ASSESSMENT OF PETRALE SOLE IN BRITISH COLUMBIA IN 2024

Petrale Sole (Eopsetta jordani). Source: Jillian Dunic, DFO.

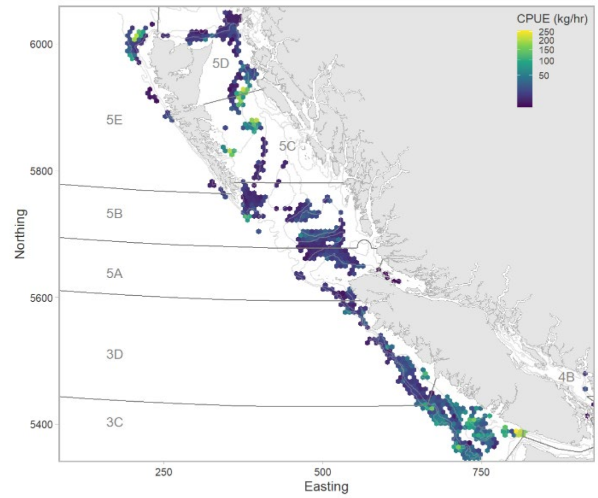

Figure 1. Average fishery catch-per-unit-effort (CPUE) for Petrale Sole off the coast of British Columbia from 1996 to 2023 shown with Pacific Marine Fisheries Commission (PMFC) major areas, which are similar, but not identical, to DFO's Groundfish Management Areas. This assessment covers one coastwide stock: PMFC areas 3CD and 5A-E. The Strait of Georgia (PFMC Area 4B) is not included in the coastwide stock. PMFC areas 3A-3B are in the USA.

CONTEXT

Fisheries and Oceans Canada (DFO) Groundfish Management Unit (GMU) has requested an assessment of Petrale Sole (*Eopsetta jordani*) in British Columbia (BC) relative to reference points that are consistent with the DFO Precautionary Approach (DFO 2009). The coastwide BC stock was last assessed in 2006, at which time a delay difference model was used due to limited age data. The accumulation of an additional 17 years of data since 2006 as well as the development of the Groundfish Multispecies Synoptic Bottom Trawl Surveys from the early 2000s has allowed the current assessment to transition to a more data-intensive modelling approach. Stock status in 2024 was estimated using a two-sex statistical catch-at-age model, and harvest advice is provided in the form of decision tables that predict the effect of a range of constant catch levels on stock status over the next 10 years.

This Science Advisory Report is from the regional peer review of July 2 – 3, 2024, on the Assessment of Petrale Sole in British Columbia in 2024. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- This stock assessment evaluated a single BC coastwide population. Petrale Sole is primarily harvested by the multi-species groundfish trawl fishery.
- A two-sex statistical catch-at-age model was used to assess Petrale Sole stock status. The model included catch data (from 1938 to 2023), and was fit to three fishery-independent survey indices (from 2003 to 2023) and age data from the fishery and fishery-independent surveys (from 2004 to 2019).
- Natural mortality (M), which had to be fixed, was identified as a key uncertainty in this stock assessment, leading to the development of an ensemble model based on three separate models with low, medium, and high M fixed estimates. This approach allowed some uncertainty in M to be incorporated into estimated stock status and harvest advice.
- Maximum sustainable yield (MSY)-based reference points were recommended for characterizing stock status and informing harvest decisions. A limit reference point (LRP) at 0.4 female spawning biomass at maximum sustainable yield (B_{MSY}), a candidate upper stock reference (USR) at 0.8B_{MSY}, and a candidate removal reference (RR) at fishing mortality at maximum sustainable yield (F_{MSY}) were used, consistent with the provisional recommendations in the Precautionary Approach (PA) policy. Stock status relative to the unfished female spawning biomass (B_0) was also presented in the assessment document.
- The stock at the beginning of 2024 was estimated to be in the Healthy zone, with female spawning biomass at the beginning of 2024 (B_{2024}) estimated to be 3.01 (95% credible interval: 1.62,5.60) times the female spawning biomass at maximum sustainable yield, B_{MSY}. Also, B_{2024} was estimated to be 0.96 (0.55,1.63) times B_0. B_{2024} is above the LRP and candidate USR with a greater than 99% probability. Additionally, fishing mortality in 2023 was below the candidate RR with a greater than 99% probability.
- The Petrale Sole stock is predicted to decline over the next 10 years, even under a no-catch scenario; however, the stock is expected to remain above the LRP and candidate USR with a very high probability (greater than 99%) at catch levels up to 1,500 t/y (compared to the average coastwide 2019–2023 catches of 630 t). Catches up to 1,250 t/y were predicted to keep the harvest rate below the maximum removal reference (F_{MSY}) in 10 years with a very high probability (greater than 98%).
- Relationships between environmental conditions, recruitment deviations, and average body condition were explored. These indicated that productivity may have increased with warmer conditions, although there was also a suggestion that further warming could become detrimental.
- Model uncertainties were explored with sensitivity analyses which varied model assumptions and data inputs. Sensitivity analyses showed that most uncertainties considered had a relatively small impact, with B_{2024} estimated to be above B_{MSY} and F_{2023} estimated to be below F_{MSY} in all cases. Assumed values for M resulted in the largest differences in estimated stock status, supporting the choice for a base ensemble model.
- Limited age composition data were identified as a key source of uncertainty in the assessment, with the lack of age data after 2019 creating high uncertainty in recent recruitment estimates.

