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DRAFT Status of the U.S. petrale sole resource in 2008

Melissa A. Haltuch and Allan Hicks
National Marine Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Blvd. E.
Seattle WA, 98112
206-860-3480 (phone)
206-860-6792 (fax)
Melissa.Haltuch@noaa.gov
Allan.Hicks@noaa.gov

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Table of Contents

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 2008. 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 and consideration of residual patterns that may be a result of inherent stock structure. 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 deepwater spawning sites but also have the ability to move long distances between spawning sites and seasonally.

Catches

The earliest catches of petrale sole are reported in 1876 in California and 1884 in Oregon. Recent annual catches during 1981–2008 range between 1,244–2,854 mt (Table a, Figure a). Petrale sole are almost exclusively caught by trawl fleets. Non-trawl gears contribute less than 2% of the catches. Based on the previous 2005 assessment, subsequent OYs were reduced due to 2499 mt. 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 1940's. Since the mid-1980s, catches during the winter months have been roughly equivalent to or exceeded catches throughout the remainder of the year (Figure a).

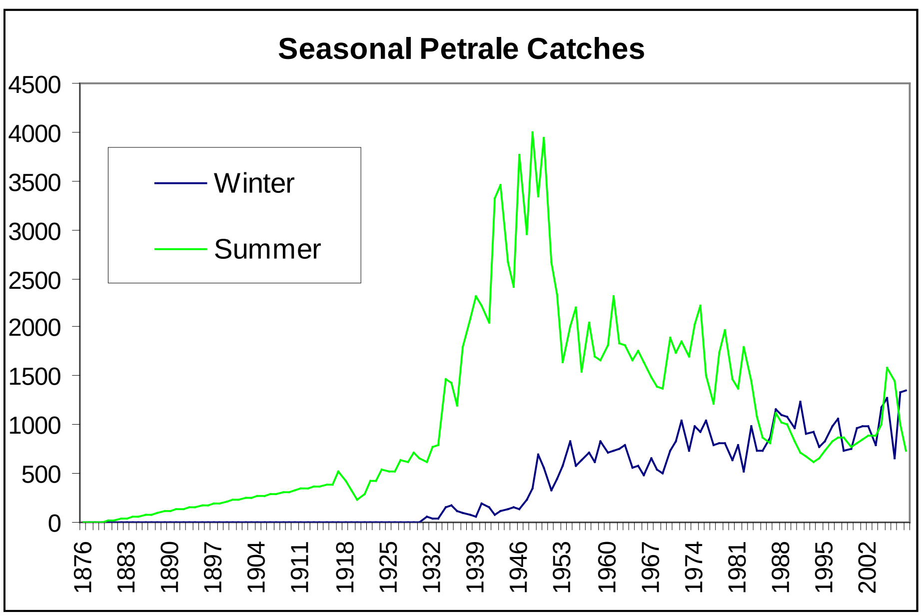

Figure a. Petrale sole catch history by season, 1876-2008.

Table a. Recent commercial fishery catches (mt) by combined summer and winter fleets.

Fishing year	Washington trawl	Oregon trawl	California trawl	Total
1999	443	517	560	1,520
2000	668	460	650	1,778
2001	675	584	579	1,838
2002	861	481	536	1,877
2003	837	408	441	1,686
2004	1,234	511	445	2,191
2005	1,319	661	874	2,854
2006	871	641	590	2,102
2007	635	732	963	2,329
2008	466	585	1,028	2,079

Data and Assessment

The previous stock assessment for petrale sole was developed during 2005 using Stock Synthesis 2. This assessment uses the Stock Synthesis 3 (SS-V3.03a-SAFE, 04/30/09) integrated length-age structured model. Due to higher wintertime catches in recent decades the assessment is based on winter (November to February) and summer (March to October) fishing seasons with the fishing year starting on November 1 and ending on October 31. The fisheries are divided into WA-Winter, WA-Summer, OR-Winter, OR-Summer, CA-Winter, and CA-Summer fisheries. The model includes catch, length- and age-frequency data from the trawl fleets described above as well as standardized CPUE indices developed by Sampson and Lee (1999) for the Oregon fleets from 1987–1997. The impact of rapidly changing regulations in the trawl fishery after these dates makes the fishery-based CPUE indices unreliable. Biological data are derived from both port and on-board observer sampling programs. The National Marine Fisheries Service (NMFS) triennial bottom trawl survey (1980, 1983, 1986, 1989, 1992, 1995, 1998, 2001, and 2004) and Northwest Fisheries Science Center (NWFSC) trawl survey (2003–2008) 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 trend 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 estimate of 2009 spawning biomass 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 and 1990s (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, this increasing trend has reversed since the 2005 assessment and the stock has been declining, most likely due to strong year classes having passed through the fishery (Table b). The estimated relative depletion level in 2009 is 11.6% (~95% asymptotic interval: ±4.8%, ~ 75% interval based on the range of states of nature: 9.4-13.8%), corresponding to 2937.6 mt (~95% asymptotic interval: ±832.7 mt, states of nature interval: 2407.8-3468.1 mt) of female spawning biomass in the base model (Table b). The base model indicates that the spawning biomass has been below 25% of the unfished level continuously since 1953.

