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

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This assessment reports the status of the Pacific ocean perch (*Sebastes alutus*) species off rockfish off the U.S. West Coast from Northern California to the Canadian Border using data through 2017. Pacific ocean perch are most abundant in the Gulf of Alaska and have observed off of Japan, in the Bering Sea, and south to Baja California, although they are sparse south of Oregon and rare in southern California. Although catches north of the US-Canada border were not included in this assessment, it is not certain the connectivity of these populations with contribution to the biomass possibly through adult migration and/or larval dispersion. Composition data indicate that good recruitment years coincide in Oregon and Washington. To date, no significant genetic differences have been found in the range covered by this assessment.

Landings

landings

The first year that harvest of Pacific ocean perch exceeded 1 mt off the US West Coast first occurred in 1929. 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 in 1966-1968 were largely a result of harvest by foreign vessels. The fishery proceed with more moderate removals ranging between 1,200 to 2,600 metric tons per year between 1969 to 1980. Removals generally declined from 1981 to 1994 to between 1,000 and 1,700 metric tons per year. Pacific ocean perch was declared overfished in 1999 resulting in large reduction in harvest in recent years since the declaration. Since 2000, catches of Pacific ocean perch have ranged between 269 - 60 mt, with catches in 2016 totaling 67 mt.

Pacific ocean perch are a desirable market species and discarding has historically been low. However, management restrictions (e.g. trip limits) have resulted in increased discarding since 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 bottom trawl fishery peaking in 2009 and 2010, prior to implementation of catch shares in 2011. Since 2011, discarding of Pacific ocean perch has been estimated to be less than 4% given observer data.

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

Year	California	Oregon	Washington	At-sea Hake	Research	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

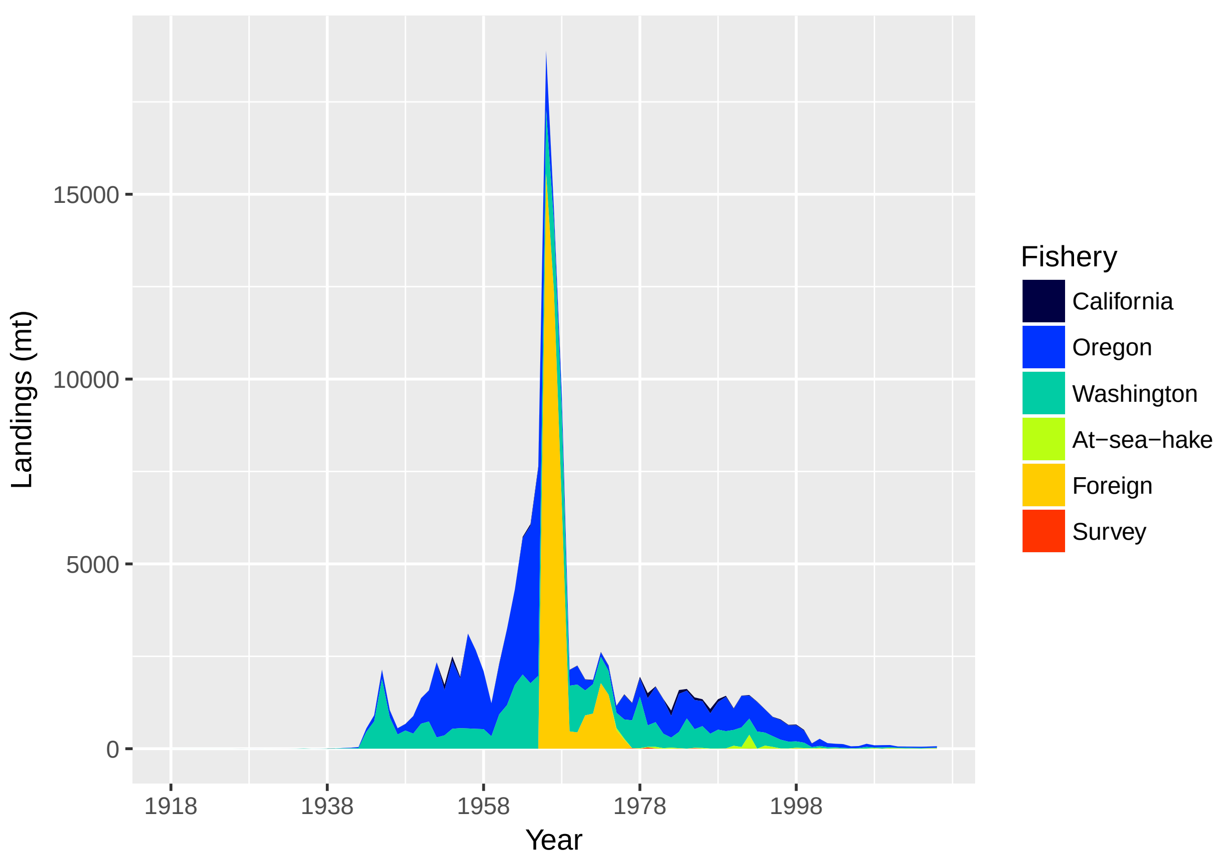

Figure a: Landings of Pacific ocean perch for California, Oregon, Washington, the Foriegn fishery (1966-1976), At-Sea Hake fishery, and fishery independent surveys. fig:Exec_catch1

Data and Assessment

data-and-assessment

This a new full assessment for Pacific ocean perch which was last assessed in 2011. In this assessment, all aspects of the model including catches, data, and modelling assumptions were re-evaluated as much as possible. The assessment was conducted using the length- and age-structured modeling software Stock Synthesis (version 3.30.30.05). The coastwide population was modeled assuming separate growth and mortality parameters for each sex (a two-sex model) from 1918 to 2017, and forecasted beyond 2017.

All of the sources of data for Pacific ocean perch have been re-evaluated for 2017, excluding the historical fishery catch-per-unit time series. Changes of varying degrees have occurred in the data from those used in previous assessments. These current data represent the best available scientific information. The landings history has been updated and extended back to 1918, harvest was negligible before that year. Survey data from the Alaska and Northwest Fisheries Science Centers have been used to construct series of indices using a spatial temporal delta GLMM model as well as length, age and conditional age-at length compositions consistent with the stratifications used for constructing the indices.

The definition of fishing fleets have been 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 occurring by fixed gear, 2) the historical foreign fleet, and 3) the at-sea hake fishery. The fleet grouping were based on discarding practices. The trawl fishery estimated a retention curve based upon 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-of-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-age, maturity-at-age, and fecundity-at-age; priors on natural mortality and the steepness of the Beverton-Holt stock-recruitment relationship; and estimates of ageing error. Recruitment at "equilibrium biomass", length-based selectivity of the fishery and surveys, retention of the fishery, catchability of the surveys, growth, the time series of biomass, age and size structure, and current and projected future stock status are outputs of the model. Natural mortality and steepness were fixed in the final model. This was done due to relatively flat likelihood surfaces, such that fixing parameters and then varying them was deemed the best way to characterize uncertainty.

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

A number of sources of uncertainty are explicitly included in this assessment. For example, allowance is made for uncertainty in survey catchability coefficients. Furthermore, 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 (M. Head, personal communication). 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 PFMC waters, and the effect of climatic variables on recruitment, growth and survival of Pacific ocean perch.

A reference case was selected which adequately captures the central tendency for those sources of uncertainty considered in the model.

Stock Biomass

stock-biomass

The predicted spawning biomass from the base model generally showed a slight decline over the time series until 1966 when the foreign fleet began. A short, but sharp decline occurred, followed by a period of the stock biomass stabilizing or with a minimal decline until the late 1990s. The stock showed increases in stock size following the year 2000 when a combination of strong recruitment and low catches resulted. The 2017 spawning biomass relative to unfished equilibrium spawning biomass is above the target of 40% of unfished spawning biomass at 2017 is 76.1% (~95% asymptotic interval: ± 53.8%-98.4%)%. Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning biomass is high.

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

tab:SpawningDeplete_mod1

Year	Spawning Output (million eggs)	~ 95% confidence interval	Estimated depletion	~ 95% confidence interval
2008	3211.00	1362 - 5060	0.48	0.330 - 0.638
2009	3346.00	1425 - 5267	0.50	0.345 - 0.664
2010	3438.00	1467 - 5408	0.52	0.355 - 0.681
2011	3500.00	1496 - 5504	0.53	0.362 - 0.693
2012	3545.00	1521 - 5570	0.53	0.368 - 0.701
2013	3584.00	1544 - 5625	0.54	0.373 - 0.708
2014	3727.00	1618 - 5835	0.56	0.390 - 0.733
2015	4118.00	1812 - 6425	0.62	0.435 - 0.807
2016	4620.00	2054 - 7186	0.70	0.491 - 0.902
2017	5047.00	2259 - 7835	0.76	0.538 - 0.984

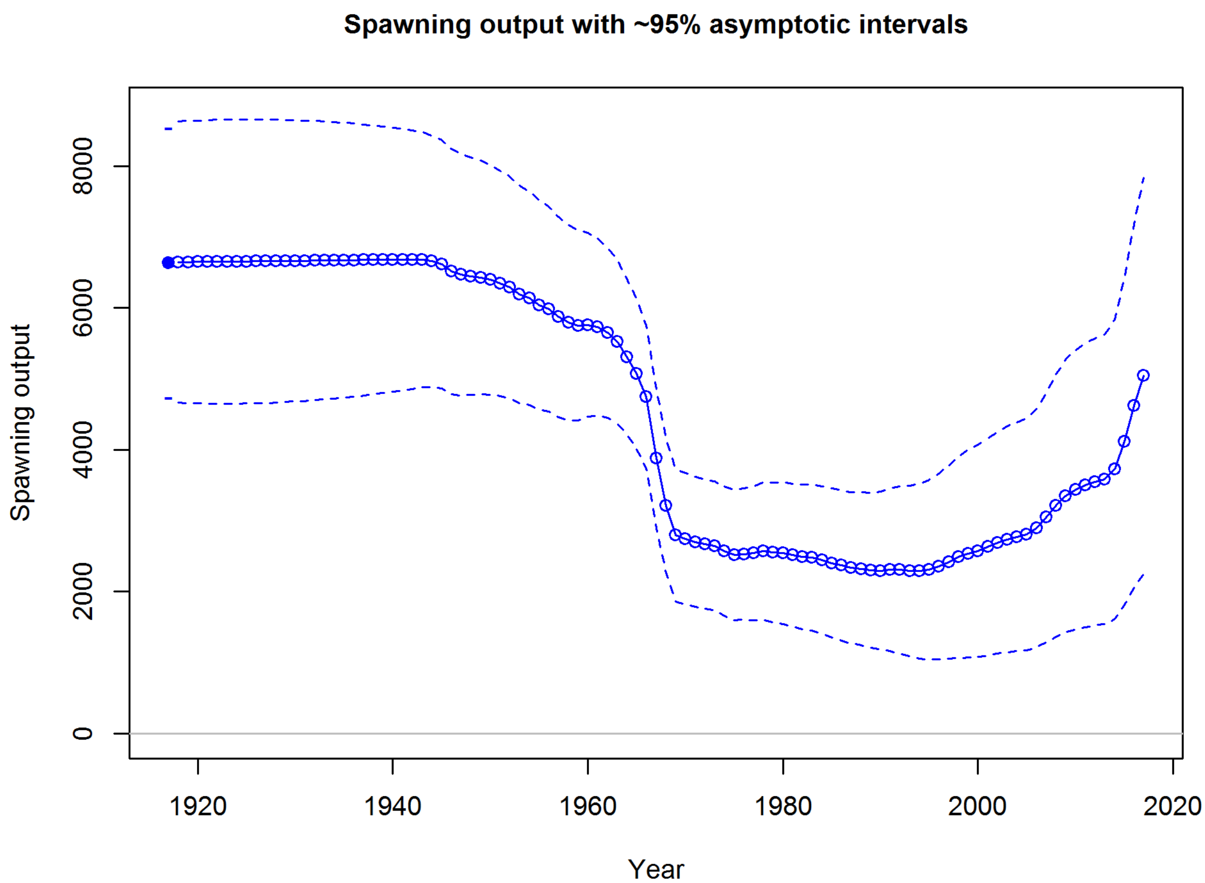

Figure b: Time series of spawning output trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base case assessment model. fig:Spawnbio_all

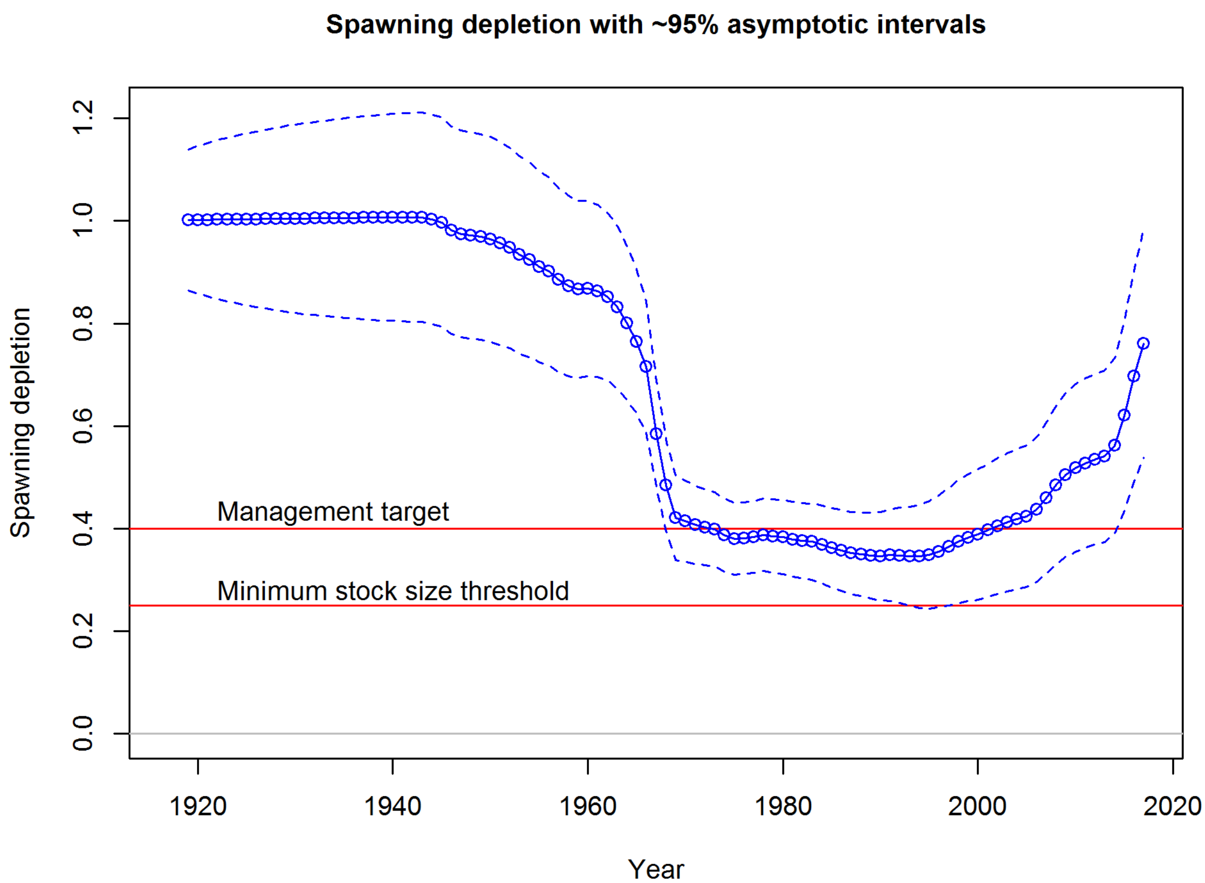

Figure c: Estimated relative spawning biomass (depletion) with approximate 95% asymptotic confidnce intervals (dashed lines) for the base case assessment model. fig:RelDeplete_all

Recruitment

recruitment

Recruitment deviations were estimated for the entire time-series modeled. There is little information regarding recruitment prior to 1965, and the uncertainty in these estimates is expressed in the model. Historically, there are estimates of large recruitments in 1999 and 2000. In recent years, a recruitment of unprecedented size is estimated to have occurred in 2008 but is highly uncertain. Additionally, there is early evidence of a strong recruitment in 2013. The four lowest recruitments (in ascending order) occurred in 2012, 2003, 1998, and 2005.

Table c: Recent estimated trend in recruitment with approximate 95/confidence intervals determined from the base model

tab:Recruit_mod1

Year	Estimated Recruitment	˜ 95% confidence interval	Estimated Recruitment Devs.	˜ 95% confidence interval
2008	133246.00	75744 - 234402	2.84	2.542 - 3.145
2009	4814.00	2070 - 11196	-0.49	-1.254 - 0.267
2010	8279.00	4007 - 17102	0.04	-0.558 - 0.633
2011	16107.00	8067 - 32159	0.70	0.146 - 1.246
2012	2113.00	870 - 5132	-1.34	-2.173 - -0.507
2013	29278.00	13512 - 63442	1.20	0.525 - 1.872
2014	5078.00	1728 - 14918	-0.65	-1.748 - 0.441
2015	10096.00	2827 - 36059	-0.00	-1.372 - 1.367
2016	10520.00	2945 - 37581	0.00	-1.372 - 1.372
2017	10816.00	3031 - 38596	0.00	-1.372 - 1.372

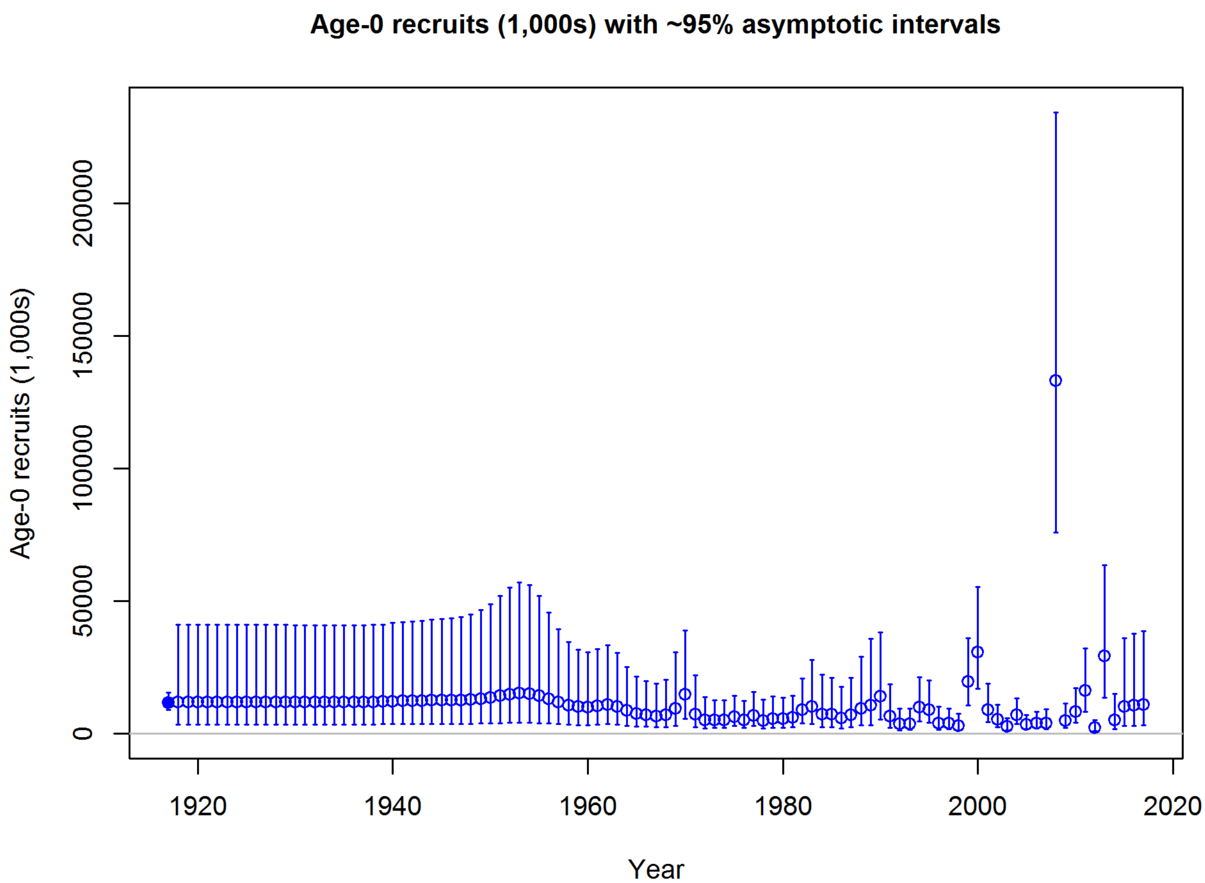

Figure d: Time series of estimated Pacific ocean perch recruitments for the base-case model with 95% confidence or credibility intervals. fig:Recruits_all

Exploitation status

exploitation-status

The spawning biomass of Pacific ocean perch reached a low in 1994. Catches for Pacific ocean perch decreased significantly in 2000 compared to previous years. The estimated relative biomass was possibly below the overfished level in the early 2000s, but has likely remained above that level otherwise, and currently is significantly greater than the 40% unfished spawning biomass target. Throughout the late 1960s and 1970s the exploitation rate and (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) and summary exploitation rate for Pacific ocean perch.

tab:SPR_Exploit_mod1

Year	(1-SPR)	~ 95% confidence interval	Exploitation rate	~ 95% confidence interval
2007	0.104	0.046 - 0.162	0.002	0.001 - 0.003
2008	0.086	0.036 - 0.135	0.002	0.001 - 0.003
2009	0.113	0.046 - 0.181	0.003	0.001 - 0.004
2010	0.107	0.044 - 0.171	0.002	0.001 - 0.004
2011	0.037	0.016 - 0.058	0.001	0.000 - 0.001
2012	0.035	0.015 - 0.054	0.001	0.000 - 0.001
2013	0.033	0.014 - 0.051	0.001	0.000 - 0.001
2014	0.029	0.013 - 0.045	0.001	0.000 - 0.001
2015	0.028	0.013 - 0.044	0.001	0.000 - 0.001
2016	0.028	0.012 - 0.043	0.001	0.000 - 0.001

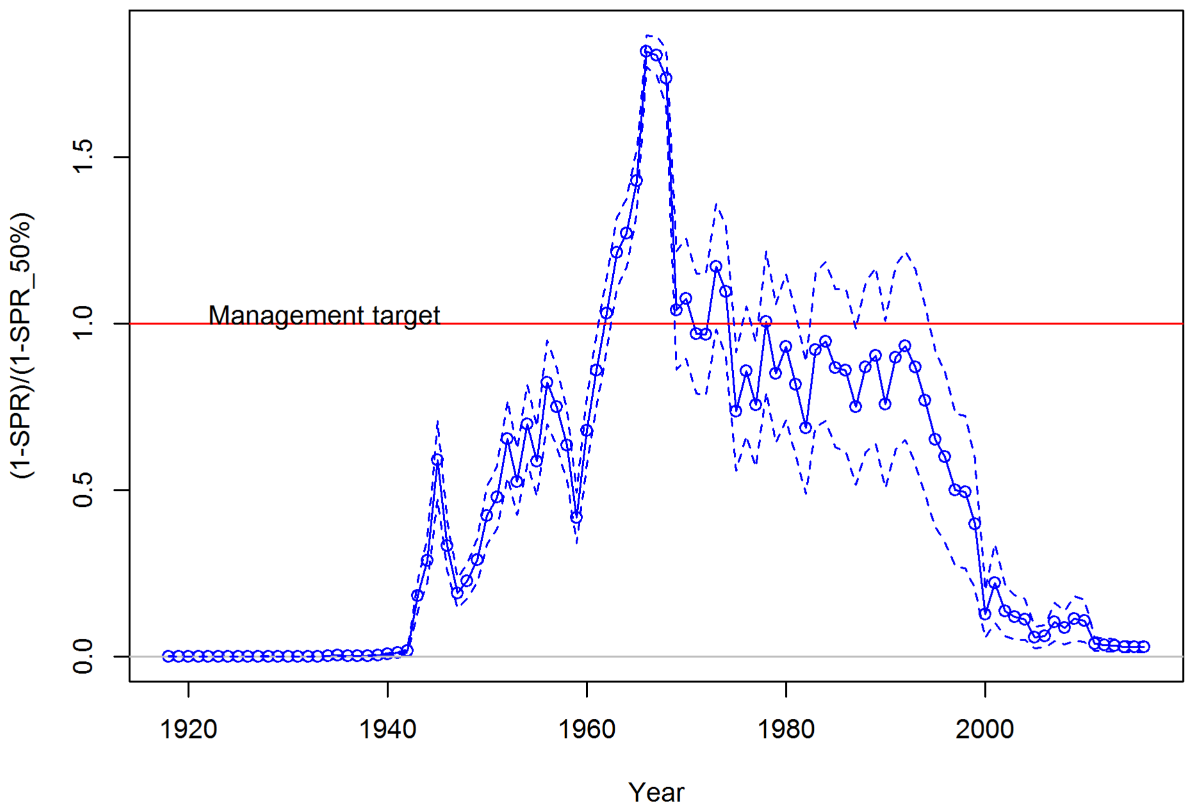

Figure e: Estimated spawning potential ratio (1-SPR)/(1-SPR50%) for the base-case model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the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

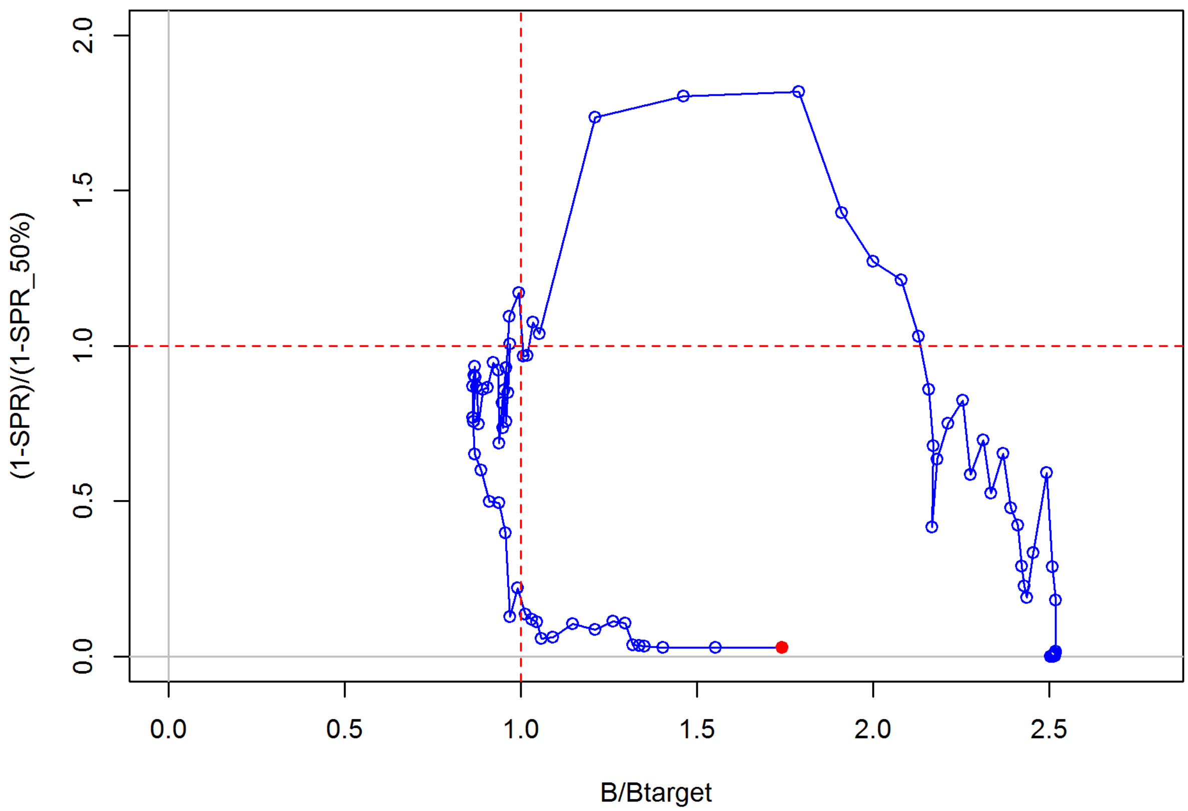

Figure f: Phase plot of estimated relative (1-SPR)/(1-SPR50%) vs. relative spawning biomass for the base case model. Relative biomass is the annual spawning biomass divided by the unfished spawning biomass. fig:Phase_all

Ecosystem Considerations

`ecosystem-considerations`

Rockfish are an important component of the California Current ecosystem along the US west coast, with its more than sixty five species filling various niches in both soft and hard bottom habitats from the nearshore to the continental slope, as well as near bottom and pelagic zones. 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 - from these species' long-term averages suggesting that environmental conditions may influence the spawning success and survival of larvae and juvenile rockfish. Pacific ocean perch showed an above average recruitment deviation in 1999 and 2000, but absolute recruitment was not as large as other years. 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 age-at-maturity, fecundity, growth, and survival which can affect how the status of the stock and its susceptibility to fishing are determined. Unfortunately, there are few data available for 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

`reference-points`

This stock assessment estimates that Pacific ocean perch in the base model are above the biomass target. Due to the large 2008 year-class, an increasing trend in spawning biomass was estimated in the base model. The estimated relative biomass level in 2017 is 76.1% (~95% asymptotic interval: ± 53.8%-98.4%), corresponding to an unfished spawning output of 5047 million eggs (~95% asymptotic interval: 2259-7835 million eggs) of spawning output in the base model. Unfished age 3+ biomass was estimated to be 139810 mt in the base case model. The target spawning output based on the biomass target ($SB_{40\%}$) is 2653.2 million eggs, which gives a catch of 1748.2 mt. Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{50\%}$ is 1764.8 mt.

