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**DRAFT**

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# Stock Assessment Update: Status of the U.S. petrale sole resource in 2014

by

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# Executive Summary

## Stock

This assessment reports the status of the petrale sole (*Eopsetta jordani*) resource off the coast of California, Oregon, and Washington using data through 2014. While petrale sole are modeled as a single stock, the spatial aspects of the coast-wide population are addressed through geographic separation of data sources/fleets where possible. There is currently no genetic evidence suggesting distinct biological stocks of petrale sole off the U.S. coast. The limited tagging data available to describe adult movement suggests that petrale sole may have some homing ability for deep water spawning sites but also have the ability to move long distances between spawning sites, inter-spawning season, as well as seasonally.

## Catches

While records do not exist, the earliest catches of petrale sole are reported in 1876 in California and 1884 in Oregon. In this assessment, fishery removals have been divided among 4 fleets: 1) winter North trawl, 2) summer North trawl, 3) winter South trawl, and 4) summer South trawl. Landings for the North fleet are defined as fish landed in Washington and Oregon ports. Landings for the South fleet are defined as fish landed in California ports. Recent annual catches during 1981–2014 range between 749-2,903 mt (Table a, Figure a). Petrale sole are caught nearly exclusively by trawl fleets; non-trawl gears contribute less than 3% of the catches. Based on the 2005 assessment, annual catch limits (ACLs) were reduced to 2499 mt for 2007-2008. Following the 2009 assessment ACLs were further reduced to a low of 976 mt for 2011 and have subsequently increased to a high value of 2,341 for 2014. From the inception of the fishery through the war years, the vast majority of catches occurred between March and October (the summer fishery), when the stock is dispersed over the continental shelf. The post-World War II period witnessed a steady decline in the amount and proportion of annual catches occurring during the summer months (March-October). Conversely, petrale catch during the winter season (November–February), when the fishery targets spawning aggregations, has exhibited a steadily increasing trend since the 1940s. From the mid-1980s through the early 2000s, catches during the winter months were roughly equivalent to or exceeded catches throughout the remainder of the year, whereas during the past 10 years the relative catches during the winter and summer have been more variable across years (Figure a).

**Table a: Recent Catches based on the November 1 – October 31 fishing year.**

| Fishing Year | North Catch (mt) | South Catch (mt) | Total Catch (mt) |
|---|---|---|---|
| 2004 | 1,759 | 444 | 2,204 |
| 2005 | 2,032 | 871 | 2,903 |
| 2006 | 1,549 | 579 | 2,128 |
| 2007 | 1,466 | 879 | 2,346 |
| 2008 | 1,196 | 933 | 2,130 |
| 2009 | 1,488 | 720 | 2,208 |
| 2010 | 550 | 199 | 749 |
| 2011 | 645 | 117 | 762 |
| 2012 | 884 | 232 | 1,116 |
| 2013 | 1516 | 408 | 1,925 |
| 2014 | 1713 | 628 | 2,341 |

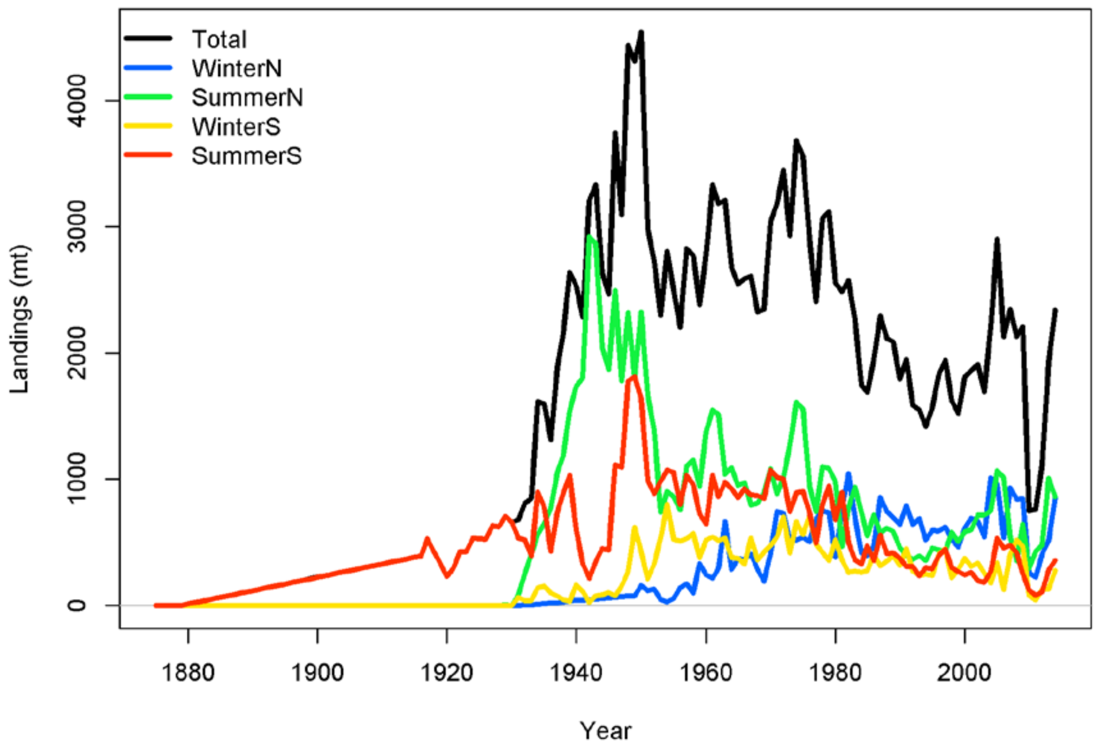


**Figure a: Catch History up to 2014.**

## Data and assessment

The previous stock assessment for petrale sole was developed during 2013 (Haltuch et al. 2013) using Stock Synthesis 3, an integrated length-age structured model (Methot and Wetzel, 2013). The current assessment has been upgraded to a newer version of SS (3.24u) and is structured as an annual model with the fishing year beginning on November 1 and ending on October 31. The fisheries are structured seasonally based on winter (November to February) and summer (March to October) fishing seasons due to the development and growth of the wintertime fishery, which began in the 1950s. In recent decades wintertime catches have often exceed summertime catches. The fisheries modeled as the North Winter and North Summer, where the north includes both Washington and Oregon, and South Winter and South Summer, which encompasses California fisheries. The model includes catch, length- and age-frequency data from the trawl fleets described above as well as standardized winter fishery catch-per-unit-effort (CPUE) indices. While the impact of rapidly changing regulations in the trawl fishery after 2000 can make fishery-based CPUE indices unreliable, the standardized fishery CPUE indices attempt to account for the impact of some of the management changes. Biological data are derived from both port and on-board observer sampling programs. The National Marine Fisheries Service (NMFS) early (1980, 1983, 1986, 1989, 1992) and late (1995, 1998, 2001, and 2004) Triennial bottom trawl survey and the Northwest Fisheries Science Center (NWFSC) trawl survey (2003–2014) relative biomass indices and biological sampling provide fishery independent information on relative trend and demographics of the petrale sole stock.