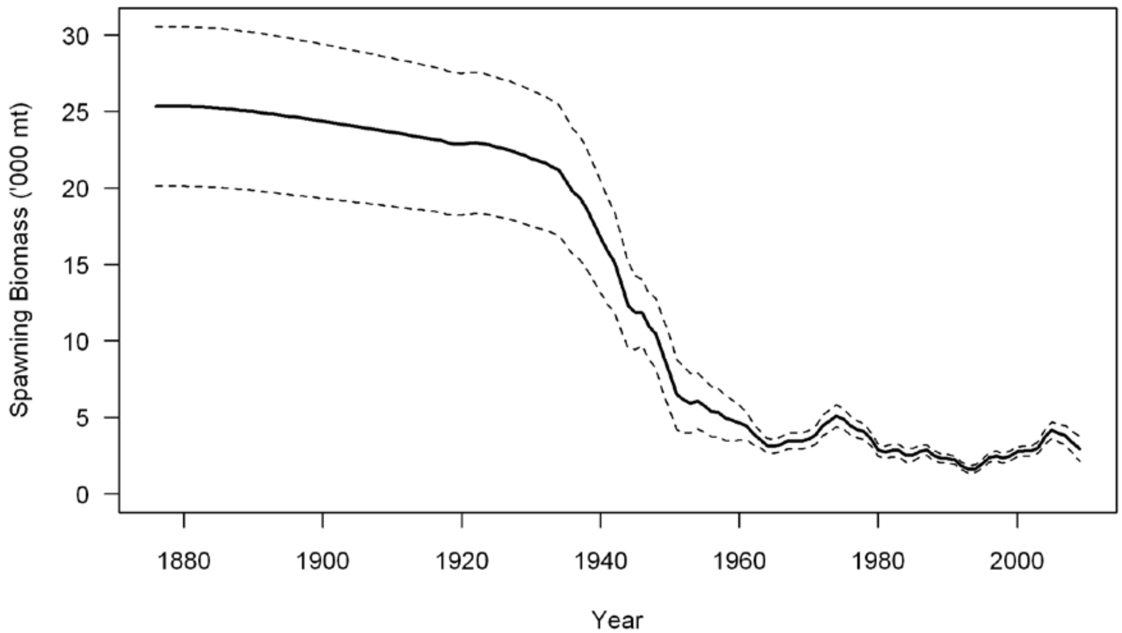

Figure b. Estimated spawning biomass time-series (1876-2009) for the base case model (solid line) with approximate asymptotic 95% confidence interval (dashed lines).

Table b. Recent trend in estimated petrale sole female spawning biomass and relative depletion.

Fishing year	Spawning biomass (mt)	~95% confidence interval	Range of states of nature	Estimated depletion	~95% confidence interval	Range of states of nature
2000	2,765.2	±329.7	2743.9-2776.9	10.9	±3.4	10.7-11.1
2001	2,810.3	±328.3	2781.5-2829.5	11.1	±3.4	10.8-11.3
2002	2,798.4	±333.6	2759.3-2827.8	11.0	±3.4	10.7-11.3
2003	3,030.0	±381.0	2969.1-3080.3	12.0	±3.8	11.5-12.3
2004	3,706.4	±463.0	3605.0-3796.5	14.6	±4.7	14.0-15.1
2005	4,160.7	±529.5	4002.0-4308.6	16.4	±5.2	15.5-17.2
2006	3,949.8	±576.0	3720.7-4169.9	15.6	±5.1	14.5-16.6
2007	3,818.0	±624.1	3507.4-4122.5	15.1	±5.1	13.6-16.4
2008	3,349.6	±704.6	2940.8-3755.2	13.2	±4.8	11.4-14.9
2009	2,937.6	±832.7	2407.8-3468.1	11.6	±4.8	9.4-13.8

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 weak relationship with the decline in spawning biomass, punctuated by larger recruitments (Figure c). The four weakest recruitments since 1939 are estimated to be in 1972, 1985-1986, 1991 and 2003. The four strongest recruitments since 1939 are estimated to be in 1939-1940, 1960, 1965, and 1997-1998 (Figure c). The most recent above average recruitment event, is estimated to be in 2005, and is about 20% smaller than of the 1997–1998 recruitment event (Table c).

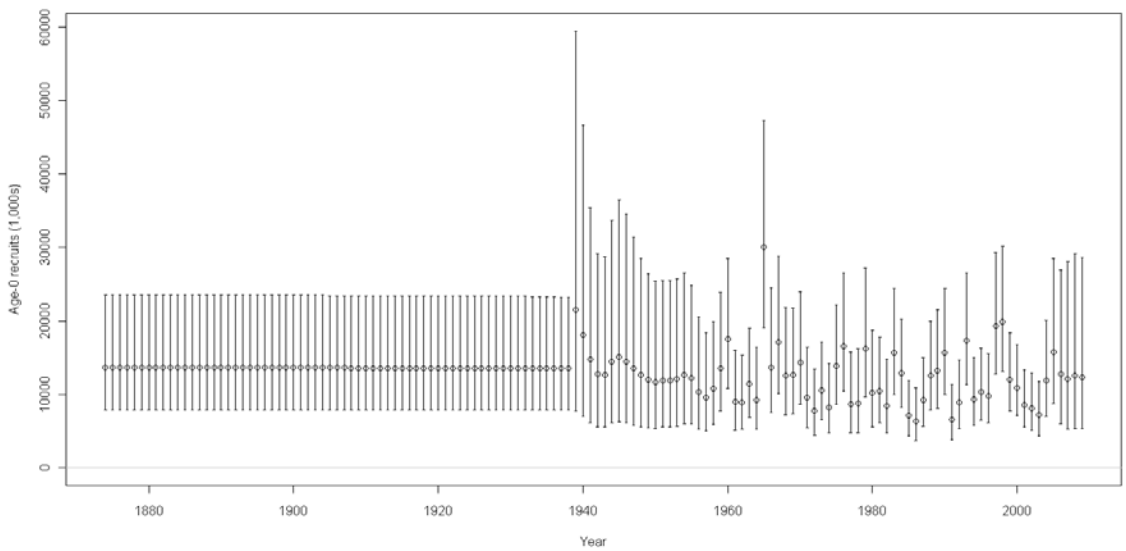

Figure c. Time series of estimated petrale sole recruitments for the base case model (round points) with approximate asymptotic 95% confidence interval (vertical bars).

Table c. Recent estimated trend in petrale sole recruitment.

Fishing year	Estimated recruitment (1000s)	~95% confidence interval	Range of states of nature
2000	10,903.2	±4,721.5	10,022.7-11,679.2
2001	8,562.7	±3,816.7	7,674-9,382.8
2002	8,161.0	±3,805.4	7,040.9-9,241.4
2003	7,164.5	±3,606.0	5,965.2-8,354.8
2004	11,897.1	±6,338.7	9,554.3-14,285.1
2005	15,770.9	±9,522.5	12,415.7-19,223.9
2006	12,740.4	±9,912.5	10,911.6-14,269.5
2007	12,048.8	±10,655.9	11,335.2-12,513
2008	12,508.7	±11,097.5	11,826.7-12,947.8
2009	10,903.2	±4,721.5	10,022.7-11,679.2

Reference Points

Unfished spawning stock biomass was estimated to be 25,334 mt in the base case model (Figure b). The target stock size ($SB_{40\%}$) is therefore 10,134 mt which gives a catch of 2060 mt (Table i, Figure b). The estimates of unfished spawning biomass, and therefore the $SB_{40\%}$ reference points were very sensitive to the assumption of stock-recruitment relationship (see section 2.9.1). Model estimates of spawning biomass at MSY and MSY yield were more robust to the assumption of stock-recruitment relationship (see section 2.9.1). Maximum sustained yield (MSY) applying recent fishery selectivity and allocations was estimated in the assessment model at 2376 mt, occuring at a spawning stock biomass of 4796 mt (SPR = 0.20) (Table i, Figures d,h,i) , which is 18.9% of the unfished level.