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

tab:Ref_pts_mod1

Quantity	**Estimate**	**95% Confidence Interval**
Unfished spawning output (million eggs)	6633.1	4736.7 - 8529.5
Unfished age 3+ biomass (mt)	139810	100052.5 - 179567.5
Unfished recruitment (R0, thousands)	11665.7	8801.4 - 15462.1
Spawning output(2017 million eggs)	5047.2	2259.2 - 7835.1
Depletion (2017)	0.761	0.538 - 0.984
Reference points based on $\mathbf{SB_{40\%}}$		
Proxy spawning output ($B_{40\%}$)	2653.2	1894.7 - 3411.8
SPR resulting in $B_{40\%}$ ($SPR_{B40\%}$)	0.55	0.55 - 0.55
Exploitation rate resulting in $B_{40\%}$	0.028	0.028 - 0.029
Yield with $SPR_{B40\%}$ at $B_{40\%}$ (mt)	1748.2	1252.4 - 2244
Reference points based on SPR proxy for MSY		
Spawning output	2211	1578.9 - 2843.2
SPR_{proxy}	0.5	
Exploitation rate corresponding to SPR_{proxy}	0.034	0.033 - 0.034
Yield with SPR_{proxy} at SB_{SPR} (mt)	1764.8	1264.8 - 2264.8
Reference points based on estimated MSY values		
Spawning output at MSY (SB_{MSY})	2315.7	1649.6 - 2981.8
SPR_{MSY}	0.512	0.51 - 0.514
Exploitation rate at MSY	0.032	0.032 - 0.033
MSY (mt)	1766.7	1266.1 - 2267.4

Management Performance

management-performance

Exploitation rates on Pacific ocean perch exceeded MSY proxy target harvest rates during the 1960s and 1970s and spawning biomass is predicted to have fallen below the proxy management target of 40%. Exploitation rates subsequently declined to rates at or below the management target in the 1980s. 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 the ACLs being set far below the OFL and ABC values.

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

tab:mnmgt_perform

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	133	157
2008	911		150	92	133
2009	1,160		189	94	190
2010	1,173		200	97	181
2011	1,026	981	180	60	61
2012	1,007	962	183	57	58
2013	844	807	150	55	57
2014	838	801	153	54	55
2015	842	805	158	58	59
2016	850	813	164	65	65

Unresolved Problems And Major Uncertainties

unresolved-problems-and-major-uncertainties

TBD after STAR panel

Decision Table

decision-table

TBD after STAR panel

Table g: Projections of potential OFL (mt) and ACL (mt) and the estimated spawning output and relative biomass.

tab:OFL_projection

Year	OFL	ACL	Spawning Output (million eggs)	Relative Biomass
2017	4306	281	5047	0.761
2018	4559	281	5369	0.809
2019	4719	4515	5625	0.848
2020	4654	4453	5657	0.853
2021	4552	4356	5654	0.852
2022	4431	4240	5606	0.845
2023	4302	4116	5528	0.833
2024	4172	3992	5431	0.819
2025	4048	3873	5324	0.803
2026	3932	3762	5211	0.786
2027	3826	3660	5096	0.768
2028	3727	3566	4981	0.751

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. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. An entry of ”–” indicates that the stock is driven to very low abundance under the particular scenario.

`tab:Decision_table_mod1`

			States of nature					
			Low State of Nature		Base State of Nature		High State of Nature	
	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
Catch Option 1	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
Catch Option 2	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
Catch Option 3	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
Average Catch	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-

Research and Data Needs

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 the 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 understanting regarding the steepness of 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 Ccast observations would help to define the connectivity between Pacific ocean perch north and south of the U.S.-Canada border.

Table i: Base model results summary.

tab:base_summary

Quantity	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Landings (mt)	911	1,160	1,173	1,026	1,007	844	838	842	850	964
Total Est. Catch (mt)	150	189	200	180	183	150	153	158	164	281
OFL (mt)	92	94	97	60	57	55	54	58	65	
ACL (mt)	133	190	181	61	58	57	55	59	65	
(1-SPR)(1-$SPR_{50\%}$)	0.09	0.11	0.11	0.04	0.03	0.03	0.03	0.03	0.03	
Exploitation rate	0	0	0	0	0	0	0	0	0	
Age 3+ biomass (mt)	73810.2	74550.2	74832.0	88388.8	95169.1	102021.0	109119.0	114333.0	121131.0	125534.0
Spawning Output	3211	3346	3438	3500	3545	3584	3727	4118	4620	5047
95% CI	1362 - 5060	1425 - 5267	1467 - 5408	1496 - 5504	1521 - 5570	1544 - 5625	1618 - 5835	1812 - 6425	2054 - 7186	2259 - 7835
Depletion	0.484	0.504	0.518	0.528	0.534	0.540	0.562	0.621	0.697	0.761
95% CI	0.330 - 0.638	0.345 - 0.664	0.355 - 0.681	0.362 - 0.693	0.368 - 0.701	0.373 - 0.708	0.390 - 0.733	0.435 - 0.807	0.491 - 0.902	0.538 - 0.984
Recruits	133246	4814	8279	16107	2113	29278	5078	10096	10520	10816
95% CI	75744 - 234402	2070 - 11196	4007 - 17102	8067 - 32159	870 - 5132	13512 - 63442	1728 - 14918	2827 - 36059	2945 - 37581	3031 - 38596

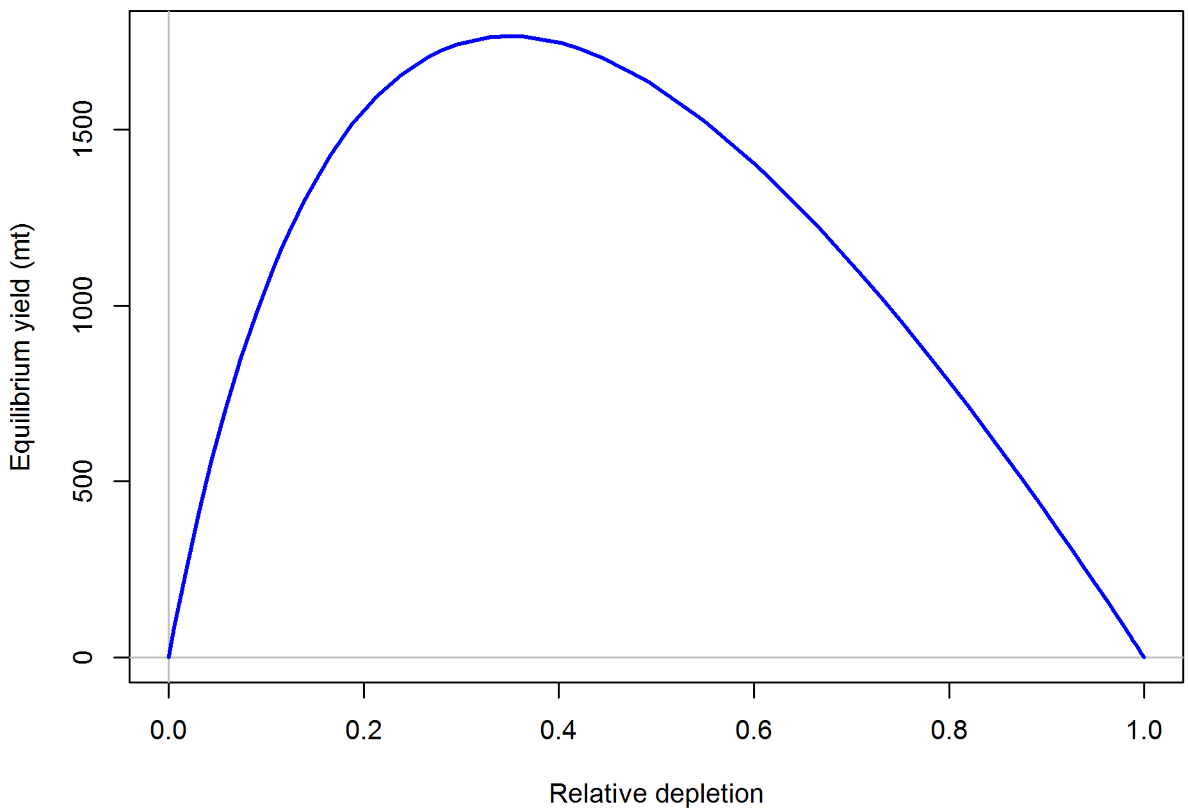

Figure g: Equilibrium yield curve for the base case model. Values are based on the 2016 fishery selectivity and with steepness fixed at 0.50. fig:Yield_all

1 Introduction

introduction

1.1 Basic Information

basic-information

Pacific ocean perch (*Sebastes alutus*) are most abundant in the Gulf of Alaska, and have been observed off of Japan, in the Bering Sea, and south to Baja California, although they are sparse south of Oregon and rare in southern California. While genetic studies have found three populations of Pacific ocean perch off of British Columbia (Seeb and Gunderson 1988, Withler et al. 2001) with, notably, a separate stock off of Vancouver Island, no significant genetic differences have been found in the range covered by this assessment. Pacific ocean perch show dimorphic growth, with females reaching a slightly large size than males. Males and females are equally abundant on rearing grounds at age 1.5.

The Pacific ocean perch population has been modeled as a single stock off of the US West Coast (essentially northern California to the Canadian border, since Pacific ocean perch are seen extremely rarely in central and southern California). Good recruitments show up in size-composition data throughout all portions of this area, which supports the single stock hypothesis. This assessment includes landings and catch data for Pacific ocean perch from the states of Washington, Oregon and California, along with records from foreign fisheries, the at-sea hake fleet, and fishery-indepenent surveys.

Prior to 1966, the Pacific ocean perch resource off of the northern portion of the US West Coast was harvested almost entirely by Canadian and United States vessels. Harvest was negligible prior to 1940, reached 1,300 mt in 1950, 3,200 mt in 1961 and exceeded 7,600 mt in 1965. Catches increased dramatically after 1965, with the introduction of large distant-water fishing fleets from the Soviet Union and Japan. Both nations employed large factory stern trawlers as their primary method for harvesting Pacific ocean perch. Peak removals by all foreign nations combined are estimated at over 15,000 mt in 1966 and remained over 12,000 mt in 1967. These numbers are based upon a re-analysis of the foreign catch data (Rogers 2003), which focused on deriving a more realistic species composition for catches previously identified only as Pacific ocean perch. Catches declined rapidly following these peak years, and Pacific ocean perch stocks were considered to be severely depleted throughout the Oregon-Vancouver Island region by 1969 (Gunderson 1977, Gunderson et al. 1977). Landed harvest averaged 1,350 mt over the period 1977-94. Landings have continued to decline since 1994, primarily due to more restrictive management (Table 1 and Figure 1).

Prior to 1977, Pacific ocean perch in the northeast Pacific were managed by the Canadian Government in its waters and by the individual states in waters off of the United States. With implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977, US territorial waters were extended to 200 miles from shore, and primary responsibility for management of the groundfish stocks off Washington, Oregon and California shifted from the states to the Pacific Fishery Management Council (PFMC) and the National Marine Fisheries Service (NMFS). At that time, however, a Fishery Management Plan (FMP) for the West Coast groundfish stocks had not yet been approved. In the interim, the state agencies worked with the PFMC to address conservation issues. In 1981, the PFMC adopted a management strategy to rebuild the depleted Pacific ocean perch stocks to levels that would produce Maximum Sustainable Yield (MSY) within 20 years. On the basis of cohort analysis (Gunderson 1978), the PFMC set Acceptable Biological Catch (ABC) levels at 600 mt for the US portion of the Vancouver INPFC area and 950 mt for the Columbia INPFC area. To implement this strategy, the states of Oregon and Washington each established landing limits for Pacific ocean perch. Trawl trip limits of various forms remained in effect through 2016 (Table 2).

Age estimates for Pacific ocean perch prior to the 1980s were made via surface ageing of otoliths, which misses the very tight annuli at the edge of the otolith once the fish reaches near maximum size. Ages are biased by around age 10-12, and maximum age was estimated to be in the 20s, which lead to an overestimate of the natural mortality rate and the productivity of the stock. Using break and burn methods, Pacific ocean perch have been aged to over 100 years, and we now know that the underlying assumptions of the early models were overly optimistic about productivity. Research surveys have been used to provide fishery-independent information about the abundance, distribution, and biological characteristics of Pacific ocean perch. A coast-wide survey of the rockfish resource was conducted in 1977 (Gunderson and Sample 1980) and was repeated every three years through 2004 (referred to as the 'Triennial Survey'). The National Marine Fisheries Service (NMFS) coordinated a cooperative research survey of the Pacific ocean perch stocks off Washington and Oregon with the Washington Department of Fisheries (WDFW) and the Oregon Department of Fish and Wildlife (ODFW) in March-May 1979 (Wilkins and Golden 1983). This survey was repeated in 1985 (referred to as the Pacific ocean perch Survey). Two slope surveys have been conducted off the West Coast in recent years, one using the research vessel Miller Freeman, which ended in 2001 (referred to as the 'AFSC Slope Survey'), and another ongoing cooperative survey using commercial fishing vessels which began in 1998 as a DTS (Dover sole, thornyhead and sablefish) survey, was expanded to other groundfish in 1999 (referred to as the 'NWFSC Slope Survey'). In 2003, this survey was expanded spatially to include the shelf. This last survey, conducted by the NWFSC, continues to cover depths from 30-700 fathoms (55-1280 meters) on an annual basis (referred to as the 'NWFSC Shelf-Slope Survey').

1.2 Summary of Management History

summary-of-management-history

The landings of Pacific ocean perch have been historically governed by harvest guidelines and trip limits, while recently management is imposed with total catch harvest limits in the form of overfishing limits (OFLs), acceptable biological catches (ABCs), and annual catch limits (ACLs). A trawl rationalization program, consisting of an individual fishing quota (IFQ) or catch shares system was implemented in 2011 for the limited entry trawl fleet targeting non-whiting groundfish, including Pacific ocean perch, and the trawl fleet targeting and delivering whiting to shore-based processors. The limited entry at-sea trawl sectors (motherships and catch-processors) that target whiting and process at sea are managed in a system of harvest cooperatives.

Limits onPacific ocean perch were first established in 1983 (Table 3). These were implemented as area closures, trip limits, and cumulative landing limits. In 1999, Pacific ocean perch was declared overfished with the assessment estimating the spawning output below the management limit (25% of virgin biomass). In reaction to the overfished decleration, harvest limits were reduced relative to previous years and a rebuilding plan was implemented in 2001.

1.3 Fisheries off Canada and Alaska

fisheries-off-canada-and-alaska

Pacific ocean perch can be found in waters off the US west coast and northward through Alaskan waters. In contrast the Pacific ocean perch stock off the US west coast, each assessed portion of the stock in Canada and Alaskan waters are estimated to be above management targets. The subset of the stock off the US west coast represents the tail of the species distribution with little to no Pacific ocean perch being encountered south of northern California. Pacific ocean perch are harvested both in Canada and Alaska. The most recent updated assessments for the Bering Sea and the Gulf of Alaska stocks determined that neither stock are in an overfished state and recommended and acceptable biological catch of 43,723 mt and 23,918 mt, respectively, for 2017.

In Canadian waters Pacific ocean perch has the largest single-species quota, accounting for approximately 25% of all rockfish landings by weight in the bottom trawl fleet. The Canadian Pacific ocean perch stock is broken into three seperate areas that are individually assessed. The status of the stock within each area are above Canadian management targets.

2 Data

data

Data used in the Pacific ocean perch assessment are summarized in Figure 2. A description of each data source is provided below.

2.1 Fishery-Independent Data:

fishery-independent-data

2.1.1 Northwest Fisheries Science Center (NWFSC) shelf-slope survey

northwest-fisheries-science-center-nwfsc-shelf-slope-survey

The NWFSC shelf-slope survey is based on a random-grid design; covering the coastal waters from a depth of 55 m to 1,280 m (Bradburn et al. 2011). This design uses four chartered industry vessels in most years, assigned to a roughly equal number of randomly selected grid cells. The survey, which has been conducted from late-May to early-October each year, is divided into two 2-vessel passes of the coast, which are executed from north to south. This design therefore incorporates both vessel-to-vessel differences in catchability as well as variance associated with selecting a relatively small number (approximately 700) of cells from a very large population of possible cells (greater than 11,000) distributed from the Mexican to the Canadian border.

The data from the NWFSC shelf-slope survey was analyzed using a spatio-temporal delta-model (Thorson et al. 2015), implemented as an R package VAST (Thorson and Barnett 2017) and publicly available online (https://github.com/James-Thorson/VAST). Spatial and spatio-temporal variation is specifically included in both encounter probability and positive catch rates, a logit-link for encounter probability, and a log-link for positive catch rates. Vessel-year effects were included for each unique combination of vessel and year in the database, to account for the random selection of commercial vessels used during sampling (Helser et al. 2004, Thorson and Ward (2014)). Spatial variation was approximated using 1000 knots, and use the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016). Further details regarding model structure are available in the user manual (https://github.com/James-Thorson/VAST/blob/master/examples/VAST_user_manual.pdf).

The smallest Pacific ocean perch tend to occur in the shallower depths ($<$ 200 m) with only larger individuals occurring at depths deeper than 300 m. Data collected by the NWFSC Shelf-Slope survey between depths of 55 - 549 m and north of 42° and south of 49° were stratified to generate an index of abundance from 2003-2016. The estimated index of abundance is shown in Table 4. The lognormal distribution with random strata-year and vessel effects had the lowest AIC and was chosen as the final model. The Q-Q plot does not show any departures from the assumed distribution (Figure 4). The indices for the NWFSC shelf-slope survey show a tentative decline in the population between 2003 and 2009, with an increasing trend in biomass between the 2009 and 2016 median point estimates.

Length, age, and conditional age-at-length compositions were expanded based upon the stratification. The number of tows with length data ranged from 33 in 2006 to 69 in 2015 (Table 5) where ages were collected for Pacific ocean perch in nearly every tow (Table 6). The expanded length frequencies from this survey show an increase in small fish starting in 2010 (Figure 5). The age frequencies provide clear evidence of large year-classes moving through the population from the 1999, 2000, and 2008 recruitment; with early indications of a large 2013 recruitment (Figure 6).

The effective sample sizes for length and marginal age composition data for all fishery-independet surveys were calculated according to Stewart & Hamel (2014) which determined that the approximate realized sample size for shelf/slope rockfish species was $2.43{*}N_{\text{tow}}$. The effective sample size of conditional-age-at-length data was set at the number of fish at each length by year.

2.1.2 Northwest Fisheries Science Center (NWFSC) slope survey

`northwest-fisheries-science-center-nwfsc-slope-survey`

The NWFSC slope survey covered waters throughout the summer from 183 m to 1280 m north of 34°30′ S, which is near Point Conception between 1999 and 2002. Tows conducted between the depths of 183 and 549 m were used to create an index of abundance using a bayesian delta-GLMM and the VAST delta-GLMM models. The estimated index of abundance is show in Table 4. Based on the diagnostics the bayesian delta-GLMM, which does not account for spatial effects, gamma distribution with year-vessel random effects was selected as the final model. The Q-Q plot does not show any departures from the assumed distribution (Figure 7). The trend of abundance across the four surveys years was generally flat with high estimated annual variance.

Length and age compositions were available for 2001 and 2002 and were expanded based upon the survey stratification (Tables 7 and 8. The expanded length frequencies from this survey shows that primarily only large fish were captured both years (Figure 8). The majority of fish observed by this survey were aged at greater than 10 years (Figure 9).

2.1.3 Alaska Fisheries Science Center (AFSC) slope survey

`alaska-fisheries-science-center-afsc-slope-survey`

The AFSC slope survey operated during autumn (October-November) aboard the R/V Miller Freeman. Partial survey coverage of the U.S. west coast occurred during 1988-96 and complete coverage (north of 34°30′ S) during 1997, 1999, 2000, and 2001. Only the four years of consistent and complete surveys plus 1996, which surveyed north of 43° N latitude to the U.S.-Canada border, were used in this assessment. The number of tows with length data ranged from 19 in 2000 to 48 in 1996 (Table 9). Because a large number of positive tows occurred in 1996, it was decided to include that year, which surveyed from 43° N latitude to the U.S.-Canada border. Therefore, only tows from 43° N latitude to the U.S.-Canada border were used.

An index of abundance was estimated based on the data using the VAST delta-GLMM model. The estimated index of abundance is shown in Table 4. The lognormal distribution with random strata-year had the lowest AIC and was chosen as the final model. The Q-Q plot does not show any departures from the assumed distribution (Figure 10). The trend in the indices was generally flat over time.

Length compositions were available for each year the survey was conducted. No age data were available from this survey. The expanded length frequencies from this survey were generally of larger fish ($>$ 30 cm), expect for 1997 where the highest frequency of fish were between 20 and 30 cm for both females and males (Figure 11).

2.1.4 Triennial Bottom Trawl Survey

`triennial-bottom-trawl-survey`

The triennial survey was first conducted by the AFSC in 1977 and spanned the time-frame from 1977-2004. The survey's design and sampling methods are most recently described in (Weinberg et al. 2002). Its basic design was a series of equally-spaced transects from which searches for tows in a specific depth range were initiated. The survey design has changed slightly over the period of time. In general, all of the surveys were conducted in the mid-summer through early fall: the 1977 survey was conducted from early July through late September; the surveys from 1980 through 1989 ran from mid-July to late September; the 1992 survey spanned from mid-July through early October; the 1995 survey was conducted from early June to late August; the 1998 survey ran from early June through early August; and the 2001 and 2004 surveys were conducted in May-July.

Haul depths ranged from 91-457 m during the 1977 survey with no hauls shallower than 91 m. The surveys in 1980, 1983, and 1986 covered the West Coast south to 36.8° N latitude and a depth range of 55-366 meters. The surveys in 1989 and 1992 covered the same depth range but extended the southern range to 34.5° N (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55-500 meters and surveyed south to 34.5° N. In the final year of the triennial series (2004), the NWFSC's Fishery Resource and Monitoring division (FRAM) conducted the survey and followed very similar protocols as the AFSC.

Given the different depths surveyed during 1977, the data from that year were not included in this assessment. Water hauls (Zimmermann et al. 2003) and tows located in Canadian waters were also excluded from the analysis of this survey. The data was examined for varying distribution of length and/or ages of fish based upon the shift in survey timing and little evidence was found of ontogenetic shifts in Pacific ocean perch during the summer months.Pacific ocean perch are rarely encountered south of 40^circ where the change in southern range of the survey would have no impact on data collected regarding Pacific ocean perch. Given these factors the Triennial survey was analyzed as a single time-series a departure from how the previous assessment which split the time-series into and an early (1980-1992) and a late period (1995-2004).

An index of abundance was estimated based on the data using the VAST delta-GLMM model. The estimated index of abundance is shown in Table 4. The lognormal distribution with random strata-year had the lowest AIC and was chosen as the final model. The Q-Q plot does not show any departures from the assumed distribution (Figure 12). The index shows a decline in abundance in the early years of the time-series and abundance remaining flat for the latter years.

Length and age compositions were expanded based upon the stratification. The number of tows with length data ranged from 17 in 1986 to 81 in 1998 10. Ages were read using surface reading methods until 1989 when the break-and-burn method replaced surface reads as the best method to age Pacific ocean perch. Unfortunately, surface reading of Pacific ocean perch otoliths results in significant underestimates of age. Due to this, these otolith were excluded from analysis. The available ages from the Triennial survey and the number of tows where otoliths were collected are shown in Table 11. The expanded length frequencies from this survey show an increase in small fish starting in 1995 (Figure 13). The age frequencies provide clear evidence of large year-classes moving through the population from the 1999 and 2000 recruitment (Figure 14).

2.1.5 Pacific ocean perch Survey

`pacific-ocean-perch-survey`

A survey targeted designed to sample Pacific ocean perch was conducted in 1979 and again in 1985 (for a detailed description see (Ianelli et al. 1992). An index of abundance was estimated based on the data using the VAST delta-GLMM model. The estimated index of abundance is shown in Table 4. The lognormal distribution with random strata-year had the lowest AIC and was chosen as the final model. The Q-Q plot does not show any departures from the assumed distribution (Figure 15). The index shows a clear decline in abundance between the two survey years.

Length and age compositions were expanded based on the stratification. The survey had 125 and 126 Pacific ocean perch tows (Table 12) and ages were only available in 1985 due to surface reads for the 1979 data (Table 13). The length frequencies for both years are highest between the 30-45 cm range (Figure 16) with ages in 1985 having a large number of fish age 40 and greater (Figure 17).

2.2 Fishery-Dependent Data

`fishery-dependent-data`

2.2.1 Commercial Fishery Landings

`commercial-fishery-landings`

Washington

Historical commercial fishery landings of Pacific ocean perch from Washington for the years 1918-2016 were obtained from Theresa Tsou (WDFW) and Phillip Weyland (WDFW). This assessment is the first Pacific ocean perch assessment to include a state provide historical catch reconstruction and hence, the historical catches for Washington vary markedly from those used in the 2011 assessment. Due to Recent landings (1981-2016) were obtained directly from Washington state rather than from PacFIN (Pacific Fisheries Information Network (PacFIN) due to identified missing catches not available within PacFIN for Pacific ocean perch.

Oregon

Historical commercial fishery landings of Pacific ocean perch from Oregon for the years 1892-1986 were obtained from Alison Dauble (ODFW). A description of the methods can be found in Karnowski et al. (2014). Recent landings (1987-2016) were obtained from PacFIN retrieval dated May 2, 2017}, Pacific States Marine Fisheries Commission, Portland, Oregon; www.psmfc.org). The catch data in from the POP and POP2 categories contained within PacFIN for Pacific ocean perch were used for this assessment. Additional catches from 1987-1999 for Pacific ocean perch under the UROCK category not yet available in PacFIN were received directly from the state and combined with the catch data available for that period within PacFIN.

California

Historical commercial fishery landings of Pacific ocean perch were obtained directly from John Field at the SWFSC due to database issues for the historical period for the California Cooperative Groundfish Survey, also known as CALCOM (128.114.3.187) for the years 1916-1980. A description of the methods can be found in (Ralston et al. 2010). Recent landings (1981-2016) were obtained from PacFIN (Pacific Fisheries Information Network (PacFIN) retrieval dated May 2, 2017, Pacific States Marine Fisheries Commission, Portland, Oregon; www.psmfc.org).

At-Sea Hake Fishery

Catches of Pacific ocean perch are monitored aboard the vessel by observers in the At-Sea hake Observer program (ASHOP) and were available for the years of 1975-2016. Observers use a spatial sample design, based on weight, to randomly choose a portion of the haul to sample for species composition. For the last decade, this is typically 30-50% of the total weight. The total weight of the sample is determined by all catch passing over a flow scale. All species other than hake are removed and weighed, by species, on a motion compensated flatbed scale. Observers record the weights of all non-hake species. Non-hake species total weights are expanded in the database by using the proportion of the haul sampled to the total weight of the haul. The catches of non-hake species in unsampled hauls is determined using bycatch rates determined from sampled hauls. Since 2001, more than 97% of the hauls have been observed and sampled.

Foreign Catches

From the 1960s through the early 1970s, foreign trawling enterprises harvested considerable amounts of rockfish off Washington and Oregon, and along with the domestic trawling fleet, landed large quantities of Pacific ocean perch. Foreign catches of individual species were estimated by Rogers (2003) and attributed to INPFC areas for the years of 1966-1976 for Pacific ocean perch. The foreign catches were combined across areas for a coastwide removal total.

2.2.2 Discards

discards

Data on discards of Pacific ocean perch are available from two different data sources. The earliest source is called the Pikitch data and comes from a study organized by Ellen Pikitch that collected trawl discards from 1985-1987 (Pikitch et al. 1988). The northern and southern boundaries of the study were 48°42′ N latitude and 42°60′ N. latitude respectively, which is primarily within the Columbia INPFC area (Pikitch et al. 1988 , Rogers and Pikitch 1992). Participation in the study was voluntary and included vessels using bottom, midwater, and shrimp trawl gears. Observers of normal fishing operations on commercial vessels collected the data, estimated the total weight of the catch by tow and recorded the weight of species retained and discarded in the sample. Results of the Pikitch data were obtained from John Wallace (pers comm, NWFSC, NOAA) in the form of ratios of discard weight to retained weight of Pacific ocean perch and sex-specific length frequencies. Discard estimates are shown in Table 14.

The second source is from the West Coast Groundfish Observer Program (WCGOP). This program is part of the NWFSC and has been recording discard observations since 2003. Table 14 shows the discard ratios (discarded/(discarded + retained)) of Pacific ocean perch from the WCGOP. Since 2011, when the trawl rationalization program was implemented, observer coverage rates increased to nearly 100% for all the limited entry trawl vessels in the program and discard rates declined compared to pre-2011 rates. Discard rates were obtained for both the catch-share and the non-catch share sector for Pacific ocean perch. A single discard rate was calculated by weighting discard rates based on the commercial landings by each sector. Coeffienct of variations were calculated by bootstrapping vessels within ports because the observer program randomly chooses vessels within porats to be observed in the non-catch shares sectors. Discard length composition for the trawl fleet varied by year, with larger fish being discarded prior to 2011 (Figure 18).

2.2.3 Historical Commercial Catch-per-unit effort

historical-commercial-catch-per-unit-effort

Data on catch-per-unit-effort (CPUE) in mt/hr from the domestic fishery were combined for the INPFC Vancouver and Columbia areas (Table 15, from Gunderson (1977)). Although these data reflect catch rates for the US fleet, the highest catch rates coincided with the beginning of removals by the foreign fleet. This suggest that, barring unaccounted changes in fishing efficiency during this period, the level of abundance was high at that time. A CV of 0.40 was used in this assessment to be consistent with the CV observed in the survey data.

2.2.4 Fishery Length And Age Data

fishery-length-and-age-data

Biological data from commercial fisheries that caught Pacific ocean perch were extracted from PacFIN (PFSMFC) on May 4, 2017. Lengths taken during port sampling in Oregon and Washington were used to calculate length and age compositions. There were no biological data for Pacific ocean perch available within PacFIN. The overwhelming majority of these data were collected from the mid-water and bottom trawl gear, but additional biological data were collected from non-trawl gear which was grouped together with trawl gear data. Tables

16 and 17 show the number of trips and fish sampled, along with the calculated sample sizes. Length and age data were acquired at the trip level, and then aggregated to the state level. The sample sizes were calculated via the Stewart Method (Ian Stewart, pers comm, IPHC) which for commercial fishery data is:

$$\text{Input effN} = N_{\text{trips}} + 0.138 * N_{\text{fish}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is} < 44$$

$$\text{Input effN} = 7.06 * N_{\text{trips}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is} \geq 44$$

2.3 Biological Data

`biological-data`

2.3.1 Natural mortality

`natural-mortality`

Historic Pacific ocean perch ages determined using scales and surface reading methods of otoliths, resulted in estimates of natural mortality (M) of between 0.10 and 0.20yr^{-1} with a longevity less than 30 years(Gunderson 1977). Based on break-and-burn method of age determination using otoliths, the maximum age of Pacific ocean perch was revised to be 90 years (Chilton and Beamish 1982). The updated understanding concerning Pacific ocean perch longevity reduced the estimate of natural mortality based on Hoenig's (1983) relationship to 0.059yr^{-1}. The previous assessment applied a prior distribution on natural mortality based upon multiple life history correlates (including Hoenig's method, Gunderson gonadosomatic index (1997), and McCoy and Gillooly's (2008) theoretical relationship) developed separately for female and male Pacific ocean perch.