The base case assessment model includes parameter uncertainty from a variety of sources, but likely underestimates the uncertainty in recent trends and current stock status. For this reason, in addition to asymptotic confidence intervals (based upon the model's analytical estimate of the variance near the converged solution), results from models that reflect alternate states of nature regarding the rate of female natural mortality are presented as a decision table.

## Stock biomass

Petrale sole were lightly exploited during the early 1900s, but by the 1950s the fishery was well developed and showing clear signs of depletion and declines in catches and biomass (Figures a, b). The rate of decline in spawning biomass accelerated through the 1930s–1970s reaching minimums generally around or below 10% of the unexploited levels during the 1980s through the early 2000s (Figure b). The petrale sole spawning stock biomass is estimated to have increased slightly from the late 1990s, peaking in 2005, in response to above average recruitment (Table b, Figure b). However, poor recruitments during the period of stock increase resulted in stock declines between 2005 and 2010 (Table b), resulting in harvests that, in hind site, were great than those suggested by the current harvest policy. Since 2010 the total biomass of the stock has increased as large recruitments during 2007 and 2008 appear to be moving into the population. The estimated relative depletion level in 2015 is 30.80% of unfished biomass (~95% asymptotic interval: 22.4% - 39.2%, ~ 75% interval based on the range of states of nature: 26.5%-35.2%), corresponding to 10,669 mt (~95% asymptotic interval: 8,774 – 12,564 mt, states of nature interval: 10,353 – 11,174 mt) of female spawning biomass in the base model (Table b). The base model indicates that the spawning biomass was generally below 25% of the unfished level between the 1960s and 2013 and was rebuilt above this target in 2014.
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**Table b: Recent trend in beginning of the year biomass and depletion**

| Fishing Year | Spawning Biomass (mt) | ~95% confidence interval | Range of states of nature | Estimated depletion | ~95% confidence interval | Range of states of nature |
|---|---|---|---|---|---|---|
| 2005 | 4,252 | 3877 - 4625 | 4064 - 4512 | 12.30% | 9.3% - 15.2% | 10.4% - 14.2% |
| 2006 | 4,029 | 3645 - 4411 | 3833 – 4290 | 11.60% | 8.8% - 14.5% | 9.8% - 13.5% |
| 2007 | 3,953 | 3558 - 4345 | 3756 - 4207 | 11.40% | 8.6% - 14.2% | 9.6% - 13.3% |
| 2008 | 3,655 | 3241 - 4068 | 3460 - 3910 | 10.60% | 7.9% - 13.2% | 8.9% - 12.3% |
| 2009 | 3,466 | 3008 - 3922 | 3266 - 3735 | 10% | 7.4% - 12.7% | 8.4% - 11.8% |
| 2010 | 3,311 | 2770 - 3851 | 3091 - 3619 | 9.60% | 6.8% - 12.3% | 7.9% - 11.4% |
| 2011 | 4,199 | 3514 - 4881 | 3945 - 4568 | 12.10% | 8.7% - 15.6% | 10.1% - 14.4% |
| 2012 | 5,713 | 4803 - 6621 | 5411 - 6170 | 16.50% | 11.9% - 21.1% | 13.9% - 19.5% |
| 2013 | 7,692 | 6465 - 8917 | 7334 - 8235 | 22.20% | 16.1% - 28.3% | 18.8% - 26.0% |
| 2014 | 9,467 | 7890 - 11042 | 9093 - 10038 | 27.30% | 19.9% - 34.8% | 23.3% - 31.7% |
| 2015 | 10,669 | 8774 - 12564 | 10353 - 11174 | 30.80% | 22.4% - 39.2% | 26.5% - 35.2% |