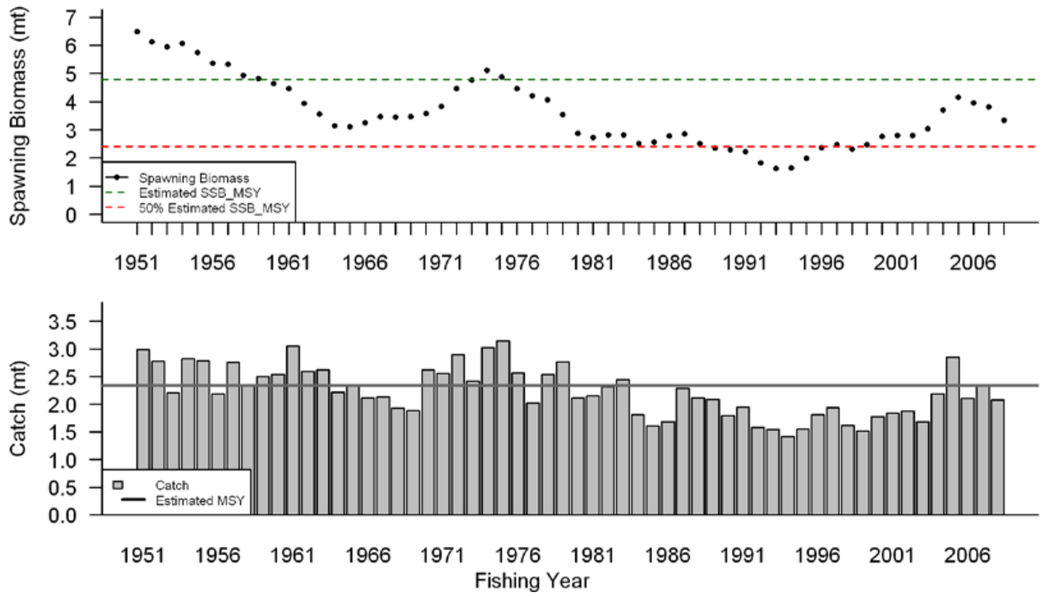

Figure d. Time series of catches startin in 1950 in comparison to the model estimated time series of spawning biomass and summary (age 3+) biomass. The solid horizontal line is the estimated MSY catch and the dashed line is the estimated spawning biomass at MSY.

Exploitation status

The abundance of petrale sole was estimated to have dropped below the $SB_{40\%}$ management target in 1949 and the overfished threshold in 1953. Beginning in 1980 the stock size was around 10–12% of unfished spawning biomass and in 1988 the stock dropped below 10% of the unfished spawning biomass (Figure e). Since 2000 the stock has increased, reaching a peak of 16.4% of unfished biomass in 2005, followed by a decreasing trend through 2009. Fishing mortality rates in excess of the current F-target for flatfish of $SPR_{40\%}$ are estimated to have begun in the late 1930s and persisted through 2008 (Table d, Figures f,g). Current F (catch/biomass of age-3 and older fish) is estimated to have been 0.29 in 2008 (Table d, Figure f).

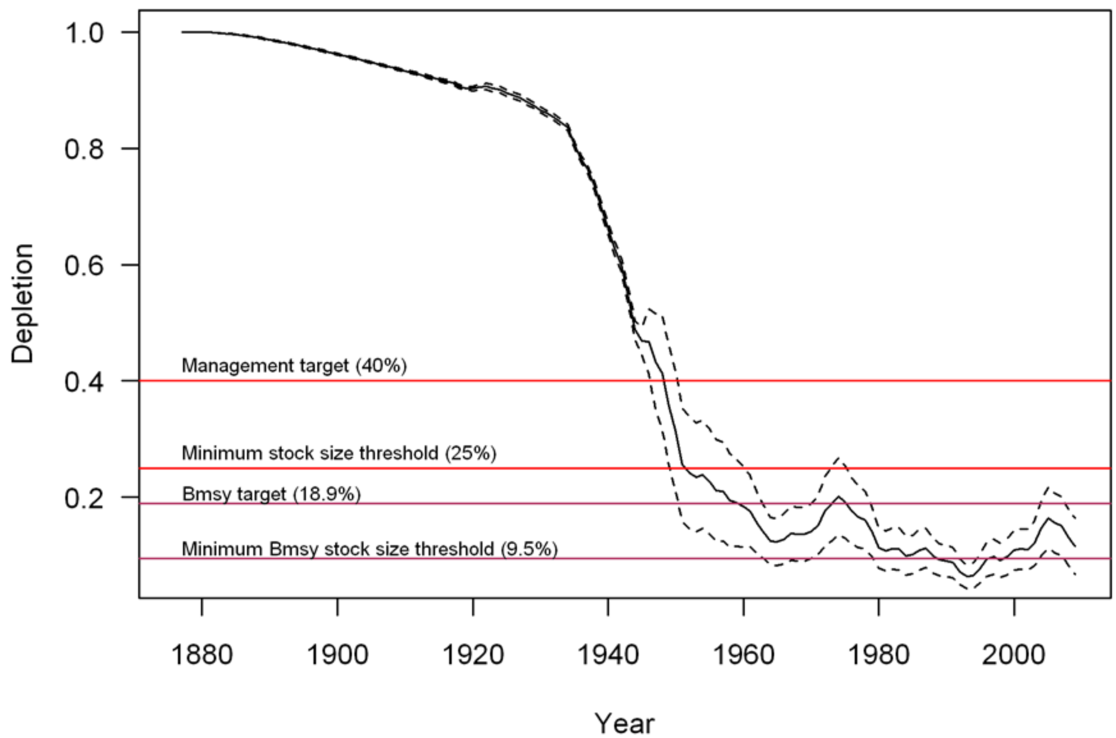

Figure e. Time series of depletion level as estimated in the base case model (round points) with approximate asymptotic 95% confidence interval (dashed lines) and alternate states of nature (light lines).

Table d. Recent trend in spawning potential ratio (1-SPR) and relative exploitation rate (catch/biomass of age-3 and older fish).