Hamel (2015) developed a method for combining meta-analytic approaches to relating the natural mortality rate M to other life-history parameters such as longevity, size, growth rate and reproductive effort, to provide a prior on M. In that same issue of ICESJMS, Then et al. (2015), provided an updated data set of estimates of M and related life history parameters across a large number of fish species, from which to develop an M estimator for fish species in general. They concluded by recommending M estimates be based on maximum age alone, based on an updated Hoenig non-linear least squares (nls) estimator M=4.899A_max^(-.916). The approach of basing M priors on maximum age alone was one that was already being used for West Coast rockfish assessments. However, in fitting the alternative model forms relating M to $A_{\max}$, Then et al. (2015) did not consistently apply their transformation. In particular, in real space, one would expect substantial heteroscedasticity in both the observation and process error associated with the observed relationship of M to $A_{\max}$. Therefore, it would be reasonable to fit all models under a log transformation. This was not done. Revaluating the data used in Then et al. (2015) by fitting the one-parameter $A_{\max}$ model under a log-log transformation (such that the slope is forced to be -1 in the transformed space (Hamel 2015)), the point estimate for M is:

$$M = \frac{5.4}{A_{\max}}$$

The above is also the median of the prior. The prior is defined as a lognormal with mean $ln(\frac{5.4}{A_{\max}})$ and SE = 0.4384343. Using a maximum age of 100 the point estimate and median of the prior is 0.054. The maximum age was selected based on available age data from all West Coast data sources. The oldest aged rockfish was 120 years, captured by the commercial fishery in 2007. However, age data are subject to ageing error which could impact this estimate of longevity. The selection of 100 years was based on the range of other ages available with had multiple observations of fish between 90 and 102 years of age.

2.3.2 Sex ratio, maturation, and fecundity

sex-ratio-maturation-and-fecundity

Examining all biological data sources, the sex ratio of young fish are within 5% of 1:1 by either length or age (Figures 23 and 24), and hence this assessment the sex ratio at birth was assumed to be 1:1. This assessment assumed a logistic maturity-at-length curve based on analysis of 537 fish maturity samples collected from the NWFSC shelf-slope survey. This is revised from the previous assessment which assumed maturity-at-age based on the work of Hannah and Parker (Hannah and Parker 2007). Additionally, the new maturity-at-length curve is based on the estimate of functional maturity an approach that classifies rockfish maturity with developing oocytes as mature or immature based on the proportion of vitellogenin in the cytoplasm and the measured frequency of atretic cells (M. Head, pers comm, NWFSC, NOAA). The 50% size-at-maturity was estimated at 32.1 cm with maturity asymptoting to one for larger fish (Figure 25). Comparison between the maturity-at-age used in the previous assessment and the updated functional maturity-at-length is shown in Figure 26.

The fecundity-at-age has also been updated from the previous assessment based on new research. Dick (2017) estimated new fecundity relationships for select West Coast stocks where fecundity for Pacific ocean perch was estimated equal to 8.66e-10$L^{4.98}$ in millions of eggs. Spawning output at length is shown in Figure 27.

2.3.3 Length-weight relationship

length-weight-relationship

The length-weight relationship for Pacific ocean perch was estimated outside the model using all biological data available from fishery and fishery-independent data sources where the female weight-at-length in grams was estimated at 1.044e-05$L^{3.09}$ and males at 1.05e-05$L^{3.08}$ where L is length in cm (Figures 28 and 29).

2.3.4 Growth (length-at-age)

growth-length-at-age

The length-at-age was estimated for male and female Pacific ocean perch using data collected from both fishery-dependent and -independent data sources that were collected from 1981-2016. Figure 30 shows the lengths and ages for all years and all data as well as predicted von Bertalanffy fits to the data. Females grow larger than males and sex specific growth parameters were estimated at the following values:

$$\text{Females } L_{\infty} = 42.32;\ k = 0.169;\ t_0 = \text{-}1.466$$

$$\text{Males } L_{\infty} = 39.03;\ k = 0.212;\ t_0 = \text{-}1.02$$

2.3.5 Ageing Precision And Bias

ageing-precision-and-bias

Uncertainty surrounding the ageing-error process for Pacific ocean perch was incorporated by estimating ageing error by age. Age-composition data used in the model were from break-and-burn otolith reads aged by the Cooperative Ageing Project (CAP) in Newport, Oregon. Break-and-burn double reads of more than 1500 otoliths were provided by the CAP lab. An ageing error estimate was made based on these double reads using a computational tool specifically developed for estimating ageing error (Punt et al. 2008), and using release 1.0.0 of the R package nwfscAgeingError (Thorson et al. 2012) for input and output diagnostics, publicly available at: https://github.com/nwfsc-assess/nwfscAgeingError. A non-linear standard error was estimated by age where there is more variability in the estimated age of older fish was estimated (Table 20, Figure 31).

2.4 History Of Modeling Approaches Used For This Stock

history-of-modeling-approaches-used-for-this-stock

2.4.1 Previous Assessments

previous-assessments

The status of Pacific ocean perch off British Columbia, Washington, and Oregon have been periodically assessed since the intensive exploitation that occured in the 1960s. Concerns regarding Pacific ocean perch status off the coast the US west coast were raised in the late 1970s (Gunderson 1978, Gunderson (1981)) and in 1981 the PFMC adopted a 20-year plan to rebuild the stock.

The 1992 assessment determined that Pacific ocean perch remained at low levels relative to the population size in 1960 (Ianelli et al. 1992) and recommended additional harvest restrictions to allow for stock rebuilding. The 1998 assessment (Ianelli and Zimmermann 1998) estimated that the stock was 13% of the unfished level, leading the National Marine Fishery Service (NMFS) to declare the stock overfished in 1999. The formal rebuilding plan was implemented in 2001. The rebuilding plan reduced the SPR harvest rate used to determine catches to 0.864, relative to the PFMC rockfish default harvest (SPR = 0.50). The last full assessment of Pacific ocean perch was conducted in 2011 (Hamel and Ono 2011) which concluded that the stock was still well below the target biomass of $0.40SB_0$ estimating the relative stock status at 19.1%.

2.4.2 Previous Assessment Recommendations

previous-assessment-recommendations

Recommendation: Considering trans-boundary stock effects should be pursued. In particular the consequences of having spawning contributions from external stock components should be evaluated relative to the steepness estimates obtained in the present assessment (see more complete discussion of this recommendation under the Unresolved Problems and Major Uncertainties section, above).

STAT response: The STAT team agrees that this should be an ongoing area of research and collaboration between the US and Canada. This assessment presents a sensitivity where the inclusion of Canadian data are included within the model.

Recommendation:The benefits of adopting the complex model used this year should be evaluated relative to simpler assumptions and models. While the transition from the simpler old model to Stock Synthesis was shown to be similar for the historical period, the depletion estimates in the most recent years were different enough to warrant further investigation.

STAT response: This assessment was performed in Stock Synthesis, an integrated model, which can be modified to either simple or complex structural forms based upon the available data and the processes being modeled. There were not addtional explorations of alternative modeling platforms.

Recommendation:Discard estimates from observer programs should be presented, reviewed (similar to the catch reconstructions), and be made available to the assessment process.

STAT response: This assessment uses discard rates and discard lengths collected by the WCGOP from 2003-2015.

Recommendation:The ability to allow different "plus groups" for specific data types should be evaluated (and implemented in Stock Synthesis). For example, this would provide the ability to use the biased surface-aged data in an appropriate way.

STAT response: Additional research needs to completed which evaluates the amount of bias and imprecision in surface-read ages. Evaluating avaiable surface-read ages within the PacFIN database fish of lengths between 23-44 cm can be aged at 10 years old. This large range of lengths at the same age indicates considerable bias in ages for fish surface-read younger aged fish.

Recommendation:Historical catch reconstruction estimates should be formally reviewed prior to being used in assessments and should be coordinated so that interactions between stocks are appropriately treated. The relative reliability of the catch estimates over time could provide an axis of uncertainty in future assessments.

STAT response: California and Oregon have ungone extensive work to create historical catch reconstructions. This is the first assessment for Pacific ocean perch which includes a Washington historical catch reconstruction. The data used in this assessment represent Washington *state's current best estimate for historical catches. Both California and Washington are conducting research to estimate uncertainty surround historical catches which could be used to propegate uncertainty within the assessment.*

3 Assessment

assessment

3.1 General Model Specifications and Assumptions

general-model-specifications-and-assumptions

Stock Synthesis v3.30.03.05 was used to estimate the parameters in the model. R4SS, revision 1.27.0, along with R version 3.3.2 were used to investigate and plot model fits. A summary of the data sources used in the model (details discussed above) is shown in Figure 2.

Stock Synthesis has many options when setting up a model and the assessment model for Pacific ocean perch was set up in the following manner.

3.1.1 Changes between the 2011 assessment model and current model

changes-between-the-2011-assessment-model-and-current-model

The current model for Pacific ocean perch has many made many similar assumptions to the 2011 assessment but differs in some key ways. This assessment disaggrated the fleets into a trawl/other gear, at-sea hake, historical foreign fleet, and research fleets. The previous assessment implemented a single fleet where removal from all sources were aggregated together. The seperating of fleets applied in this assessment allowed for differing assumptions regarding current and historical discarding practices. Although there are no compositional data available from the foreign fleet, it is assumed that very little discarding to no discarding of fish occured. Additionally, the at-sea hake fishery removals are represent both discarded and retained fish and hence an additional discard rate would not be appropriate. Similar logic was applied in regard to survey and research removals.

The historical landing used in the model differs from those used in 2011. The assessment includes the first state provided historical reconstruction landings for Washington state. The historical reconstruction provided Pacific ocean perch landing within Washington state starting in 1916 and have larger removals in the 1940s relative to those used in 2011 32. Given the increase in historical removals prior to 1940, the 2011 model starting year, the starting year for modeling the stock was revised to 1918, the first year Pacific ocean perch landings exceeded 1 mt, for this assessment. Explorations were conducted relative to the model starting year and no differences were found between the 1918 start year compared to starting the model in 1892, the first record of Pacific ocean perch landings between California, Oregon, and Washington catch data.

Selectivity in this model is assumed to be length-based and is modeled using double-normal for all fleets, expect the Pacific ocean perch survey which retained the previous assessment assumption of logistic selectivity. The previous assessment mirrored selectivity amont the Pacific ocean perch and both slope surveys (AFSC and NWFSC). This assessment allow for survey specific estimated double-normal selectivity.

All fishery-independent indices have been reevaluated for this assessment using a spatial-temporal delta generalized linear mixed model (VAST delta-GLMM) which is updated from 2011 which used a bayesian delta-GLMM which did not incorporate spatial effects. An additional update to the treatment of survey data was the decision to use the Triennial survey as a single time series ranging from 1980-2004. The previous assessment opted to split this survey into early and a late index of abundance based upon the change in southern sampling and a shift in survey timing. Northern California is considered to be the southern end of Pacific ocean perch West Coast distribution with rare encounters in central or southern California waters. The biological data from the Triennial survey showed no discernable ontogenetic shifts in Pacific ocean perch during the early or late period of summer samples. Based upon these investigations, the Triennial survey was retained as a single index of abundance.

Maturity and fecundity were updated for this assessment based upon new research. Fecundity for Pacific ocean perch used in this assessment was base on reevaluation of the fecundity of West Coast rockfish by Dick et al. (2017) updating the previous fecundity estimates used in the 2011 assessment (Dick 2009) (Figure 27). Maturity in this assessment was based on examination of 537 fish samples which were used to estimate functional maturity, an approach that classifies rockfish maturity with developing oocytes as mature or immature based on the proportion of vitellogenin in the cytoplasm and the measured frequency of atretic cells (M. Head, pers comm, NWFSC, NOAA). The updated maturity curve was based on maturity-at-length where the previous estimates used in 2011 were based on maturity-at-age (Figure 26).

In this assessment, the beta prior developed from a meta-analysis of West Coast groundfish was updated to the 2017 value (J. Thorson, pers comm, NWFSC, NOAA) in preliminary models, with steepness fixed in the final base model. Additionally, the prior for natural mortality was updated base on analysis conducted by Owen Hamel (pers comm, NWFSC, NOAA), where female natural mortality was fixed at the prior median with males estimated as an offset from the female value.

3.1.2 Summary of Fleets and Areas

`summary-of-fleets-and-areas`

Pacific ocean perch are most frequently observed in Oregon and Washington waters, however, they are observed along the entire US West Coast in survey and fishery observations. Multiple fisheries encounter Pacific ocean perch. Trawl, fixed gear, and the at-sea (mid-water) hake fisheries account for the majority of the Pacific ocean perch landings both historically and currently.

The majoirty of removals of Pacific ocean perch were observed by eht bottom trawl fishery with fixed gear accounting for a small fraction of the catches avaiable within PacFIN. Trawl and fixed gears were combined into a coast-wide fleet. For the period from 1918 to the early 1990s, prior to the introduction of trip limits for rockfish, limited discarding of Pacific ocean perch was assumed. Observations of Pacific ocean perch in the Pikitch et al. (1988) data (1986-1987) allowed for a formal analysis of discard rates which were applied to the historical period of the fishery. Foreign trawl catches (1966-1976) was modeled as a single fleet. The at-sea fishery operates as a mid-water fishery targeting Pacific whiting but encounters Pacific ocean perch as a bycatch species. This fleet was also modeled as a single fleet.

3.1.3 Other Specifications

other-specifications

The specifications of the assessment are listed in Table 21. The model is a two-sex, age-structured model starting in 1918 with an accumulated age group at 60 years. Growth was estimated and natural mortality was fixed at the median of the prior. The lengths in the population were tracked by 1 cm intervals and the length data were binned into 1 cm intervals. A curvilinear ageing imprecision relationship was estimated and used to model ageing error. Fecundity-at-length was defined fixed at the values from Dick et al. (2017) for Pacific ocean perch and spawning output was defined in millions of eggs.

The Triennial survey was kept as a single series. Assessment of other groundfish have split this survey into an early and a late series, based mostly on the shift to deeper depths and the timing of the survey, by estimating different catchability parameters and selectivity parameters for each period. Age data were available for the commercial and at-sea hake fishery, as well as the Triennial, the Pacific ocean perch, the NWFSC slope, and the NWFSC shelf-slope survies. The ages from the NWFSC shelf-slope survey and were entered into the model as conditional age-at-length. Length-frequencies were calculated for the Triennial, Pacific ocean perch, AFSC slope, NWFSC slope, and the NWFSC shelf-slope surveys within each stratum, and then combined across strata using the biomass in each stratum as the weighting factor. This reduced the influence of a few fish observed in a large area.

The specification of when to estimate recruitment deviations is an assumption that likely affects model uncertainty. It was decided to estimate recruitment deviations from 1900-2014 to appropriately quantify uncertainty. The earliest length-composition data occur in 1966 and the earliest age data were in 1981. The most informed years for estimating recruitment deviations were from about the mid-1970s to about 2011. The period from 1900-1974 was fit using an early series with little or no bias adjustment, the main period of recruitment deviates occurred from 1975-2014 with an upward and downward ramping of bias adjustment, and 2015 onward was fit using forecast recruitment deviates with little bias adjustment. Methot and Taylor (2011) summarize the reasoning behind varying levels of bias adjustment based on the information available to estimate the deviates. Recruitment deviation was assumed to be 0.70.

The recommended selectivity type in Stock Synthesis is the double normal and was used in this assessment for the all fleets, except the Pacific ocean perch survey which was assumed logistic based on the length composition data. Changes in retention curves were estimated for the commercial fishery.

Time blocks for the bottom trawl, midwater trawl, and hook-and-line fishery are provided in Table 21. Fishery selectivity retention has changed over the modeled period due to management changes. The time block on the retention curves for the trawl fishery were set from 1918-1991, 1992-2001, 2002-2007, 2008, 2009-2010, 2011-2016 based on available discarding data and changes in trip limits that likely resulted in changes to discarding patterns of Pacific ocean perch. No discarding was assumed in the at-sea hake and the foreign fisheries.

The following distributions were assumed for data fitting. Survey indices were lognormal, total discards were lognormal.

3.1.4 Modeling Software

`modeling-software`

The STAT team used Stock Synthesis version 3.30.03.05 by Dr. Richard Methot at the NWFSC (Methot and Wetzel 2013). This most recent version was used, since it included improvements and corrections to older versions. The previous assessment of Pacific ocean perch also used Stock Synthesis but a earlier version, 3.24, model bridging was performed between both version of Stock Synthesis and are shown in Figure 33.

3.1.5 Priors

`priors`

A prior distribution was developed for the natural mortality parameter from an analysis of a maximum age of 100 years. The analysis was performed by Owen Hamel (pers comm, NWFSC, NOAA) and used data from Then et al. (2015) to provide a lognormal distribution for natural mortality. The median of the lognormal prior is 0.054 and has a standard error of 0.4384343.

The prior for steepness (h) assumes a beta distribution with parameters based on an update of the Dorn rockfish prior (commonly used in past West Coast rockfish assessments) conducted by J. Thorson (pers comm, NWFSC, NOAA) which was reviewed and endorsed by the SSC in 2017. The prior is a beta distribution with μ=0.72 and σ=0.15. However, fixing steepness within the model resulted in unrealistic relative biomass levels (> 1), it was also decided to fix steepness at 0.50. The previous assessment estimated and fixed steepness equal to 0.40. The current data does not contain information regarding steepness and 0.50 was selected as an intermediate value between the prior and the previous assessment value. The steepness value of 0.50 was contained within the estimated uncertainty envelope from the assessment model when either the prior value of 0.72 or 0.40 values were assumed.

3.1.6 Data Weighting

data-weighting

The base case was weighted such that the various data sources were mostly consistent with each other in terms of the relationship between input and effective sample sizes. Length and age-at-length compositions from the NWFSC shelf-slope survey were fit along with length and marginal age compositions from the fishery fleets. Length data started with a sample size determined from the equation listed in Section 2.2.4 and 2.1.1. Age-at-length data assumed that each age was a random sample within the length bin and started with a sample size equal to the number of fish in that length bin. However, the 2016 NWFSC shelf-slope age-at-length data was variable compared to previous years for both males and females relative to all other years with observed fish being smaller at age. Due to the increased variability within this data year, the effective sample size for this year was reduced to 50% of the number of fish within each length-age bin.

One extra variability parameter that was added to the input variance was estimated for the Triennial and the NWFSC shelf-slope survey indices. Vessels present in the WCGOP data were bootstrapped to provide uncertainty of the total discards (Table 14).

The base case assessment model was weighted based on the "Francis method", which was based on equation TA1.8 in Francis (2011). This formulation looks at the mean length or age and the variance of the mean to determine if across years, the variability is explained by the model. If the variability around the mean does not encompass the model predictions, then that data source should be down-weighted. This method does account for correlation in the data (i.e., the multinomial distribution) as opposed to the McAllister and Ianelli (1997) method of looking at the difference between individual observations and predictions.

3.1.7 Estimated And Fixed Parameters

estimated-and-fixed-parameters

There were 164 estimated parameters in the base case model. These included one parameter for R_0, 8 parameters for growth, 2 parameters for extra variability on the Triennial and NWFSC shelf-slope surveys indices, 24 parameters for selectivity, retention, and time blocking of the fleets and the surveys, 117 recruitment deviations, and 12 forecast recruitment deviations (Table 23).

Fixed parameters in the model were as follows. Steepness was fixed at 0.50. A sensitivity analysis and a likelihood profile were done for steepness. Natural mortality was fixed at 0.054 for females and males, which is the median of the prior. The standard deviation of recruitment deviates was fixed at 0.70. Maturity at age was fixed as described in Section 2.3.2. Length-weight parameters were fixed at estimates using all length-weight observations (Figure 29).

Dome-shaped selectivity was explored for both the fishery and the surveys. Older Pacific ocean perch are often found in deeper waters and may move into areas that limit their availability to fishing gear, especially trawl gear. Domed shape selectivity was assumed for the fishery fleet and the Triennial survey. The final base model assumed asymptotic selectivity for the at-sea hake fishery, and all other surveys.

3.2 Model Selection and Evaluation

model-selection-and-evaluation

The base case assessment model for Pacific ocean perch was developed to balance parsimony and realism, and the goal was to estimate a biomass trajectory for the population of Pacific ocean perch on the west coast of the United States. The model contains many assumptions to achieve parsimony and uses many different sources of data to estimate reality. A series of investigative model runs were done to achieve the final base case model.

3.2.1 Key Assumptions and Structural Choices

key-assumptions-and-structural-choices

The key assumptions in the model were that the assessed population is a single stock with biological parameters characterizing the entire coast, maturity at age has remained constant over the period modeled, weight-at-length has remained constant over the period modeled, the standard deviation in recruitment deviation is 0.70, and steepness is 0.50. These are simplifying assumptions that unfortunately cannot be verified or disproven. Sensitivity analyses were conducted for most of these assumptions to determine their effect on the results.

Structurally, the model assumed that the catches from each fleet were representative of the coastwide population, instead of specific areas, and fishing mortality prior to 1918 was negligible. It also assumed that discards were low prior to 1992 and after 2010.

3.2.2 Alternate Models Considered

alternate-models-considered

The exploration of models began by bridging from the 2011 assessment to SS version 3.24U, which produced no discernable difference. The updated catch series with discards added per the 2011 assessment produced insignificant differences in the relative scale of the population although the updated historical removals resulted in an increase in the estimate of unfished biomass. Updating the survey indices produced small differences in the relative scale of the population. Adding age and length data each resulted in less of a population decline from the 1970s to pre-2000, resulting in an increase in the estimated final stock status as of 2017. However, the addition of new data resulted in an early pattern within recruitment, indicating that the assumptions within the previous model may not represent the best fit to the current data.

This assessment estimated discards in the model, so time was spent investigating time blocks for changes in selectivity and retention to match the limited discard data as best as possible. Using major changes in management and observed changes in landings, a set of blocks for retention was found for the bottom trawl fleets. In the spirit of parsimony, we used as few blocks as possible, allowed blocks only for time periods with data, and added new blocks when we felt they were justified by changes in management and they improved the fit to the data.

Natural mortality was also investigated and a new prior was developed assuming a maximum age of 100 years for females and males. The previous assessment estimated male natural mortality as an offset from female natural mortality which was fixed at the median of the 2011 prior. This assessment attempted to estimate natural mortality for both sexes using the 2017 updated prior, but there was little to no information on natural mortality within the data and hence opted to fix the value for females. Upon additional exploration, the model estimated very little difference in male natural mortality relative to females (< 0.002) and in the interest of selecting the model that fit the data with the fewest parameters required, males were fixed equal to the female natural mortality.

Finally, multiple models were investigated where steepness either estimated, fixed at the prior, or at an alternate value. The assessment in 2011 determined that there was sufficient information concerning steepness where the parameter was estimated and then fixed at 0.40. Based upon likelihood profiles performed on the current assessment, there was no longer support for a steepness value of 0.40 and the likelihood profile was flat across various levels of steepness with a very small improvement in likelihood (<0.50 log likelihood units) at the lowest steepness values. Estimating steepness starting at the median of the "type C" prior, the meta-analysis prior evaluated omitting information from Pacific ocean perch, of 0.76 resulted in very little if any movement from the median value due to the flat likelihood surface across values for this parameter with final relative stock status for 2017 being estimated to $> 100\%$ of unfished biomass. Fixing steepness at the median of the prior of 0.72 resulted in relative stock status estimates for 2017 at 98.6% of unfished biomass. It was determined that the resulting stock status estimates when steepness was fixed at the meta-analysis prior were overly optomistic and unrealistic given the biology and historical exploitation of Pacific ocean perch.

3.2.3 Convergence

`convergence`

Proper convergence was determined by starting the minimization process from dispersed values of the maximum likelihood estimates to determine if the model found a better minimum. This was repeated 100 times and a better minimum was not found (Table 22). The model did not experience convergence issues when provided reasonable starting values. Through the jittering done as explained above and likelihood profiles, we are confident that the base case as presented represents the best fit to the data given the assumptions made. There were no difficulties in inverting the Hessian to obtain estimates of variability, although much of the early model investigation was done without attempting to estimate a Hessian.

3.3 Response To The Current STAR Panel Requests

response-to-the-current-star-panel-requests

Request No. 1: Add after STAR panel.

Rationale: Add after STAR panel.

STAT Response: Add after STAR panel.

Request No. 2: Add after STAR panel.

Rationale: Add after STAR panel.

STAT Response: Add after STAR panel.

Request No. 3: Add after STAR panel.

Rationale: Add after STAR panel.

STAT Response: Add after STAR panel.

Request No. 4: Example of a request that may have a list:

- **Item No. 1**
- **Item No. 2**
- **Item No. 3, etc.**

3.4 Base Model Results

base-model-results

The base model parameter estimates along with approximate asymptotic standard errors are shown in Table 23 and the likelihood components are shown in Table 24. Estimates of key derived parameters and approximate 95% asymptotic confidence intervals are shown in Table 25.

3.4.1 Parameter Estimates

parameter-estimates

3.4.2 Uncertainty and Sensitivity Analyses

uncertainty-and-sensitivity-analyses

A number of sensitivity analyses were conducted, including:

1. Data weighting according to the harmonic mean.

2. Fixed steepness at the prior value of 0.72.

3. Estimate natural mortality for female and male Pacific ocean perch.

4. Maturity relationship used in the previous assessment.

5. Fecundity relationship used in the previous assessment.

6. Split the Triennial survey into two time-series, early (1980-1995) and late (1998-2004).

7. Remove the historical commercial CPUE index.

8. Inclusion of available Canadian fishery and survey data (does not constitute all data used in Canadian assessments).

9. Inclusion of historical Washington research lengths.

10. Inclusion of Oregon special projects length and age data which are sampled at the dockside of processing facilities.

Likelihood values and estimates of key paramters from each sensitivity are available in Tables 26 and 27. Plots of the estimated time-series of spawning output and relative biomass are shown in Figures 111, 112, 113, and 114.

The sensitivities which explored steepness or natural mortality had the largest change in estimated stock status relative to the base model. Fixing steepness at the prior value resulted in the stock being near unfished spawning biomass output. When natural mortality was esimated the esimated values were higher relative to the median of the prior used in base model, resulting in the relative biomass to be > 93%.

Including additional data from either Canada, Washington research lengths, and or Oregon special projects data resulted in estimated lower stock status relative to the base model. However, the status was still well above the management target.

Weighting the data according to the harmonic means resulted in the largest decrease in the estimated stock status relative to the base model with the stock being estimated at 68% of unfished biomass.

3.4.3 Retrospective Analysis

retrospective-analysis

A 5-year retrospective analysis was conducted by running the model using data only through 2011, 2012, 2013, 2014, and 2015, progressively (Figure 115 and 116). The initial scale of the spawning population was basically unchanged for all of these retrospectives. The estimation of the 2008 recruitment deviation decreased as more data was removed. Overall, no alarming trends were present in the retrospective analysis.

A look at past assessments shows that the prediction of spawning biomass has generally increased with each assessment (Figure 78). This assessment (2015) predicts the largest spawning biomass. All assessments show similar trends.

3.4.4 Likelihood Profiles

likelihood-profiles

Likelihood profiles were conducted for R_0, steepness, and over natural mortality values seperately. These likelihood profiles were conducted by fixing the parameter at specific values and estimated the remaining parameters based on the fixed parameter value.

For steepness, the negative log-likelihood was minimized at a steepness of 0.30, but the 95% confidence interval extends over the entire range of possible steepness values (excluding 0.20) (Figure 117). Likelihood components by data source show that the fishery length and age data supports a low steepness value, but the NWFSC shelf-slope age data supports a higher value for steepness. The Triennial survey index indicates a low value of steepness while the other surveys do not provide information concerning steepness. The relative biomass for Pacific ocean perch has a wide range across different assumed values of steepness (Figure 118).

The negative log-likelihood was minimized at a natural mortality value of 0.06, but the 95% confidence interval extends over the majority of natural moratility values. The age and length data likelihood contribution was minimized at natural morality values ranging from 0.055-0.06 (Figure 119). The relative biomass for Pacific ocean perch widely varied across alternative values of natural mortality (Figure 120).

In regards to values of R_0, the negative log-likehood was minimized at approximately $\log(R_0)$ of 9.30 (Figure 121. The fishery and survey composition data was in opposition regarding values of R_0 where the fishery legnth and age data indicated lower values or R_0 while the survey ages from the Pacific ocean perch and the NWFSC shelf-slope surveys indicated a higher value.

3.4.5 Reference Points

reference-points-1

Reference points were calculated using the estimated selectivities and catch distribution among fleets in the most recent year of the model (2016). Sustainable total yields (landings plus discards) were 1764.8 mt when using an $SPR_{50\%}$ reference harvest rate and with a 95% confidence interval of 'r 1264.8 - 2264.8 mt based on estimates of uncertainty. The spawning output equivalent to 40% of the unfished spawning output ($SB_{40\%}$) was 2653.2 millions of eggs. The recent catches (landings plus discards) have been below the point estimate of potential long-term yields calculated using an $SPR_{50\%}$ reference point and the population has been increasing over the last decade.

The predicted spawning biomass from the base model generally showed a sharp decline during the 1960s, steep increase above unfished equilibrium levels, followed by less of a decline until 2001 (Figure 39). Since 2001, the spawning biomass has been increasing due to small catches, and recently, above average recruitment. The 2017 spawning biomass relative to unfished equilibrium spawning biomass is above the target of 40% of unfished spawning biomass (Figure 40). The fishing intensity (relative 1-SPR) exceeded the current estimates of the harvest rate limit ($SPR_{50\%}$) throughout the 1960s as seen in Figure 122. Recent exploitation rates on Pacific ocean perch were predicted to be much less than target levels. In recent years, the stock has experienced exploitation rates that have been below the target level while the biomass level has remained above the target level.