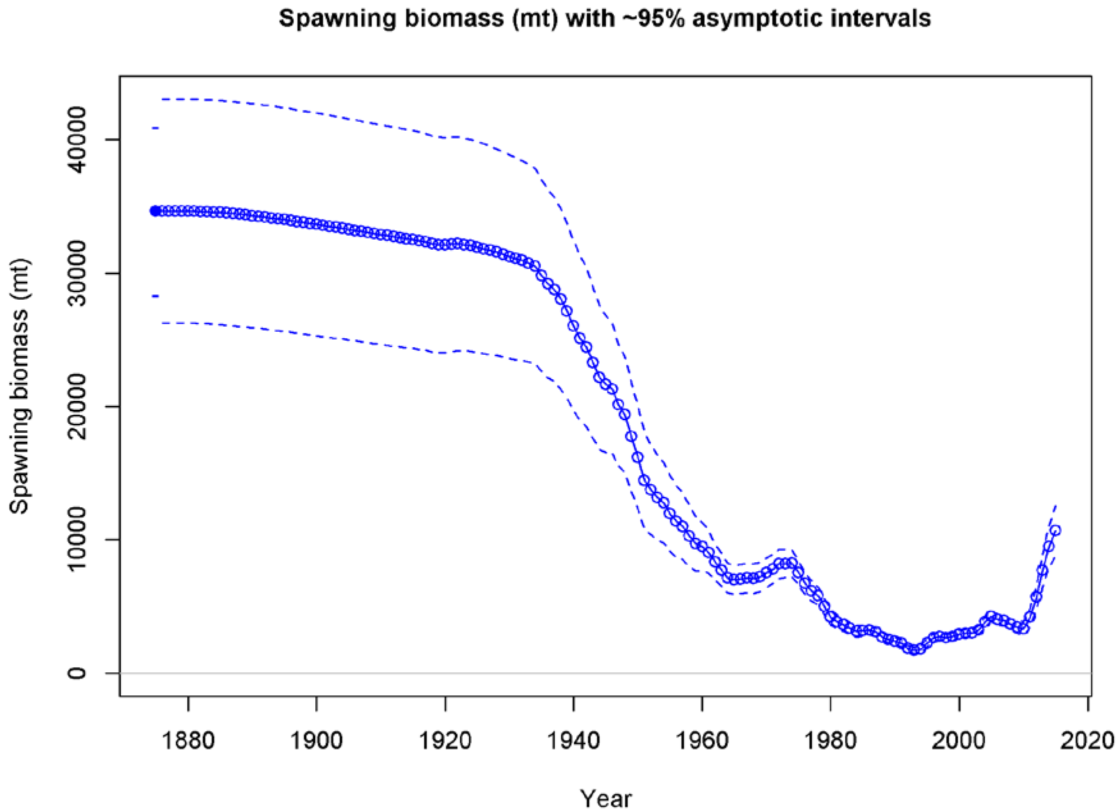


**Figure b: Biomass time series.**

## Recruitment

Annual recruitment was treated as stochastic, and estimated as annual deviations from log-mean recruitment where mean recruitment is the fitted Beverton-Holt stock recruitment curve. The time-series of estimated recruitments shows a relationship with the decline in spawning biomass, punctuated by larger recruitments (Figure c). The three strongest recruitments during the last 10 years are estimated to be from 2006, 2007, and 2008, with the 2007 and 2008 year classes being the third-largest and largest recrutiments estimated during the assessed period. The four weakest recruitments are estimated to be from 2005, 2010, and 2011 (Table c, Figure c).

**Table c: Recent recruitment**

| Fishing Year | Estimated recruitment (1,000's) | ~95% confidence interval | Range of states of nature |
|---|---|---|---|
| 2005 | 9,501 | 6600 - 13679 | 7547 - 12079 |
| 2006 | 16,408 | 11592 - 23227 | 13025 - 20913 |
| 2007 | 22,867 | 16170 - 32338 | 18169 - 29008 |
| 2008 | 31,400 | 22355 - 44107 | 25010 - 39369 |
| 2009 | 13,034 | 8586 - 19788 | 10433 - 16180 |
| 2010 | 10,207 | 6442 - 16176 | 8287 - 12548 |
| 2011 | 10,286 | 6065 - 17447 | 8340 - 12738 |
| 2012 | 14,683 | 7965 - 27069 | 11661 - 18242 |
| 2013 | 12,421 | 5722 - 26965 | 9611 - 15958 |
| 2014 | 13,496 | 5955 - 30587 | 10285 - 17612 |
| 2015 | 13,658 | 1937 - 25379 | 10351 - 17893 |

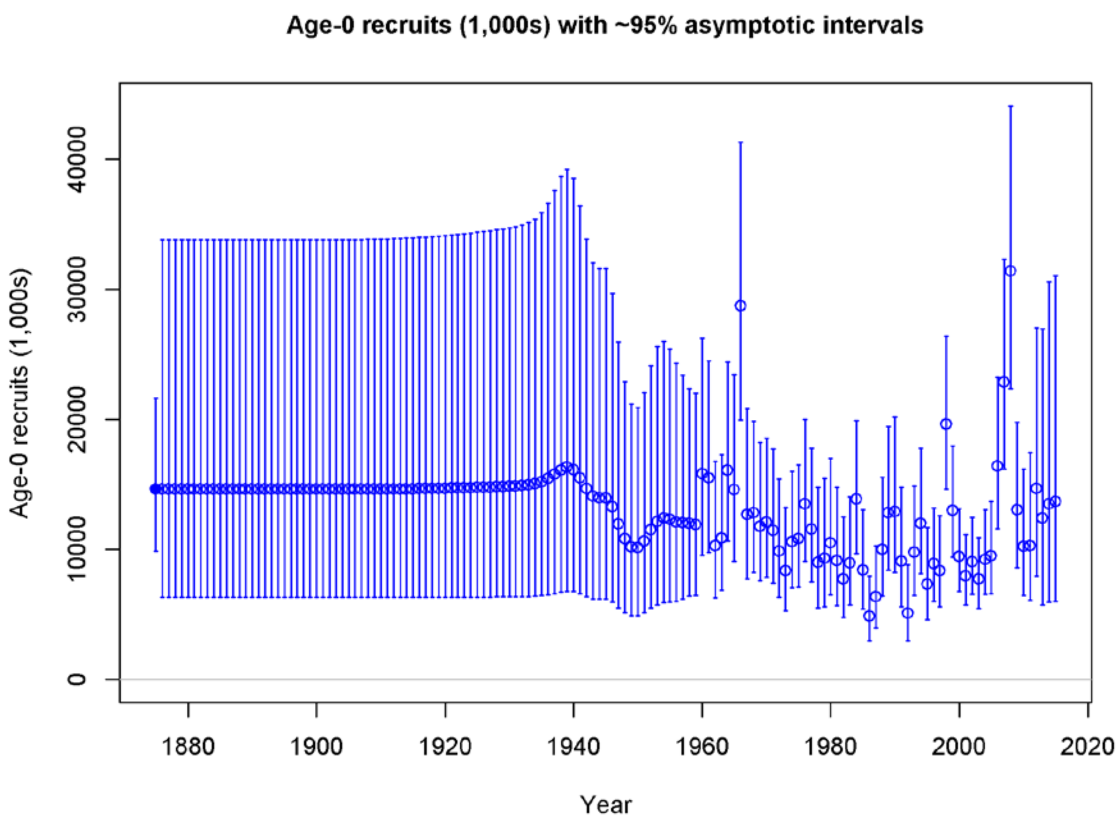


**Figure c: Recruitment time series.**

## Exploitation status

The abundance of petrale sole was estimated to have dropped below the $SB_{25\%}$ management target during the 1960s and stayed under that level through the beginning of 2013 (Figure d). The stock declined below the $SB_{12.5\%}$ overfished threshold from the early 1980s until the early 2000s. In 1984 the stock dropped below 10% of the unfished spawning biomass and did not rise above the 10% level until 2001 (Figure d). From 2000 to 2005 the stock increased, reaching a peak of 14.2% of unfished biomass in 2005, then declining through 2010, and again increasing from 2011-2014 (Table d, Figure d). Fishing mortality rates in excess of the current F-target for flatfish of $SPR_{30\%}$ are estimated to have begun during the 1950s and continued until 2010 (Table d, Figures e, f). Current F (catch/biomass of age-3 and older fish) is estimated to be 0.14 during 2015 (Table d, Figures e,f). The model is projected from 2015 to 2026 assuming F meets management targets.