Fishing year	Estimated 1-SPR (%)	Range of states of nature	F	Range of states of nature
2000	0.86	0.86-0.86	0.28	0.28-0.27
2001	0.87	0.87-0.86	0.27	0.27-0.27
2002	0.86	0.87-0.86	0.26	0.27-0.26
2003	0.82	0.83-0.81	0.21	0.22-0.21
2004	0.83	0.84-0.83	0.25	0.26-0.24
2005	0.87	0.87-0.86	0.32	0.34-0.31
2006	0.83	0.85-0.82	0.27	0.29-0.25
2007	0.85	0.87-0.83	0.31	0.34-0.28
2008	0.85	0.87-0.83	0.29	0.34-0.26
2009	0.90	0.93-0.87	0.36	0.45-0.31

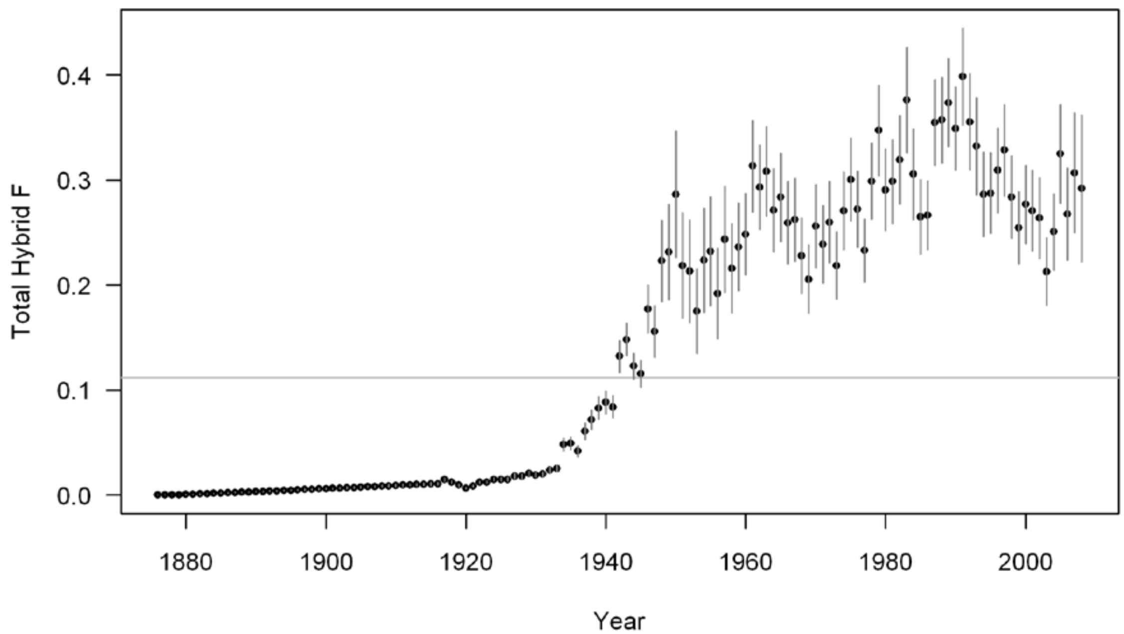

Figure f. Time series of estimated relative exploitation rate (catch/age 3 and older biomass) for the base case model (round points). Values of relative exploitation rate in excess of horizontal line are above the rate corresponding to the overfishing proxy from the base case.

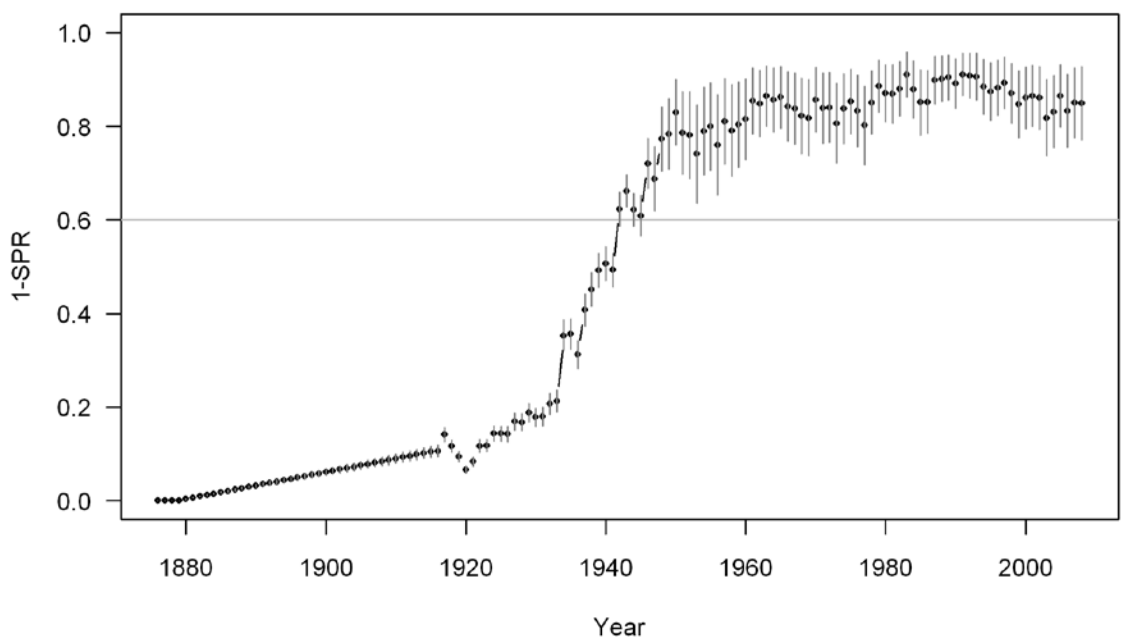

Figure g. Estimated spawning potential ratio from the base case model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis.

Management performance

The most recent 2005 assessment of petrale sole stock assessment split the stock into two areas, the northern area that included U.S. Vancouver and Columbia INPFC areas and the southern area that included the Eureka, Monterey and Conception INPFC areas (Lai et al. 2006). In 2005 petrale sole were estimated to be at 34 and 29 percent of unfished spawning stock biomass in the northern and southern areas, respectively. Based on the 2005 stock assessment coast-wide ABCs were set at 3025 mt and 2919 mt for 2007 and 2008, respectively, with an OY of 2499 mt for both years (Table e). Recent coast-wide annual landings have not exceeded the ABC except for 2005 when the ABC was exceeded by 92 mt, 3.3%. The 2005 stock assessment estimated that petrale sole have been below the Pacific Council's minimum stock size threshold of 25 percent of unfished biomass from the mid-1970s until recently with estimated harvest rates in excess of the target fishing mortality rate of F40%. The 2005 assessment estimated the spawning stock biomass in 1998 at 12 percent of unfished stock biomass. The current assessment estimates that petrale sole have been below the $SB_{40\%}$ management target since 1949 and below the overfished threshold since 1953 (Table b, Figures e) with fishing mortality rates in excess of the current F-target for flatfish of $SPR_{40\%}$ since the late 1930s (Table d, Figure h). Using reference points based on the model estimates of Bmsy from the base case model suggests that the petrale sole fishery has been fishing at or near the management targets for a large portion of the time (Figure i). A summary of recent trends in the fishery and petrale sole population can be found in Table h.

Table e. Recent trend in estimated total petrale sole catch and commercial landings (mt) relative to management guidelines.

