0 | 0 | 0 | 0 | 0.01 | 0.01 | 0.01 | 0.04 | 0.06 | NA |
| Age 4+ biomass (mt) | 106,867 | 107,098 | 126,117 | 130,681 | 144,306 | 145,255 | 142,506 | 171,160 | 182,799 | 180,855 |
| Spawning Biomass | 50,864 | 53,403 | 56,192 | 60,047 | 64,421 | 68,547 | 72,782 | 76,824 | 79,032 | 80,910 |
| ~95% Confidence Interval | 31,199–70,529 | 33,186–73,620 | 35,332–77,051 | 38,128–81,965 | 41,214–87,627 | 44,090–93,003 | 46,970–98,594 | 49,668–103,979 | 50,137–107,927 | 49,484–112,335 |
| Recruitment | 101,007 | 6,740 | 6,074 | 240,825 | 101,692 | 34,200 | 63,177 | 40,750 | 37,521 | 49,257 |
| ~95% Confidence Interval | 60,929–167,448 | 3,220–14,107 | 3,040–12,134 | 144,209–402,171 | 47,924–215,784 | 14,729–79,408 | 22,368–178,435 | 13,832–120,048 | 12,654–111,256 | 15,883–152,756 |
| Depletion (%) | 57.8 | 60.7 | 63.9 | 68.2 | 73.2 | 77.9 | 82.7 | 87.3 | 89.8 | 91.9 |
| ~95% Confidence Interval | 43.4–72.2 | 46.3–75.1 | 49.4–78.3 | 53.4–83.0 | 57.9–88.5 | 62.0–93.8 | 66.2–99.2 | 70.1–104.5 | 71.2–108.4 | 70.8–113.1 |

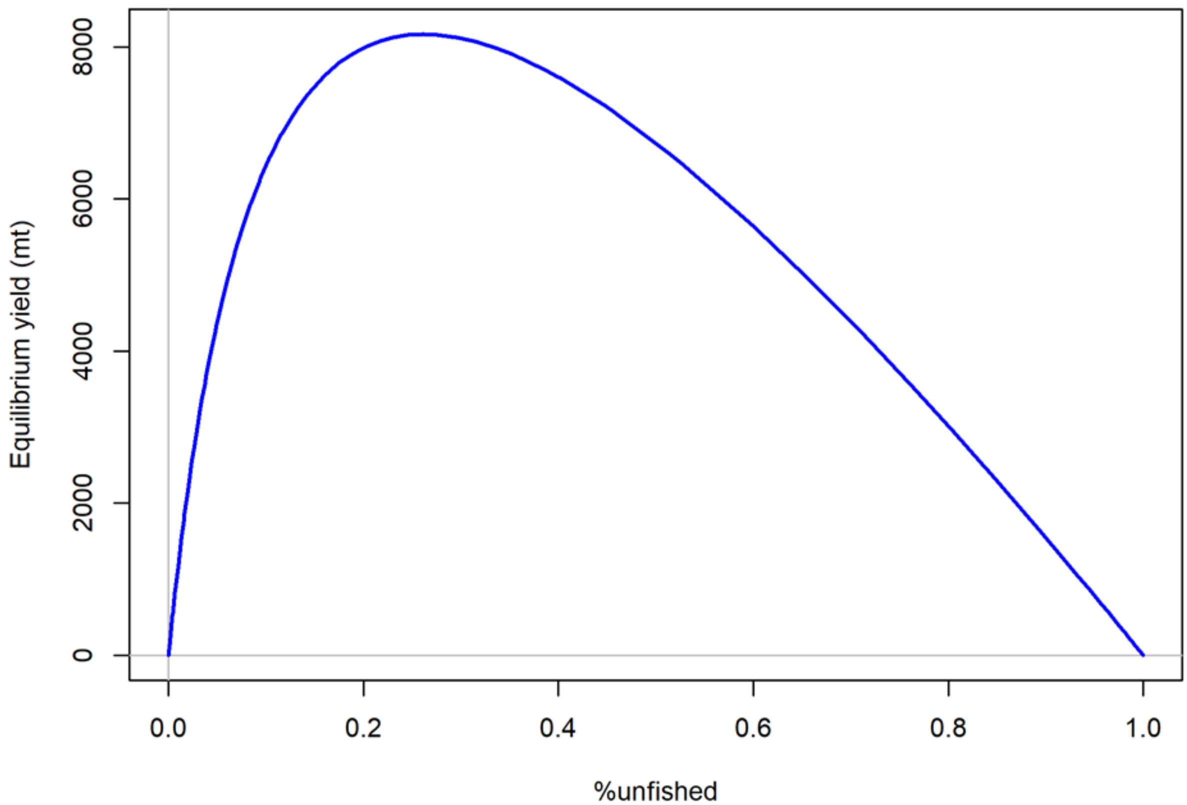


**Figure h. Equilibrium yield curve for the base case model. Values are based on 2019 fishery selectivity and distribution with steepness fixed at 0.720. The %unfished is relative to unfished spawning biomass.**