**Table d. Recent trend in spawning potential ratio (entered as 1-SPR) and summary exploitation rate (catch divided by biomass of age-3 and older fish).**

| Fishing Year | Estimated 1-SPR (%) | ~95% confidence interval | Harvest rate (proportion) | ~95% confidence interval |
|---|---|---|---|---|
| 2005 | 0.87 | 0.85-0.89 | 0.33 | 0.32 - 0.35 |
| 2006 | 0.84 | 0.81-0.86 | 0.26 | 0.25 - 0.27 |
| 2007 | 0.85 | 0.82-0.87 | 0.29 | 0.27 - 0.31 |
| 2008 | 0.84 | 0.82-0.87 | 0.28 | 0.26 - 0.30 |
| 2009 | 0.86 | 0.83-0.88 | 0.29 | 0.27 - 0.31 |
| 2010 | 0.69 | 0.64-0.73 | 0.10 | 0.09 - 0.11 |
| 2011 | 0.60 | 0.55-0.65 | 0.06 | 0.05 - 0.07 |
| 2012 | 0.61 | 0.56-0.66 | 0.07 | 0.06 - 0.08 |
| 2013 | 0.67 | 0.63-0.71 | 0.11 | 0.10 - 0.12 |
| 2014 | 0.67 | 0.62-0.71 | 0.12 | 0.11 - 0.13 |
| 2015 | 0.68 | 0.64-0.72 | 0.14 | 0.13-0.15 |