Fishing year	ABC (mt)	OY (mt)	Commercial Landings (mt)	Estimated[1] Total Catch (mt) for the Annual Year	Estimated Total Catch (mt) for the Fishing Year
1999	2,700	2,700	1,520	1,617	1,591
2000	2,950	2,950	1,778	1,888	1,856
2001	2,762	2,762	1,838	1,975	1,934
2002	2,762	2,762	1,877	2,066	2,024
2003	2,762	2,762	1,686	1,786	1,809
2004	2,762	2,762	2,191	2,273	2,284
2005	2,762	2,762	2,854	2,948	2,960
2006	2,762	2,762	2,102	2,173	2,183
2007	3,025	2,499	2,329	2,372	2,376
2008	2,919	2,499	2,079	2,114	2,117

[1] Total annual catches reflect the commercial landings plus the model estimated annual discard biomass (commercial landings * retained catch/total catch). The total amounts of discard may differ from those reported in the NWFSC reports on total catch for some of these years.

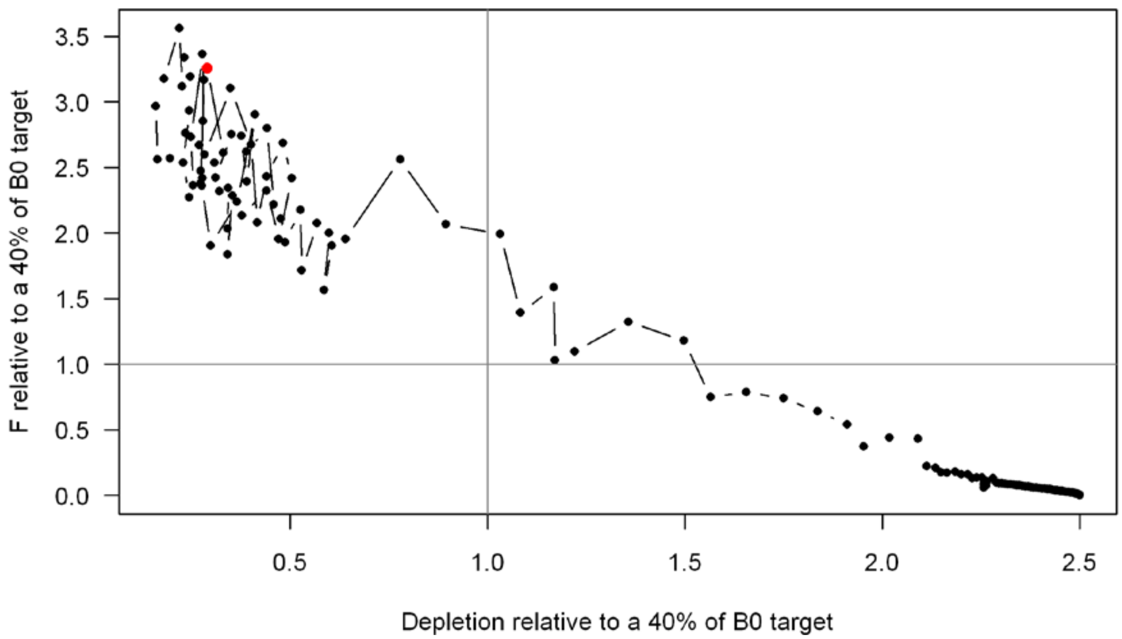

Figure h. Phase plot of estimated fishing intensity vs. relative spawning biomass for the base case model. Fishing intensity is the relative exploitation rate divided by the level corresponding to the overfishing proxy. Relative spawning biomass is annual spawning biomass relative to virgin spawning biomass divided by the 40% rebuilding target. The red point is 2009.

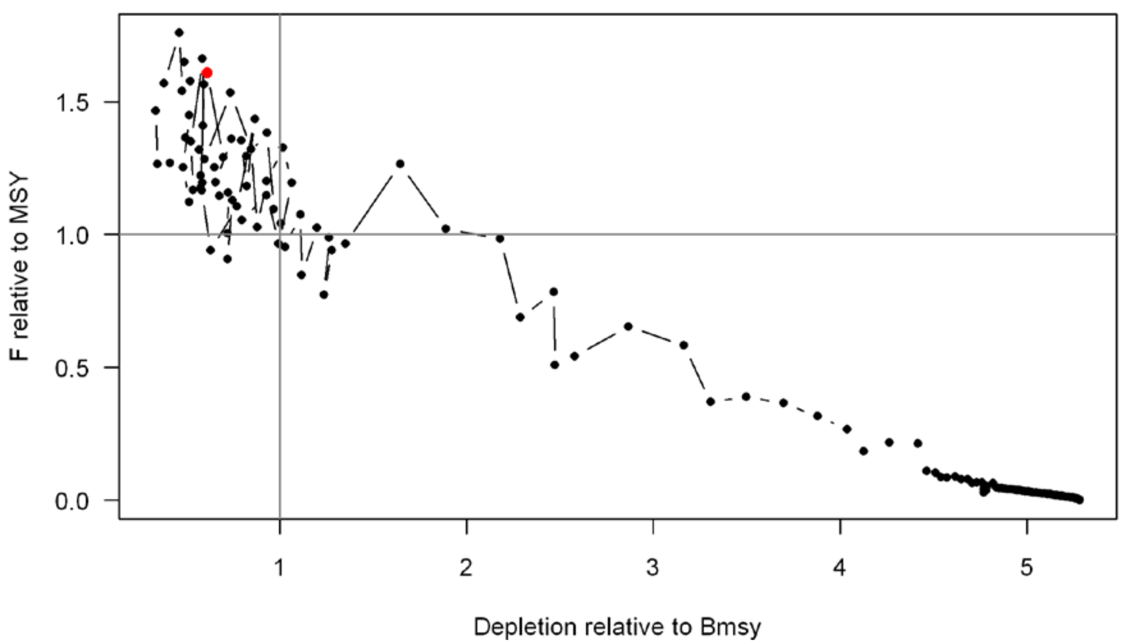

Figure i. Phase plot of estimated fishing intensity vs. relative spawning biomass for the base case model. Fishing intensity is the relative exploitation rate divided by the level corresponding to Fmsy. Relative spawning biomass is annual spawning biomass relative to the model estimate of Bmsy. The red point is 2009.

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 using both the model submitted to the STAR panel and variations which were evaluated during the STAR meeting. The most notable explorations involved the sensitivity of model estimates to the specification of the stock-recruitment relationship.