Table 25 shows the full suite of estimated reference points for the base model and Figure 123 shows the equilibrium curve based on a steepness value fixed at 0.50.

4 Harvest Projections and Decision Tables

harvest-projections-and-decision-tables

A twelve year projection of the base model with catches equal to the estimated ACL for years 2019-2028 and a catch allocation equal to the percentages for each fleet over the period of 2014-2016 predicts an increase in the spawning output due to large 2008 cohort, with a slight downturn beginning in 2023 (Table 29).

Add additional projection post STAR based upon the decision table.

Table 30

5 Regional Management Considerations

regional-management-considerations

6 Research Needs

research-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 the 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 understanting regarding the steepness of 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 Ccast observations would help to define the connectivity between Pacific ocean perch north and south of the U.S.-Canada border.

7 Acknowledgments

`acknowledgments`

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We are very grateful to Patrick McDonald and the team of agers at CAP for their hard work reading numerous otoliths and availability to answer questions when needed. Beth Horness was always eager to help, quick to supply survey extractions, and answered numerous questions we had. Jason Jannot and Kayleigh Sommers assisted with data from the WCGOP and entertained our many questions. We would like to acknowledge our survey team and their dedication to improving the assessments we do. The assessment was greatly improved through the many discussions within the Population Ecology team in the FRAM division at the NWFSC.

8 Tables

tables

Table 1: Landings for each state (all gears combined), the At-Sea Hake fishery, the Foreign fleet, and research.

tab:Comm_Catch

Year	California	Oregon	Washington	At-Sea Hake	Foreign	Research
1892	0.0	0.1	0.0	0.0	0	0.0
1893	0.0	0.1	0.0	0.0	0	0.0
1894	0.0	0.1	0.0	0.0	0	0.0
1895	0.0	0.0	0.0	0.0	0	0.0
1896	0.0	0.0	0.0	0.0	0	0.0
1897	0.0	0.0	0.0	0.0	0	0.0
1898	0.0	0.0	0.0	0.0	0	0.0
1899	0.0	0.0	0.0	0.0	0	0.0
1900	0.0	0.0	0.0	0.0	0	0.0
1901	0.0	0.0	0.0	0.0	0	0.0
1902	0.0	0.0	0.0	0.0	0	0.0
1903	0.0	0.0	0.0	0.0	0	0.0
1904	0.0	0.0	0.0	0.0	0	0.0
1905	0.0	0.0	0.0	0.0	0	0.0
1906	0.0	0.0	0.0	0.0	0	0.0
1907	0.0	0.0	0.0	0.0	0	0.0
1908	0.0	0.0	0.1	0.0	0	0.0
1909	0.0	0.0	0.1	0.0	0	0.0
1910	0.0	0.0	0.1	0.0	0	0.0
1911	0.0	0.0	0.1	0.0	0	0.0
1912	0.0	0.0	0.0	0.0	0	0.0
1913	0.0	0.0	0.0	0.0	0	0.0
1914	0.0	0.0	0.0	0.0	0	0.0
1915	0.0	0.0	0.0	0.0	0	0.0
1916	0.0	0.0	0.4	0.0	0	0.0
1917	0.1	0.0	0.8	0.0	0	0.0
1918	0.1	0.0	1.1	0.0	0	0.0
1919	0.0	0.0	0.4	0.0	0	0.0
1920	0.0	0.0	0.3	0.0	0	0.0
1921	0.0	0.0	0.3	0.0	0	0.0
1922	0.0	0.0	0.1	0.0	0	0.0
1923	0.0	0.0	0.2	0.0	0	0.0
1924	0.1	0.0	0.5	0.0	0	0.0
1925	0.1	0.0	0.6	0.0	0	0.0
1926	0.1	0.0	1.0	0.0	0	0.0
1927	0.1	0.0	1.4	0.0	0	0.0
1928	0.1	0.1	1.2	0.0	0	0.0
1929	0.3	0.1	0.7	0.0	0	0.0
1930	0.2	0.1	0.9	0.0	0	0.0
1931	0.4	0.1	0.4	0.0	0	0.0

Year	California	Oregon	Washington	At-Sea Hake	Foreign	Research
1932	0.3	0.1	0.4	0.0	0	0.0
1933	0.6	0.1	0.5	0.0	0	0.0
1934	0.4	0.0	2.3	0.0	0	0.0
1935	0.4	0.1	7.7	0.0	0	0.0
1936	0.2	0.2	1.6	0.0	0	0.0
1937	0.5	0.4	2.0	0.0	0	0.0
1938	0.6	0.1	5.1	0.0	0	0.0
1939	0.9	0.4	8.7	0.0	0	0.0
1940	0.9	9.1	12.2	0.0	0	0.0
1941	1.3	14.0	13.6	0.0	0	0.0
1942	0.4	26.6	18.6	0.0	0	0.0
1943	1.0	94.3	453.6	0.0	0	0.0
1944	2.8	164.5	739.3	0.0	0	0.0
1945	6.7	247.1	1887.1	0.0	0	0.0
1946	7.3	193.2	845.9	0.0	0	0.0
1947	2.6	167.2	385.3	0.0	0	0.0
1948	3.9	177.8	491.1	0.0	0	0.0
1949	2.0	472.9	409.5	0.0	0	0.0
1950	1.5	690.1	675.7	0.0	0	0.0
1951	4.3	840.1	735.1	0.0	0	0.0
1952	2.9	2030.5	305.6	0.0	0	0.0
1953	145.6	1223.5	361.6	0.0	0	0.0
1954	123.2	1837.5	538.8	0.0	0	0.0
1955	48.8	1346.4	555.6	0.0	0	0.0
1956	3.8	2563.8	548.2	0.0	0	0.0
1957	1.6	2128.1	538.5	0.0	0	0.0
1958	2.9	1564.9	530.4	0.0	0	0.0
1959	1.5	892.6	337.0	0.0	0	0.0
1960	19.6	1358.8	928.1	0.0	0	0.0
1961	1.1	2061.9	1179.8	0.0	0	0.0
1962	0.6	2584.9	1725.2	0.0	0	0.0
1963	32.5	3693.9	2006.0	0.0	0	0.0
1964	46.1	4261.6	1770.7	0.0	0	0.0
1965	34.9	5627.8	1972.1	0.0	0	0.0
1966	5.2	1591.2	1725.5	0.0	15561	0.0
1967	17.8	354.7	1861.0	0.0	12357	0.0
1968	21.9	466.4	2501.2	0.0	6639	0.0
1969	8.4	422.3	1236.0	0.0	469	0.0
1970	8.7	507.4	1293.3	0.0	441	0.0
1971	12.2	290.4	673.6	0.0	902	0.0
1972	11.4	105.3	796.5	0.0	950	0.0
1973	11.9	121.2	713.1	0.0	1773	0.0
1974	15.7	136.7	641.8	0.0	1457	0.0
1975	11.4	181.3	413.9	62.3	496	0.0
1976	17.1	663.7	521.1	31.9	239	0.0

Year	California	Oregon	Washington	At-Sea Hake	Foreign	Research
1977	16.7	457.1	752.0	3.8	0	11.9
1978	42.5	498.7	1391.5	15.4	0	0.0
1979	136.7	735.9	581.4	15.1	0	34.5
1980	19.2	948.6	666.2	47.0	0	4.6
1981	10.8	929.7	390.3	15.4	0	0.0
1982	145.9	584.0	273.0	28.3	0	0.0
1983	102.0	1032.7	437.7	10.9	0	4.4
1984	47.6	750.4	815.7	2.3	0	0.9
1985	70.9	789.5	503.2	11.4	0	13.6
1986	52.8	676.5	588.9	19.8	0	1.4
1987	120.9	550.0	399.4	5.4	0	0.0
1988	75.4	749.8	509.8	4.5	0	0.5
1989	29.5	927.8	466.2	4.3	0	4.2
1990	18.3	567.8	427.2	80.9	0	0.0
1991	8.4	853.2	530.1	46.1	0	0.0
1992	15.3	623.4	435.2	373.3	0	4.9
1993	11.0	797.8	464.7	0.9	0	0.2
1994	6.7	626.4	352.0	83.8	0	0.0
1995	9.2	515.0	289.8	46.6	0	2.8
1996	18.4	531.1	236.7	6.3	0	1.2
1997	15.8	439.1	184.9	6.4	0	0.1
1998	21.6	436.7	172.4	22.3	0	3.8
1999	19.8	326.8	145.8	16.5	0	1.4
2000	6.8	95.1	33.0	10.1	0	0.6
2001	0.5	193.4	51.8	21.0	0	2.8
2002	0.8	107.0	39.5	3.9	0	0.3
2003	0.2	94.6	30.2	6.3	0	3.6
2004	2.1	97.7	22.3	1.1	0	2.5
2005	0.1	51.2	10.4	1.7	0	1.8
2006	0.2	52.2	15.8	3.1	0	1.2
2007	0.2	83.7	45.1	4.0	0	0.6
2008	0.4	58.6	16.6	15.9	0	0.8
2009	0.9	58.7	33.2	1.6	0	2.7
2010	0.1	58.0	22.3	16.9	0	1.7
2011	0.1	30.3	19.7	9.2	0	1.9
2012	0.2	30.4	21.8	4.5	0	1.6
2013	0.1	34.9	14.8	5.4	0	1.7
2014	0.2	33.9	15.8	3.9	0	0.6
2015	0.1	38.1	11.4	8.7	0	1.6
2016	0.2	40.8	13.1	10.3	0	3.1
2017	0.0	13.0	0.0	0.0	0	0.0

Table 2: West Coast history of regulations.

tab:Regs

Date	Area	Regulation
11/10/1983	Columbia	Closed Columbia area to Pacific ocean perch fishing until the end of the year, as 950 mt OY for this species has been reached;
11/10/1983	Vancouver	retained 5,000-pound trip limit or 10% of total trip weight on landings of Pacific ocean perch in the Vancouver area.
1/1/1984	ALL	Continued 5,000-pound trip limit or 10% of total trip weight on Pacific ocean perch as specified in FMP. Fishery to close when area OYs are reached (see action effective November 10, 1983 above).
8/1/1984	Vancouver Columbia	Reduced trip limit for Pacific ocean perch in the Vancouver and Columbia areas to 20% by weight of all fish on board, not to exceed 5,000 pounds per vessel per trip.
8/16/1984	Columbia	Commercial fishing for Pacific ocean perch in the Columbia area closed for remainder of the year.
1/10/1985	Vancouver Columbia	Established Vancouver and Columbia areas Pacific ocean perch trip limit of 20% by weight of all fish on board (no 5,000-pound limit as specified in last half of 1984).
4/28/1985	Vancouver Columbia	Reduced the Vancouver and Columbia areas Pacific ocean perch trip limit to 5,000 pounds or 20% by weight of all fish on board, whichever is less.
4/28/1985	ALL	Landings of Pacific ocean perch less than 1,000 pounds will be unrestricted. The fishery for this species will close when the OY in each area is reached.
6/10/1985	ALL	Landings of Pacific ocean perch up to 1,000 pounds per trip will be unrestricted regardless of the percentage of these fish on board.
1/1/1986	Cape Blanco North	Established the Pacific ocean perch trip limit north of Cape Blanco (4250) at 20% (by weight) of all fish on board or 10,000 pounds whichever is less;
1/1/1986	ALL	landings of Pacific ocean perch unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY = 600 mt; Columbia area OY =950 mt.
12/1/1986	Vancouver	OY quota for Pacific ocean perch reached in the Vancouver area; fishery closed until January 1, 1987.
1/1/1987	ALL	Established coastwide Pacific ocean perch limit at 20% of all legal fish on board or 5,000 pounds whichever is less (in round weight); landings of Pacific ocean perch unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY =500 mt; Columbia area OY = 800 mt.
1/1/1988	ALL	Established the coastwide Pacific ocean perch trip limit at 20% (by weight) of all fish on board or 5,000 pounds, whichever is less; landings of Pacific ocean perch unrestricted if less than 1,000 pounds regardless of percentage on board;
1/1/1989	ALL	Established the coastwide Pacific ocean perch trip limit at 20% (by weight) of all fish on board or 5,000 pounds whichever is less;
1/1/1989	ALL	landings of Pacific ocean perch unrestricted if less than 1,000 pounds regardless of percentage on board (Vancouver area OY =500 mt; Columbia area OY =800 mt).
7/26/1989	ALL	Reduced the coastwide trip limit for Pacific ocean perch to 2,000 pounds or 20% of all fish on board, whichever is less, with no trip frequency restriction.
12/13/1989	Columbia	Closed the Pacific ocean perch fishery in the Columbia area because 1,040 mt OY reached.
1/1/1990	ALL	Established the coastwide Pacific ocean perch trip limit at 20% (by weight) of all fish on board or 3,000 pounds whichever is less; landings of Pacific ocean perch be unrestricted if less than 1,000 pounds regardless of percentage on board. (Vancouver area OY = 500 mt; Columbia area OY = 1,040 mt).
1/1/1991	ALL	Established the coastwide Pacific ocean perch trip limit at 20% (by weight) of all groundfish on board or 3,000 pounds whichever is less; landings of Pacific ocean perch be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,000 mt).
1/1/1992	ALL	For Pacific ocean perch, established the coastwide trip limit at 20% (by weight) of all groundfish on board or 3,000 pounds whichever is less; landings of Pacific ocean perch be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,550 mt).

Date	Area	Regulation
1/1/1993	Cape Mendocino Coos Bay	For Pacific ocean perch, continued the coastwide trip limit at 20% (by weight) of all groundfish on board or 3,000 pounds whichever is less; landings of Pacific ocean perch unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,550 mt).
1/1/1994	ALL	Pacific Ocean Perch trip limit of 3,000 pounds or 20% of all fish on board, whichever is less, in landings of Pacific ocean perch above 1,000 pounds.
1/1/1995	ALL	For Pacific Ocean Perch, established a cumulative trip limit of 6,000 pounds per month
1/1/1996	ALL	Pacific Ocean Perch cumulative trip limit of 10,000 pounds per two-month period.
7/1/1996	4030 North	Reduced the cumulative 2-month limit for Pacific ocean perch to 8,000 pounds, and established the cumulative 2-month limit for Dover sole north of Cape Mendocino at 38,000 pounds
1/1/1997	ALL	Pacific Ocean Perch limited entry fishery cumulative trip limit of 8,000 pounds per two-month period
1/1/1998	ALL	Pacific Ocean Perch: limited entry fishery Cumulative trip limit of 8,000 pounds per two-month period.
7/1/1998	ALL	Open Access Rockfish: removed overall rockfish monthly limit and replaced it with limits for component rockfish species: for Sebastes complex, monthly cumulative limit is 33,000 pounds, for widow rockfish, monthly cumulative trip limit is 3,000 pounds, for Pacific Ocean Perch, monthly cumulative trip limit is 4,000 pounds.
1/1/1999	ALL	for the limited entry fishery A new three phase cumulative limit period system is introduced for 1999. Phase 1 is a single cumulative limit period that is 3months long, from January 1 - March 31. Phase 2 has 3 separate 2 month cumulative limit periods of April 1 - May 31, June 1 - July 31, and August 1 - September 30. Phase 3 has 3 separate 1 month cumulative limit periods of October 1-31, November 1-30, and December 1-31. For all species except Pacific ocean perch and Bocaccio, there will be no monthly limit within the cumulative landings limit periods. An option to apply cumulative trip limits lagged by 2 weeks (from the 16th to the 15th) was made available to limited entry trawl vessels when their permits were renewed for 1999. Vessels that are authorized to operate in this "B" platoon may take and retain, but may not land, groundfish during January 1-15, 1999.
1/1/1999	ALL	for the limited entry fishery Pacific Ocean Perch: cumulative limit, Phase 1: 4,000 pounds per month; Phase 2: 4,000 pounds per month; Phase 3: 4,000pounds per month.
1/1/1999	ALL	for open access gear: Pacific Ocean Perch: coastwide, 100 pounds per month.
1/1/2000	ALL	Limited entry trawl, Pacific Ocean Perch, 500 lbs per month
1/1/2000	ALL	Pacific Ocean Perch, Open Access gear except exempted trawl, 100 lbs per month
1/1/2000	ALL	Pacific Ocean Perch, limited entry fixed gear, 500 lbs per month
5/1/2000	ALL	Limited entry trawl, Pacific Ocean Perch, 2500 lbs per 2 months
5/1/2000	ALL	Pacific Ocean Perch, limited entry fixed gear, 2500 lbs per month
11/1/2000	ALL	Limited entry trawl, Pacific Ocean Perch, 500 lbs per month
11/1/2000	ALL	Pacific Ocean Perch, limited entry fixed gear, 500 lbs per month
1/1/2001	3600 North	Pacific Ocean Perch, open access, 100 lbs per month
1/1/2001	4010 North	Pacific Ocean Perch, limited entry trawl, 1500 lbs per mont
1/1/2001	ALL	Pacific Ocean Perch, limited entry fixed gear, 1500 lbs per month
5/1/2001	4010 North	Pacific Ocean Perch, limited entry trawl, 2500 lbs per month
5/1/2001	ALL	Pacific Ocean Perch, limited entry fixed gear, 2500 lbs per month
10/1/2001	4010 North	Pacific Ocean Perch, limited entry trawl, 1500 lbs per month
11/1/2001	ALL	Pacific Ocean Perch, limited entry fixed gear, 1500 lbs per month
1/1/2002	4010 North	Pacific Ocean Perch, open access, 100 lbs per month
1/1/2002	4010 North	Pacific Ocean Perch, limited entry fixed gear, 2000 lbs per month
1/1/2002	4010 North	Pacific Ocean Perch, limited entry trawl, 2000 lbs per month
4/1/2002	4010 North	Pacific Ocean Perch, limited entry fixed gear, 4000 lbs per month
5/1/2002	4010 North	Pacific Ocean Perch, limited entry trawl, 4000 lbs per month
11/1/2002	4010 North	Pacific Ocean Perch, limited entry fixed gear, 2000 lbs per month
11/1/2002	4010 North	Pacific Ocean Perch, limited entry trawl, 2000 lbs per month
1/1/2003	3800 South	minor slope rockfish south including pacific ocean perch, open access gear, 10000 lbs per 2 months

Date	Area	Regulation
1/1/2003	3800 South	Minor slope rockfish south including Pacific ocean perch, limited entry fixed gear, 30000 lbs per 2 months
1/1/2003	3800 South	Minor slope rockfish south including Pacific ocean perch , limited entry trawl, 30000 lbs per 2 months
1/1/2003	3800 4010	minor slope rockfish south including pacific ocean perch, open access gear, per trip no more than 25% (by weight) of sablefish landed
1/1/2003	3800 4010	Minor slope rockfish south including Pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2003	3800 4010	Minor slope rockfish south including Pacific ocean perch , limited entry trawl, 1800 lbs per 2 months
1/1/2003	4010 North	pacific ocean perch, open access gears, 100 lbs per month
1/1/2003	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2003	4010 North	Pacific Ocean Perch, Limited entry trawl gear, 3000 lbs per 2 months
3/1/2003	3800 4010	Minor slope rockfish south including Pacific ocean perch, limited entry fixed gear, no more than 25% of the weight of sablefish landed per trip
11/1/2003	3800 4010	Minor slope rockfish south including Pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2004	3800 South	Minor slope rockfish south including Pacific ocean perch, open access gear, 10000 lbs per 2 months
1/1/2004	3800 South	minor slope rockfish south inclding pacific ocean perch, limited entry fixed gear, 40000 lbs per 2 months
1/1/2004	3800 South	minor slope rockfish south including pacific ocean perch, limited entry trawl, 40000 lbs per 2 months
1/1/2004	3800 4010	Minor slope rockfish south including Pacific ocean perch, open access gear, per trip no more than 25% of the weight of sablefish landed
1/1/2004	3800 4010	minor slope rockfish south including pacific ocean perch, limited entry fixed gear, 7000 lbs per 2 months
1/1/2004	3800 4010	minor slope rockfish south including pacific ocean perch, limited entry trawl, 7000 lbs per 2 months
1/1/2004	4010 North	pacific ocean perch, open access gear, 100 lbs per month
1/1/2004	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2004	4010 North	pacific ocean perch, limited entry trawl, 3000 lbs per 2 months
5/1/2004	3800 South	minor slope rockfish south inclding pacific ocean perch, limited entry fixed gear, 50000 lbs per 2 months
5/1/2004	3800 South	minor slope rockfish south including pacific ocean perch, limited entry trawl, 50000 lbs per 2 months
5/1/2004	3800 4010	minor slope rockfish south including pacific ocean perch, limited entry fixed gear, 50000 lbs per 2 months
5/1/2004	3800 4010	minor slope rockfish south including pacific ocean perch, limited entry trawl, 50000 lbs per 2 months
11/1/2004	3800 South	minor slope rockfish south inclding pacific ocean perch, limited entry fixed gear, 50000 lbs per 2 months
11/1/2004	3800 South	minor slope rockfish south including pacific ocean perch, limited entry trawl, 50000 lbs per 2 months
11/1/2004	3800 4010	minor slope rockfish south including pacific ocean perch, limited entry fixed gear, 10000 lbs per 2 months
11/1/2004	3800 4010	minor slope rockfish south including pacific ocean perch, limited entry trawl, 10000 lbs per 2 months
1/1/2005	3800 South	minor slope rockfish south including darkblotched and pacific ocean perch, open access gear, 10000 lbs per 2 months
1/1/2005	3800 South	minor slope rockfish south including darkblotched rockfish and pacific ocean perch, limited entry trawl, closed
1/1/2005	3800 4010	minor slope rockfish south including darkblotched and pacific ocean perch, open access gear, per trip no more than 25% of weight of sablefish onboard
1/1/2005	3800 4010	minor slope rockfish south including darkblotched rockfish and pacific ocean perch, limited entry trawl, 4000 lbs per 2 months
1/1/2005	4010 North	pacific ocean perch, open access gears, 100 lbs per month
1/1/2005	4010 North	pacific ocean perch, limited entry trawl gear, 3000 lbs per 2 months
1/1/2005	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2005	4010 South	minor slope rockfish south including darkblotched and pacific ocean perch, limited entry fixed gear, 40000 lbs per 2 months
5/1/2005	3800 4010	minor slope rockfish south including darkblotched rockfish and pacific ocean perch, limited entry trawl, 8000 lbs per 2 months

Date	Area	Regulation
1/1/2008	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, limited entry trawl, 15000 lbs per 2 months
1/1/2008	4010 North	pacific ocean perch, limited entry trawl, 1500 lbs per 2 months
1/1/2009	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2009	4010 South	minor slope rockfish south including pacific ocean perch and darkblotched, limited entry fixed gear, 40000 lbs per 2 months
1/1/2009	3800 South	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, 10000 lbs per 2 months
1/1/2009	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, per trip no more than 25% (by weight) of sablefish landed
1/1/2009	4010 North	pacific ocean perch, open access gears, 100 lbs per month
1/1/2009	3800 South	minor slope rockfish southincluding pacific ocean perch and darkblotched rockfish, limited entry trawl, 55000 lbs per 2 months
1/1/2009	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, limited entry trawl, 15000 lbs per 2 months
1/1/2009	4010 North	pacific ocean perch, limited entry trawl, 1500 lbs per 2 months
7/1/2009	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, limited entry trawl, 10000 lbs per 2 months
11/1/2009	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, limited entry trawl, 15000 lbs per 2 months
1/1/2010	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2010	4010 South	minor slope rockfish south including pacific ocean perch and darkblotched,limited entry fixed gear, 40000 lbs per 2 months
1/1/2010	3800 South	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, 10000 lbs per 2 months
1/1/2010	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, per trip no more than 25% (by weight) of sablefish landed
1/1/2010	4010 North	pacific ocean perch, open access gears, 100 lbs per month
1/1/2010	3800 South	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, limited entry trawl, 55000 lbs per 2 months
1/1/2010	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, limited entry trawl, 15000 lbs per 2 months
1/1/2010	4010 North	pacific ocean perch, limited entry trawl, 1500 lbs per 2 months
1/1/2011	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2011	4010 South	minor slope rockfish south including pacific ocean perch and darkblotched, limited entry fixed gear, 40000 lbs per 2 months
1/1/2011	3800 South	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, 10000 lbs per 2 months
1/1/2011	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, per trip no more than 25% (by weight) of sablefish landed
1/1/2011	4010 North	pacific ocean perch, open access gears, 100 lbs per month
1/1/2011	ALL	Pacific Ocean Perch managed in part by IFQ
1/1/2012	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2012	4010 South	minor slope rockfish southincluding pacific ocean perch and darkblotched, limited entry fixed gear, 40000 lbs per 2 months
1/1/2012	3800 South	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, 10000 lbs per 2 months
1/1/2012	3800 4010	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, per trip no more than 25% (by weight) of sablefish landed
1/1/2012	4010 North	pacific ocean perch, open access gears, 100 lbs per month
1/1/2013	4010 North	pacific ocean perch, open access gears, 100 lbs per month
1/1/2013	4010 North	pacific ocean perch, limited entry fixed gear, 1800 lbs per 2 months
1/1/2013	4010 South	minor slope rockfish south including pacific ocean perch and darkblotched, limited entry fixed gear, 40000 lbs per 2 months no more than 1375 lbs may be blackgill
1/1/2013	4010 South	minor slope rockfish south including pacific ocean perch and darkblotched rockfish, open access gear, 10000 lbs per 2 months no more than 475 lbs of which may be blackgill rockfish
1/1/2014	4010 North	non-trawl, limited entry, pacific ocean perch, 1800 lbs per 2 months
1/1/2014	4010 South	non-trawl, limited entry, minor slope rockfish and darkblotched rockfish and pacific ocean perch, 40000 lbs per 2 months of which no more than 1375 lbs may be blackgill rockfish

Date	Area	Regulation
1/1/2014	4010 North	non-trawl, open access, pacific ocean perch, 100 lbs per month
1/1/2014	4010 South	non-trawl, open access, minor slope rockfish including darkblotched rockfishand pacific ocean perch, 10000 lbs per 2 months of which no more than 475 lbs may be blackgill rockfish
1/1/2015	4010 North	non-trawl, limited entry, pacific ocean perch, 1800 lbs per 2 months
1/1/2015	4010 South	non-trawl, limited entry, minor slope rockfish and darkblotched rockfish and pacific ocean perch, 40000 lbs per 2 months of which no more than 1375 lbs may be blackgill rockfish
1/1/2015	4010 North	non-trawl, open access, pacific ocean perch, 100 lbs per month
1/1/2015	4010 South	non-trawl, open access, minor slope rockfish including darkblotched rockfishand pacific ocean perch, 10000 lbs per 2 months of which no more than 475 lbs may be blackgill rockfish
7/1/2015	4010 South	non-trawl, limited entry, minor slope rockfish and darkblotched rockfish and pacific ocean perch, 40000 lbs per 2 months of which no more than 1600 lbs may be blackgill rockfish
7/1/2015	4010 South	non-trawl, open access, minor slope rockfish including darkblotched rockfishand pacific ocean perch, 10000 lbs per 2 months of which no more than 550 lbs may be blackgill rockfish
1/1/2016	4010 North	non-trawl, limited entry, pacific ocean perch, 1800 lbs per 2 months
1/1/2016	4010 North	non-trawl, open access, pacific ocean perch, 100 lbs per month
1/1/2016	4010 South	non-trawl, open access, minor slope rockfish including darkblotched rockfishand pacific ocean perch, 10000 lbs per 2 months of which no more than 475 lbs may be blackgill rockfish
7/1/2016	4010 South	non-trawl, open access, minor slope rockfish including darkblotched rockfishand pacific ocean perch, 10000 lbs per 2 months of which no more than 550 lbs may be blackgill rockfish

Table 3: Recent trend in estimated total catch relative to management guidelines.
tab:mnmgt_perform_tables

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	133	157
2008	911		150	92	133
2009	1,160		189	94	190
2010	1,173		200	97	181
2011	1,026	981	180	60	61
2012	1,007	962	183	57	58
2013	844	807	150	55	57
2014	838	801	153	54	55
2015	842	805	158	58	59
2016	850	813	164	65	65

Table 4: Summary of the fishery-independant biomass/abundance time-series used in the stock assessment. The standard error includes the input annual standard error and model estimated added variance.

tab:Index_Summary

	POP		Triennial		AFSC Slope		NWFSC Slope		NWFSC Shelf-Slope	
Year	Obs	SE	Obs	SE	Obs	SE	Obs	SE	Obs	SE
1979	56461	0.27	-	-	-	-	-	-	-	-
1980	-	-	10384	0.65	-	-	-	-	-	-
1983	-	-	8974	0.59	-	-	-	-	-	-
1985	34645	0.29	-	-	-	-	-	-	-	-
1986	-	-	2977	0.66	-	-	-	-	-	-
1989	-	-	4873	0.66	-	-	-	-	-	-
1992	-	-	3207	0.64	-	-	-	-	-	-
1995	-	-	2724	0.63	-	-	-	-	-	-
1996	-	-	-	-	7621	0.51	-	-	-	-
1997	-	-	-	-	3807	0.51	-	-	-	-
1998	-	-	4163	0.64	-	-	-	-	-	-
1999	-	-	-	-	4694	0.50	3643	0.63	-	-
2000	-	-	-	-	4243	0.53	4120	0.58	-	-
2001	-	-	1494	0.64	4187	0.49	2325	0.59	-	-
2002	-	-	-	-	-	-	1903	0.60	-	-
2003	-	-	-	-	-	-	-	-	9646	0.37
2004	-	-	2922	0.67	-	-	-	-	5284	0.40
2005	-	-	-	-	-	-	-	-	7528	0.40
2006	-	-	-	-	-	-	-	-	6010	0.42
2007	-	-	-	-	-	-	-	-	6268	0.37
2008	-	-	-	-	-	-	-	-	3867	0.40
2009	-	-	-	-	-	-	-	-	2745	0.37
2010	-	-	-	-	-	-	-	-	5404	0.35
2011	-	-	-	-	-	-	-	-	7533	0.36
2012	-	-	-	-	-	-	-	-	9289	0.36
2013	-	-	-	-	-	-	-	-	8093	0.35
2014	-	-	-	-	-	-	-	-	4914	0.35
2015	-	-	-	-	-	-	-	-	5752	0.32
2016	-	-	-	-	-	-	-	-	11770	0.37