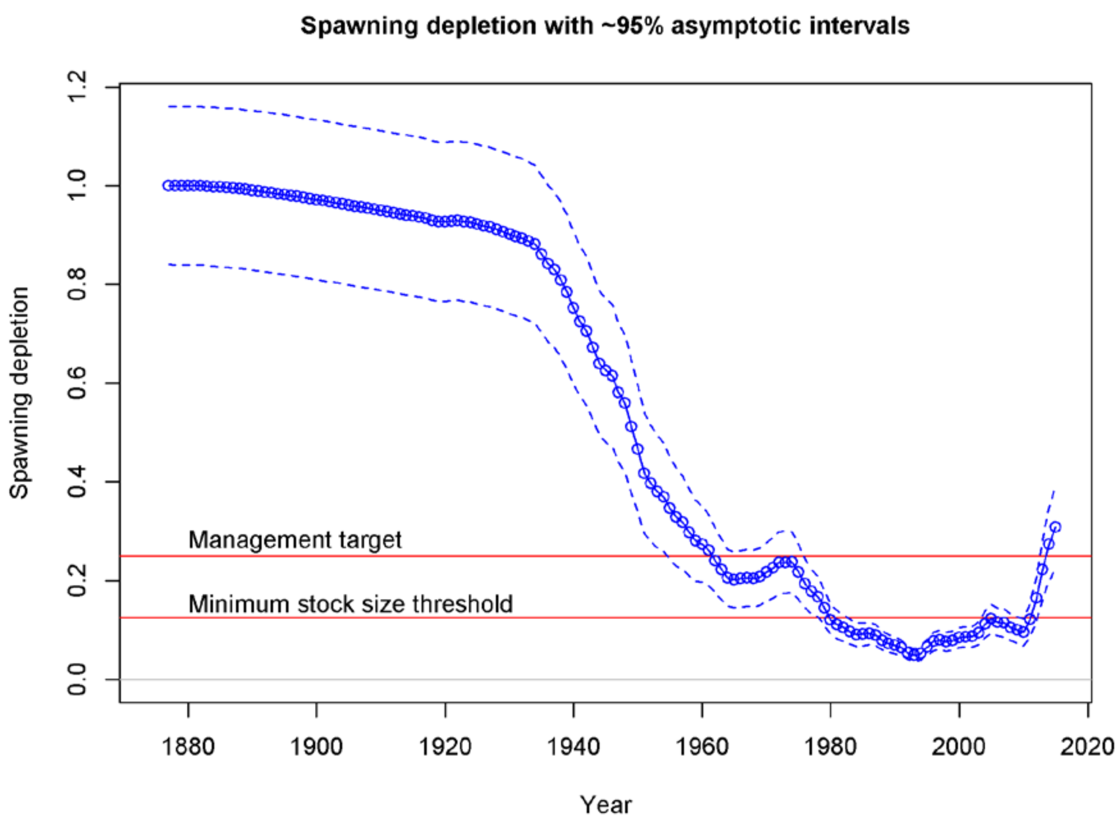


**Figure d. Estimated relative depletion with approximate 95% asymptotic confidence intervals (dashed lines).**

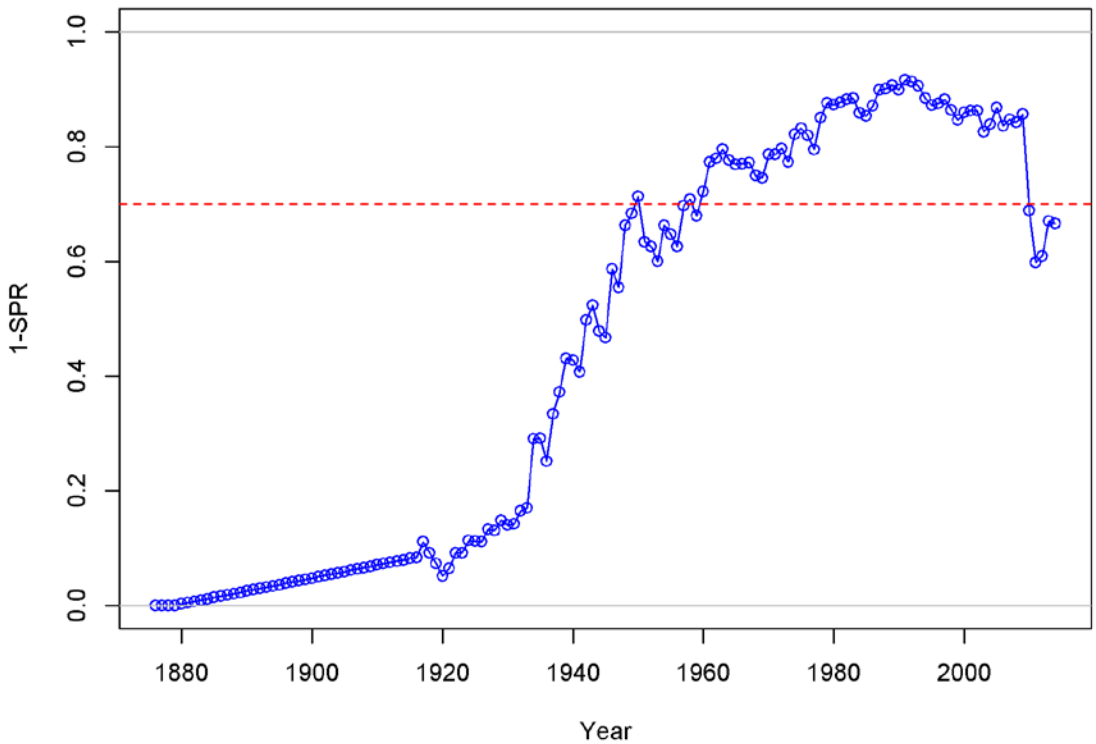


**Figure e. Estimated spawning potential ratio (SPR). One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the $SPR_{30\%}$ harvest rate. The last year in the time series is 2014.**

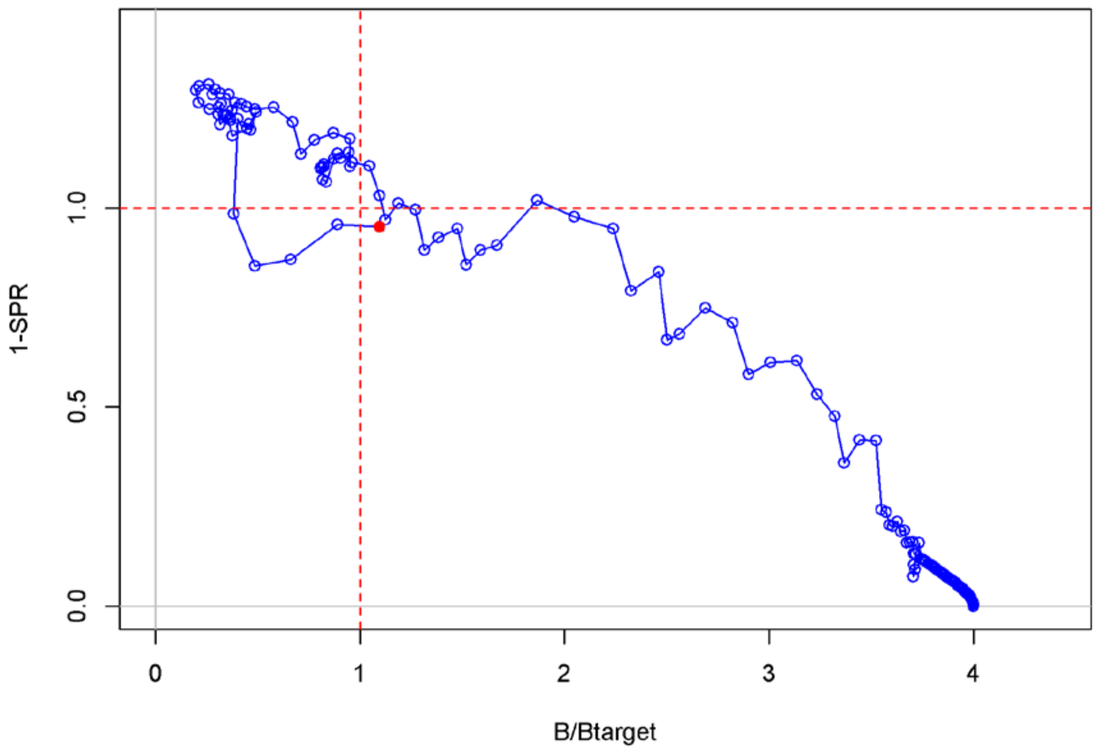


**Figure f. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base case model. The relative (1-SPR) is (1-SPR) divided by SPR 30% (the SPR target). Relative depletion is the annual spawning biomass divided by the spawning biomass corresponding to 25% of the unfished spawning biomass. The red point indicates 2014.**

## Ecosystem considerations

Ecosystem factors have not been explicitly modeled in this assessment, but there are several aspects of the California current ecosystem that may impact petrale sole population dynamics and warrant further research. Castillo (1992) and Castillo et al. (1995) suggest that density-independent survival of early life stages is low and show that offshore Ekman transportation of eggs and larvae may be an important source of variation in year-class strength in the Columbia INPFC area. The effects of the Pacific Decadal Oscillation (PDO) on California current temperature and productivity (Mantua et al. 1997) may also contribute to non-stationary recruitment dynamics for petrale sole. The prevalence of a strong late 1990s year-class for many West Coast groundfish species suggests that environmentally driven recruitment variation may be correlated among species with relatively diverse life history strategies. Although current research efforts along these lines are limited, a more explicit exploration of ecosystem processes may be possible in future petrale sole stock assessments if resources are available for such investigations.

## Reference points

Pacific coast flatfish, including petrale sole, are considered overfished when a stock falls below 12.5% of unfished spawning biomass and rebuilt when it reaches 25% of unfished spawning biomass.

Unfished spawning stock biomass was estimated to be 34,637 mt in 2015 in the base case model (Figure b). The target stock size ($SB_{25\%}$) is therefore 8,660 mt which gives a catch of 2,781s mt (Table e, Figure b). Model estimates of spawning biomass at MSY are slightly lower than those specified under the current harvest control rule. Maximum sustained yield (MSY) applying recent fishery selectivity and allocations was estimated at 2,800 mt, occurring at a spawning stock biomass of 7,292 mt (SPR = 0.25) (Table e).