The comparability of age data within and between age-reading laboratories over time due to changes in ageing methods, a variety of ageing methods being applied to the same sample, inadequate otolith sampling, and between-laboratory variation is a major source of uncertainty. The application of the 'combo' age reading method for petrale, where petrale up to approximately age 10 are surface read and those otoliths thought to be greater than age 10 are broken and burned leads to a high level of variability in the age data, especially at older ages, when the 'combo' method is applied. Recent bomb radiocarbon analysis shows that the best ages for petrale are obtained using the break and burn method. The break and burn method should be used for ageing petrale sole.

There are problems with the Oregon commercial age data from 1981–1999. Ages from this period were aged using a combination of methods and non-randomly (i.e. one individual aged all males and another individual aged all females). While age reader information exists it is not currently in the PacFIN database, making it impossible to closely examine the impact of varying ageing methods and non-random reader design. This leads to large levels of ageing error for ages from this period of the Oregon fishery. If possible, these otoliths should be re-aged and age reader information needs to routinely be included in PacFIN.

Forecasts

The forecast of stock abundance and yield was developed using the base model. The total catch in 2009 and 2010 are set at 2433 and 2393 mt. The exploitation rate for 2011 and beyond is based upon an SPR of 40%. The 40:10 control rule reduces forecasted yields below those corresponding to $F_{40\%}$ because the stocks are estimated to be lower than the management target of $SB_{40\%}$ (Table f). The 2008 exploitation rate was used to distribute catches among the fisheries. Uncertainty in the forecasts is based upon the three states of nature agreed upon at the STAR panel. The high and low states are differentiated from the base case by the size of the 2009 spawning biomass, assuming values that were 1.25 standard deviations higher and lower, respectively, than the base case.. Manipulation of the amount of NWFSC survey biomass in 2008 was used to achieve these alternative sizes for the 2009 spawning biomass. Each forecast scenario includes random variability in future recruitment deviations (Table g). Current medium-term forecasts predict a declining trend in abundance and catch through 2011, with OY values for 2011 set at zero catch under the 40-10 harvest policy. This decline is followed by increasing abundance and catches, with the stock moving above the minimum stock size threshold of $SB_{25\%}$ in 2015. The following table shows the projection of expected petrale sole catch, spawning biomass and depletion from the base model using the 40-10 control rule (Table f).

Table f. Projection of potential petrale sole ABC, OY , spawning biomass and depletion for the base case model based on the SPR= 40% fishing mortality target used for the last plan (OY) and $F_{40\%}$ overfishing limit/target (ABC). Assuming the OYs of 2433 and 2393 mt are attained in 2009 and 2010.

Year	ABC (mt)	OY (mt)	Age 3+ biomass (mt)	Spawning biomass (mt)	Depletion
2009	2,499	2,433	7,151	2,938	11.6%
2010	2,499	2,393	6,776	2,400	9.5%
2011	535	0	6,468	2,171	8.6%
2012	802	311	8,646	3,427	13.5%
2013	1,068	680	10,680	4,712	18.6%
2014	1,301	997	12,358	5,843	23.1%
2015	1,489	1,311	13,675	6,778	26.8%
2016	1,631	1,489	14,678	7,503	29.6%
2017	1,735	1,621	15,437	8,037	31.7%
2018	1,812	1,718	16,022	8,431	33.3%
2019	1,870	1,794	16,482	8,740	34.5%
2020	1,917	1,838	16,850	8,991	35.5%

Decision table

Relative probabilities of each state of nature are based on the 2009 estimate of spawning biomass. Landings in 2009–2010 are 2,433 and 2,393 mt for all cases. Selectivity and fleet allocations are projected based on 2008 values.

Table g. Decision table of 12-year projections for alternate states of nature (columns) and management options (rows) beginning in 2011. There are two values for depletion, the first calculates depetion using the SB40% Bmsy proxy and the second calculates depletion relative to the model estimate of Bmsy. Relative probabilities of each state of nature are based on identifying low and high values from the model-estimated distribution of 2009 spawning biomass, those high and low values for 2009 were achieved through changing the size of the 2008 NWFSC survey biomass. Landings in 2009–2010 are 2433 mt

			State of nature								
			Low 2009 Spawning Biomass (-1.25 SD)			Base case			High 2009 Spawning Biomass (+1.25 SD)		
Relative probability			0.25			0.5			0.25		
			Depletion		Spawning biomass	Depletion		Spawning biomass	Depletion		Spawning biomass
Management decision	Year	Catch (mt)	SB0	Bmsy	(mt)	SB0	Bmsy	(mt)	SB0	Bmsy	(mt)
Catches Near Zero (3 mt)	2011	3	5%	29%	1,397	9%	48%	2,295	13%	67%	3,229
	2012	3	9%	50%	2,380	14%	74%	3,572	19%	100%	4,786
	2013	3	14%	75%	3,600	20%	105%	5,012	26%	134%	6,426
	2014	3	19%	104%	4,976	26%	136%	6,514	32%	168%	8,033
	2015	3	25%	134%	6,423	32%	167%	8,025	38%	200%	9,589
	2016	3	31%	164%	7,856	37%	198%	9,493	44%	231%	11,068
	2017	3	36%	192%	9,217	43%	227%	10,884	50%	260%	12,452
	2018	3	41%	219%	10,511	48%	254%	12,197	55%	286%	13,739
	2019	3	46%	245%	11,766	53%	280%	13,440	59%	311%	14,933
	2020	3	50%	271%	12,984	58%	305%	14,613	64%	334%	16,034
Half 40-10 catches from base case	2011	0	5%	50%	1,397	9%	48%	2,295	13%	67%	3,229
	2012	156	9%	37%	2,382	14%	75%	3,574	18%	95%	4,554
	2013	340	14%	29%	3,524	19%	103%	4,932	24%	127%	6,090
	2014	499	18%	50%	4,710	25%	130%	6,239	30%	156%	7,493
	2015	656	23%	73%	5,861	29%	155%	7,451	35%	182%	8,750
	2016	745	27%	98%	6,893	34%	178%	8,520	39%	205%	9,837
	2017	810	30%	122%	7,796	37%	197%	9,460	43%	225%	10,785
	2018	859	33%	144%	8,604	41%	215%	10,297	46%	242%	11,615
	2019	897	36%	163%	9,365	44%	231%	11,060	49%	257%	12,349
	2020	919	39%	179%	10,097	46%	245%	11,763	52%	271%	13,004
40-10 catches from base case	2011	0	5%	29%	1,397	9%	48%	2,295	13%	67%	3,229
	2012	311	9%	50%	2,382	14%	75%	3,574	19%	100%	4,788
	2013	680	13%	72%	3,444	19%	101%	4,849	25%	130%	6,258
	2014	997	17%	93%	4,439	24%	124%	5,959	30%	156%	7,469
	2015	1,311	21%	110%	5,291	27%	143%	6,871	34%	176%	8,418
	2016	1,489	23%	123%	5,918	30%	158%	7,576	36%	190%	9,095
	2017	1,621	25%	133%	6,358	32%	169%	8,096	38%	200%	9,579
	2018	1,718	26%	139%	6,669	33%	177%	8,480	39%	207%	9,920
	2019	1,794	27%	144%	6,923	35%	183%	8,782	40%	212%	10,161
	2020	1,838	28%	149%	7,152	36%	188%	9,026	41%	215%	10,331

Table g continued.

