Agenda Item E.8
Attachment 3
September 2017

Status of Pacific ocean perch (*Sebastes alutus*) along the US west coast in 2017

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Please cite as:
Wetzel, C.R., Cronin-Fine, L., and Johnson, K.F. 2017. Status of Pacific ocean perch (*Sebastes alutus*) along the US west coast in 2017. Pacific Fishery Managment Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Status of Pacific ocean perch (*Sebastes alutus*) along the US west coast in 2017

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Stock

This assessment reports the status of the Pacific ocean perch rockfish (*Sebastes alutus*) off the US west coast from Northern California to the Canadian border using data through 2016. Pacific ocean perch are most abundant in the Gulf of Alaska and have been observed off of Japan, in the Bering Sea, and south to Baja California, though they are sparse south of Oregon and rare in southern California. Although neither catches nor other data from north of the US-Canada border were included in this assessment, the conectivity of these populations and the contribution to the biomass possibly through adult migration and/or larval dispersion is not certain. To date, no significant genetic differences have been found in the range covered by this assessment.

Landings

Harvest of Pacific ocean perch first exceeded 1 mt off the US west coast in 1918. Catches ramped up in the 1940s with large removals in Washington waters. During the 1950s the removals primary occurred in Oregon waters with catches from Washington declining following the 1940s. The largest removals, occurring between 1966-1968, were largely a result of harvest by foreign vessels. The fishery proceeded with more moderate removals ranging between 1165 to 2619 metric tons (mt) per year between 1969 and 1980. Removals generally declined from 1981 to 1994 to between 1031 and 1617 mt per year. Pacific ocean perch was declared overfished in 1999, resulting in large reductions in harvest in years since the declaration. Since 2000, annual landings of Pacific ocean perch have ranged between 54-270 mt, with landings in 2016 totaling 68 mt.

Pacific ocean perch are a desirable market species and discarding has historically been low. However, management restrictions (e.g. trip limits) resulted in increased discarding starting in the early 1990s. During the 2000s discarding increased for Pacific ocean perch due to harvest restrictions imposed to allow rebuilding, with estimated discard rates from the fishery peaking in 2009 and 2010 to approximately 50%, prior to implementation of catch shares in 2011. Since 2011, discarding of Pacific ocean perch has been estimated to be less than 3.5%.

Table a: Landings (mt) for the past 10 years for Pacific ocean perch by source.

Year	California	Oregon	Washington	At-sea hake	Survey	Total Landings
2007	0.15	83.65	45.12	4.05	0.58	133.55
2008	0.39	58.64	16.61	15.93	0.80	92.36
2009	0.92	58.74	33.22	1.56	2.72	97.17
2010	0.14	58.00	22.29	16.87	1.68	98.98
2011	0.12	30.26	19.66	9.17	1.94	61.14
2012	0.18	30.41	21.79	4.52	1.62	58.51
2013	0.08	34.86	14.83	5.41	1.71	56.89
2014	0.18	33.91	15.82	3.92	0.57	54.40
2015	0.12	38.05	11.41	8.71	1.59	59.88
2016	0.23	40.81	13.12	10.30	3.10	67.56

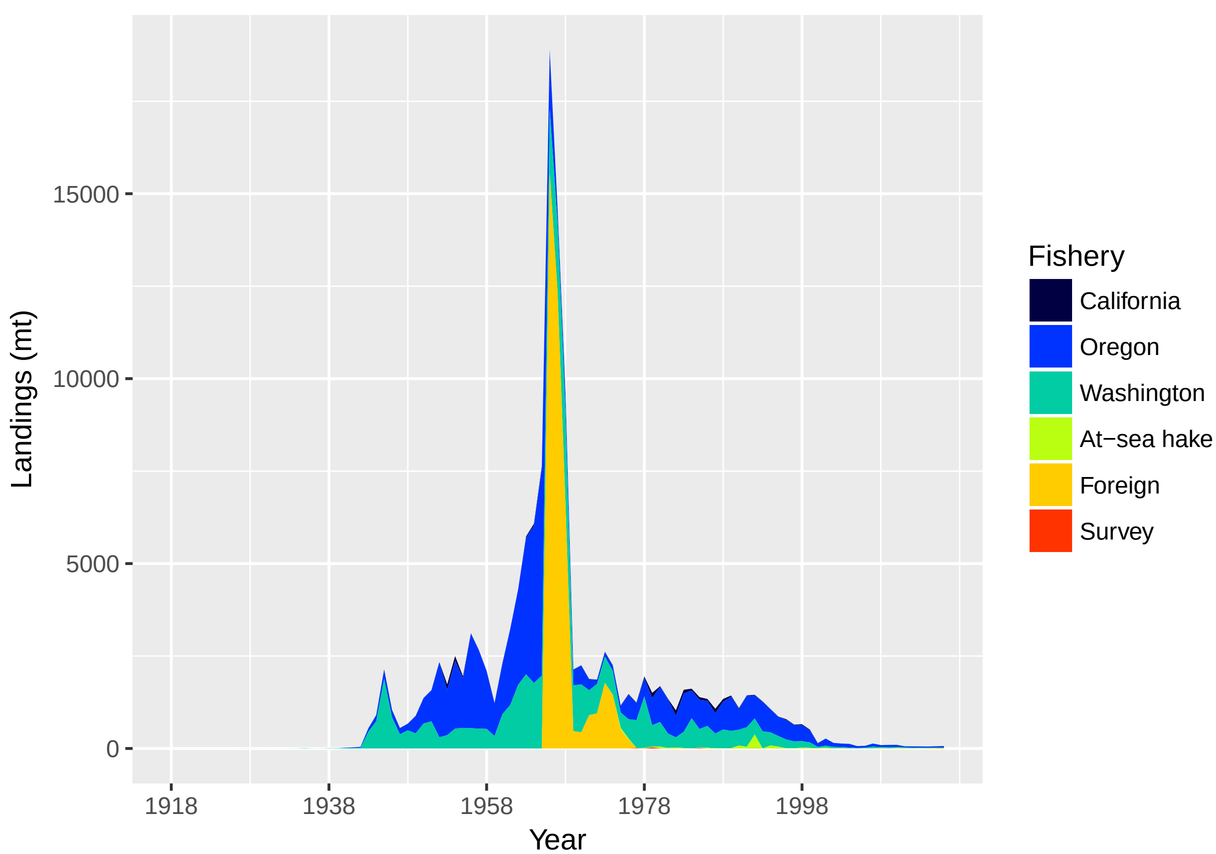

Figure a: Landings of Pacific ocean perch for California, Oregon, Washington, the foriegn fishery (1966-1976), at-sea hake fishery, and fishery-independent surveys.