- It is recommended that formal stock assessments occur every 5 years, but could be up to 10 years given the current high estimated stock status. During intervening years, abundance trends can be tracked using indices from the Groundfish Multispecies Synoptic Bottom Trawl Surveys.

INTRODUCTION

Petrale Sole (*Eopsetta jordani*) is a right-eyed flatfish of the family Pleuronectidae that inhabits the Northeast Pacific Ocean, with a range extending from Baja California to the Aleutian Islands in Alaska (Love 2011). Petrale Sole is typically found on soft-bottom substrata at depths from 0 to 500 m, depending on the time of year. In winter months, Petrale Sole tends to aggregate in well-defined deepwater spawning locations, while in summer the species is more evenly dispersed at shallower depths along the continental shelf (Pedersen 1975, Powell et al. 2022).

Within British Columbia (BC), Petrale Sole is primarily harvested by the multi-species groundfish trawl fishery. The Petrale Sole fishery in BC developed rapidly between the 1930s and 1950s due to high demand for Petrale Sole as a food fish. Much of the catch in early years was taken by US vessels fishing in Canadian waters (Ketchen and Forrester 1966). The discovery of deepwater spawning aggregations of Petrale Sole off Vancouver Island in 1953 helped maintain relatively stable annual catch levels despite declining catches from inshore, summertime fishing localities. By the late 1950s and 1960s, Petrale Sole abundance in BC was considered depressed due to overexploitation. Management restrictions were put in place to protect spawning aggregations and limit directed fisheries. Seasonal trip limits and restrictions on directed fishing remained in place until the move to Individual Transferable Quota (ITQ) management for the Integrated Groundfish Fishery starting in 1996-1997, at which time a coastwide Total Allowable Catch (TAC) was implemented. Catch levels, including discards, over 2019–2023 have averaged 630 t per year, with a range of 485 – 769 t (Fig. 3A).Petrale Sole discards are relatively low.

For the purpose of this stock assessment, a single BC stock covering all offshore management areas (3CD, 5A-E) was assumed for several reasons. First, there is no single, clearly defined breakpoint between northern and southern areas along the BC coast given the overlap on summer feeding grounds of fish tagged at different spawning aggregations further south. Second, observations that a small subset of Petrale Sole individuals made long-distance migrations along the coast (Ketchen and Forrester 1966), combined with substantial possible northward movement of pelagic life stages along the BC coast (Santa Cruz et al. 2023), suggest that genetic mixing could be occurring between spawning aggregations. Finally, there are no apparent differences in estimated growth parameters between management areas (3CD, 5AB, and 5CD).

ASSESSMENT

A two-sex statistical catch-at-age model implemented using the Stock Synthesis (SS) modelling framework (Methot and Wetzel 2013, Methot et al. 2020) was used to model Petrale Sole population dynamics in the combined PMFC areas 3CD+5ABCDE. Initial attempts to estimate natural mortality (M) during model fitting were unsuccessful, so M needed to be fixed at an assumed value. Natural mortality is often an uncertain and difficult parameter to estimate in stock assessments; however it can be highly influential as it is related to productivity and reference points and hence management advice (Maunder et al. 2023). Sensitivity analyses (see below) did show a large impact on model output regarding the fixed value assumed for M. In order to incorporate uncertainty in M into the model and management advice, an ensemble model approach that combined three different models that differed in the assumed value on M

was used. Although the fixed estimate of 0.154 was considered the most plausible value for *M*, model output from assessments assuming fixed *M* estimates at 0.124 and 0.184 were combined within an ensemble. The medium *M* ('baseM') value of 0.154 was based on maximum age from the meta-analytic relationship developed in Hamel and Cope (2022) [using the maximum age for each sex of Petrale Sole in the database]. The low and high *M* assumptions were an arbitrary difference of ±0.03 from the assumption based on maximum age. To create the ensemble model, the posteriors of the individual models with different *M* values were combined with 50%/25%/25% weighting for the medium, low, and high *M* choices, respectively.

The model was fit to catch data (from 1938 to 2023), three survey indices (QCS, HS, and WCVI Synoptic Surveys from 2003 to 2023), and age composition data from the fishery and surveys (from 2004 to 2019; Fig. 2). Given the availability and magnitude of historical catch data, the model began at unfished equilibrium in 1938, which was the first year of recorded catches for Petrale Sole. The expected spatial trawl survey biomass densities were modelled using geostatistical spatiotemporal GLMMs (generalized linear mixed effect models; Anderson et al. 2024), applied to data from each of the three synoptic trawl surveys independently.

Age composition data were available from the Synoptic Surveys from 2004 to 2018/2019 depending on the survey; commercial age data were available from 2004 to 2013. Age composition data were expanded (from raw aged samples to stock-wide survey and commercial catch proportions caught at age) using the same method as the Redstripe Rockfish assessment (Starr and Haigh 2021). A bootstrapping procedure, similar to that developed in Stewart and Hamel (2014), was used to determine input sample sizes as a measure of sampling variance for the compositions fit in the assessment models. The age compositions were fit with a multinomial likelihood.