			State of nature								
			Low 2009 Spawning Biomass (-1.25 SD)			Base case			High 2009 Spawning Biomass (+1.25 SD)		
Relative probability			0.25			0.5			0.25		
			Depletion		Spawning biomass	Depletion		Spawning biomass	Depletion		Spawning biomass
Management decision	Year	Catch (mt)	SB0	Bmsy	(mt)	SB0	Bmsy	(mt)	SB0	Bmsy	(mt)
Constant 500 mt	2011	500	5%	29%	1,397	9%	48%	2,295	13%	67%	3,229
	2012	500	8%	44%	2,134	13%	69%	3,314	18%	94%	4,522
	2013	500	12%	64%	3,056	18%	93%	4,455	23%	122%	5,861
	2014	500	16%	86%	4,109	22%	118%	5,639	28%	149%	7,153
	2015	500	20%	109%	5,228	27%	142%	6,833	33%	175%	8,397
	2016	500	25%	132%	6,342	32%	167%	7,997	38%	200%	9,578
	2017	500	29%	154%	7,403	36%	190%	9,104	43%	223%	10,687
	2018	500	33%	176%	8,418	40%	212%	10,157	47%	244%	11,723
	2019	500	37%	196%	9,415	44%	233%	11,165	51%	265%	12,694
	2020	500	40%	217%	10,401	48%	253%	12,129	54%	284%	13,599
Constant 1500 mt	2011	1,500	5%	29%	1,397	9%	48%	2,295	13%	67%	3,229
	2012	1,500	6%	34%	1,649	11%	58%	2,802	16%	83%	3,995
	2013	1,500	8%	41%	1,979	13%	70%	3,341	19%	99%	4,728
	2014	1,500	9%	49%	2,367	15%	81%	3,874	21%	112%	5,375
	2015	1,500	11%	58%	2,791	17%	92%	4,407	24%	125%	5,973
	2016	1,500	12%	67%	3,210	19%	103%	4,926	26%	136%	6,534
	2017	1,500	14%	75%	3,599	21%	113%	5,424	28%	147%	7,062
	2018	1,500	15%	83%	3,968	23%	123%	5,907	30%	158%	7,564
	2019	1,500	17%	91%	4,348	25%	133%	6,388	32%	168%	8,050
	2020	1,500	18%	99%	4,752	27%	143%	6,869	34%	178%	8,519
Constant 2/3 Fmsy	2011	36	5%	29%	1,397	9%	48%	2,295	13%	67%	3,229
	2012	86	9%	50%	2,375	14%	74%	3,555	19%	100%	4,781
	2013	166	14%	75%	3,576	20%	103%	4,948	25%	133%	6,400
	2014	274	19%	102%	4,905	25%	132%	6,354	32%	166%	7,960
	2015	447	24%	131%	6,261	30%	161%	7,703	38%	196%	9,421
	2016	582	29%	157%	7,517	35%	186%	8,930	43%	224%	10,721
	2017	714	34%	180%	8,629	39%	209%	10,000	47%	247%	11,856
	2018	837	37%	200%	9,602	43%	228%	10,918	51%	267%	12,825
	2019	949	41%	218%	10,473	46%	244%	11,706	54%	284%	13,641
	2020	1,020	44%	235%	11,252	49%	258%	12,376	57%	298%	14,314
Ramp down catches between 2/3 Fmsy at Bmsy and 0 catch at 50%Bmsy	2011	0	5%	29%	1,397	9%	48%	2,295	13%	67%	3,229
	2012	354	9%	50%	2,382	14%	75%	3,574	18%	93%	4,478
	2013	764	14%	75%	3,603	19%	101%	4,826	24%	123%	5,921
	2014	977	19%	100%	4,795	23%	123%	5,888	29%	152%	7,307
	2015	1,161	23%	121%	5,819	27%	142%	6,807	34%	176%	8,421
	2016	1,280	26%	139%	6,650	30%	158%	7,585	37%	194%	9,306
	2017	1,379	28%	153%	7,320	32%	171%	8,224	40%	209%	10,030
	2018	1,461	31%	164%	7,868	35%	183%	8,754	42%	221%	10,618
	2019	1,530	32%	174%	8,354	36%	192%	9,211	44%	231%	11,100
	2020	1,574	34%	184%	8,801	38%	200%	9,610	46%	240%	11,494

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. The estimate of the NWFSC survey catchability in the base case model is higher than expected. This may be due to the use of the total area within each strata during the expansion of the survey data rather than the trawlable areas only. At this time there are no area estimates for trawlable and untrawlable areas. However the petrale sole population is most likely well surveyed by the trawl survey and expanding using areas that include untrawlable areas may not be appropriate.
2. In the past many assessments have derived historical catches independently. Since 2005 each of the states has undertaken comprehensive historical catch reconstructions. At the time of this assessment only a partial reconstruction was available for Washington, and no catch reconstruction was available from Oregon Department of Fish and Wildlife. Completion of the Washington and Oregon catch reconstructions would provide the best possible estimated catch series that accounts for all the catch and makes sense for flatfish as a group.
3. Due to limited data, new studies on both the maturity and fecundity relationships for petrale sole would be beneficial.
4. Increased collection of commercial fishery age data from California would help reduce uncertainty. No recent age data are available from the California fleet. However, the greatest landings by state have come from California in the most recent two years. Without age data, the ability to estimate year-class strength and the extent of variation in recruitment is compromised.
5. The comparability of ages between agencies is unknown. A common set of otoliths should be aged by each agency to be able to compile between agency age error information.
6. Where possible historicalotoliths should be re-aged using the break-and-burn method.
7. Effect of fishery regulations. The impacts of trip-limits and other management approaches, such as closed areas, on discards and fishery selectivity requires further study.
8. Studies on stock structure and movement of petrale sole, particularly with regard to the winter-summer spawning migration of petrale sole.
9. Continue and if possible increase the recent collection of length compositions for discarded petrale sole for both the winter (Nov–Feb) and summer (Mar–Oct) fisheries.