Data and Assessment

This a new full assessment for Pacific ocean perch, which was last assessed in 2011. In this assessment, aspects of the model including landings, data, and modelling assumptions were re-evaluated. The assessment was conducted using the length- and age-structured modeling software Stock Synthesis (version 3.30.03.05). The coastwide population was modeled allowing separate growth and mortality parameters for each sex (a two-sex model) from 1918 to 2017 and forecasted beyond 2017.

All of the data sources included in the base model for Pacific ocean perch have been re-evaluated for 2017. Changes of varying degrees have occurred in the data from those used in previous assessments. The landings history has been updated and extended back to 1918. Harvest was negligible prior to that year. Survey data from the Alaska and Northwest Fisheries Science Centers have been used to construct indices of abundance analyzed using a spatio-temporal delta-model. Length, marginal age, or conditional age-at-length compositions were also created for each fishery-dependent and -independent data source.

The definition of fishing fleets have changed from those in the 2011 assessment. Three fishing fleets were specified within the model: 1) a combined bottom trawl, mid-water trawl, and fixed gear fleet, where only a small fraction of Pacific ocean perch were captured by fixed gear (termed the fishery fleet), 2) the historical foreign fleet, and 3) the at-sea hake fishery. The fleet grouping were based on discarding practices. The fishery fleet estimated a retention curve based on discarding data and known management restrictions. However, very little if any discarding is assumed to have occurred by the foreign fleet and the catch reported by the at-sea hake fishery accounts for both discarded and landed fish and hence, no additional mortality was estimated for each of these fleets.

The assessment uses landings data and discard-fraction estimates; catch-per-unit-effort and survey indices; length- or age-composition data for each year and fishery or survey (with conditional age-at-length compositional data for the NWFSC shelf-slope survey); information on weight-at-length, maturity-at-length, and fecundity-at-length; information on natural mortality and the steepness of the Beverton-Holt stock-recruitment relationship; and estimates of ageing error. Recruitment at "equilibrium spawning output", length-based selectivity of the fisheries and surveys, retention of the fishery, catchability of the surveys, growth, the time-series of spawning output, age and size structure, and current and projected future stock status are outputs of the model. Natural mortality (0.054 yr^{-1}) and steepness (0.72) were fixed in the final model. This was done due to relatively flat likelihood surfaces, such that fixing parameters and then varying them in sensitivity analyses was deemed the best way to characterize uncertainty.

Although this assessment using many types of data since the 1980s, there is little information about steepness and natural mortality. Estimates of steepness are uncertain partly because of highly variable recruitment. Uncertainty in natural mortality is common in many fish stock assessments even when length and age data are available.

A number of sources of uncertainty are explicitly included in this assessment. This assessment includes gender differences in growth, a non-linear relationship between individual spawner biomass and effective spawning output, and an updated relationship between length and maturity, based upon non-published information (Melissa Head, personal communication, NOAA, NWFSC). As is always the case, overall uncertainty is greater than that predicted by a single model specification. Among other sources of uncertainty that are not included in the current model are the degree of connectivity between the stocks of Pacific ocean perch off of Vancouver Island, British Columbia and those in US waters, and the effect of climatic variables on recruitment, growth and survival.

A base model was selected that best captures the central tendency for those sources of uncertainty considered in the model.

Stock Biomass

The predicted spawning output from the base model generally showed a slight decline prior to 1966 when fishing by the foreign fleet commenced. A short, but sharp decline occurred between 1966 and 1970, followed by a period of the spawning output stabilizing or with a minimal decline until the late 1990s. The stock showed increases in stock size following the year 2000 due to a combination of strong recruitment and low catches. The 2017 estimated spawning output relative to unfished equilibrium spawning output is above the target of 40% of unfished spawning output at 96.4% ($\sim$ 95% asymptotic interval: $\pm$ 77.1%-116%). Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning output is high.

Table b: Recent trend in estimated spawning output (million eggs) and estimated relative spawning output (depletion).

Year	Spawning Output (million eggs)	˜ 95% confidence interval	Estimated depletion	˜ 95% confidence interval
2008	4955.00	2542 - 7368	0.69	0.538 - 0.833
2009	5143.00	2647 - 7639	0.71	0.559 - 0.864
2010	5267.00	2716 - 7818	0.73	0.574 - 0.884
2011	5345.00	2761 - 7930	0.74	0.583 - 0.896
2012	5394.00	2793 - 7996	0.75	0.590 - 0.903
2013	5427.00	2818 - 8037	0.75	0.594 - 0.907
2014	5566.00	2904 - 8228	0.77	0.612 - 0.928
2015	5979.00	3144 - 8814	0.83	0.661 - 0.994
2016	6515.00	3449 - 9582	0.90	0.722 - 1.081
2017	6966.00	3702 - 10230	0.96	0.771 - 1.156