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

| Quantity | Estimate | ~95% Confidence Interval |
|---|---|---|
| Unfished Spawning biomass (mt) | 34,637 | 6,299 |
| Unfished age 3+ biomass (mt) | 53,300 | 8,226 |
| Unfished recruitment (R0) | 14,619 | 5,793 |
| Depletion (2015) | 0.31 | 0.08 |
| **Reference points based on $SB_{25\%}$** | | |
| Proxy spawning biomass ($B_{25\%}$) | 8,660 | 1,575 |
| SPR resulting in $B25_{\%}$ ($SPR_{30\%}$) | 0.27 | 0.02 |
| Exploitation rate resulting in $B_{25\%}$ | 0.17 | 0.02 |
| Yield with *SPR* at $B_{25\%}$ (mt) | 2,781 | 223 |
| **Reference points based on SPR proxy for MSY** | | |
| Spawning biomass | 9,608 | 2,089 |
| $SPR_{proxy}$ | 0.3 | 0 |
| Exploitation rate corresponding to $SPR_{proxy}$ | 0.15 | 0.02 |
| Yield with $SPR_{proxy}$ at $SB_{SPR}$ (mt) | 2,749 | 261 |
| **Reference points based on estimated MSY values** | | |
| Spawning biomass at *MSY* ($SB_{MSY}$) | 7,292 | 1,800 |
| $SPR_{MSY}$ | 0.24 | 0.06 |
| Exploitation rate corresponding to $SPR_{MSY}$ | 0.19 | 0.03 |
| *MSY* (mt) | 2,800 | 197 |

## Management performance

The 2009 stock assessment estimated petrale sole to be at 11.6% of unfished spawning stock biomass in 2010. Based on the 2009 stock assessment, the 2010 coast-wide ACL was reduced to

1,200 mt to reflect the overfished status of the stock and the 2011 coast-wide overfishing limit (OFL) and ACL were set at 1,021 mt and 976 mt, respectively (Table f). Recent coast-wide annual landings have not exceeded the ACL. The 2005, 2009, and 2011 stock assessments all estimated that petrale sole had been below 25 percent of unfished biomass since the 1960s , with estimated harvest rates in excess of a fishing mortality rate of $F_{30\%}$. The length of time that the petrale sole stock had been below the 25 percent of unfished level while sustaining relatively stable annual landings led the 2009 STAR panel and SSC to investigate new reference points for all flatfish managed by the PFMC. The end result is that new reference points were specified for flatfish. The new reference points are as follows: the target reference point is 25 percent of the unfished biomass, the overfished reference point is 12.5 percent of the unfished level, the limit reference point is 5% of the unfished level, and the F target is $F_{30\%}$. The 2011 and 2013 assessments continued to estimate that petrale sole have been below the $SB_{25\%}$ management target since the 1960s and below the overfished threshold between the early 1980s and the early 2000s with fishing mortality rates in excess of the current F-target for flatfish of $SPR_{30\%}$ since the mid-1930s. This 2015 assessment update estimates that petrale sole have rebuilt above the $SB_{25\%}$ management target.

**Table f. Recent trend in total catch and commercial landings (mt) based on the calendar year relative to the management guidelines. Estimated total catch reflect the commercial landings plus the model estimated discarded biomass for the calendar year.**

| **Calendar Year** | OFL (mt) | ACL (mt) | Commercial Landings (mt) | Estimated Total Catch (mt) |
|---|---|---|---|---|
| 2005 | 2,762 | 2,762 | 2,903 | 2,964 |
| 2006 | 2,762 | 2,762 | 2,128 | 2,179 |
| 2007 | 3,025 | 2,499 | 2,346 | 2,378 |
| 2008 | 2,919 | 2,499 | 2,130 | 2,157 |
| 2009 | 2,811 | 2,433 | 2,208 | 2,274 |
| 2010 | 2,751 | 1,200 | 749 | 884 |
| 2011 | 1,021 | 976 | 762 | 775 |
| 2012 | 1,279 | 1,160 | 1,116 | 1,129 |
| 2013 | 2,711 | 2,592 | 1,925 | 1,946 |
| 2014 | 2,774 | 2,652 | 2,341 | 2,356 |
| 2015 | 3,073 | 2,938 | | |
| 2016 | 3,208 | 3,067 | | |

## Unresolved problems and major uncertainties

Parameter uncertainty is explicitly captured in the asymptotic confidence intervals reported throughout this assessment for key parameters and management quantities. These intervals reflect the uncertainty in the model fit to the data sources included in the assessment, but do not include uncertainty associated with alternative model configurations, weighting of data sources (a combination of input sample sizes and relative weighting of likelihood components), or fixed parameters.

There are a number of major uncertainties regarding model parameters that have been explored via sensitivity analysis. The most notable explorations involved the sensitivity of model estimates to 1) value of female natural mortality, 2) removal of final year's Northwest Fishery Science Center (NWFSC) survey index and composition data, 3) use and treatment of revised winter commercial CPUE indices, and 4) removal of time blocks on catchability (q) parameters.

To date a comprehensive reconstruction of Washington landings has not been completed for West Coast groundfish. This is an issue as early Washington landings for petrale sole may have been larger than the current data indicate (T.Tsou , pers. comm.). This assessment would benefit from the completion of a comprehensive groundfish catch reconstruction for the state of Washington.

## Decision table

The forecast of stock abundance and yield was developed using the base model. The total catches in 2015 and 2016 are set to the PFMC adopted ACLs. The exploitation rate for 2017 and beyond is based upon an SPR of 30% (Table g). The 25:5 control rule reduces forecasted yields below those corresponding to $F_{30\%}$ if the stocks are estimated to be lower than the management target of $SB_{25\%}$. The average 2012-2014 exploitation rates were used to distribute catches among the fisheries. Uncertainty in the forecasts is based upon the three states of nature based on the likelihood profile of female M, chosen using a change of 1.2 NLL units (75% interval) from the minimum value to correspond to the midpoints of the lower 25% probability and upper 25% probability regions from the base model and are low (0.12, rounded to the second decimal place) and high (0.16, rounded to the second decimal place) values for female natural mortality. Each forecast scenario includes random variability in future recruitment deviations. Current base model medium-term forecasts project that the stock, under the current control rule, will increase through 2017 as recent large recruitments continue to mature into the spawning biomass, reaching a stock depletion of 32% during 2016-2017 (Tables f and g). In the absence of strong recruitments into the future, the stock is then expected to decline and stabilize around a stock depletion of 29% (Tables g and h). Catches during the projection period under the current control rule are projected to be approximately between 2700 mt - 3100 mt, while a control rule with an SPR of 34% and a target biomas of 30% of the unfished biomass produces catches that range between 2600 mt - 2700 mt, and under a control rule with an SPR of 45% and a target biomass of 40% of the unfished biomass catches range between 1700 mt - 2200 mt (Tables g and h).