Table h. Summary of recent trends in estimated petrale sole exploitation and stock levels from the base case model; all values reported at the beginning of the fishing year.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Commercial landings (mt)	1778	1838	1877	1686	2191	2854	2102	2329	2079	
Total catch (mt)	1895	1987	2088	1793	2276	2951	2176	2373	2115	
ABC (mt)	2950	2762	2762	2762	2762	2762	2762	3025	2919	2433
OY	2950	2762	2762	2762	2762	2762	2762	2499	2499	2499
1-SPR	0.86	0.87	0.86	0.82	0.83	0.87	0.83	0.85	0.85	0.9
Exploitation rate (catch/age 3+ biomass)	0.28	0.27	0.26	0.21	0.25	0.32	0.27	0.31	0.29	0.36
Age 3+ biomass (mt)	6846.92	7337.86	7912.96	8422.52	9079.6	9082.01	8132.41	7735.76	7240.22	7150.57
Spawning biomass (mt)	2,765.20	2,810.30	2,798.40	3,030.00	3,706.40	4,160.70	3,949.80	3,818.00	3,349.60	2,937.60
~95% Confidence interval	±329.7	±328.3	±333.6	±381.0	±463.0	±529.5	±576.0	±624.1	±704.6	±832.7
Range of states of nature	2743.9-2776.9	2781.5-2829.5	2759.3-2827.8	2969.1-3080.3	3605.0-3796.5	4002.0-4308.6	3720.7-4169.9	3507.4-4122.5	2940.8-3755.2	2407.8-3468.1
Recruitment	10,903.20	8,562.70	8,161.00	7,164.50	11,897.10	15,770.90	12,740.40	12,048.80	12,508.70	10,903.20
~95% Confidence interval	±4,721.5	±3,816.7	±3,805.4	±3,606.0	±6,338.7	±9,522.5	±9,912.5	±10,655.9	±11,097.5	±4,721.5
Range of states of nature	10,022.7-11,679.2	7,674-9,382.8	7,040.9-9,241.4	5,965.2-8,354.8	9,554.3-14,285.1	12,415.7-19,223.9	10,911.6-14,269.5	11,335.2-12,513	11,826.7-12,947.8	10,022.7-11,679.2
Depletion (%)	10.9	11.1	11	12	14.6	16.4	15.6	15.1	13.2	11.6
~95% Confidence interval	±3.4	±3.4	±3.4	±3.8	±4.7	±5.2	±5.1	±5.1	±4.8	±4.8
Range of states of nature	10.7-11.1	10.8-11.3	10.7-11.3	11.5-12.3	14.0-15.1	15.5-17.2	14.5-16.6	13.6-16.4	11.4-14.9	9.4-13.8

Table i. Summary of petrale sole reference points from the base case model. Values are based on 2008 fishery selectivity and allocation.

Quantity	Estimate	~95% Confidence interval
Unfished spawning stock biomass (SB_0, mt)	25,334	±5,209
Unfished 3+ biomass (mt)	39,211	±5296
Unfished recruitment (R_0, thousands)	13,604	±7,590
Reference points based on $SB_{40\%}$		
MSY Proxy Spawning Stock Biomass ($SB_{40\%}$)	10,134	±2084
SPR resulting in $SB_{40\%}$ ($SPR_{SB40\%}$)	0.408	±0.0178
Exploitation rate resulting in $SB_{40\%}$	0.112	±0.0197
Yield with $SPR_{SB40\%}$ at $SB_{40\%}$ (mt)	2,060	±162
Reference points based on SPR proxy for MSY		
Spawning Stock Biomass at SPR (SB_{SPR})(mt)	9,928	±2,476
$SPR_{MSY\text{-}proxy}$	0.4	NA
Exploitation rate corresponding to SPR	0.115	±0.0263
Yield with $SPR_{MSY\text{-}proxy}$ at SB_{SPR} (mt)	2,080	±203
Reference points based on estimated MSY values		
Spawning Stock Biomass at *MSY* (SB_{MSY}) (mt)	4,796	±582
SPR_{MSY}	0.200	±0.07
Exploitation Rate corresponding to SPR_{MSY}	0.23	±0.03
MSY (mt)	2,376	±86

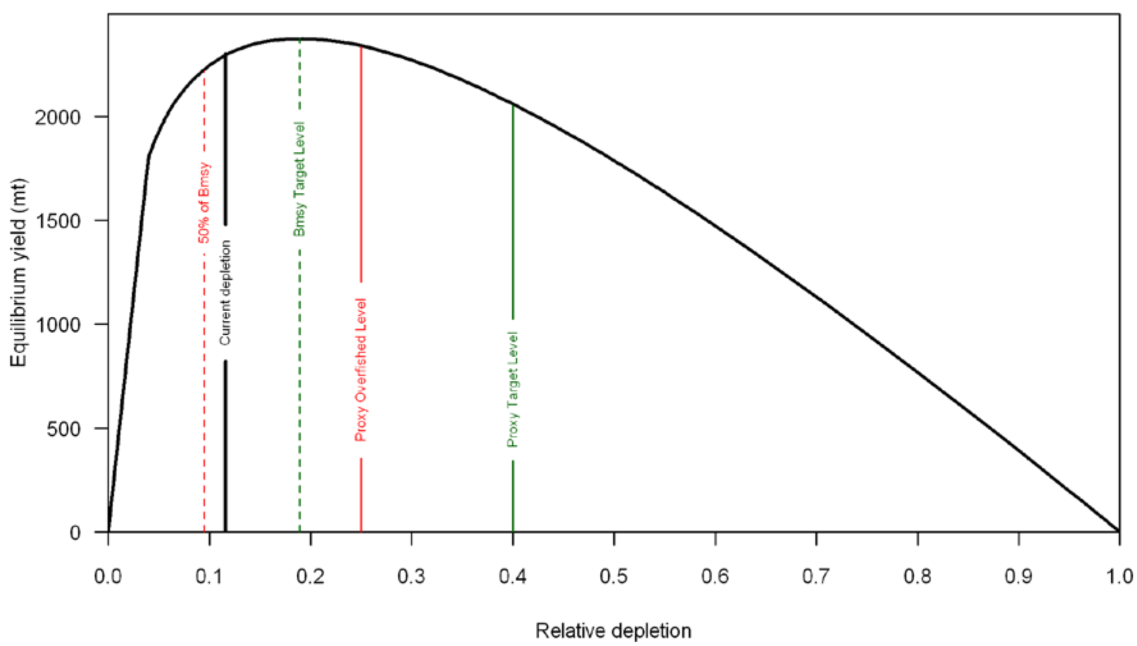

Figure j. Equilibrium yield curve (derived from reference point values reported in table i) for the base case model. Values are based on 2008 fishery selectivity and allocation. The depletion is relative to unfished spawning biomass