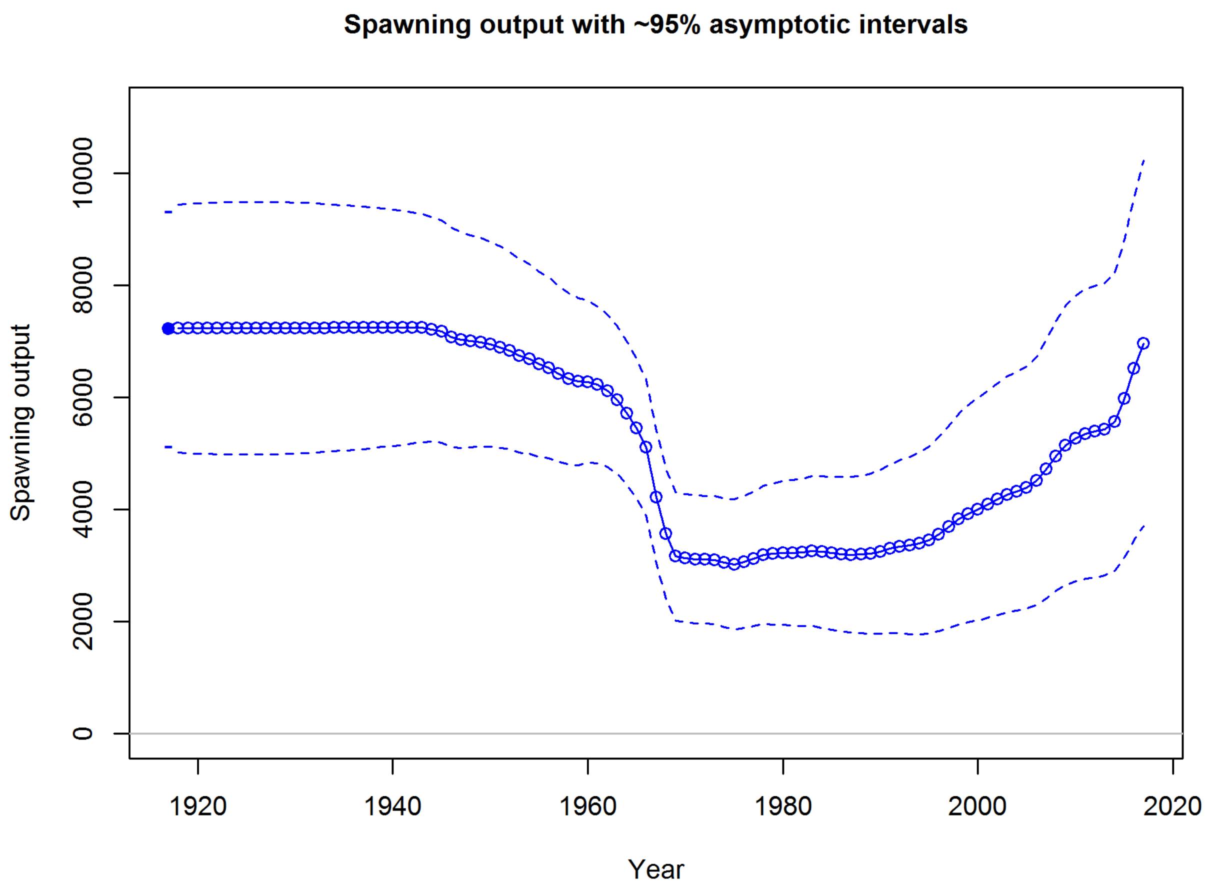

Figure b: Time-series of spawning output trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base assessment model.

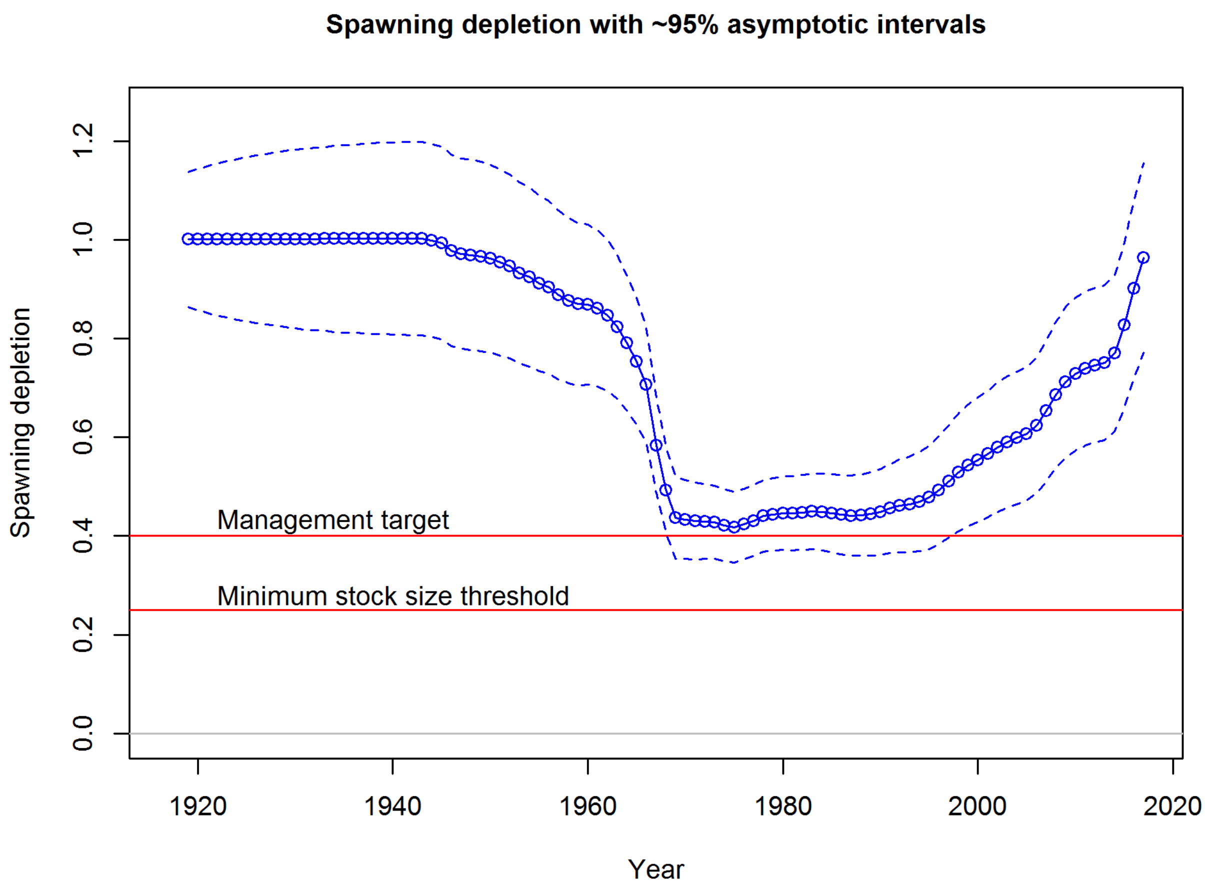

Figure c: Estimated relative spawning output (depletion) with approximate 95% asymptotic confidnce intervals (dashed lines) for the base assessment model.