The stock recruitment steepness parameter was estimated using an informative prior distribution that had been previously developed for Rock Sole (Holt et al. 2016) and assumed a beta distribution with a mean of 0.85 and a CV of 10%. A von Bertalanffy growth model was assumed for length-at-age, a linear regression for log(weight) : log(length) relationship, and maturity-at-age was modelled as logistic. Spatial heterogeneity of a coastwide population was addressed by estimating separate selectivities for the three surveys. Selectivity-at-age was estimated as an asymptotic function (forced from a double normal parameterization) and was time invariant for the fishery and surveys. Male selectivity parameters were offset from female selectivity parameters. All three models which made up the ensemble were fitted using a Bayesian estimation routine that used MCMC 'No U-turn Sampling' (NUTS) (Monnahan and Kristensen 2018).

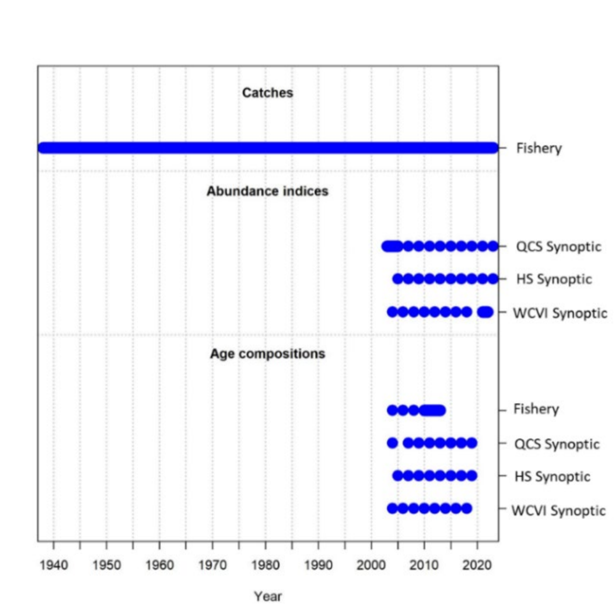

Figure 2. Data used in the base ensemble model from 1938 to 2023. QCS : Queen Charlotte Sound, HS: Hecate Strait, WCVI : West Coast Vancouver Island.

Four different reference points were used to characterize stock status and provide harvest advice, with reference points set at provisional values identified in DFO's Fishery Decision-making Framework Incorporating the Precautionary Approach (DFO 2009):

1. Limit reference point (LRP) set at $0.4B_{MSY}$
2. Upper stock reference (USR) set at $0.8B_{MSY}$
3. Target reference point set at B_{MSY}
4. A maximum reference removal rate at F_{MSY}

MSY-based reference points, including estimates B_{MSY} and F_{MSY}, as well as the estimated ratio of B_{MSY} / B_0, were robust to the range of uncertainties considered through sensitivity analyses. While unreliable estimates of B_{MSY} can be a justification for selecting proxies to MSY (Barrett et al. 2024), there was no reason to reject MSY-based quantities in this case. While B_{MSY} and F_{MSY} were somewhat sensitive to assumed values of *M*, the ensemble model approach attempted to capture this uncertainty when characterizing stock status and harvest advice using three different levels of *M*.

Based on results from the base ensemble model, the Petrale Sole stock was assessed to be above the LRP and candidate USR, and fishing mortality was below the candidate RR at the beginning of 2024 (Figs. 3B and 3C, Table 1). Median estimated B_t rapidly declined in early years and dropped below the USR for the first time in 1955. The stock continued to decline and dropped below the LRP for the first time in 1966. Median estimated B_t reached its lowest level in 1977 at $0.20B_{MSY}$. The stock then increased above the LRP in 1983. Median estimated B_{2024} was at 3.01 B_{MSY}. However, the uncertainty was large, with a 95% posterior credible interval from 1.62 B_{MSY} to 5.60 B_{MSY}. The median estimated fishing mortality rapidly increased in early years and then increased above F_{MSY} for the first time in 1945, and remained below F_{MSY} since 1996.