Table 5: Summary of NWFSC shelf-slope survey length samples used in the stock assessment.
tab:NWcombo_Lengths

Year	Tows	Fish	Sample Size
2003	46	80	111
2004	34	56	82
2005	38	81	92
2006	33	73	80
2007	50	74	121
2008	39	75	94
2009	46	61	111
2010	53	73	128
2011	53	72	128
2012	50	79	121
2013	45	76	109
2014	52	77	126
2015	69	67	167
2016	50	58	121

Table 6: Summary of NWFSC shelf-slope survey age samples used in the stock assessment.
tab:NWcombo_Ages

Year	Tows	Fish	Sample Size
2003	45	265	109
2004	34	149	82
2005	38	192	92
2006	33	170	80
2007	50	228	121
2008	39	218	94
2009	45	190	109
2010	53	292	128
2011	53	258	128
2012	49	217	119
2013	44	308	106
2014	52	195	126
2015	68	182	165
2016	44	281	106

Table 7: Summary of NWFSC slope survey length samples used in the stock assessment.
tab:NWslope_Lengths

Year	Tows	Fish	Sample Size
2001	18	27	43
2002	24	54	58

Table 8: Summary of NWFSC slope survey age samples used in the stock assessment.
tab:NWslope_Ages

Year	Tows	Fish	Sample Size
2001	17	125	41
2002	24	216	58

Table 9: Summary of AFSC slope survey length samples used in the stock assessment.
tab:AFSC_Lengths

Year	Tows	Fish	Sample Size
1996	48	1396	116
1997	21	347	51
1999	21	562	51
2000	19	353	46
2001	23	390	55

Table 10: Summary of Triennial survey length samples used in the stock assessment.
tab:TriennialLengths

Year	Tows	Fish	Sample Size
1980	18	1315	43
1983	40	2820	97
1986	17	877	41
1989	42	1851	102
1992	33	1182	80
1995	71	1136	172
1998	81	1482	196
2001	74	669	179
2004	63	1240	153

Table 11: Summary of Triennial survey age samples used in the stock assessment.
tab:Triennial_Ages

Year	Tows	Fish	Sample Size
1989	15	577	36
1992	10	373	24
1995	12	275	29
1998	28	352	68
2001	43	342	104
2004	57	416	138

Table 12: Summary of Pacific ocean perch survey length samples used in the stock assessment.
tab:POP_Lengths

Year	Tows	Fish	Sample Size
1979	125	2375	303
1985	126	2558	306

Table 13: Summary of Pacific ocean perch survey age samples used in the stock assessment.
tab:POP_Ages

Year	Tows	Fish	Sample Size
1985	29	1635	70

Table 14: Summary of discard rates used in the model by each data source.
tab:Discard

Year	Source	Discard	Standard Error
1985	Pikitch	0.027	0.068
1986	Pikitch	0.024	0.063
1987	Pikitch	0.039	0.083
1992	Management Restrictions	0.100	0.300
2002	WCGOP	0.150	0.164
2003	WCGOP	0.183	0.268
2004	WCGOP	0.203	0.206
2005	WCGOP	0.175	0.346
2006	WCGOP	0.148	0.243
2007	WCGOP	0.171	0.261
2008	WCGOP	0.362	0.172
2009	WCGOP	0.504	0.153
2010	WCGOP	0.487	0.195
2011	WCGOP	0.015	0.053
2012	WCGOP	0.028	0.054
2013	WCGOP	0.027	0.054
2014	WCGOP	0.035	0.050
2015	WCGOP	0.010	0.053

Table 15: Summary of the commercial catch-per-unit effort time-series used in the stock assessment.

tab:CPUE_Summary

Year	Obs	SE
1956	0.40	0.40
1957	0.30	0.40
1958	0.32	0.40
1959	0.29	0.40
1960	0.28	0.40
1961	0.31	0.40
1962	0.29	0.40
1963	0.34	0.40
1964	0.35	0.40
1965	0.55	0.40
1966	0.47	0.40
1967	0.30	0.40
1968	0.17	0.40
1969	0.18	0.40
1970	0.17	0.40
1971	0.20	0.40
1972	0.20	0.40
1973	0.11	0.40

Table 16: Summary of commercial fishery length samples used in the stock assessment.
tab:Comm_Lengths

Year	Trips	Fish	Sample Size
1966	1	238	7
1967	5	1020	35
1968	3	912	21
1969	4	1213	28
1970	13	1830	92
1971	22	4698	155
1972	23	4561	162
1973	17	4134	120
1974	20	4806	141
1975	19	3637	134
1976	21	3677	148
1977	32	4846	226
1978	52	7715	367
1979	34	3414	240
1980	55	5425	388
1981	40	3921	282
1982	48	4824	339
1983	39	3944	275
1984	31	3102	219
1985	45	4508	318
1986	40	4002	282
1987	43	3053	304
1988	9	601	64
1989	16	798	113
1990	12	599	85
1991	8	216	38
1994	43	2608	304
1995	49	3161	346
1996	64	3085	452
1997	76	3570	537
1998	56	3450	395
1999	58	2812	409
2000	49	2004	326
2001	59	1696	293
2002	50	1666	280

Year	Trips	Fish	Sample Size
2003	67	1661	296
2004	53	1202	219
2005	51	1277	227
2006	59	1486	264
2007	81	2248	391
2008	101	3058	523
2009	107	3207	550
2010	134	2872	530
2011	100	1943	368
2012	97	1873	355
2013	117	2167	416
2014	140	2850	533
2015	110	2504	456
2016	131	2158	429

Table 17: Summary of commercial fishery age samples used in the stock assessment.

tab:Comm_Ages

Year	Trips	Fish	Sample Size
1981	20	1901	141
1982	40	2776	282
1983	33	3317	233
1984	27	2625	191
1985	21	2096	148
1986	17	1693	120
1987	24	1193	169
1988	4	199	28
1994	8	238	41
1999	18	863	127
2000	14	677	99
2001	40	1349	226
2002	38	1414	233
2003	40	1309	221
2004	30	854	148
2005	37	1018	177
2006	49	1258	223
2007	63	1825	315
2008	44	1129	200
2009	75	1548	289
2010	54	1264	228
2011	85	1230	255
2012	7	331	49
2013	10	265	47
2014	91	587	172
2015	78	513	149
2016	21	254	56

Table 18: Summary of At-Sea hake fishery length samples used in the stock assessment. tab:ASHOP_Lengths

Year	Trips	Fish	Sample Size
2003	153	805	263
2004	128	329	172
2005	221	734	321
2006	210	751	312
2007	319	1119	470
2008	26	2491	162
2009	12	366	63
2010	22	1794	155
2011	36	1748	226
2012	26	881	148
2013	26	834	140
2014	31	532	103
2015	23	925	150
2016	35	1947	240

Table 19: Summary of At-sea hake fishery age samples used in the stock assessment. tab:ASHOP_Ages

Year	Trips	Fish	Sample Size
2003	142	378	194
2006	198	410	255
2007	297	620	383
2014	22	101	36

Table 20: Estimated ageing error from the CAPS lab used in the assessment model
tab:Age_Error

True Age (yr)	SD of Observed Age (yr)	True Age (yr)	SD of Observed Age (yr)
0.5	0.156	31.5	2.772
1.5	0.156	32.5	2.854
2.5	0.249	33.5	2.935
3.5	0.341	34.5	3.016
4.5	0.433	35.5	3.097
5.5	0.524	36.5	3.177
6.5	0.615	37.5	3.257
7.5	0.706	38.5	3.337
8.5	0.796	39.5	3.416
9.5	0.886	40.5	3.495
10.5	0.976	41.5	3.574
11.5	1.065	42.5	3.652
12.5	1.154	43.5	3.73
13.5	1.242	44.5	3.808
14.5	1.33	45.5	3.885
15.5	1.418	46.5	3.962
16.5	1.505	47.5	4.039
17.5	1.592	48.5	4.115
18.5	1.679	49.5	4.191
19.5	1.765	50.5	4.267
20.5	1.851	51.5	4.342
21.5	1.937	52.5	4.417
22.5	2.022	53.5	4.492
23.5	2.107	54.5	4.566
24.5	2.191	55.5	4.641
25.5	2.275	56.5	4.714
26.5	2.359	57.5	4.788
27.5	2.442	58.5	4.861
28.5	2.525	59.5	4.934
29.5	2.608	60.5	5.007
30.5	2.69		

Table 21: Specifications of the base model for Pacific ocean perch.
tab:Model_setup

Model Specification	Base Model
Starting year	1918
Population characteristics	
Maximum age	60
Gender	2
Population lengths	5-50 cm by 1 cm bins
Summary biomass (mt)	Age 3+
Data characteristics	
Data lengths	11-47 cm by 1 cm bins
Data ages	1-40
Minimun age for growth calculations	3
Maximum age for growth calculations	20
First mature age	0
Starting year of estimated recruitment	1940
Fishery characteristics	
Fishery timing	mid-year
Fishing mortality method	discrete
Maximum F	0.9
Catchability	Analytical estimate
Fishery selectivity	Double Normal
At-Sea Hake selectivity	Double Normal
POP survey selectivity	Logistic
Triennial survey	Double Normal
AFSC slope survey	Double Normal
NWFSC slope survey	Double Normal
NWFSC shelf/slope survey	Double Normal
Fishery time blocks	
Fishery selectivity	none
Fishery retention	1918-1991, 1992-2001, 2002-2007, 2008, 2009-2010, 2011-2016

Table 22: Results from 100 jitters from the base model.

tab:jitter

Status	Base.Model
Returned to base case	33
Found local minimum	45
Found better solution	0
Error in likelihood	22
Total	100

Table 23: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
NatM_p_1_Fem_GP_1	0.054	-5	(0.02, 0.1)			Log_Norm (-2.92, 0.44)
L_at_Amin_Fem_GP_1	20.7848	3	(15, 25)	OK	0.14	None
L_at_Amax_Fem_GP_1	41.5953	2	(35, 45)	OK	0.15	None
VonBert_K_Fem_GP_1	0.167029	3	(0.1, 0.4)	OK	0.00	None
SD_young_Fem_GP_1	1.34323	5	(0.03, 5)	OK	0.06	None
SD_old_Fem_GP_1	2.5618	5	(0.03, 5)	OK	0.12	None
Wtlen_1_Fem	1.044e-05	-99	(0, 3)			None
Wtlen_2_Fem	3.088	-99	(2, 4)			None
Mat50%_Fem	32.1	-99	(20, 40)			None
Mat_slope_Fem	-1	-99	(-2, 4)			None
Eggs_scalar_Fem	8.66e-10	-99	(0, 6)			None
Eggs_exp_len_Fem	4.9767	-99	(-3, 5)			None
NatM_p_1_Mal_GP_1	0.054	-5	(0, 0.3)			Normal (0.05, 0.1)
L_at_Amin_Mal_GP_1	20.7848	-2	(6, 68)			None
L_at_Amax_Mal_GP_1	38.8999	2	(13, 122)	OK	0.00	None
VonBert_K_Mal_GP_1	0.199	3	(0.04, 1.09)	OK	0.03	None
SD_young_Mal_GP_1	1.34323	-5	(0, 742.07)			None
SD_old_Mal_GP_1	2.287	5	(0, 742.07)	OK	0.06	None
Wtlen_1_Mal	1.05e-05	-99	(0, 3)			None
Wtlen_2_Mal	3.083	-99	(2, 4)			None
CohortGrowDev	1	-99	(0, 2)			None
FracFemale_GP_1	0.5	-99	(0.01, 0.99)			None
SR_LN(R0)	9.36441	1	(5, 20)	OK	0.14	None
SR_BH_steep	0.5	-2	(0.2, 1)			Full_Beta (0.72, 0.15)
SR_sigmaR	0.7	-6	(0.5, 1.2)			None
SR_regime	0	-99	(-5, 5)			None

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Table 23: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
SR_autocorr	0	-99	(0, 2)			None
Early_InitAge_18	0.00423169	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_17	0.00444885	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_16	0.00467384	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_15	0.00490632	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_14	0.00514567	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_13	0.00539119	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_12	0.00564178	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_11	0.0058963	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_10	0.00615286	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_9	0.00640947	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_8	0.006662	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_7	0.00690763	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_6	0.00714936	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_5	0.00739472	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_4	0.0076478	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_3	0.00790868	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_2	0.00817704	3	(-6, 6)	act	0.70	dev (NA, NA)
Early_InitAge_1	0.00845291	3	(-6, 6)	act	0.70	dev (NA, NA)
LnQ_base_Fishery(1)	-12.313	-1	(-15, 15)			None
LnQ_base_POP(4)	-0.122911	-1	(-15, 15)			None
LnQ_base_Triennial(5)	-1.82534	-1	(-15, 15)			None
Q_extraSD_Triennial(5)	0.390454	2	(0, 0.5)	OK	0.15	None
LnQ_base_AFSCSlope(6)	-2.48805	-1	(-15, 15)			None
LnQ_base_NWFSCSlope(7)	-2.84895	-1	(-15, 15)			None
LnQ_base_NWFSCcombo(8)	-2.62228	-1	(-15, 15)			None

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Table 23: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Q_extraSD_NWFSCcombo(8)	0.029722	2	(0, 0.5)	OK	0.07	None
SizeSel_P1_Fishery(1)	37.9626	1	(20, 45)	OK	0.18	None
SizeSel_P2_Fishery(1)	-5	-2	(-6, 4)			None
SizeSel_P3_Fishery(1)	3.67946	3	(-1, 9)	OK	0.13	None
SizeSel_P4_Fishery(1)	-1.65	-3	(-9, 9)			None
SizeSel_P5_Fishery(1)	-3.5	-4	(-5, 9)			None
SizeSel_P6_Fishery(1)	0.496266	2	(-5, 9)	OK	0.31	None
Retain_P1_Fishery(1)	28.2834	1	(15, 45)	OK	0.34	None
Retain_P2_Fishery(1)	1.07725	1	(0.1, 10)	OK	0.13	None
Retain_P3_Fishery(1)	6.97035	1	(-10, 10)	OK	1.36	None
Retain_P4_Fishery(1)	0	-3	(0, 0)			None
SizeSel_P1_ASHOP(2)	49.495	1	(20, 49.5)	HI	0.16	None
SizeSel_P2_ASHOP(2)	-5	-2	(-6, 4)			None
SizeSel_P3_ASHOP(2)	5.06196	3	(-1, 9)	OK	0.18	None
SizeSel_P4_ASHOP(2)	1	-3	(-1, 9)			None
SizeSel_P5_ASHOP(2)	-4.35	-4	(-9, 9)			None
SizeSel_P6_ASHOP(2)	999	-2	(-5, 999)			None
SizeSel_P1_POP(4)	24.4703	1	(20, 70)	OK	2.24	None
SizeSel_P2_POP(4)	11.1655	3	(0.001, 50)	OK	4.04	None
SizeSel_P1_Triennial(5)	27.6389	1	(20, 45)	OK	5.03	None
SizeSel_P2_Triennial(5)	-5	-2	(-6, 4)			None
SizeSel_P3_Triennial(5)	5.5	-3	(-1, 9)			None
SizeSel_P4_Triennial(5)	3.297	3	(-1, 9)	OK	2.29	None
SizeSel_P5_Triennial(5)	-5	-4	(-5, 9)			None
SizeSel_P6_Triennial(5)	-0.782413	2	(-5, 9)	OK	0.64	None
SizeSel_P1_AFSCSlope(6)	21.7007	1	(20, 45)	OK	6.45	None

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Table 23: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
SizeSel_P2_AFSCSlope(6)	-5	-2	(-6, 4)			None
SizeSel_P3_AFSCSlope(6)	1.23847	3	(-1, 9)	OK	6.47	None
SizeSel_P4_AFSCSlope(6)	1	-3	(-1, 9)			None
SizeSel_P5_AFSCSlope(6)	-9	-4	(-9, 9)			None
SizeSel_P6_AFSCSlope(6)	999	-2	(-5, 999)			None
SizeSel_P1_NWFSCSlope(7)	35.9583	1	(20, 45)	OK	2.22	None
SizeSel_P2_NWFSCSlope(7)	-5	-2	(-6, 4)			None
SizeSel_P3_NWFSCSlope(7)	1.77694	3	(-1, 9)	OK	1.85	None
SizeSel_P4_NWFSCSlope(7)	1	-3	(-1, 9)			None
SizeSel_P5_NWFSCSlope(7)	-9	-4	(-9, 9)			None
SizeSel_P6_NWFSCSlope(7)	999	-2	(-5, 999)			None
SizeSel_P1_NWFSCcombo(8)	21.3537	1	(18, 49.5)	OK	5.84	None
SizeSel_P2_NWFSCcombo(8)	-5	-2	(-6, 4)			None
SizeSel_P3_NWFSCcombo(8)	2.86381	3	(-1, 9)	OK	3.06	None
SizeSel_P4_NWFSCcombo(8)	1	-3	(-1, 9)			None
SizeSel_P5_NWFSCcombo(8)	-9	-4	(-9, 9)			None
SizeSel_P6_NWFSCcombo(8)	999	-2	(-5, 999)			None
Retain_P3_Fishery(1)_BLK1repl_1918	3.98279	4	(-10, 10)	OK	0.09	None
Retain_P3_Fishery(1)_BLK1repl_1992	2.30477	4	(-10, 10)	OK	0.37	None
Retain_P3_Fishery(1)_BLK1repl_2002	1.71753	4	(-10, 10)	OK	0.12	None
Retain_P3_Fishery(1)_BLK1repl_2008	0.608476	4	(-10, 10)	OK	0.28	None
Retain_P3_Fishery(1)_BLK1repl_2009	-0.0174503	4	(-10, 10)	OK	0.24	None

tab:model_params

Table 24: Likelihood components from the base model

tab:like

Likelihood Component	Value
Total	1726.16
Survey	0
Discard	-25.51
Length-frequency data	-34.22
Age-frequency data	135.74
Recruitment	1636.59
Forecast Recruitment	12.54
Parameter Priors	0

Table 25: Summary of reference points and management quantities for the base case.
tab:Ref_pts

Quantity	**Estimate**	**~95% Confidence Interval**
Unfished spawning output (million eggs)	6633.1	4736.7 - 8529.5
Unfished age 3+ biomass (mt)	139810	100052.5 - 179567.5
Unfished recruitment (R0, thousands)	11665.7	8801.4 - 15462.1
Spawning output(2017 million eggs)	5047.2	2259.2 - 7835.1
Depletion (2017)	0.761	0.538 - 0.984
Reference points based on $\mathbf{SB_{40\%}}$		
Proxy spawning output ($B_{40\%}$)	2653.2	1894.7 - 3411.8
SPR resulting in $B_{40\%}$ ($SPR_{B40\%}$)	0.55	0.55 - 0.55
Exploitation rate resulting in $B_{40\%}$	0.028	0.028 - 0.029
Yield with $SPR_{B40\%}$ at $B_{40\%}$ (mt)	1748.2	1252.4 - 2244
Reference points based on SPR proxy for MSY		
Spawning output	2211	1578.9 - 2843.2
SPR_{proxy}	0.5	
Exploitation rate corresponding to SPR_{proxy}	0.034	0.033 - 0.034
Yield with SPR_{proxy} at SB_{SPR} (mt)	1764.8	1264.8 - 2264.8
Reference points based on estimated MSY values		
Spawning output at MSY (SB_{MSY})	2315.7	1649.6 - 2981.8
SPR_{MSY}	0.512	0.51 - 0.514
Exploitation rate at MSY	0.032	0.032 - 0.033
MSY (mt)	1766.7	1266.1 - 2267.4

Table 26: Sensitivity of the base model

tab:Sensitivity1

Label	Base	Harmonic weights	Steepness at prior	Estimate M	Old Maturity	NA
Total Likelihood	1726.16	2432.50	1726.05	1725.66	1726.17	1726.18
Survey Likelihood	-25.51	-25.88	-24.99	-25.68	-25.52	-25.49
Discard Likelihood	-34.22	-27.17	-34.28	-34.29	-34.22	-34.22
Length Likelihood	135.74	748.49	136.05	135.75	135.74	135.75
Age Likelihood	1636.59	1717.85	1636.26	1636.59	1636.62	1636.58
Recruitment Likelihood	12.54	18.20	12.87	12.34	12.54	12.54
Forecast Recruitment Likelihood	0.00	0.00	0.00	0.00	0.00	0.00
Parameter Priors Likelihood	1.00	1.00	0.13	0.94	1.00	1.00
Parameter Deviation Likelihood	0.00	0.00	0.00	0.00	0.00	0.00
log(R0)	9.36	9.27	9.41	9.74	9.36	9.37
SB Virgin	6633.08	6136.91	6979.48	7885.80	6505.70	7745.48
SB 2017	5047.16	4199.96	6883.61	7436.66	5070.80	6103.65
Depletion 2017	0.76	0.68	0.99	0.94	0.78	0.79
Total Yield	1764.80	1605.33	2482.46	2329.27	1759.53	1788.51
Steepness	0.50	0.50	0.72	0.50	0.50	0.50
Natural Mortality - Female	0.05	0.05	0.05	0.06	0.05	0.05
Length at Amin - Female	20.78	20.87	20.79	20.78	20.78	20.78
Length at Amax - Female	41.60	41.72	41.61	41.61	41.60	41.60
Von Bert. k - Female	0.17	0.17	0.17	0.17	0.17	0.17
SD young - Female	1.34	1.35	1.34	1.34	1.34	1.34
SD old - Female	2.56	2.76	2.56	2.56	2.56	2.56
Natural Mortality - Male	0.05	0.05	0.05	0.06	0.05	0.05
Length at Amin - Male	20.78	20.87	20.79	20.78	20.78	20.78
Length at Amax - Male	38.90	38.91	38.91	38.90	38.90	38.90
Von Bert. k - Male	0.20	0.20	0.20	0.20	0.20	0.20
SD young - Male	1.34	1.35	1.34	1.34	1.34	1.34
SD old - Male	2.29	2.60	2.29	2.29	2.29	2.29

Table 27: Sensitivity of the base model

tab:Sensitivity2

Label	Base	Split Trien-nial	Remove CPUE	Canadian Data	WA Re-search Lengths	OR Special Projects
Total Likelihood	1726.16	1724.43	1738.84	1829.64	1747.71	1793.59
Survey Likelihood	-25.51	-27.89	-12.72	-25.91	-26.03	-26.02
Discard Likelihood	-34.22	-34.22	-34.21	-33.26	-34.17	-34.27
Length Likelihood	135.74	135.54	135.66	184.34	156.08	166.78
Age Likelihood	1636.59	1637.33	1636.69	1690.33	1637.74	1671.26
Recruitment Likelihood	12.54	12.65	12.40	13.13	13.08	14.81
Forecast Recruitment Likelihood	0.00	0.00	0.00	0.00	0.00	0.00
Parameter Priors Likelihood	1.00	1.00	1.00	1.00	1.00	1.00
Parameter Deviation Likelihood	0.00	0.00	0.00	0.00	0.00	0.00
log(R0)	9.36	9.40	9.36	9.36	9.33	9.28
SB Virgin	6633.08	6884.08	6594.29	6700.11	6356.26	6128.38
SB 2017	5047.16	5434.58	4992.37	4716.26	4673.44	4392.80
Depletion 2017	0.76	0.79	0.76	0.70	0.74	0.72
Total Yield	1764.80	1830.92	1754.69	1777.27	1705.62	1626.60
Steepness	0.50	0.50	0.50	0.50	0.50	0.50
Natural Mortality - Female	0.05	0.05	0.05	0.05	0.05	0.05
Length at Amin - Female	20.78	20.78	20.78	20.75	20.77	20.80
Length at Amax - Female	41.60	41.60	41.59	41.68	41.52	41.62
Von Bert. k - Female	0.17	0.17	0.17	0.17	0.17	0.17
SD young - Female	1.34	1.34	1.34	1.35	1.34	1.33
SD old - Female	2.56	2.56	2.56	2.54	2.56	2.58
Natural Mortality - Male	0.05	0.05	0.05	0.05	0.05	0.05
Length at Amin - Male	20.78	20.78	20.78	20.75	20.77	20.80
Length at Amax - Male	38.90	38.91	38.90	38.96	38.87	38.93
Von Bert. k - Male	0.20	0.20	0.20	0.20	0.20	0.20
SD young - Male	1.34	1.34	1.34	1.35	1.34	1.33
SD old - Male	2.29	2.29	2.29	2.28	2.30	2.35

Table 28: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning output (million eggs)	Summary biomass 3+	Relative biomass	Age-0 re-cruits	Estimated total catch (mt)	1-SPR	Exp. rate
1918	140160	6644	139432	1.00	11773	0	0	0
1919	140191	6646	139462	1.00	11777	1	0	0
1920	140222	6647	139494	1.00	11781	0	0	0
1921	140255	6648	139526	1.00	11785	0	0	0
1922	140288	6650	139559	1.00	11790	0	0	0
1923	140322	6651	139593	1.00	11794	0	0	0
1924	140357	6653	139627	1.00	11798	0	0	0
1925	140392	6654	139662	1.00	11802	1	0	0
1926	140428	6656	139698	1.00	11806	1	0	0
1927	140464	6658	139734	1.00	11810	1	0	0
1928	140500	6659	139770	1.00	11813	1	0	0
1929	140538	6661	139807	1.00	11817	1	0	0
1930	140576	6663	139844	1.00	11820	1	0	0
1931	140614	6664	139883	1.00	11822	1	0	0
1932	140653	6666	139922	1.00	11825	1	0	0
1933	140693	6668	139961	1.00	11828	1	0	0
1934	140732	6670	140000	1.00	11832	1	0	0
1935	140770	6671	140038	1.00	11837	3	0	0
1936	140802	6673	140070	1.00	11847	8	0	0
1937	140842	6675	140109	1.00	11862	2	0	0
1938	140881	6677	140147	1.00	11886	3	0	0
1939	140918	6678	140183	1.01	11919	6	0	0
1940	140954	6680	140217	1.01	12146	10	0.005	0
1941	140983	6681	140242	1.01	12203	23	0.005	0
1942	141018	6681	140265	1.01	12269	30	0.01	0
1943	141056	6681	140300	1.01	12341	47	0.09	0
1944	140602	6656	139842	1.00	12405	562	0.145	0.004
1945	139822	6614	139058	1.00	12466	929	0.295	0.007
1946	137832	6512	137064	0.98	12511	2194	0.165	0.016
1947	137052	6466	136280	0.97	12620	1072	0.095	0.008
1948	136839	6448	136062	0.97	12813	569	0.115	0.004
1949	136558	6426	135773	0.97	13116	690	0.145	0.005
1950	136122	6396	135323	0.96	13560	906	0.21	0.007
1951	135270	6345	134450	0.95	14128	1401	0.24	0.01
1952	134310	6287	133460	0.95	14724	1619	0.325	0.012
1953	132711	6194	131826	0.93	15069	2398	0.26	0.018
1954	131916	6135	131000	0.92	14941	1775	0.35	0.014
1955	130512	6042	129584	0.91	14203	2564	0.295	0.02

Table 28: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning output (million eggs)	Summary biomass 3+	Relative biomass	Age-0 re-cruits	Estimated total catch (mt)	1-SPR	Exp. rate
1956	129852	5981	128942	0.90	12989	2002	0.41	0.016
1957	128117	5871	127262	0.88	11722	3198	0.375	0.025
1958	126915	5791	126135	0.87	10675	2739	0.315	0.022
1959	126275	5750	125569	0.87	10004	2154	0.21	0.017
1960	126415	5761	125766	0.87	9845	1264	0.34	0.01
1961	125275	5728	124657	0.86	10252	2367	0.43	0.019
1962	123003	5651	122386	0.85	10774	3327	0.515	0.027
1963	119505	5519	118864	0.83	10117	4420	0.605	0.037
1964	114480	5309	113829	0.80	8593	5877	0.635	0.052
1965	109077	5071	108480	0.76	7553	6231	0.715	0.057
1966	102042	4747	101530	0.71	7030	7828	0.91	0.077
1967	83867	3877	83412	0.58	6588	18969	0.9	0.227
1968	70229	3212	69803	0.48	6869	14651	0.87	0.21
1969	61697	2793	61280	0.42	9376	9712	0.52	0.158
1970	60813	2747	60334	0.41	14602	2183	0.535	0.036
1971	59909	2700	59263	0.41	7299	2300	0.485	0.039
1972	59604	2671	58826	0.40	5143	1905	0.485	0.032
1973	59479	2639	59064	0.40	5037	1888	0.585	0.032
1974	58489	2568	58173	0.39	5064	2643	0.545	0.045
1975	57748	2516	57433	0.38	6344	2275	0.37	0.04
1976	57966	2527	57636	0.38	5048	1183	0.43	0.021
1977	57717	2541	57341	0.38	6659	1507	0.38	0.026
1978	57590	2572	57256	0.39	4884	1263	0.505	0.022
1979	56599	2555	56214	0.38	5599	1998	0.425	0.036
1980	56021	2544	55707	0.38	5514	1507	0.465	0.027
1981	55123	2513	54778	0.38	5878	1723	0.41	0.031
1982	54527	2491	54173	0.37	8884	1380	0.345	0.025
1983	54257	2482	53841	0.37	10035	1057	0.46	0.02
1984	53504	2444	52943	0.37	7130	1624	0.47	0.031
1985	52905	2402	52332	0.36	7183	1658	0.435	0.032
1986	52705	2368	52266	0.36	5839	1412	0.43	0.027
1987	52596	2335	52171	0.35	7017	1375	0.375	0.026
1988	52807	2320	52421	0.35	9406	1107	0.435	0.021
1989	52778	2302	52302	0.35	10569	1379	0.45	0.026
1990	52787	2295	52177	0.35	14046	1469	0.38	0.028
1991	53355	2308	52663	0.35	6385	1123	0.45	0.021
1992	53782	2305	53046	0.35	3456	1478	0.465	0.028
1993	54258	2292	53911	0.34	3469	1567	0.435	0.029