Recruitment

Recruitment deviations were estimated for the entire assessment period. There is little information regarding recruitment prior to 1965, and the uncertainty in these estimates is expressed in the model. Past assessments estimated large recruitments in 1999 and 2000. In recent years, a recruitment of unprecedented size is estimated to have occurred in 2008. Additionally, there is early evidence of a strong recruitment in 2013. The four lowest recruitments estimated within the model (in ascending order) occurred in 2012, 2003, 2005, and 2007.

Table c: Recent estimated trend in recruitment and estimated recruitment deviations determined from the base model

Year	Estimated Recruitment	˜ 95% confidence interval	Estimated Recruitment Devs.	˜ 95% confidence interval
2008	150412.00	90890 - 248913	2.69	2.385 - 2.997
2009	5928.00	2614 - 13441	-0.55	-1.311 - 0.216
2010	9600.00	4808 - 19171	-0.07	-0.666 - 0.529
2011	18888.00	9954 - 35841	0.61	0.076 - 1.137
2012	2661.00	1127 - 6280	-1.35	-2.178 - -0.532
2013	37397.00	18056 - 77455	1.20	0.549 - 1.854
2014	5672.00	2000 - 16087	-0.77	-1.836 - 0.289
2015	12354.00	3501 - 43585	-0.00	-1.372 - 1.365
2016	12515.00	3540 - 44248	0.00	-1.372 - 1.372
2017	12602.00	3565 - 44546	0.00	-1.372 - 1.372

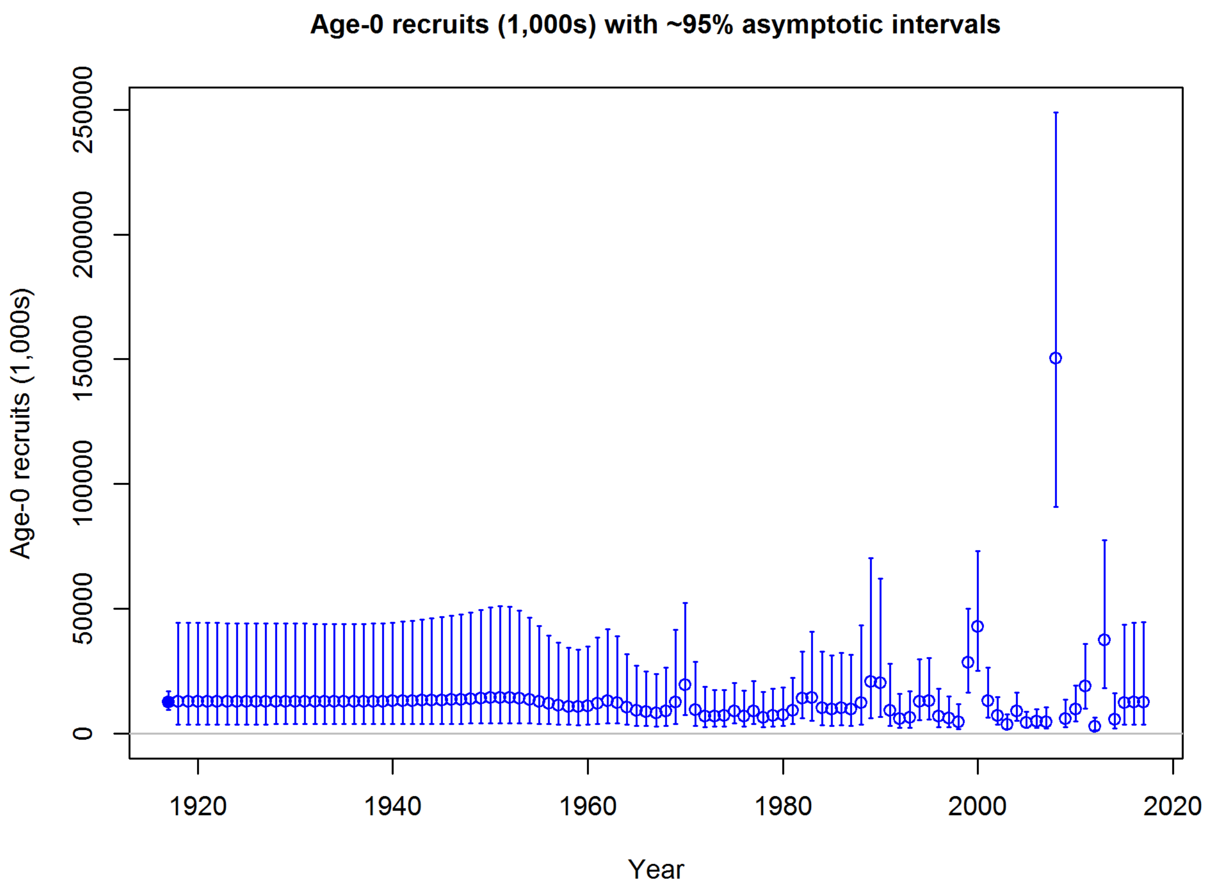

Figure d: Time-series of estimated Pacific ocean perch recruitments for the base model with 95% confidence or credibility intervals.