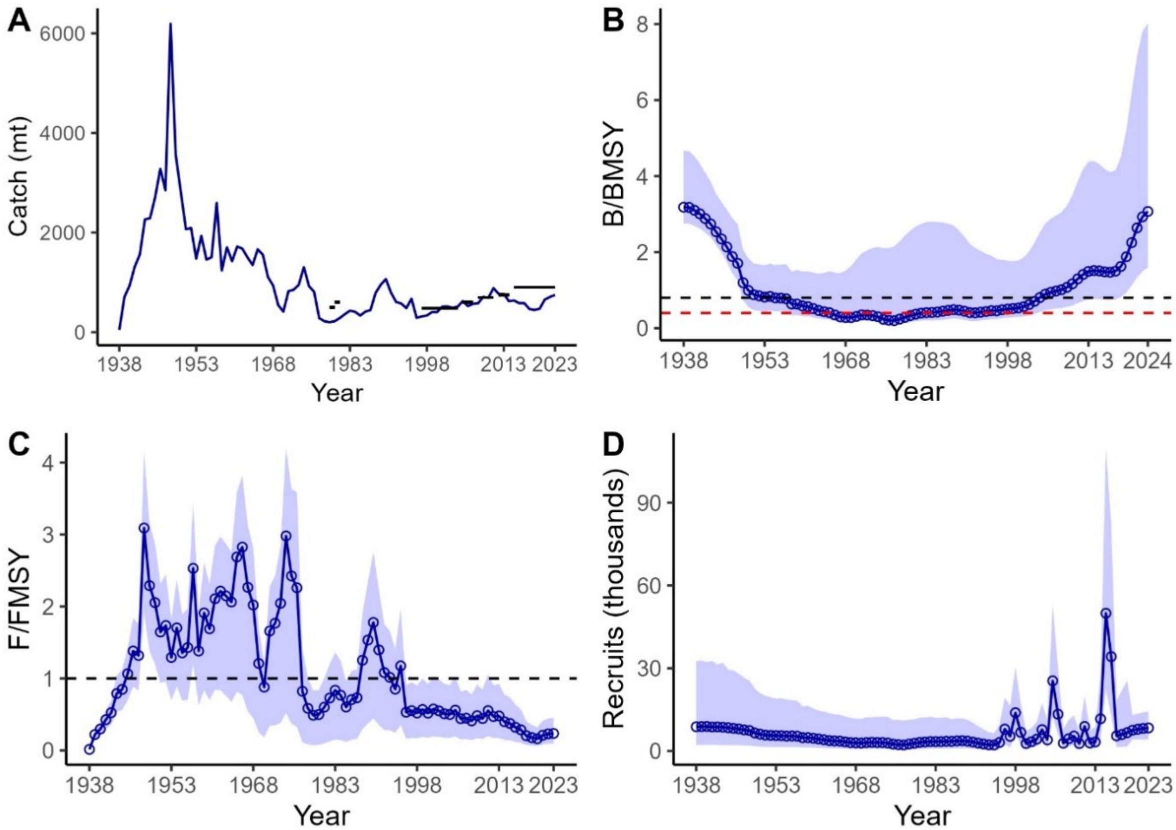

Figure 3. A) catch (dark blue line) and total allowable catches (horizontal black lines); B) median estimated female spawning biomass relative to estimated female spawning biomass at MSY with Limit Reference Point (dashed red line) and Upper Stock Reference (dashed black line) and 95% credible intervals; C) median estimated fishing mortality relative to estimated fishing mortality at MSY with candidate Removal Reference (dashed black line) and 95% credible intervals; D) median estimated recruitment and 95% credible intervals.

Table 1. Estimated management quantities for the base ensemble model (combined posteriors), shown as the 2.5th, 50th, and 97.5th percentiles from the ensemble posterior distribution.

Management Quantity	**2.5%**	**50%**	**97.5%**
B_{2024}	10,830	**17,330**	27,977
B_{MSY}	2,793	**5,704**	8,323
B_{2024}/B_{MSY}	1.62	**3.01**	5.60
$0.4B_{MSY}$	1,117	**2,282**	3,329
$B_{2024}/0.4B_{MSY}$	4.05	**7.53**	14.01
$0.8B_{MSY}$	2,234	**4,563**	6,658
$B_{2024}/0.8B_{MSY}$	2.03	**3.76**	7.00
B_0	12,215	**18,102**	24,349
B_{2024}/B_0	0.55	**0.96**	1.63
F_{2023}	0.013	**0.022**	0.036
F_{MSY}	0.067	**0.092**	0.171
F_{2023}/F_{MSY}	0.1	**0.24**	0.47
MSY	1,052	**1,352**	1,866

Decision tables give the projected stock status and fishing mortality rate relative to reference points under different constant catch harvest policies. Uncertainty in M was explicitly addressed by projecting with the base ensemble model, which combined posteriors from models with three different M assumptions. The population was projected for ten years under varying catch levels. Model assumptions and parameters used in the forecast period were the same as in the base ensemble stock assessment model. Recruitment was predicted from the spawner-recruit curve based on average mean recruitment (R_0).

Projections show that stock status has a high probability of remaining above both the LRP and candidate USR over a range of constant catch policies (Tables 2 and 3; Fig. 4). The probability that B_t exceeded $0.4B_{\text{MSY}}$ was >99% for annual catches from 0 to 2,000 t for the ten-year projection period. The probability that B_t exceeded $0.8B_{\text{MSY}}$ was >99% for 0-1,500 t of catch over the ten year period. Catch levels of 1,750-2,000 t resulted in probabilities just under 99% near the end of the ten years. The probability that F_t in the projection period was below F_{MSY} was >99% for 0-1,000 t of catch over ten years (Table 4). Probabilities of F_t being below F_{MSY} were still high for 1,250-1,500 t of catch (>84%). Probabilities became lower with 1,750-2,000 t of catch, with the lowest being 30% for 2,000 t/y of catch at the end of the projection period in 2034.

Table 2. Probability that female spawning stock biomass in the projection exceeds the limit reference point ($0.4B_{MSY}$) under varying catch levels in t for the ensemble model.

Catch (t/y)	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

Table 3. Probability that female spawning stock biomass in the projection exceeds the candidate upper stock reference ($0.8B_{MSY}$) under varying catch levels in t for the ensemble model.

Catch (t/y)	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.98
2000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.97	0.95

Table 4. Probability that fishing mortality in the projection is below the candidate removal reference (F_{MSY}) under varying catch levels in t for the ensemble model.