Table 28: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning output (million eggs)	Summary biomass 3+	Relative biomass	Age-0 re-cruits	Estimated total catch (mt)	1-SPR	Exp. rate
1994	54699	2290	54469	0.34	9862	1418	0.385	0.026
1995	55205	2308	54888	0.35	9012	1180	0.325	0.022
1996	55849	2354	55266	0.35	3880	952	0.3	0.017
1997	56573	2418	56100	0.36	3814	879	0.25	0.016
1998	57307	2487	57070	0.37	2935	716	0.245	0.013
1999	57798	2535	57535	0.38	19539	721	0.2	0.013
2000	58403	2574	57923	0.39	30595	562	0.065	0.01
2001	59724	2630	58388	0.40	8937	160	0.11	0.003
2002	61725	2685	60195	0.40	5185	293	0.07	0.005
2003	64401	2736	63916	0.41	2597	179	0.06	0.003
2004	66917	2772	66628	0.42	6944	155	0.055	0.002
2005	69212	2810	68989	0.42	3345	147	0.03	0.002
2006	71239	2896	70867	0.44	3865	76	0.03	0.001
2007	72918	3046	72703	0.46	3723	85	0.05	0.001
2008	74370	3211	73810	0.48	133246	157	0.045	0.002
2009	76575	3346	74550	0.50	4814	133	0.055	0.002
2010	80990	3438	74832	0.52	8279	190	0.055	0.003
2011	88763	3500	88389	0.53	16107	181	0.02	0.002
2012	95774	3545	95169	0.53	2113	61	0.015	0.001
2013	102857	3584	102021	0.54	29279	58	0.015	0.001
2014	109633	3727	109119	0.56	5078	57	0.015	0.001
2015	115762	4118	114333	0.62	10096	55	0.015	0
2016	121528	4620	121131	0.70	10520	59	0.015	0
2017	126167	5047	125534	0.76	10816	65	0.055	0.001
2018	129828	5369	129171	0.81	11017	-	-	-
2019	132735	5625	132062	0.85	11166	-	-	-
2020	130783	5657	130099	0.85	11184	-	-	-
2021	128376	5654	127685	0.85	11182	-	-	-
2022	125691	5606	124999	0.84	11155	-	-	-
2023	122860	5528	122169	0.83	11110	-	-	-
2024	119983	5431	119294	0.82	11054	-	-	-
2025	117128	5324	116442	0.80	10990	-	-	-
2026	114343	5211	113661	0.78	10921	-	-	-
2027	111655	5096	110977	0.77	10848	-	-	-
2028	109081	4981	108407	0.75	10772	-	-	-

tab:Timeseries_mod1

Table 29: Projection of potential OFL, spawning biomass, and depletion for the base case model.

tab:Forecast_mod1

Year	OFL (mt)	ACL (mt)	Age 3+ biomass (mt)	Spawning Output	Depletion
2017	4306	281	125534	5047	0.76
2018	4559	281	129171	5369	0.81
2019	4719	4515	132062	5625	0.85
2020	4654	4453	130099	5657	0.85
2021	4552	4356	127685	5654	0.85
2022	4431	4240	124999	5606	0.85
2023	4302	4116	122169	5528	0.83
2024	4172	3992	119294	5431	0.82
2025	4048	3873	116442	5324	0.80
2026	3932	3762	113661	5211	0.79
2027	3826	3660	110977	5096	0.77
2028	3727	3566	108407	4981	0.75

Table 30: Summary of 10-year projections beginning in 2019 for alternate states of nature based on an axis of uncertainty for the base model. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. An entry of "–" indicates that the stock is driven to very low abundance under the particular scenario.

tab:Decision_table_mod1_back

			States of nature					
			Low State of Nature		Base State of Nature		High State of Nature	
	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
Catch Option 1	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
Catch Option 2	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
Catch Option 3	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-
Average Catch	2019	-	-	-	-	-	-	-
	2020	-	-	-	-	-	-	-
	2021	-	-	-	-	-	-	-
	2022	-	-	-	-	-	-	-
	2023	-	-	-	-	-	-	-
	2024	-	-	-	-	-	-	-
	2025	-	-	-	-	-	-	-
	2026	-	-	-	-	-	-	-
	2027	-	-	-	-	-	-	-
	2028	-	-	-	-	-	-	-

9 Figures

figures

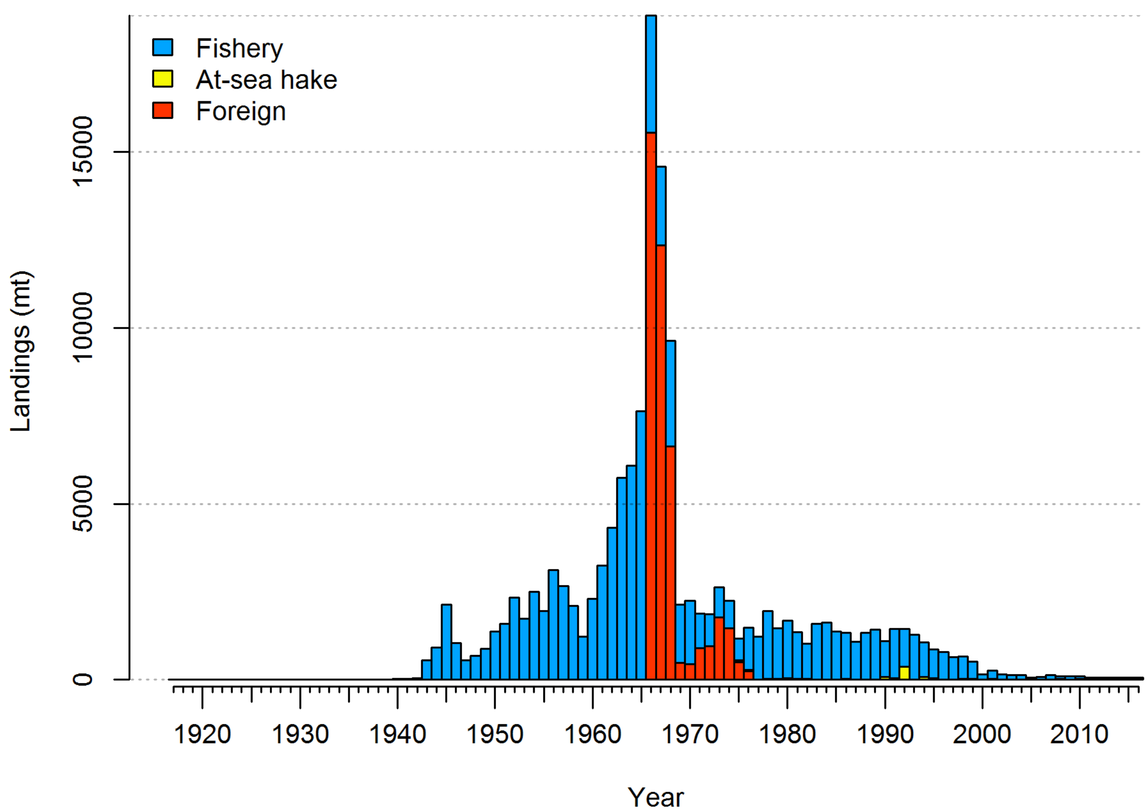

Figure 1: Total catches Pacific ocean perch through 2016. fig:Catch

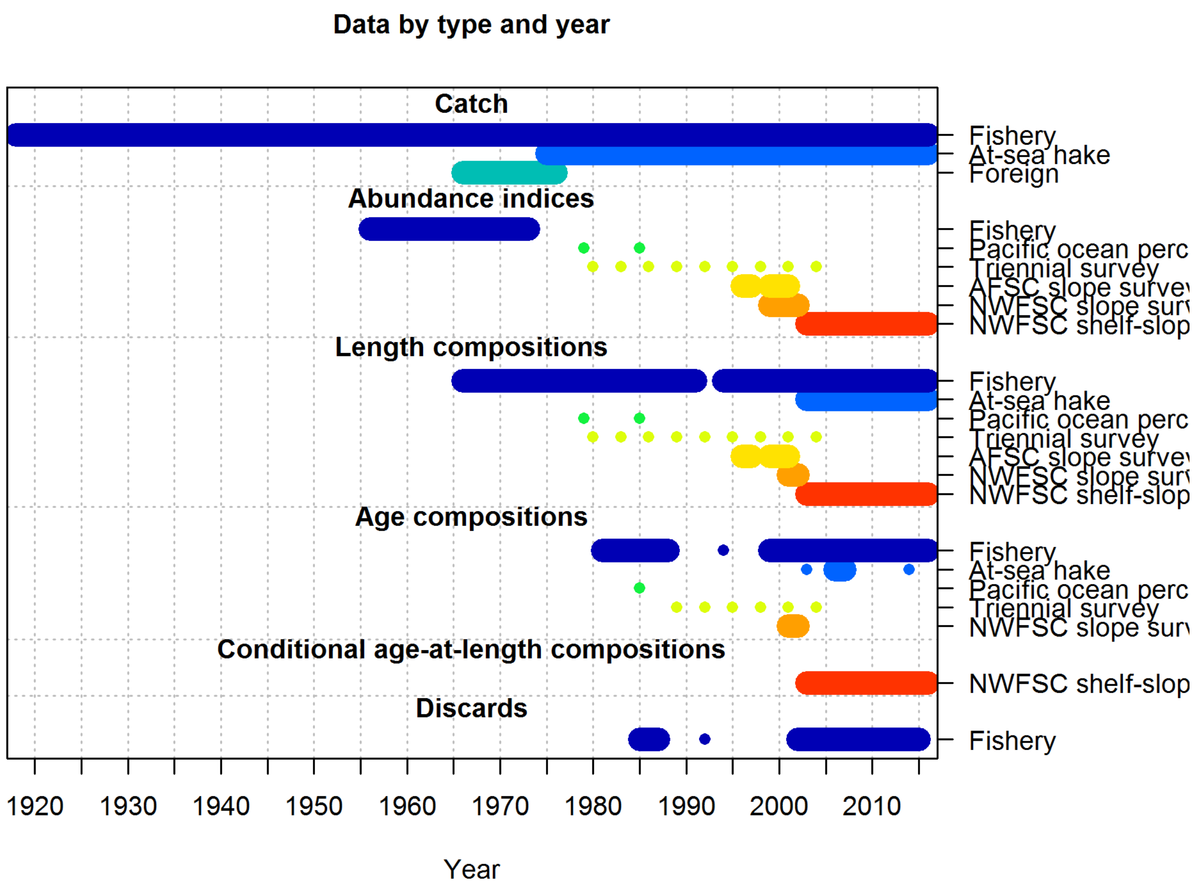

Figure 2: Summary of data sources used in the base model. fig:data_plot

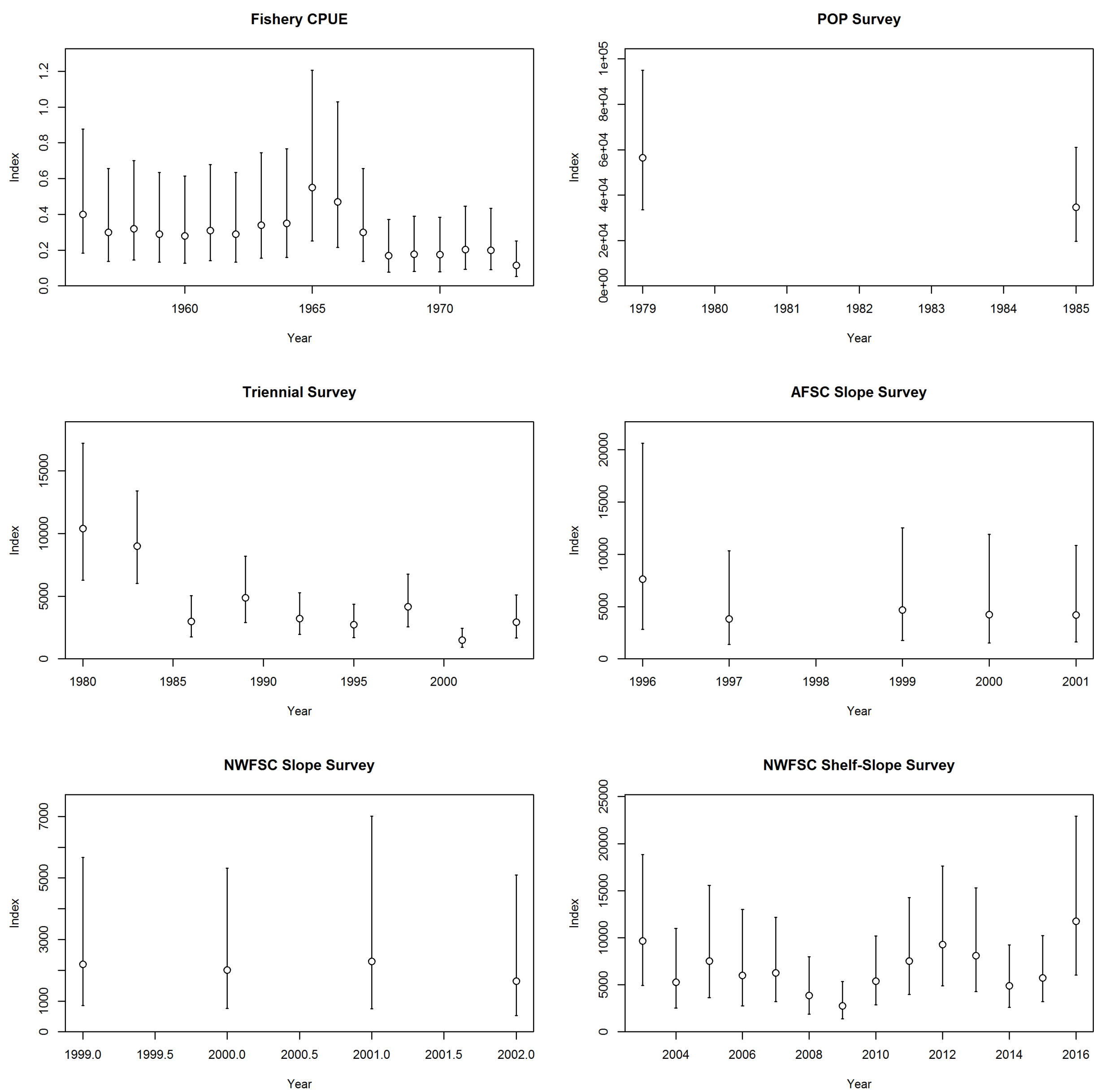

Figure 3: Fishery-dependent and fishery-independent indices for Pacific ocean perch. fig:indices

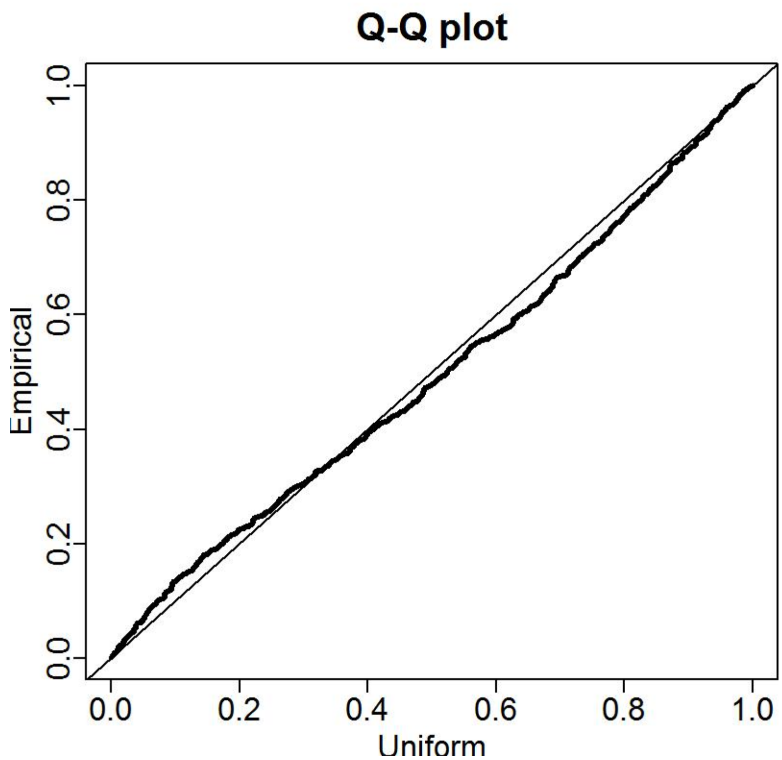

Figure 4: Q-Q plots for the VAST lognormal distribution for the NWFSC shelf-slope survey. fig:nw_qq

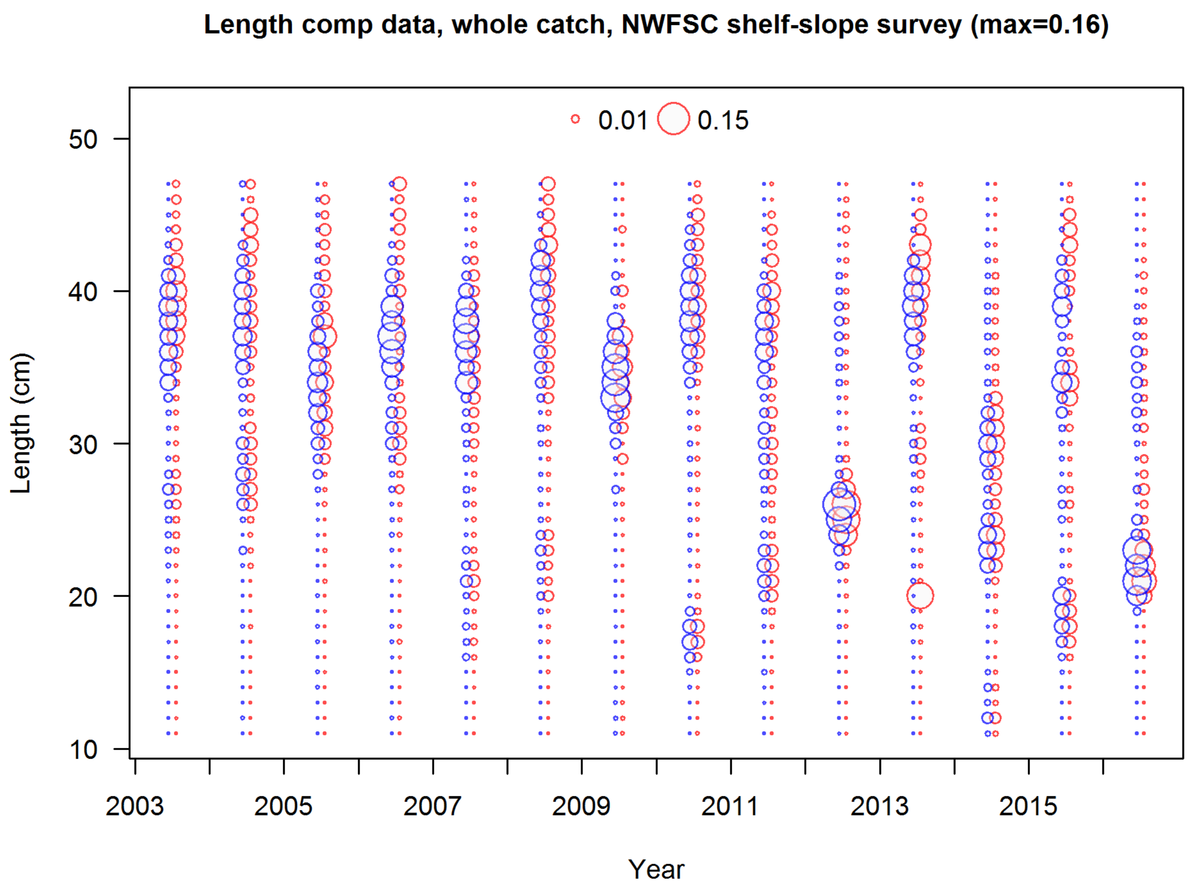

Figure 5: NWFSC shelf-slope survey length frequency distributions for Pacific ocean perch. fig:nw_Length

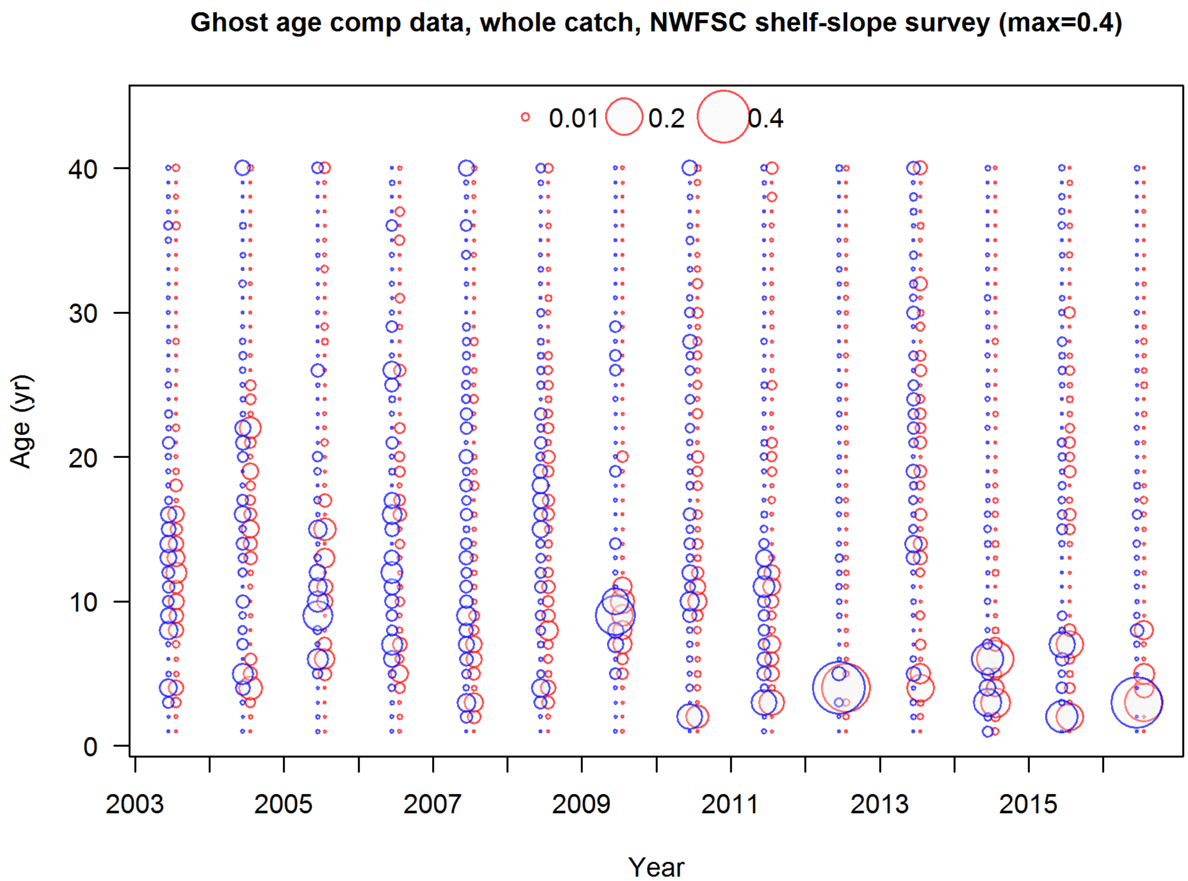

Figure 6: NWFSC shelf-slope survey age frequency distributions for Pacific ocean perch. fig:nw_Age

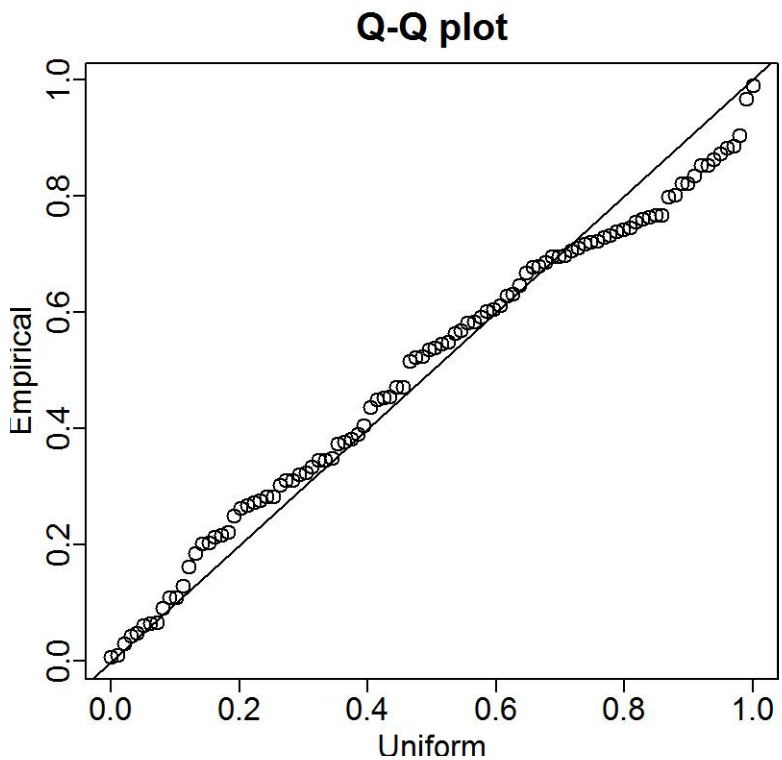

Figure 7: Q-Q plots for the VAST lognormal distribution for the NWFSC slope survey. fig:nw_slope_q

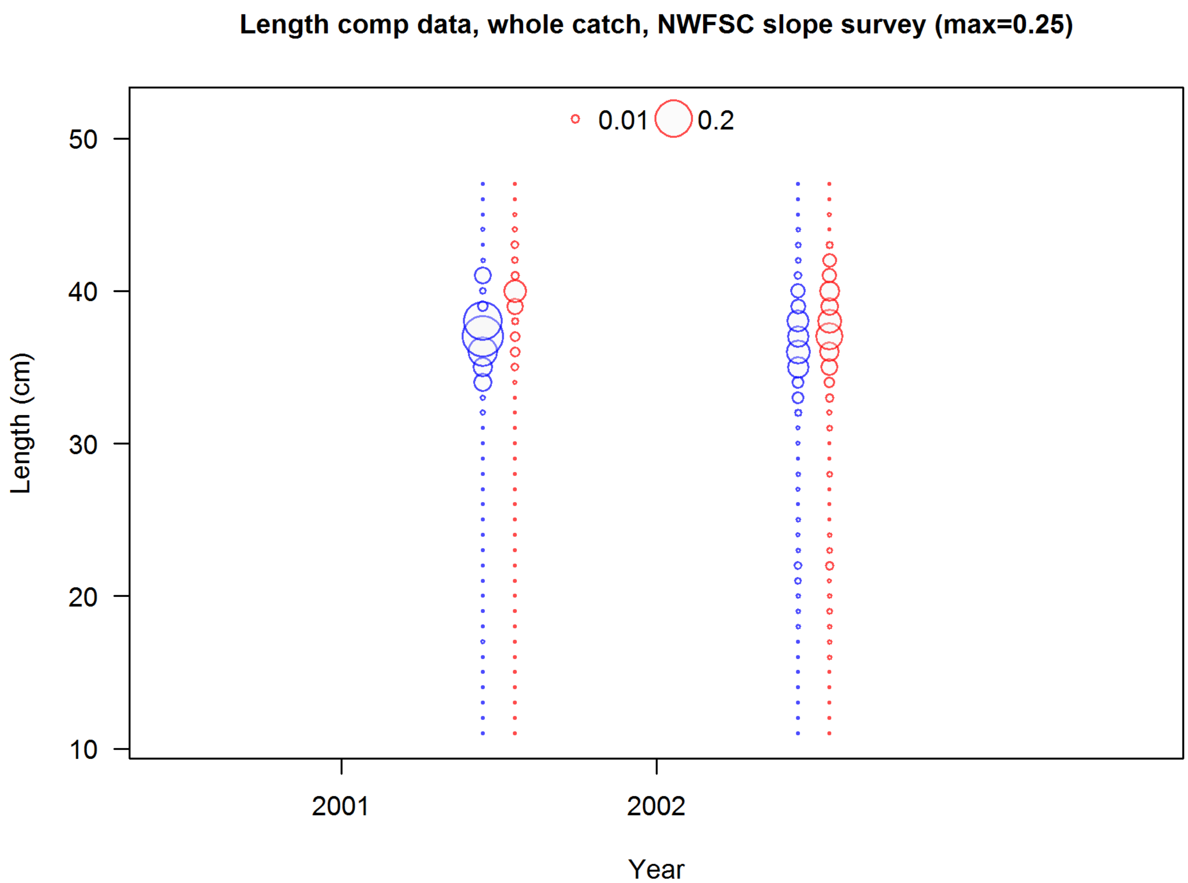

Figure 8: NWFSC slope survey length frequency distributions for Pacific ocean perch. fig:nw_slope_Le