Exploitation Status

The spawning output of Pacific ocean perch reached a low in 1975. Landings for Pacific ocean perch decreased significantly in 2000 compared to previous years. The estimated relative depletion was possibly below the target biomass level between the 1970s and 1990s, but has likely remained above the target otherwise, and currently is significantly greater than the 40% unfished spawning output target. Throughout the late 1960s and the early 1970s the exploitation rate and values of relative spawning potential ((1-SPR)/(1-$SPR_{50\%}$)) were mostly above target levels. Recent exploitation rates on Pacific ocean perch were predicted to be significantly below target levels.

Table d: Recent trend in spawning potential ratio (1-SPR)/(1-SPR50) and summary exploitation rate for Pacific ocean perch.

Year	(1-SPR)/ (1-SPR50%)	˜ 95% confidence interval	Exploitation rate	˜ 95% confidence interval
2007	0.066	0.034 - 0.097	0.001	0.001 - 0.002
2008	0.054	0.027 - 0.082	0.001	0.001 - 0.002
2009	0.073	0.035 - 0.111	0.002	0.001 - 0.003
2010	0.069	0.034 - 0.105	0.002	0.001 - 0.002
2011	0.024	0.013 - 0.036	0.000	0.000 - 0.001
2012	0.023	0.012 - 0.034	0.000	0.000 - 0.001
2013	0.022	0.012 - 0.032	0.000	0.000 - 0.001
2014	0.019	0.010 - 0.029	0.000	0.000 - 0.001
2015	0.020	0.011 - 0.029	0.000	0.000 - 0.001
2016	0.020	0.011 - 0.030	0.000	0.000 - 0.001

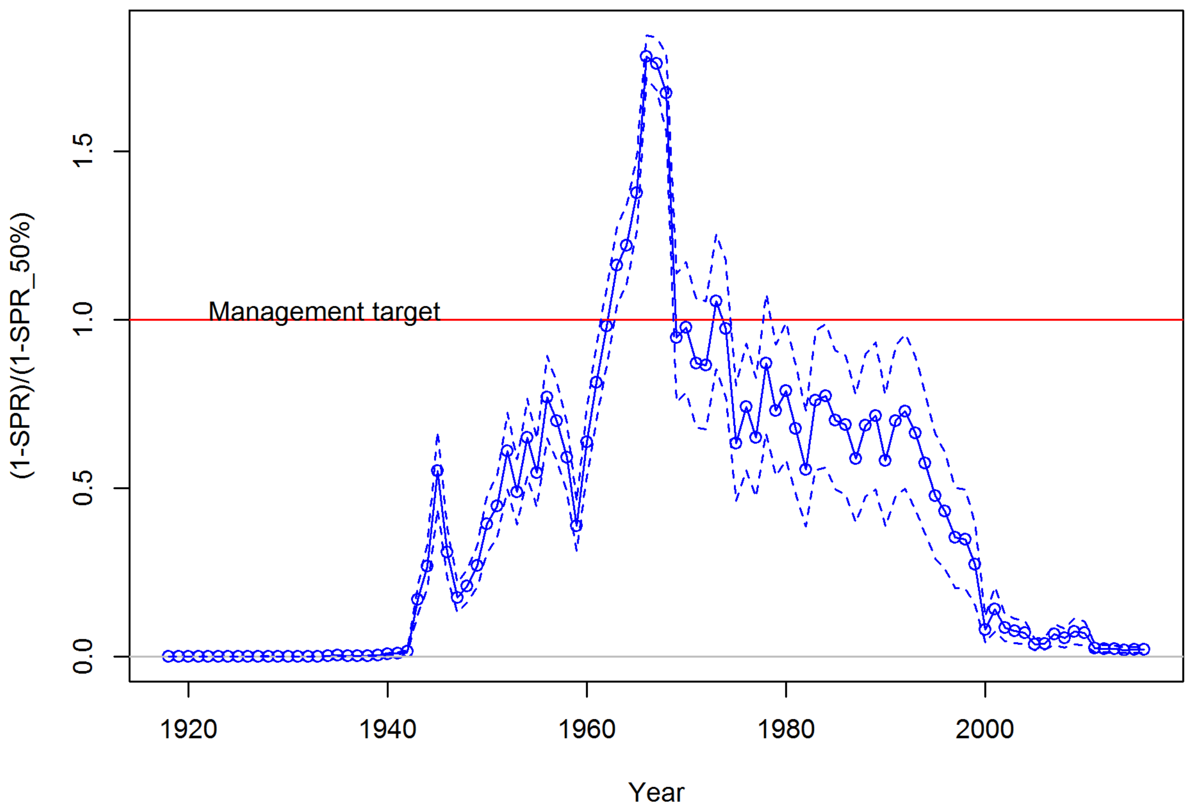

Figure e: Estimated relative spawning potential ratio (1-SPR)/(1-SPR50%) for the base model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR50% harvest rate. The last year in the time-series is 2016.