Catch (t/y)	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.98	0.98
1500	>0.99	>0.99	>0.99	0.98	0.97	0.95	0.93	0.91	0.89	0.85
1750	0.97	0.96	0.94	0.91	0.88	0.84	0.78	0.72	0.66	0.58
2000	0.92	0.89	0.85	0.79	0.72	0.64	0.55	0.47	0.38	0.3

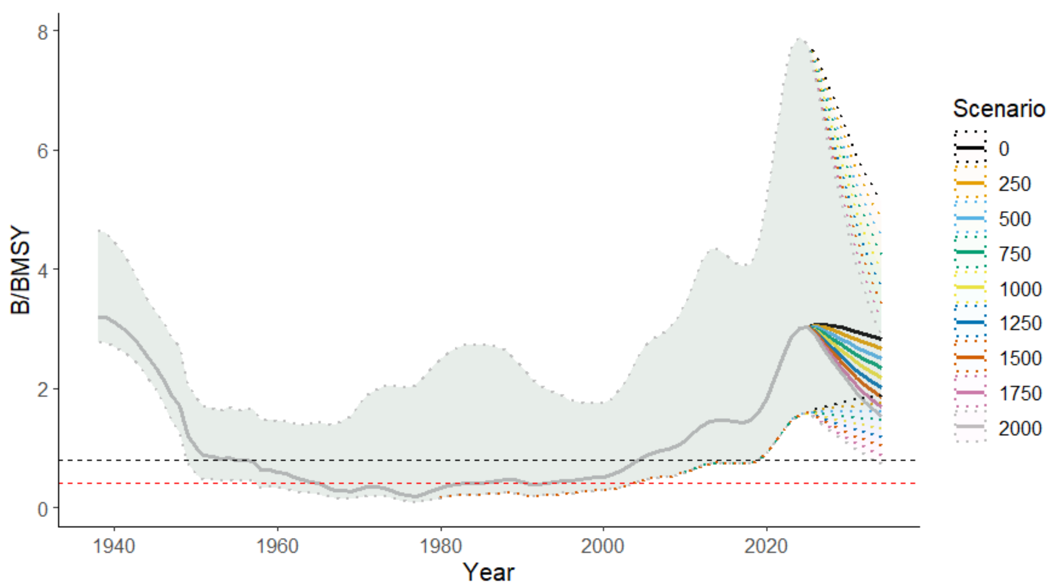

Figure 4. Median ratio (solid lines) of female spawning biomass to female spawning biomass at maximum sustainable yield (B/B_{MSY}) with 95% credible intervals (dotted lines) predicted under each of the catch levels (coloured scenarios). The horizontal red dashed line represents the limit reference point at $0.4B_{MSY}$, and the horizontal black dashed line represents the candidate upper stock reference at $0.8B_{MSY}$.

Ecosystem Considerations and Climate Change

Future Petrale Sole stock assessments could be improved by better understanding productivity, climate impacts, and prey availability. Steepness was estimated to be around 0.6, which is at the low end of what may be expected for flatfish (Myers et al. 1999). However, Petrale Sole in BC occurs at the northern end of the range of their distribution, so a steepness of 0.6 may be realistic. Steepness is also impacted by life history traits, such as maturity and mass at age, and these can change over time (Miller and Brooks 2021). Thus, steepness may have changed between 1938 and 2023 with changing environmental conditions.

The environmental analyses in this assessment provide hypotheses as to how productivity may have changed. To assess possible impacts of environmental conditions on Petrale Sole, both recruitment and body condition were considered as biological responses. For recruitment, 100 MCMC samples of the recruitment deviations from the model with an *M* assumption of 0.154 were used. Body condition was characterized using samples from the parameter distribution for an index of average Le Cren's deviations from sex-specific estimated length-weight relationships (Le Cren 1951), and standardized using a spatiotemporal model. For each pair of recruitment and body condition time series samples (100 pairs per year), the correlation between body condition and recruitment in the following year was tested. These biological responses were then related with a range of environmental or ecosystem indices that were hypothesized to be important for Petrale Sole based on the life history and the existing literature. Correlations were tested using a Bayesian implementation of a time-series regression.

Positive correlations between recruitment deviations and warmer SST in winter and spring were found (Figure 5), as well as between sea floor temperature and body condition indices. Furthermore, there was a weak positive relationship between the index of body condition for mature individuals and recruitment in the following year. This may suggest that steepness could increase under warmer conditions. The relationship between recruitment and temperature was consistent with published findings in the literature, but this relationship could be related to wind direction facilitating inshore advection of eggs and larvae rather than temperature directly (Ketchen and Forrester 1966, Castillo et al. 1994).