**Table g. Projection of potential OFL, ACL, landings, and catch, summary biomass (age-3 and older), spawning biomass, and depletion projected with status quo catches in 2015 and 2016, and catches at the ACL from 2017 forward. The 2015 and 2016 ACL's are values specified by the PFMC and not**

**predicted by this assessment. The ACL from 2015 forward is the calculated total catch determined by $\boldsymbol{F_{SPR}}$.**

| Year | Predicted OFL (mt) | ACL Catch (mt) | Age 3+ biomass (mt) | Spawning Biomass (mt) | Depletion (%) |
|---|---|---|---|---|---|
| 2015 | 3,073 | 2,816 | 20,047 | 10,670 | 0.31 |
| 2016 | 3,208 | 2,910 | 20,215 | 11,077 | 0.32 |
| 2017 | 3,220 | 3,091 | 20,119 | 11,075 | 0.32 |
| 2018 | 3,139 | 3,013 | 19,750 | 10,822 | 0.31 |
| 2019 | 3,051 | 2,929 | 19,418 | 10,572 | 0.31 |
| 2020 | 2,982 | 2,862 | 19,169 | 10,374 | 0.30 |
| 2021 | 2,936 | 2,818 | 19,001 | 10,239 | 0.30 |
| 2022 | 2,909 | 2,792 | 18,892 | 10,156 | 0.29 |
| 2023 | 2,893 | 2,777 | 18,822 | 10,107 | 0.29 |
| 2024 | 2,884 | 2,768 | 18,774 | 10,076 | 0.29 |
| 2025 | 2,878 | 2,762 | 18,739 | 10,055 | 0.29 |
| 2026 | 2,874 | 2,758 | 18,711 | 10,038 | 0.29 |

**Table h. Summary table of 12-year projections beginning in 2017 for alternate states of nature based on an axis uncertainty. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.**

| | | | State of nature | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Low Female M = 0.12 | | Base case Female M = 0.14 | | High Female M = 0.16 | |
| Relative probability | | | 0.25 | | 0.5 | | 0.25 | |
| Manage-ment decision | Year | Catch (mt) | Spawning biomass (mt) | Depletion | Spawning biomass (mt) | Depletion | Spawning biomass (mt) | Depletion |
| ABC 25:5 Rule | 2017 | 3112 | 10952 | 0.282 | 11069 | 0.319 | 11233 | 0.356 |
| | 2018 | 3028 | 10801 | 0.278 | 10801 | 0.311 | 10834 | 0.343 |
| | 2019 | 2940 | 10617 | 0.273 | 10543 | 0.304 | 10484 | 0.332 |
| | 2020 | 2872 | 10446 | 0.269 | 10344 | 0.298 | 10235 | 0.324 |
| | 2021 | 2828 | 10304 | 0.265 | 10213 | 0.294 | 10088 | 0.320 |
| | 2022 | 2802 | 10191 | 0.262 | 10134 | 0.292 | 10014 | 0.317 |
| | 2023 | 2788 | 10098 | 0.260 | 10089 | 0.291 | 9982 | 0.316 |
| | 2024 | 2780 | 10019 | 0.258 | 10062 | 0.290 | 9969 | 0.316 |
| | 2025 | 2775 | 9950 | 0.256 | 10044 | 0.290 | 9962 | 0.316 |
| | 2026 | 2772 | 9886 | 0.255 | 10030 | 0.289 | 9955 | 0.315 |
| SPR target = 0.34; Biomass target = 0.3 | 2017 | 2627 | 11017 | 0.282 | 11126 | 0.319 | 11290 | 0.356 |
| | 2018 | 2629 | 11168 | 0.286 | 11149 | 0.320 | 11185 | 0.353 |
| | 2019 | 2615 | 11245 | 0.288 | 11134 | 0.320 | 11075 | 0.349 |
| | 2020 | 2605 | 11289 | 0.289 | 11127 | 0.319 | 11010 | 0.347 |
| | 2021 | 2602 | 11321 | 0.290 | 11142 | 0.320 | 10997 | 0.347 |
| | 2022 | 2607 | 11347 | 0.291 | 11173 | 0.321 | 11019 | 0.348 |
| | 2023 | 2615 | 11366 | 0.291 | 11212 | 0.322 | 11058 | 0.349 |
| | 2024 | 2624 | 11379 | 0.292 | 11251 | 0.323 | 11099 | 0.350 |
| | 2025 | 2632 | 11385 | 0.292 | 11285 | 0.324 | 11135 | 0.351 |
| | 2026 | 2639 | 11385 | 0.292 | 11315 | 0.325 | 11166 | 0.352 |
| SPR target = 0.45; Biomass target = 0.3 | 2017 | 1711 | 11017 | 0.282 | 11126 | 0.319 | 11290 | 0.356 |
| | 2018 | 1804 | 11737 | 0.301 | 11708 | 0.336 | 11736 | 0.370 |
| | 2019 | 1877 | 12351 | 0.317 | 12206 | 0.350 | 12119 | 0.382 |
| | 2020 | 1941 | 12879 | 0.330 | 12646 | 0.363 | 12471 | 0.393 |
| | 2021 | 1998 | 13335 | 0.342 | 13040 | 0.374 | 12798 | 0.404 |
| | 2022 | 2050 | 13729 | 0.352 | 13388 | 0.384 | 13095 | 0.413 |
| | 2023 | 2096 | 14066 | 0.361 | 13691 | 0.393 | 13356 | 0.421 |
| | 2024 | 2136 | 14353 | 0.368 | 13953 | 0.400 | 13580 | 0.428 |
| | 2025 | 2171 | 14596 | 0.374 | 14178 | 0.407 | 13772 | 0.434 |
| | 2026 | 2200 | 14803 | 0.380 | 14371 | 0.412 | 13935 | 0.440 |

## Research and data needs

Progress on a number of research topics and data issues would substantially improve the ability of this assessment to reliably and precisely model petrale sole population dynamics in the future:

1. In the past many assessments have derived historical catches independently. The states of California and Oregon have completed comprehensive historical catch reconstructions. At the time of this assessment, a comprehensive historical catch reconstruction is not available for Washington. Completion of a Washington catch reconstruction would provide the best possible estimated catch series that accounts for all the catch and better resolves historical catch uncertainty for flatfish as a group.
2. Due to limited data, new studies on both the maturity and fecundity relationships for petrale sole would be beneficial.
3. Where possible, historical otolith samples aged using a combination of surface and break-and-burn methods should be re-aged using the break-and-burn method. Early surface read otoliths should also be re-aged using the break-and-burn method. Historical otoliths aged with a standard method will allow the further evaluation of the potential impacts of consistent under ageing using surface methods, changes in selectivity during early periods of time without any composition information, and potential changes in growth.
4. The effect of the implementation of the IFQ (catch shares) program that began during 2011 on fleet behavior, including impacts on discards, fishery selectivity, and fishing locations would benefit from further study.
5. Studies on stock structure and movement of petrale sole, particularly with regard to the winter-summer spawning migration of petrale sole and the likely trans-boundary movement of petrale sole between U.S. and Canadian waters seasonally.
6. The extent of spatial variability on productivity processes such as growth, recruitment, and maturity is currently unknown and would benefit from further research.