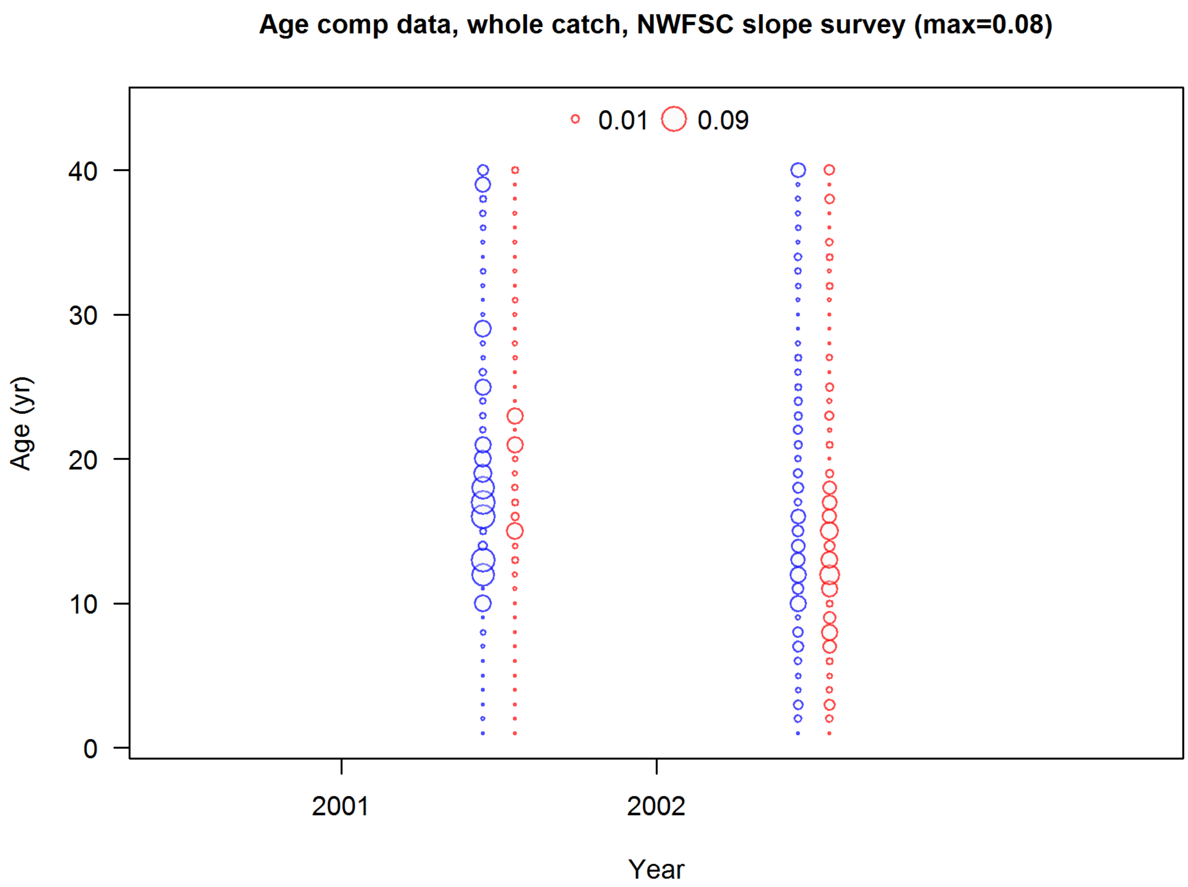

Figure 9: NWFSC slope survey age frequency distributions for Pacific ocean perch. fig:nw_slope_Age

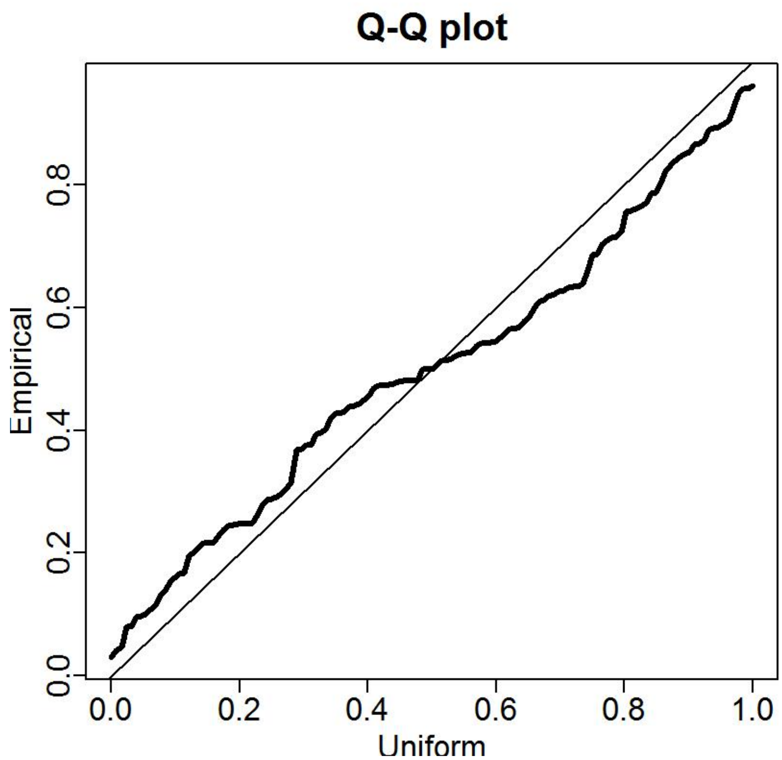

Figure 10: Q-Q plots for the VAST lognormal distribution for the AFSC slope survey. fig:afsc_qq

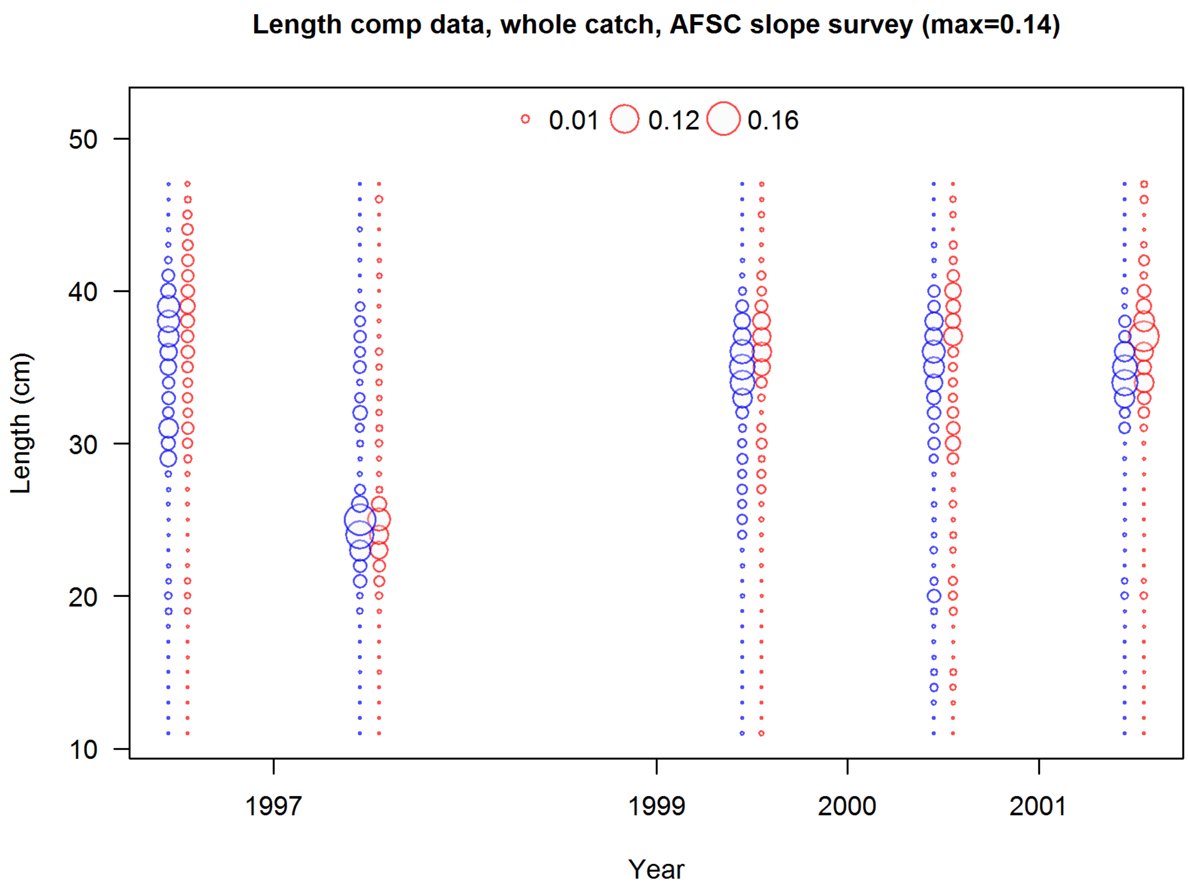

Figure 11: AFSC slope survey length frequency distributions for Pacific ocean perch. fig:afsc_Length

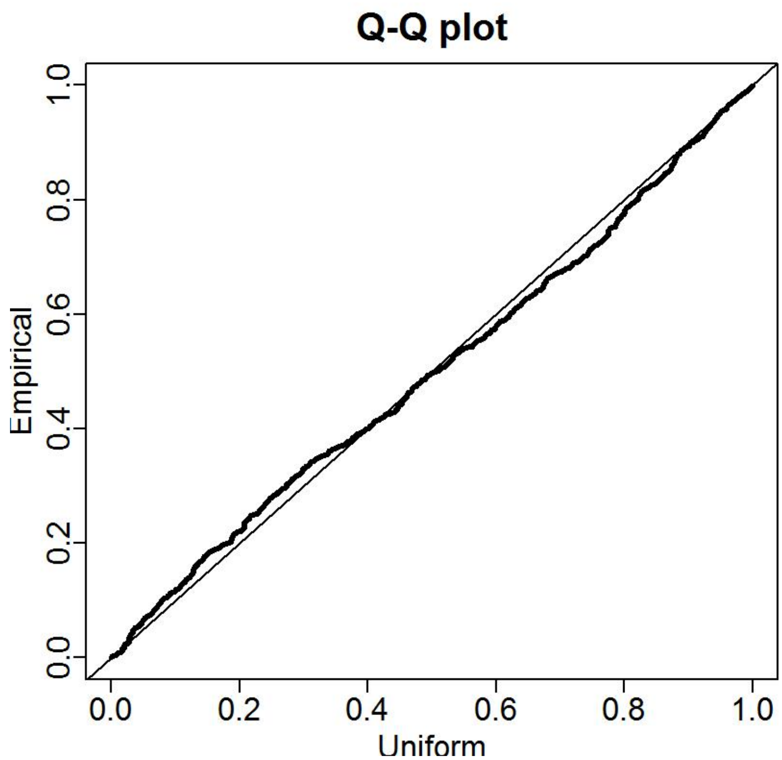

Figure 12: Q-Q plots for the VAST lognormal distribution for the Triennial survey. fig:tri_qq

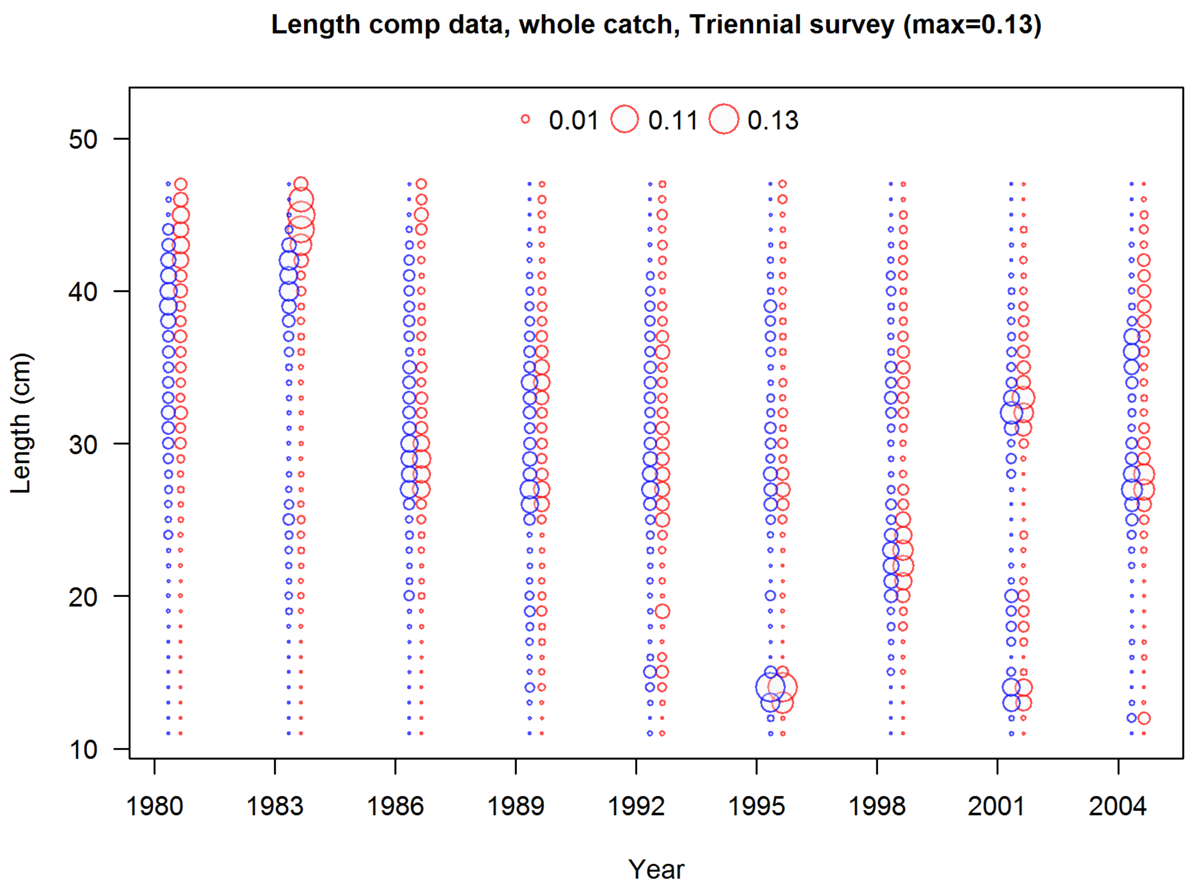

Figure 13: Triennial survey length frequency distributions for Pacific ocean perch. fig:Tri_Length

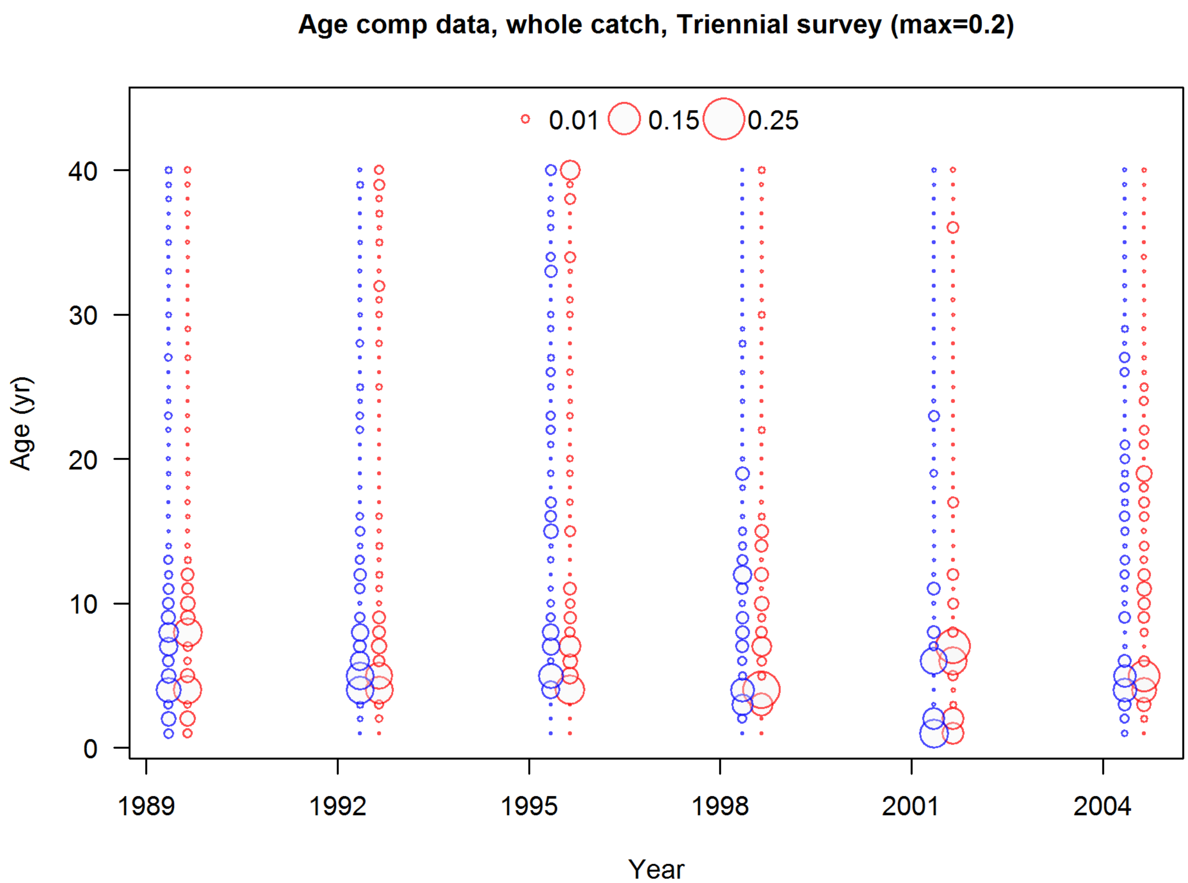

Figure 14: Triennial survey age frequency distributions for Pacific ocean perch. fig:Tri_Age

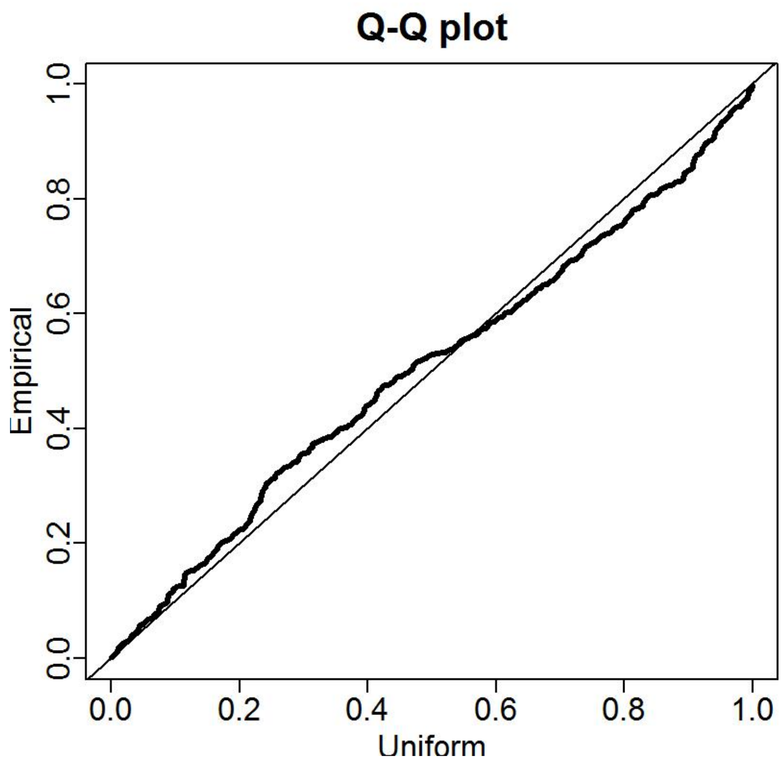

Figure 15: Q-Q plots for the VAST lognormal distribution for the Pacific ocean perch survey.
fig:pop_qq

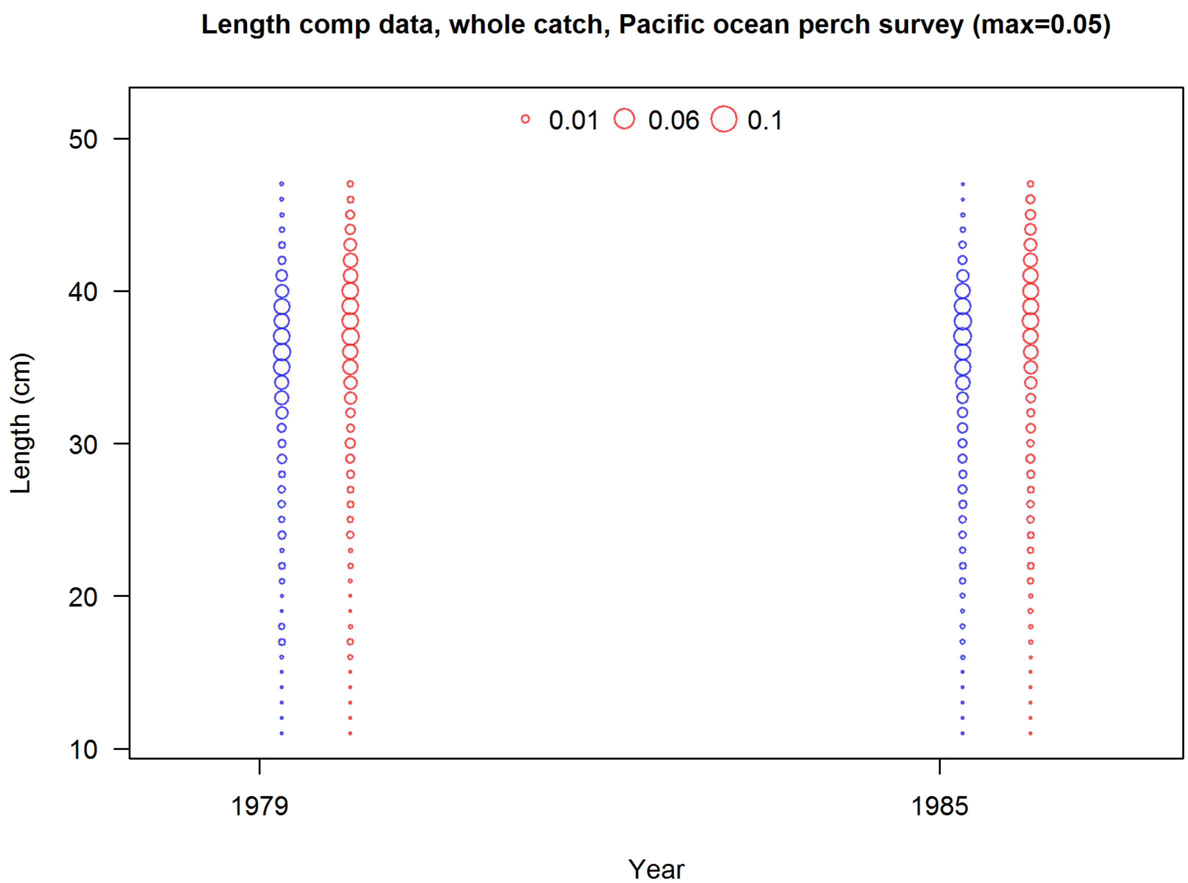

Figure 16: Pacific ocean perch survey length frequency distributions for Pacific ocean perch. fig:POP_Lengt

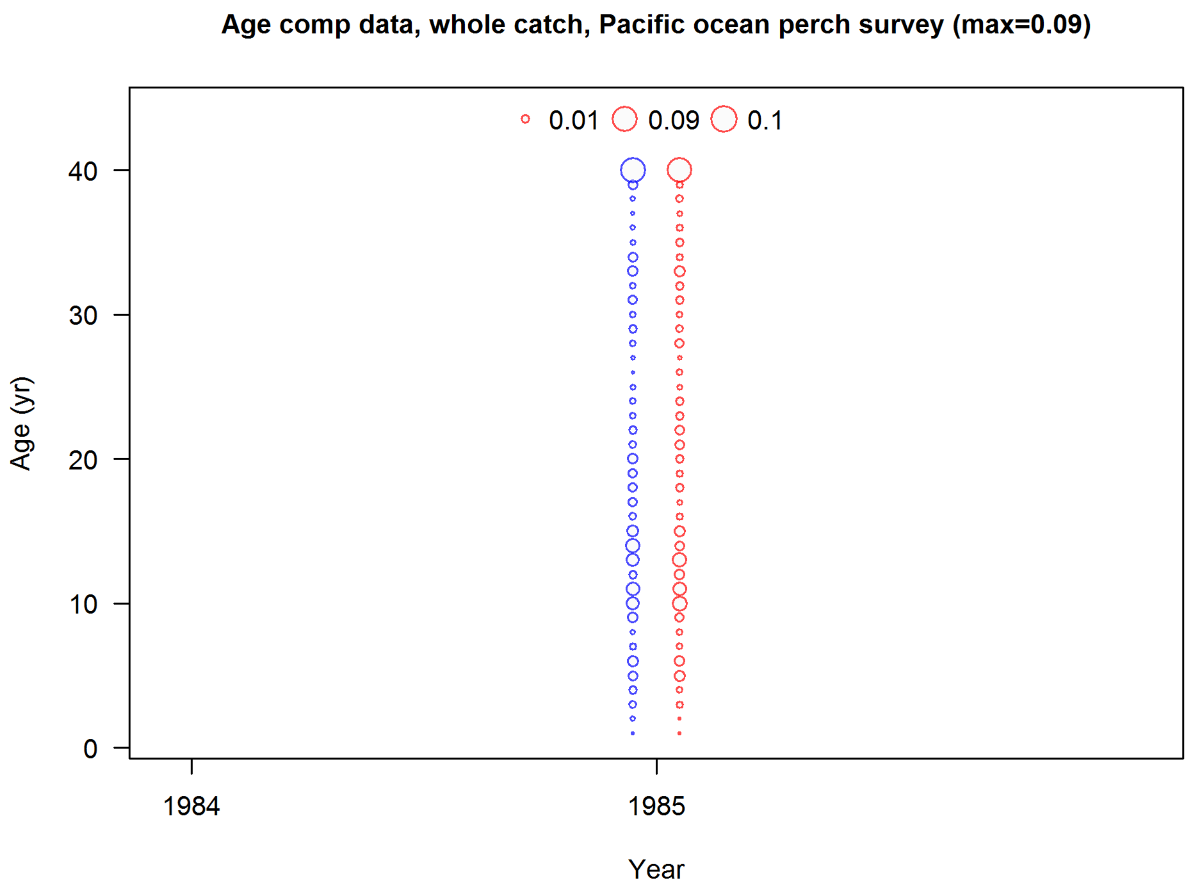

Figure 17: Pacific ocean perch survey age frequency distributions for Pacific ocean perch. fig:POP_Age

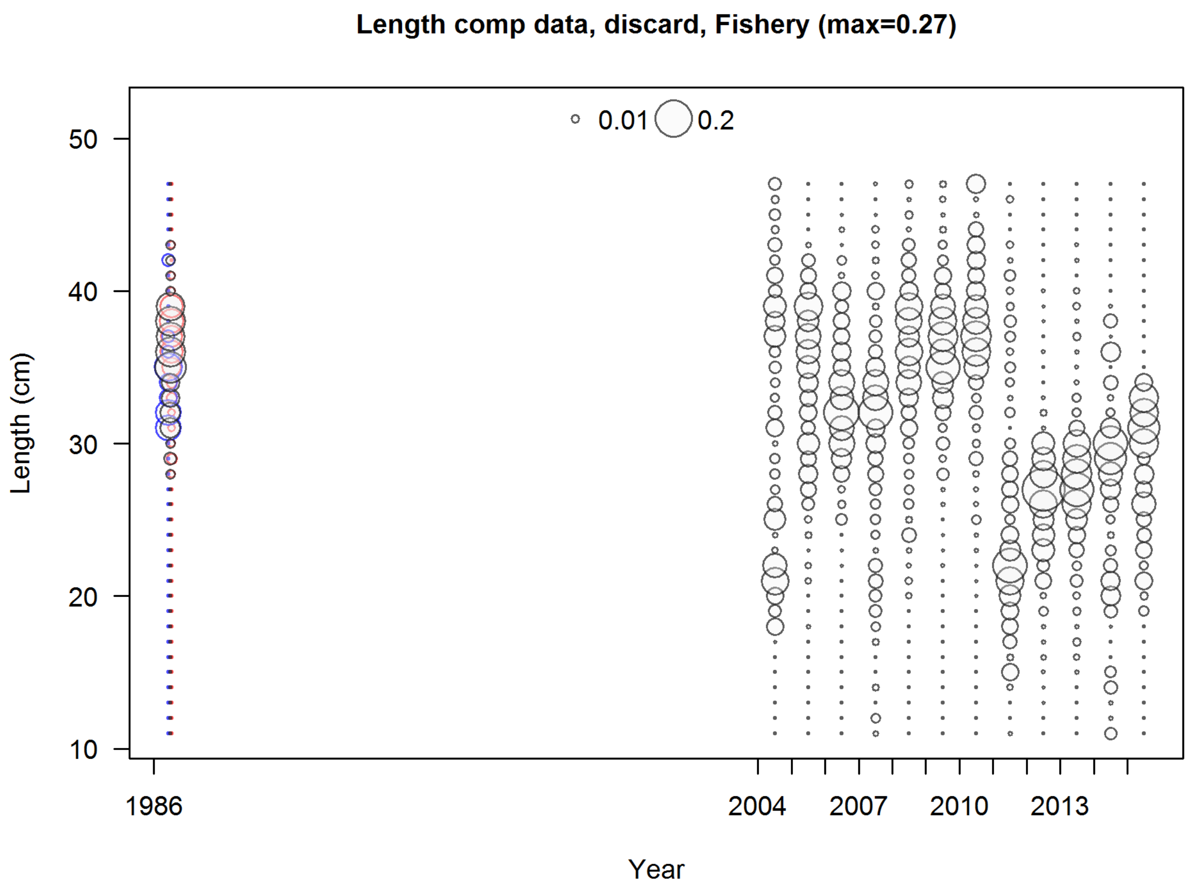

Figure 18: Discard length frequency distributions from WCGOP for Pacific ocean perch. fig:WCGOP_disc

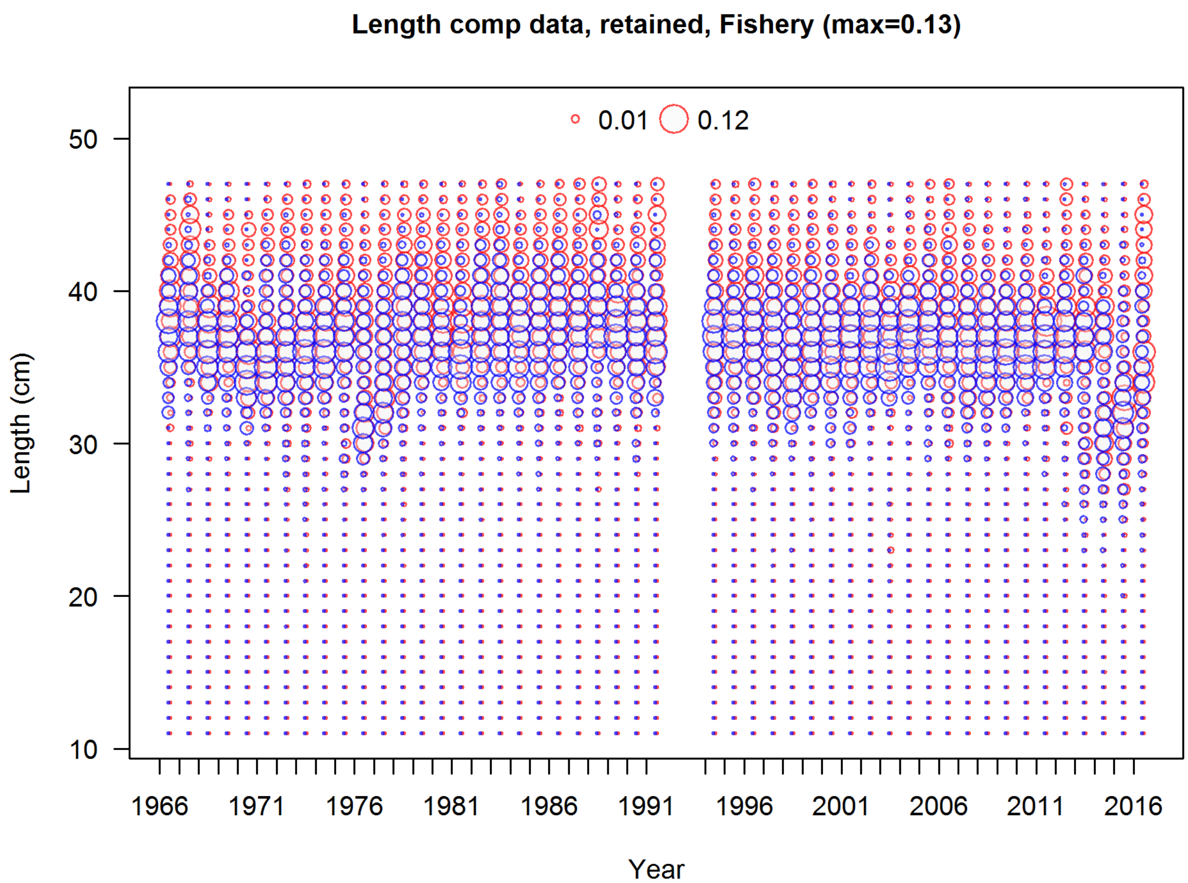

Figure 19: Commercial fishery length frequency distributions for Pacific ocean perch. fig:Comm_Length