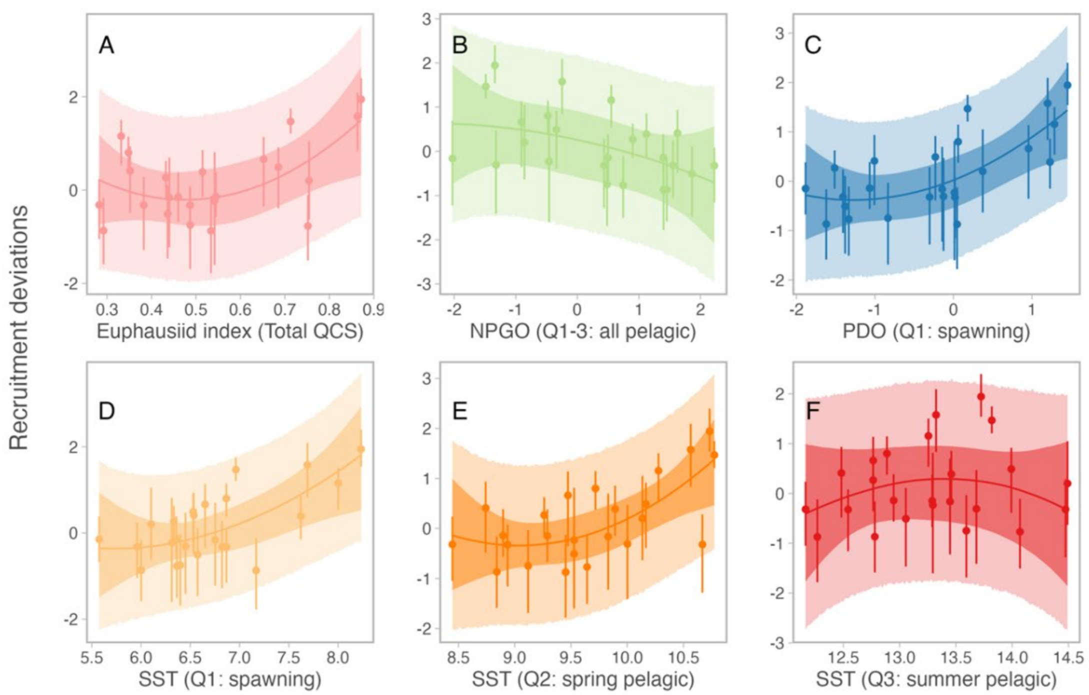

Figure 5. The strongest predicted relationships between environmental conditions and recruitment deviations from the model from the ensemble with M of 0.154 for 1995 through 2018. The darker shading represents 95% CI on the predicted relationships. Lighter shading includes uncertainty if observing new recruitment deviations. Vertical dot-lines represent the median and 95th percentiles from 100 estimated recruitment deviations.

This analysis considered the range of conditions between 1995 and 2018, which suggested that further warming could be detrimental. This conclusion was based on the relationship between recruitment and summer SST, which was slightly dome-shaped, suggesting that impacts on recruitment might be negative at SST over 14 ^{o}C (Box F, Figure 5).

Euphausiid abundance was also positively correlated with both recruitment (Figure 5) and mature male body condition. Immature body condition showed negative relationships with both primary production and total euphausiids, and positive relationships with both sea floor oxygen concentration and NPGO, possibly suggesting some negative impact from upwelling conditions, potentially through impacts on oxygen concentrations.

Gathering additional data and expanding investigations to include additional oceanographic variables, information on contemporary diets, and prey availability is recommended. Specifically, contemporary diet data is lacking, hampering the identification of relevant prey availability indices. Future assessments should also consider whether incorporation of environmental variables into the stock assessment model could improve modelling of recruitment dynamics and/or steepness.

Sources of Uncertainty

As with all stock assessments, results are dependent on assumptions about model structure, parameter values, specified prior distributions, and data selection. A variety of sensitivity analyses were conducted to explore uncertainties in the stock assessment. The range of sensitivities considered had a relatively small impact on trends in estimated biomass and fishing mortality through time, with B_{2024} estimated to be above B_{MSY} and F_{2023} estimated to be below F_{MSY} in all cases (Figure 6, Figure 7).