## Rebuilding projections

This assessment indicates that petrale sole are rebuilt above the overfished threshold of 25% of unfished biomass at the start of 2015 and are projected to stay above this threshold under current management.

**Table i. Summary table of the results.**

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| Comm. landings (mt) | 2,903 | 2,128 | 2,346 | 2,130 | 2,208 | 749 | 762 | 1,116 | 1,925 | 2,341 |
| Total Est. catch (mt) | 2,964 | 2,179 | 2,378 | 2,157 | 2,274 | 884 | 775 | 1,129 | 1,946 | 2,356 |
| OFL (mt) | 2,762 | 2,762 | 3,025 | 2,919 | 2,811 | 2,751 | 1,021 | 1,279 | 2,711 | 2,774 |
| ACL (mt) | 2,762 | 2,762 | 2,499 | 2,499 | 2,433 | 1,200 | 976 | 1,160 | 2,592 | 2,652 |
| 1-SPR | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 |
| Exploitation rate | 0.33 | 0.26 | 0.29 | 0.28 | 0.29 | 0.1 | 0.06 | 0.07 | 0.11 | 0.12 |
| Age 3+ biomass (mt) | 20,047 | 20,215 | 20,119 | 19,750 | 19,418 | 19,169 | 19,001 | 18,892 | 18,822 | 18,774 |
| Spawning Biomass | 4,252 | 4,029 | 3,953 | 3,655 | 3,466 | 3,311 | 4,199 | 5,713 | 7,692 | 9,467 |
| ~95% CI | 3877 - 4625 | 3645 - 4411 | 3558 - 4345 | 3241 - 4068 | 3008 - 3922 | 2770 - 3851 | 3514 - 4881 | 4803 - 6621 | 6465 - 8917 | 7890 - 11042 |
| Recruits (mt) | 9,501 | 16,408 | 22,867 | 31,400 | 13,034 | 10,207 | 10,286 | 14,683 | 12,421 | 13,496 |
| ~95% CI | 6600 - 13679 | 11592 - 23227 | 16170 - 32338 | 22355 - 44107 | 8586 - 19788 | 6442 - 16176 | 6065 - 17447 | 7965 - 27069 | 5722 - 26965 | 5955 - 30587 |
| Depletion (%) | 12.30% | 11.60% | 11.40% | 10.60% | 10% | 9.60% | 12.10% | 16.50% | 22.20% | 27.30% |
| ~95% CI | 9.3% - 15.2% | 8.8% - 14.5% | 8.6% - 14.2% | 7.9% - 13.2% | 7.4% - 12.7% | 6.8% - 12.3% | 8.7% - 15.6% | 11.9% - 21.1% | 16.1% - 28.3% | 19.9% - 34.8% |

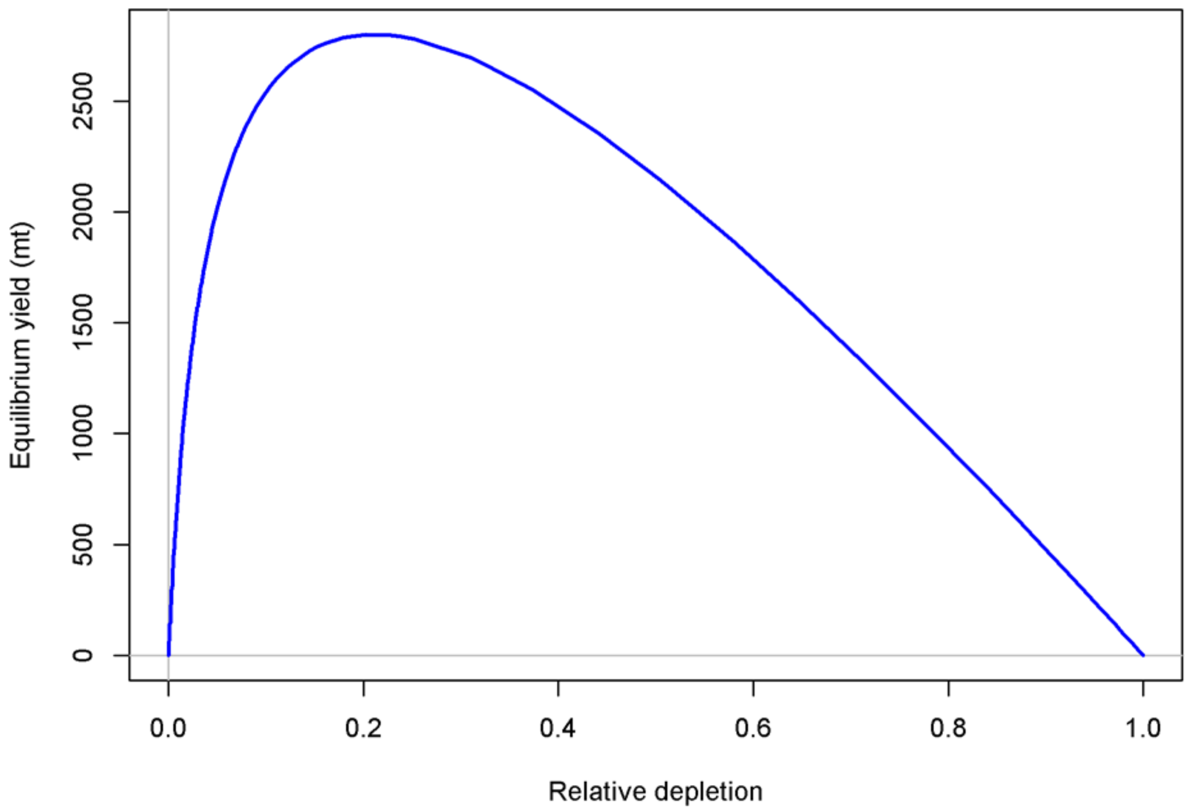


**Figure g. Equilibrium yield curve. Values are based on 2014 fishery selectivity and distribution.**