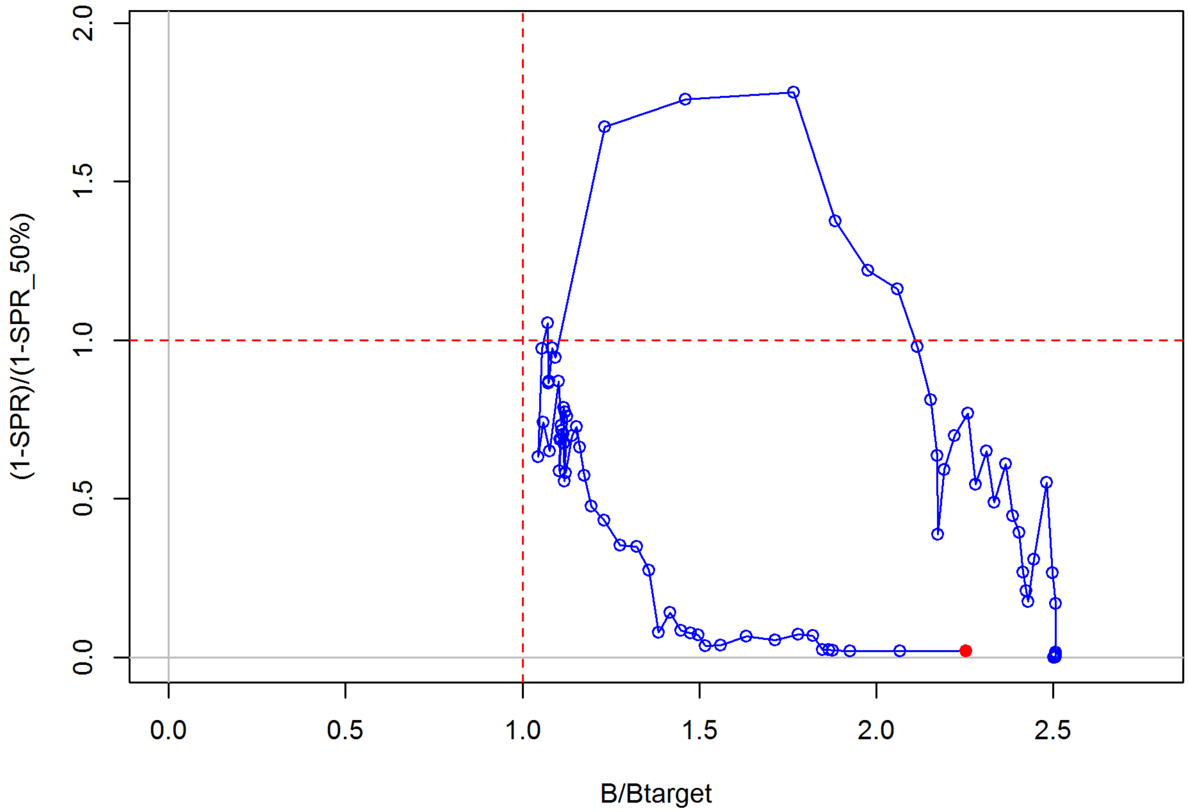

Figure f: Phase plot of estimated (1-SPR)/(1-SPR50%) vs. relative spawning output (depletion) for the base case model.

Ecosystem Considerations

Rockfish are an important component of the California Current ecosystem along the US west coast, with more than sixty five species filling various niches in both soft and hard bottom habitats from the nearshore to the continental slope, as well as near bottom and pelagic zones. Pacific ocean perch are generally considered to be semi-demersal, but there can, at times, be a significant pelagic component to their distribution.

Recruitment is one mechanism by which the ecosystem may directly impact the population dynamics of Pacific ocean perch. The 1999 cohort for many species of rockfish was large – sometimes significantly so. Long-term averages suggest that environmental conditions may influence the spawning success and survival of larvae and juvenile rockfish. Pacific ocean perch showed above average recruitment deviations in 1999 and 2000. The specific pathways through which environmental conditions exert influence on Pacific ocean perch dynamics are unclear; however, changes in water temperature and currents, distribution of prey and predators, and the amount and timing of upwelling are all possible linkages. Changes in the environment may also result in changes in length-at-maturity, fecundity, growth, and survival which can affect the status of the stock and its susceptibility to fishing. Unfortunately, there are few data available for Pacific ocean perch that provide insights into these effects.

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

Reference Points

This stock assessment estimates that the spawning output of Pacific ocean perch is above the management target. Due to reduced landing and the large 2008 year-class, an increasing trend in spawning output was estimated in the base model. The estimated depletion in 2017 is 96.4% ($\sim$ 95% asymptotic interval: $\pm$ 77.1%-116%), corresponding to an unfished spawning output of 6,966 million eggs ($\sim$ 95% asymptotic interval: 3,702-10,230 million eggs). Unfished age 3+ biomass was estimated to be 154,084 mt in the base model. The target spawning output based on the biomass target ($SB_{40\%}$) is 2,891.2 million eggs, with an equilibrium catch of 2,680.8 mt. Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{50\%}$ is 2,555.8 mt. Estimated MSY catch is at a 2,860.7 spawning output of 1,942.8 million eggs (26.9% depletion)

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

Quantity	**Estimate**	**~95% Confidence Interval**
Unfished spawning output (million eggs)	7228	5126.5 - 9329.4
Unfished age 3+ biomass (mt)	154084	109381.3 - 198786.7
Unfished recruitment (R0, thousands)	12647.9	9483.8 - 16867.7
Spawning output(2017 million eggs)	6966	3701.9 - 10230.1
Relative spawning output (depletion) (2017)	0.964	0.771 - 1.2
Reference points based on $\mathbf{SB_{40\%}}$		
Proxy spawning output ($B_{40\%}$)	2891.2	2050.6 - 3731.8
SPR resulting in $B_{40\%}$ ($SPR_{B40\%}$)	0.458	0.458 - 0.458
Exploitation rate resulting in $B_{40\%}$	0.038	0.038 - 0.039
Yield with $SPR_{B40\%}$ at $B_{40\%}$ (mt)	2680.8	1906.1 - 3455.6
Reference points based on SPR proxy for MSY		
Spawning output	3224.8	2287.2 - 4162.4
SPR_{proxy}	0.5	
Exploitation rate corresponding to SPR_{proxy}	0.033	0.033 - 0.034
Yield with SPR_{proxy} at SB_{SPR} (mt)	2555.8	1816.8 - 3294.7
Reference points based on estimated MSY values		
Spawning output at MSY (SB_{MSY})	1942.8	1374.4 - 2511.1
SPR_{MSY}	0.34	0.338 - 0.342
Exploitation rate at MSY	0.057	0.056 - 0.058
MSY (mt)	2860.7	2034.9 - 3686.5

Management Performance

Exploitation rates on Pacific ocean perch exceeded MSY proxy target harvest rates during the 1960s and 1970s, resulting in sharp declines in the spawning output. Exploitation rates subsequently declined to rates at or below the management target in the late 1970s. Management restrictions imposed in the 1990s further reduced exploitation rates. An overfished declaration for Pacific ocean perch resulted in very low exploitation rates since 2001 with Annual Catch Limits (ACLs) being set far below the Overfishing Limit (OFL) and Acceptable Biological Catch (ABC) values.