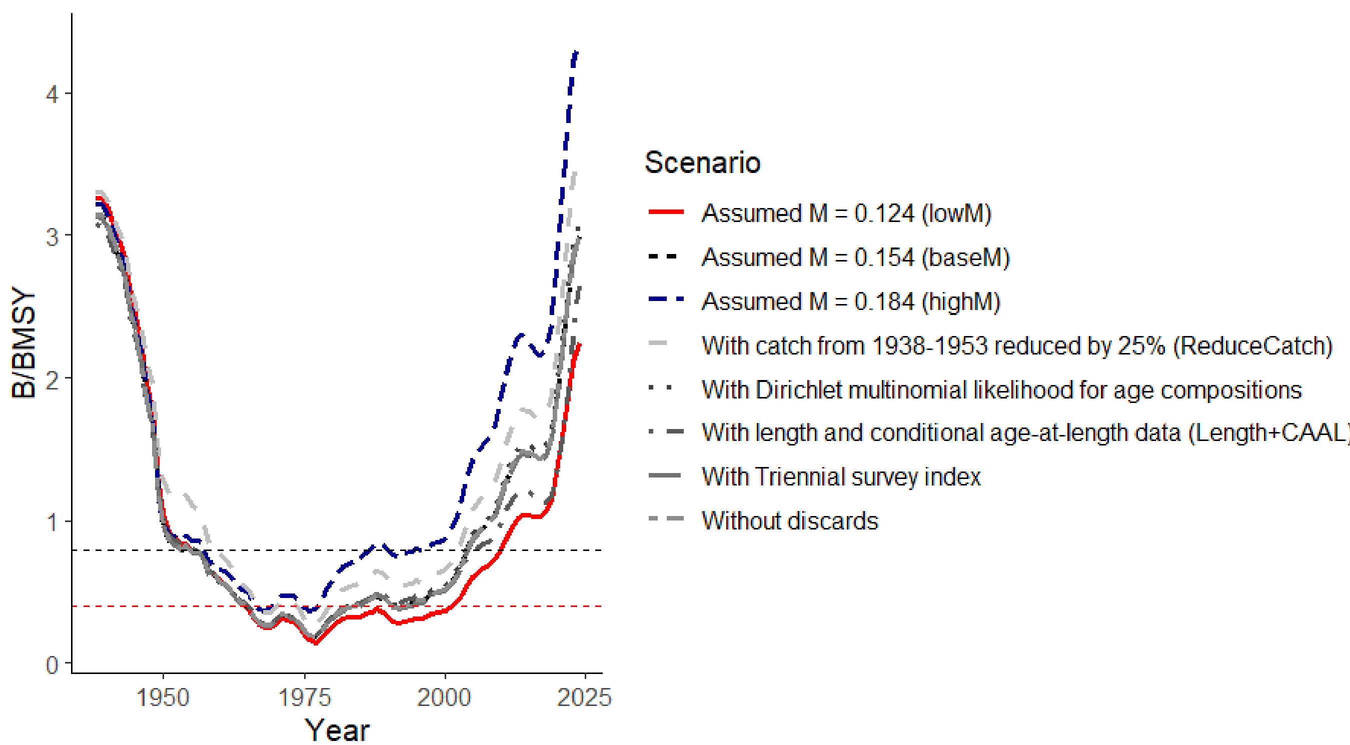

Figure 6. Median estimated female spawning stock biomass to female spawning stock biomass at maximum sustainable yield ratio from the model with M=0.154 from the base ensemble model and selected sensitivities, which also assume M=0.154 aside from the 'highM' (0.184) and 'lowM' (0.124) scenarios. The dashed red line represents 0.4B_{MSY}, and the dashed black line represents 0.8B_{MSY}.

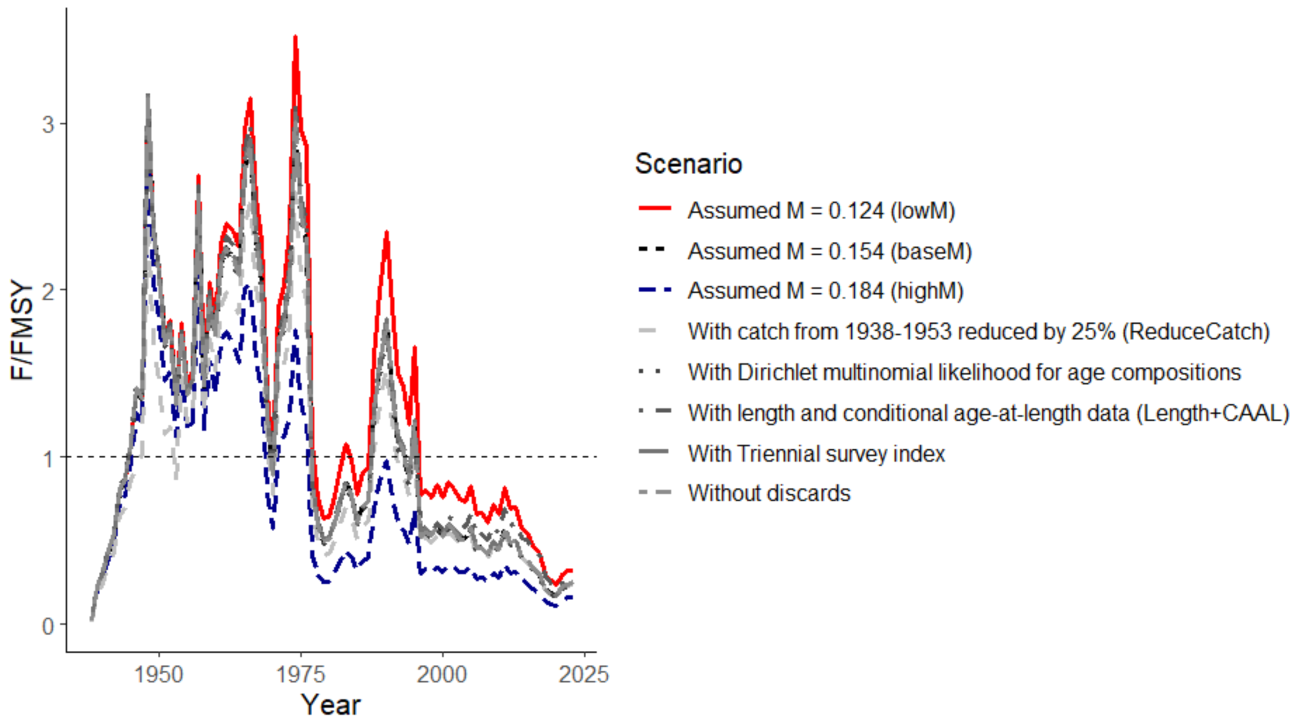

Figure 7. Median estimated fishing mortality to fishing mortality at maximum sustainable yield ratio from the model with M=0.154 from the base ensemble model and selected sensitivities, which also assume M=0.154 aside from the 'highM' (0.184) and 'lowM' (0.124) scenarios. The black dashed line represents F_{MSY}.

Among the sensitivity analyses considered, the assumed value of *M* had the largest effect on model results. Stock status in 2024 was highest under the 'highM' scenario and lowest under the 'lowM' scenario. This result led to the specification of an ensemble model that incorporated uncertainty in assumed *M* values into the stock status and harvest advice. However, the range of the three *M* values in the ensemble was relatively narrow (*M* = 0.124 – 0.184; a 19% increase or decrease from the base assumption of *M* = 0.154) due to the model failing to converge when higher or lower values of *M* than those in the ensemble model were used.

Limitations in the coverage and reliability of the age composition data were also key sources of uncertainty. Age composition data cover only a small portion of the reconstructed time period, with data ranging from 2004 to 2019. As a result, the assessment assumed a single-fishery selectivity curve over time and coastwide, which is an uncertain assumption given large changes in management regulations and fleet behaviour. The lack of recent (later than 2019) age composition data also led to uncertainty in recent recruitment estimates (Fig. 3D). Furthermore, the spatial distribution of aged Petrale Sole samples from both the fishery and DFO's Synoptic trawl surveys showed limited spatial coverage in most years.

An alternative model structure that made use of the more abundant length composition data was explored as a sensitivity analysis (a length- and conditional age-at-length model, referred to as "Length+CAAL") to see whether adding length data to the assessment affected assessment outcomes. The Length+CAAL model estimated lower biomass and higher fishing mortality in recent years than the 'baseM' model due to down-scaling of the large recruitment estimates in 2015 and 2016. However, this model also estimated B_{2024} to be in the Healthy zone, and that F_{2023} was below F_{MSY}. Future work to develop length- and conditional-age-at-length models for Petrale Sole (or other groundfish species) in an attempt to compensate for limited age data should explore methods to represent variation in growth patterns among fish in the same cohort. In addition, research could include simulation analyses examining the effect of sparse age data on the performance of age-structured and conditional age-at-length models, or equivalently a literature review of current simulation studies on the topic.

Prioritization of the collection of age and length data from trawl fisheries, as well as a review of the methods used to select otoliths for age reading from the synoptic trawl surveys, are recommended to improve the reliability of both age and length data for future stock assessments. This issue is not specific to Petrale Sole, as it is one of many species that would greatly benefit from a higher level of biological sampling from the fishery and ageing of otoliths from the surveys. Tradeoffs in allocating ageing resources among species and a broader multi-species review of prioritization of age sampling and reading should be considered.

The historical catch data series used in this assessment is another source of uncertainty. Catch data prior to 1954 came from documented reconstructions (Ketchen and Forrester 1966). Catch estimates during this period were much greater than recent catch levels, which resulted in high estimates of fishing mortality in early years. While previous stock assessments in BC did not use records prior to 1954 due to concerns about reliability, historical records were included due to the potential value of information from this early period of fishery development. In addition, including these data allowed the assessment to start at an unfished equilibrium state in 1938, which avoided highly uncertain assumptions associated with starting the population at a fished state at some later point in time. The sensitivity of assessment results to this historic catch was tested using the ‘ReduceCatch’ sensitivity, in which catch levels between 1938 and 1954 were arbitrarily reduced by 25%. This ‘ReduceCatch’ scenario did result in lower historic estimates of fishing mortality and higher estimated stock status in 2024 compared to the base model.

The other sources of uncertainty explored via sensitivity analyses had very little effect on model outputs. These included the addition of another survey index based on the US National Oceanic and Atmospheric Administration’s (NOAA) Triennial survey, eliminating discards, and using an alternative data weighting procedure based on a Dirichlet-Multinomial likelihood.

Finally, a closed population was assumed, but Petrale Sole is known to migrate between the U.S.A. and Canada as both adults and pelagic larvae (Pedersen 1975, Santa Cruz et al. 2023). The U.S. Petrale Sole stock assessment also acknowledged this issue (Taylor et al. 2023). The similar estimated stock trends (especially in earlier years) by the U.S. assessment and this assessment provide further support that Petrale Sole may be a transboundary stock. Future assessments may want to consider testing the effect of assuming a single, closed BC stock in light of documented movement of Petrale Sole between BC and Washington state. Further studies on Petrale Sole movement and genetic stock delineation would also be beneficial to such an effort.

CONCLUSIONS AND ADVICE

Stock Synthesis was used to fit a stock assessment model for Petrale Sole with catch data, three survey indices, and fishery and survey age composition data. Natural mortality was a key uncertainty in this stock assessment, leading to the development of an ensemble model which combined the posterior distributions from three models that were based on three fixed values for M (0.124, 0.154, 0.184). MSY-based reference points were recommended since the historical based reference points from the last Petrale Sole assessment were no longer appropriate, and MSY-based reference points were robust across sensitivities. Based on results from the base ensemble model, the Petrale Sole stock was assessed to be above the LRP and candidate USR at the beginning of 2024, and fishing mortality in 2023 was assessed to be below the candidate

RR. Projections for ten years from 2025 to 2034 under varying catch levels showed that stock status had a high probability of remaining above both the LRP and candidate USR over all constant catch policies considered. The probability that fishing mortality F in the projection was below the candidate RR was also high (>99%), at least until catches rose to 1,750 t/year or higher. It is recommended that formal stock assessments occur every 5 years, but could be delayed up to 10 years given the high values of estimated stock status in 2024. During intervening years, abundance trends could be tracked using indices from the Groundfish Multispecies Synoptic Trawl Surveys using the groundfish synopsis report (cast et al. 2019; Anderson et al. 2020; Anderson et al. 2024), which is updated regularly. The stock was estimated to be under the candidate USR in 2003, so a model-based coastwide index, estimated using a geostatistical model, that falls below the mean 2003 index value may signify that the stock should be reassessed. Individual survey indices from the synoptic surveys could be used as secondary sources of information for prioritizing reassessment.

OTHER CONSIDERATIONS

Including indigenous knowledge systems into stock assessment objectives and alternative reference points were discussed by participants during the meeting, specifically that stock status could be determined using alternative reference points such as B_0. Using and interpreting alternative perspectives and thresholds were beyond the scope of this paper and meeting, but participants felt it was an important consideration and worth encouraging scientists and managers to consider this in future stock assessments.

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