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

Year	OFL (mt; ABC prior to 2011)	ABC (mt)	ACL (mt; OY prior to 2011)	Total landings (mt)	Estimated total catch (mt)
2007	900		150	134	159
2008	911		150	92	134
2009	1,160		189	97	193
2010	1,173		200	99	182
2011	1,026	981	180	61	62
2012	1,007	962	183	59	60
2013	844	807	150	57	58
2014	838	801	153	54	56
2015	842	805	158	60	61
2016	850	813	164	68	68

Unresolved Problems and Major Uncertainties

1. Pacific ocean perch off the US west coast may be a fraction of a much large population extending into Canada or even Alaska. Modelling only a part of the total population might contribute to the lack of correspondence between the survey indices and other data sources, as seen in the $\ln(R0)$ profiles and age-structured production model diagnostics as well as some of the observation variability. While this comment is not intended to reflect badly on the STAT's capabilities, it is important to recognize that stock structure could potentially be a major source of uncertainty regarding the assessment results.

2. The indices of abundance used in the final base model provide almost no information on population scale, as demonstrated in the $\ln(R0)$ profiles examined during the review. The Triennial survey was the only index that provided signal with respect to population scale. However, this survey was removed in the final base model due to concerns about the quality of the survey and conflicts with other data. There are large amounts of composition data in the model, with both age- and length-compositions being included for some fleets. The compositional data and catch are providing the majority of the information on the estimated and derived quantities.

3. Use of conditional-age-at-length composition data provides information on parameters beyond those of the length-at-age relationship. The conditional-age-at-length data are robust to length-based processes (Piner et al. 2016), however they are also influenced by age-based processes (Lee et al. 2017). No age-based observation model processes were used in the assessment model as a link to the data, meaning that the conditional-age-at-length data were assumed to be unbiased with respect to the population. The conditional-age-at-length data were shown to be very influential on the estimated dynamics beyond growth estimates. More theoretical work in this area is needed to understand how to best the use this type of information and what potential systems or observation model processes could invalidate the assumption of randomness at length.

Decision Table

Model uncertainty has been described by the estimated uncertainty within the base model and by the sensitivities to different model structure. The estimated parameter that resulted in the most variability of predicted status and yield advice was natural mortality (M). The 12.5% and 87.5% quantiles based on spwaning output uncertainty were used to determine the low and high values for M of 0.045 and 0.06 yr^{-1}. An alternative decision table was also provided which based the range of natural mortality values on the uncertainty in the parameter prior. This approach was suggestion post-STAR panel review by Owen Hamel as a method to explore a greater range of uncertainty. The low and high stated of nature values were based on the 12.5% and 87.5% quantiles when the uncertainty was divided between the data used to generate the prior and the uncertainty surrounding the estimated value.

This assessment synthesizes many sources of data and estimates recruitment variability, thus it is classified as a Category 1 stock assessment. Therefore, the sigma for P* to determine the catch reduction to account for scientific uncertainty is 0.36, since the estimated sigma in the assessment is less than this for current spawning biomass (0.24).

Table g: Projections of potential OFL (mt) and ACL (mt) and the estimated spawning output and relative depletion based on ACL removals. The ACL values for 2017 and 2018 are set at the harvest limits currently set by management.

Year	OFL	ACL	Spawning Output (million eggs)	Relative Depletion
2017	5861	281	6966	0.964
2018	6116	281	7299	1.010
2019	6251	5981	7559	1.046
2020	6091	5827	7539	1.043
2021	5894	5639	7485	1.036
2022	5685	5439	7382	1.021
2023	5475	5238	7246	1.002
2024	5270	5042	7089	0.981
2025	5077	4857	6921	0.958
2026	4899	4688	6748	0.934
2027	4738	4533	6572	0.909
2028	4590	4391	6398	0.885

Table h: Summary of 10-year projections beginning in 2019 for alternate states of nature based on an axis of uncertainty for the base model. The range of natural mortality values corresponded to the 12.5 and 87.5th quantile from the uncertainty around final spawning biomass. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. The SPR50 catch stream is based on the equilibrium yield applying the SPR50 harvest rate.

			States of nature					
			M = 0.045		M = 0.054		M = 0.060	
	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
ABC	2019	5981	5533	86	7559	105	9565	114
	2020	5827	5486	86	7541	104	9564	114
	2021	5639	5414	84	7488	104	9517	114
	2022	5439	5307	83	7388	102	9411	112
	2023	5238	5177	81	7253	100	9263	111
	2024	5042	5032	79	7098	98	9089	109
	2025	4857	4881	76	6932	96	8902	106
	2026	4688	4726	74	6760	94	8706	104
	2027	4533	4572	71	6586	91	8508	102
	2028	4391	4419	69	6413	89	8310	99
SPR50	2019	2556	5533	86	7559	105	9565	114
	2020	2556	5640	88	7694	106	9716	116
	2021	2556	5721	89	7792	108	9819	117
	2022	2556	5762	90	7835	108	9854	118
	2023	2556	5770	90	7834	108	9837	117
	2024	2556	5755	90	7802	108	9782	117
	2025	2556	5721	89	7747	107	9701	116
	2026	2556	5673	88	7673	106	9599	115
	2027	2556	5613	88	7585	105	9482	113
	2028	2556	5545	87	7487	104	9354	112

Table i: Alternative decision table. Summary of 10-year projections beginning in 2019 for alternate states of nature based on an axis of uncertainty for the base model. The range of natural mortality values are based on the 12.5 and 87.5th quantiles of the natural mortality prior. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. The SPR50 catch stream is based on the equilibrium yield applying the SPR50 harvest rate.

			States of nature					
			M = 0.038		M = 0.054		M = 0.077	
	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
ABC	2019	5981	4214	69	7559	105	41065	130
	2020	5827	4141	67	7541	104	41501	131
	2021	5639	4047	66	7488	104	41736	132
	2022	5439	3927	64	7388	102	41699	132
	2023	5238	3789	62	7253	100	41471	131
	2024	5042	3643	59	7098	98	41125	130
	2025	4857	3493	57	6932	96	40699	129
	2026	4688	3342	54	6760	94	40219	127
	2027	4533	3192	52	6586	91	39706	125
	2028	4391	3045	50	6413	89	39174	124
SPR50	2019	2556	4214	69	7559	105	41065	130
	2020	2556	4295	70	7694	106	41651	132
	2021	2556	4356	71	7792	108	42032	133
	2022	2556	4387	71	7835	108	42130	133
	2023	2556	4393	72	7834	108	42024	133
	2024	2556	4381	71	7802	108	41786	132
	2025	2556	4354	71	7747	107	41455	131
	2026	2556	4316	70	7673	106	41057	130
	2027	2556	4270	70	7585	105	40611	128
	2028	2556	4216	69	7487	104	40136	127

Research and Data Needs

There are many areas of research that could be improved to benefit the understanding and assessment of Pacific ocean perch. Below, are issues that are considered of importance.

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

2. **Steepness**: The amount of stock resilience, steepness, dictates the rate at which a stock can rebuild from low stock sizes. Improved understating regarding the steepness parameter for US west coast Pacific ocean perch will reduce our uncertainty regarding current stock status.

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

Table j: Base model results summary.

Quantity	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
OFL (mt)	911	1,160	1,173	1,026	1,007	844	838	842	850	964
ACL (mt)	150	189	200	180	183	150	153	158	164	281
Landings (mt)	92	97	99	61	59	57	54	60	68	
Total Est. Catch (mt)	134	193	182	62	60	58	56	61	68	
(1-SPR)(1-$SPR_{50\%}$)	0.054	0.073	0.069	0.024	0.023	0.022	0.019	0.020	0.020	
Exploitation rate	0.001	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	
Age 3+ biomass (mt)	113935	114656	114685	129549	136687	143823	151230	156447	163853	168288
Spawning Output	4955	5143	5267	5345	5394	5427	5566	5979	6515	6966
95% CI	2542 - 7368	2647 - 7639	2716 - 7818	2761 - 7930	2793 - 7996	2818 - 8037	2904 - 8228	3144 - 8814	3449 - 9582	3702 - 10230
Relative Depletion	0.686	0.712	0.729	0.740	0.746	0.751	0.770	0.827	0.901	0.964
95% CI	0.538 - 0.833	0.559 - 0.864	0.574 - 0.884	0.583 - 0.896	0.590 - 0.903	0.594 - 0.907	0.612 - 0.928	0.661 - 0.994	0.722 - 1.081	0.771 - 1.156
Recruits	150412	5928	9600	18888	2661	37397	5672	12354	12515	12602
95% CI	90890 - 248913	2614 - 13441	4808 - 19171	9954 - 35841	1127 - 6280	18056 - 77455	2000 - 16087	3501 - 43585	3540 - 44248	3565 - 44546

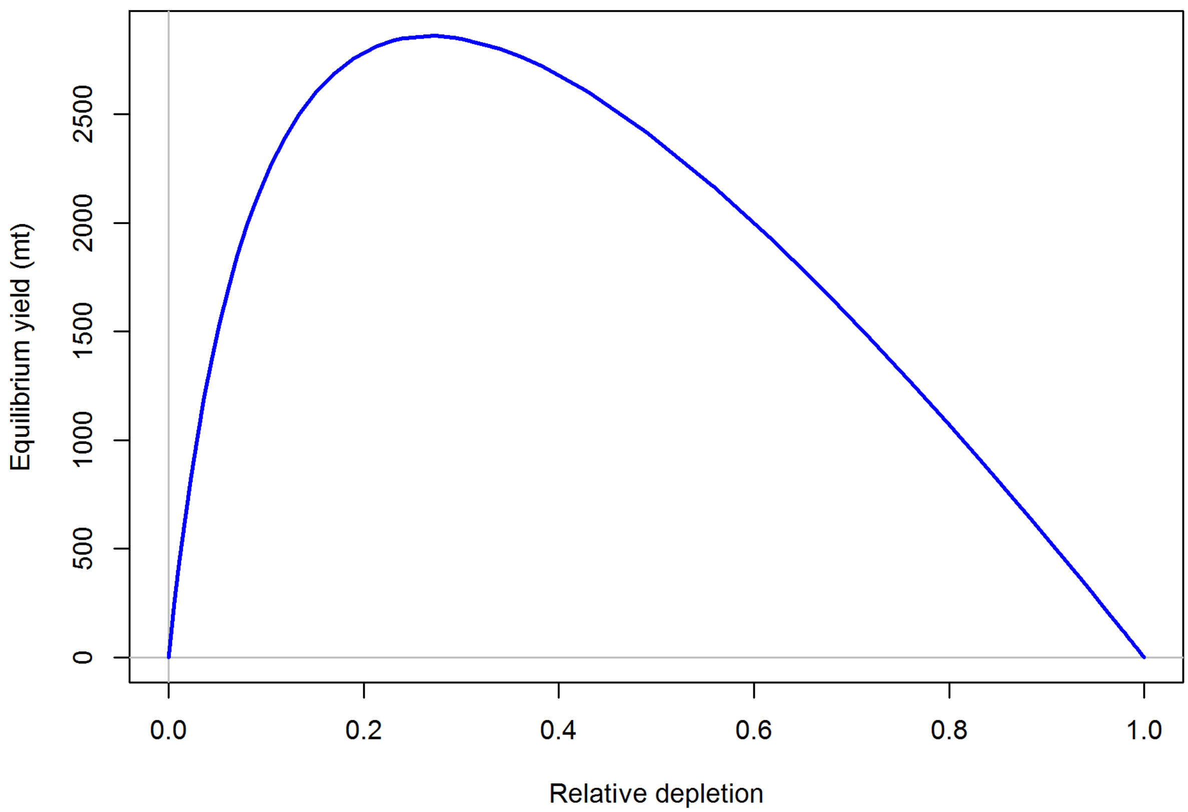

Figure g: Equilibrium yield curve for the base case model. Values are based on the 2016 fishery selectivity and with steepness fixed at 0.72.