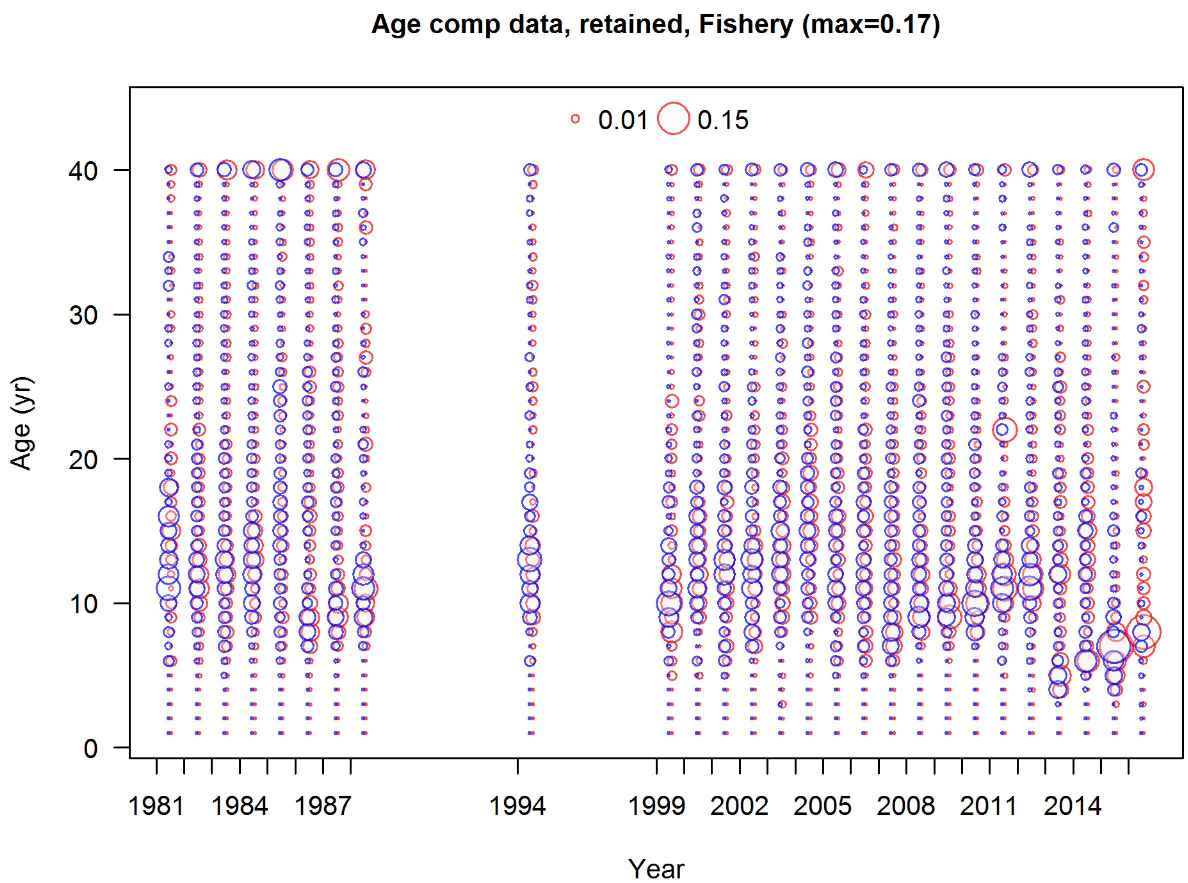

Figure 20: Commercial fishery age frequency distributions for Pacific ocean perch. fig:Comm_Age

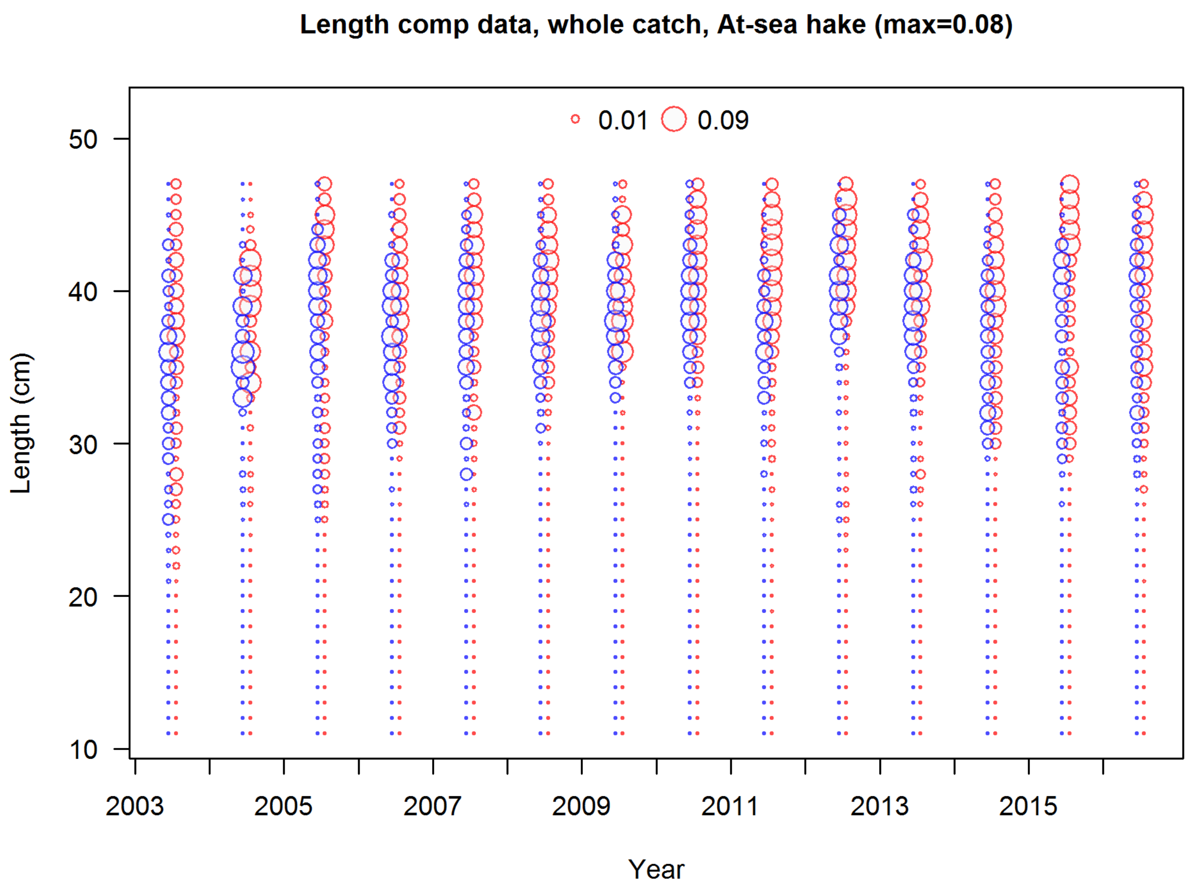

Figure 21: At-Sea hake fishery length frequency distributions for Pacific ocean perch. fig:ASHOP_Lengt

Figure 22: At-Sea hake fishery age frequency distributions for Pacific ocean perch. fig:ASHOP_Age

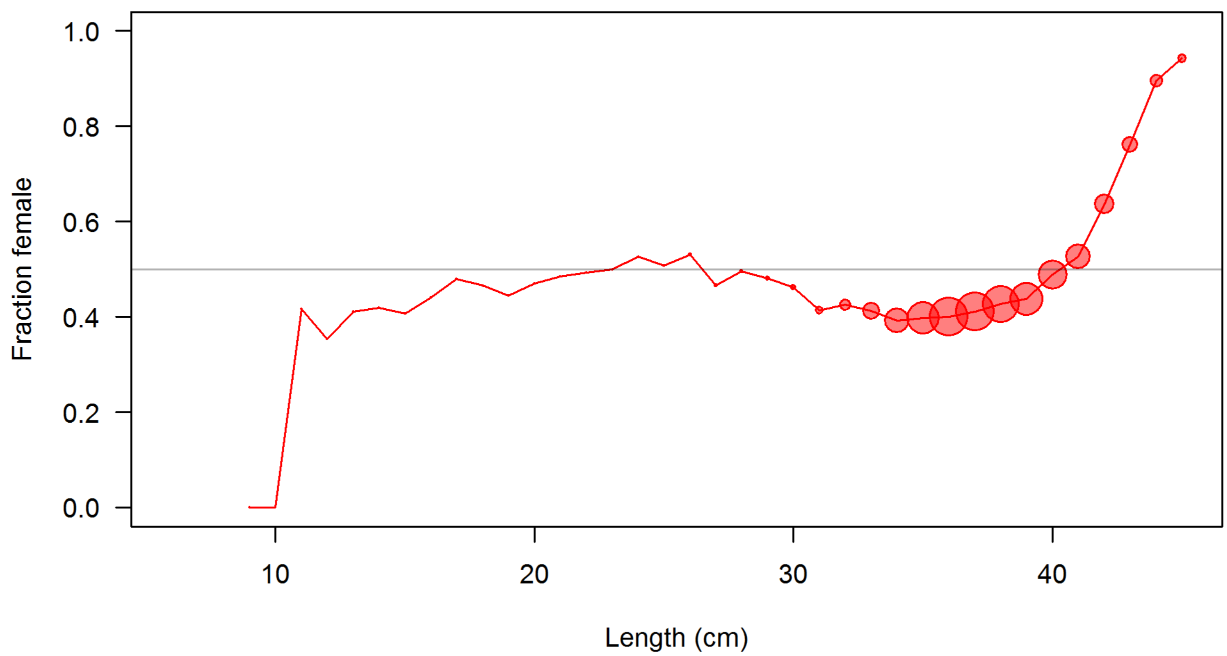

Figure 23: The estimated sex ratio of Pacific ocean perch at length from all biological data sources. fig:sexratio

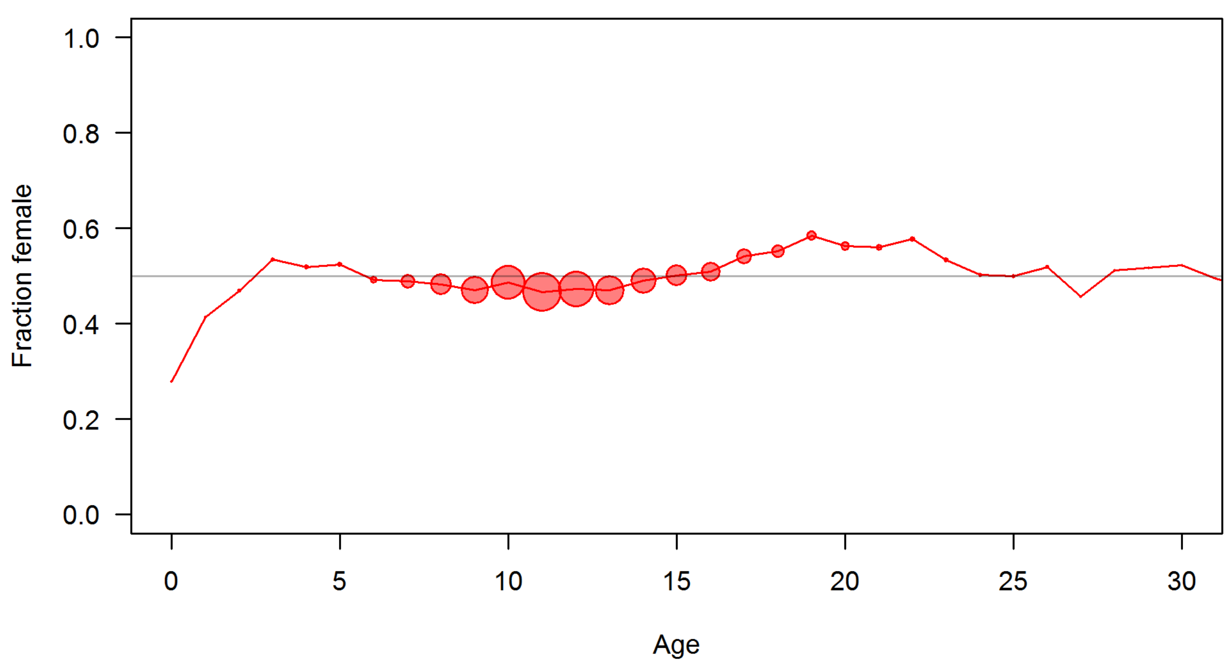

Figure 24: The estimated sex ratio of Pacific ocean perch at age from all biological data sources. fig:sexratio_Age

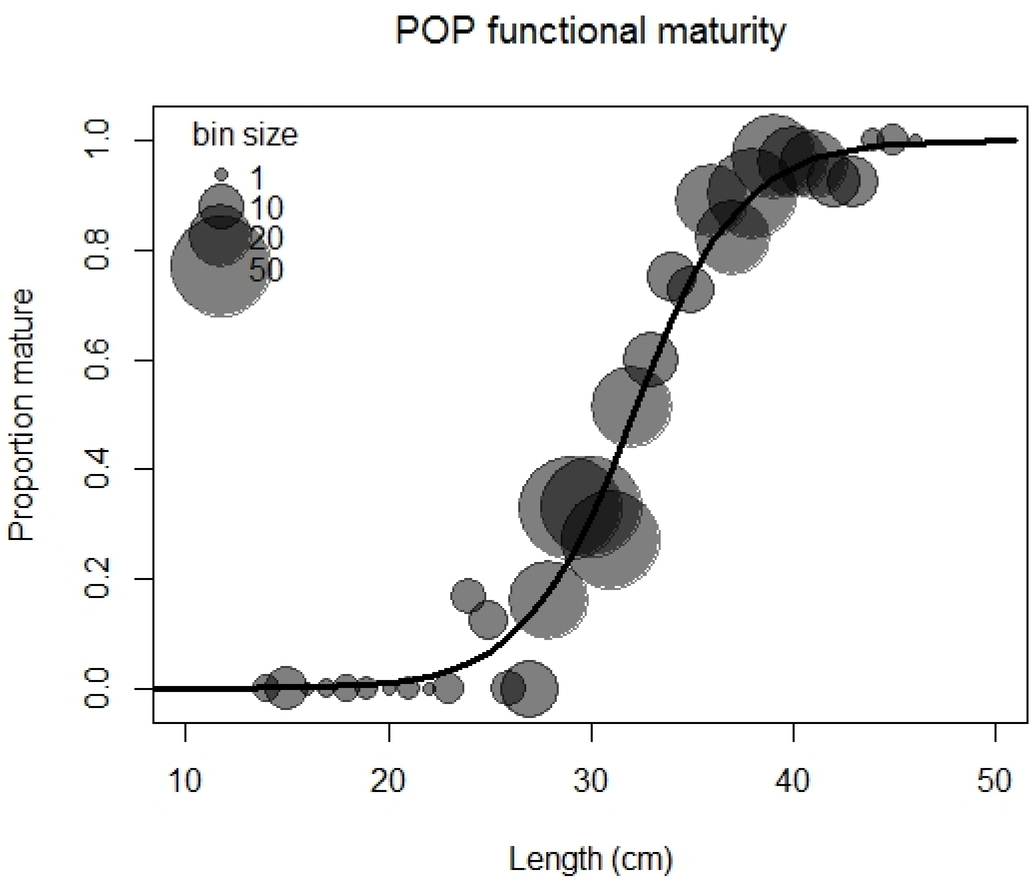

Figure 25: The estimated functional maturity of Pacific ocean perch at length. fig:mat

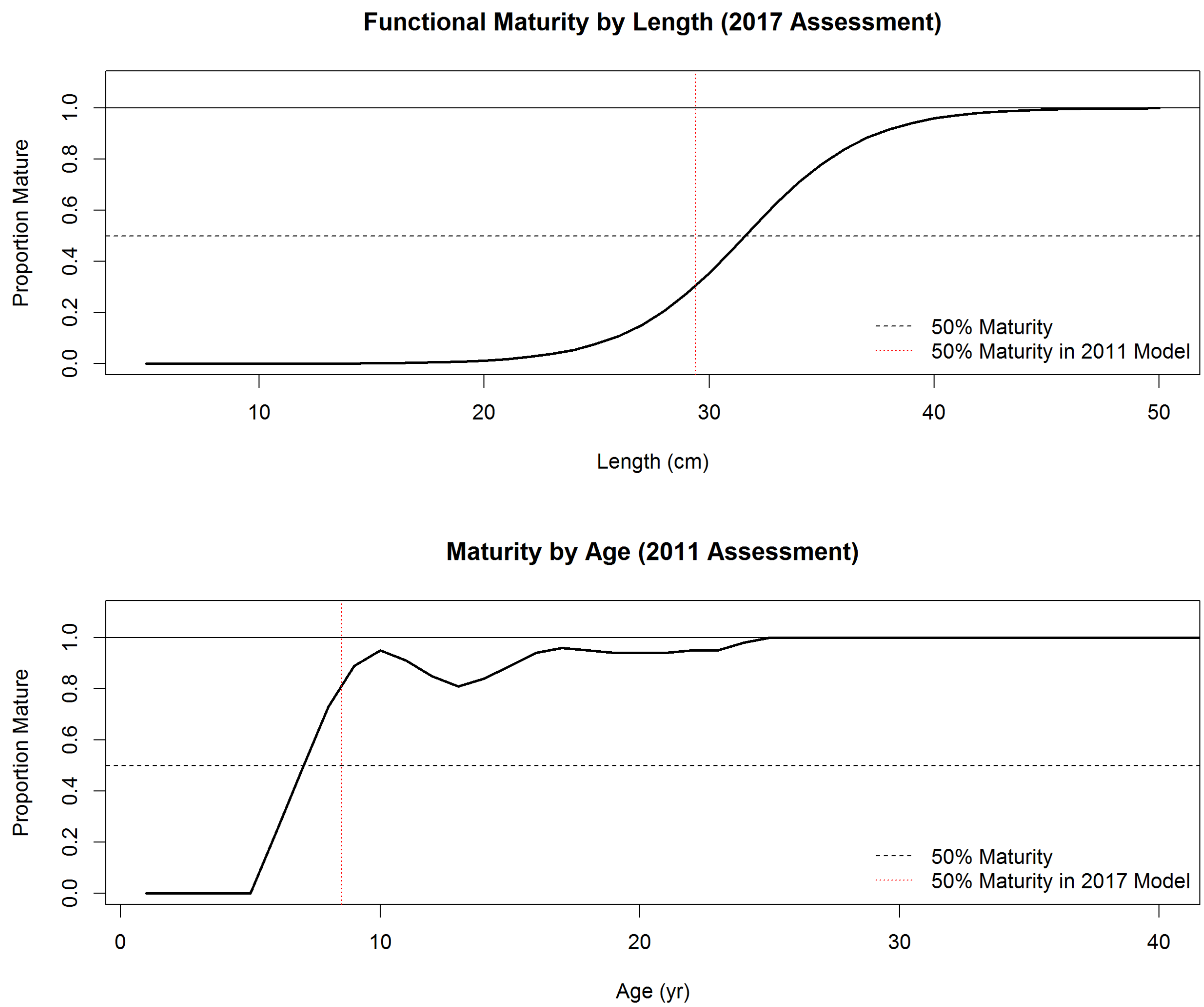

Figure 26: Comparison between estimated maturity-at-length used in this assessment and maturity-at-age applied in the 2011 assessment of Pacific ocean perch. fig:mat_compare

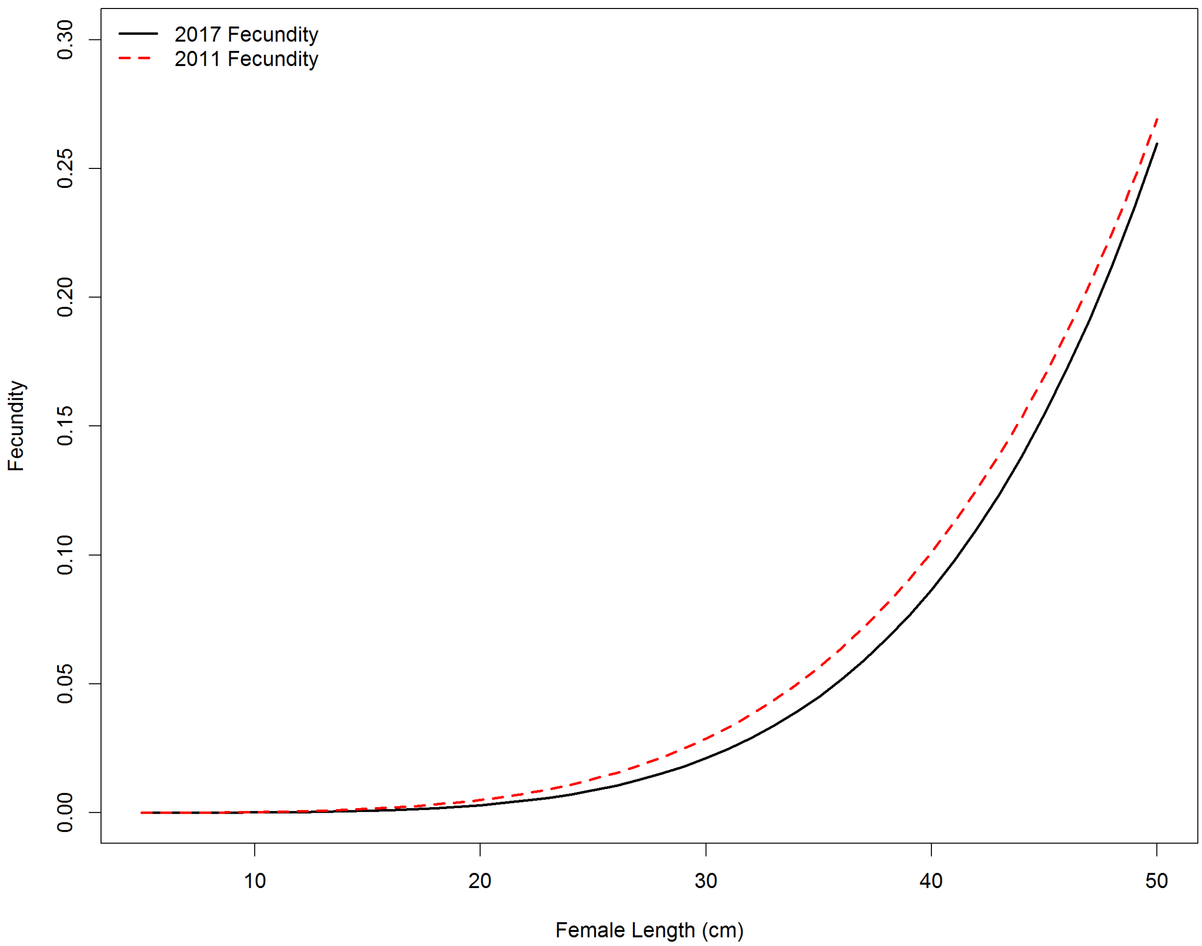

Figure 27: Fecundity at length of Pacific ocean perch in the base model and a comparison of the fecundity in the 2011 assessment. fig:fecundity

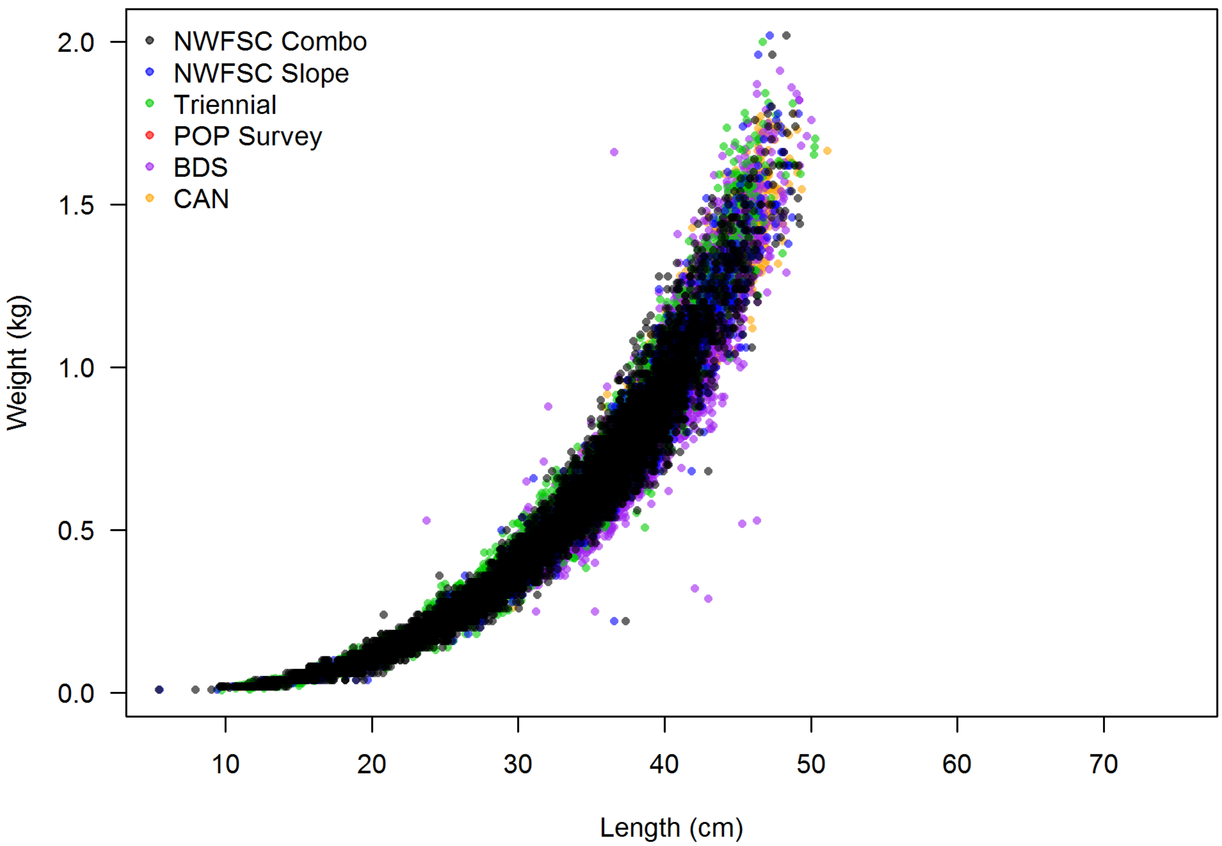

Figure 28: Weight-at-length for Pacific ocean perch from all data sources. fig:Wt_len

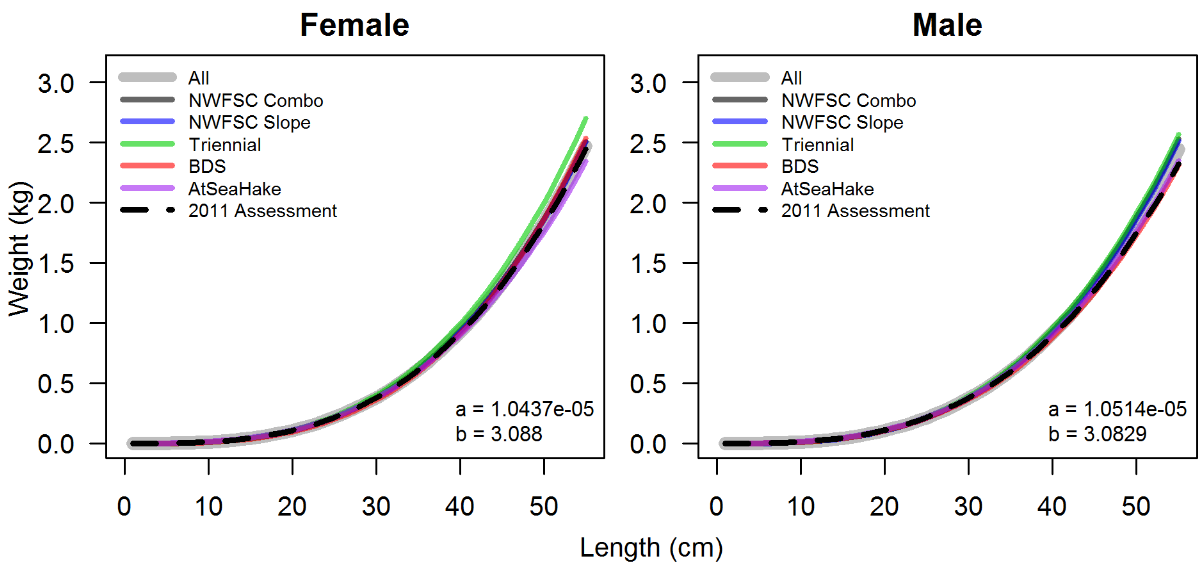

Figure 29: Estimated weight-at-length for Pacific ocean perch from all data sources. fig:Wt_len_pred

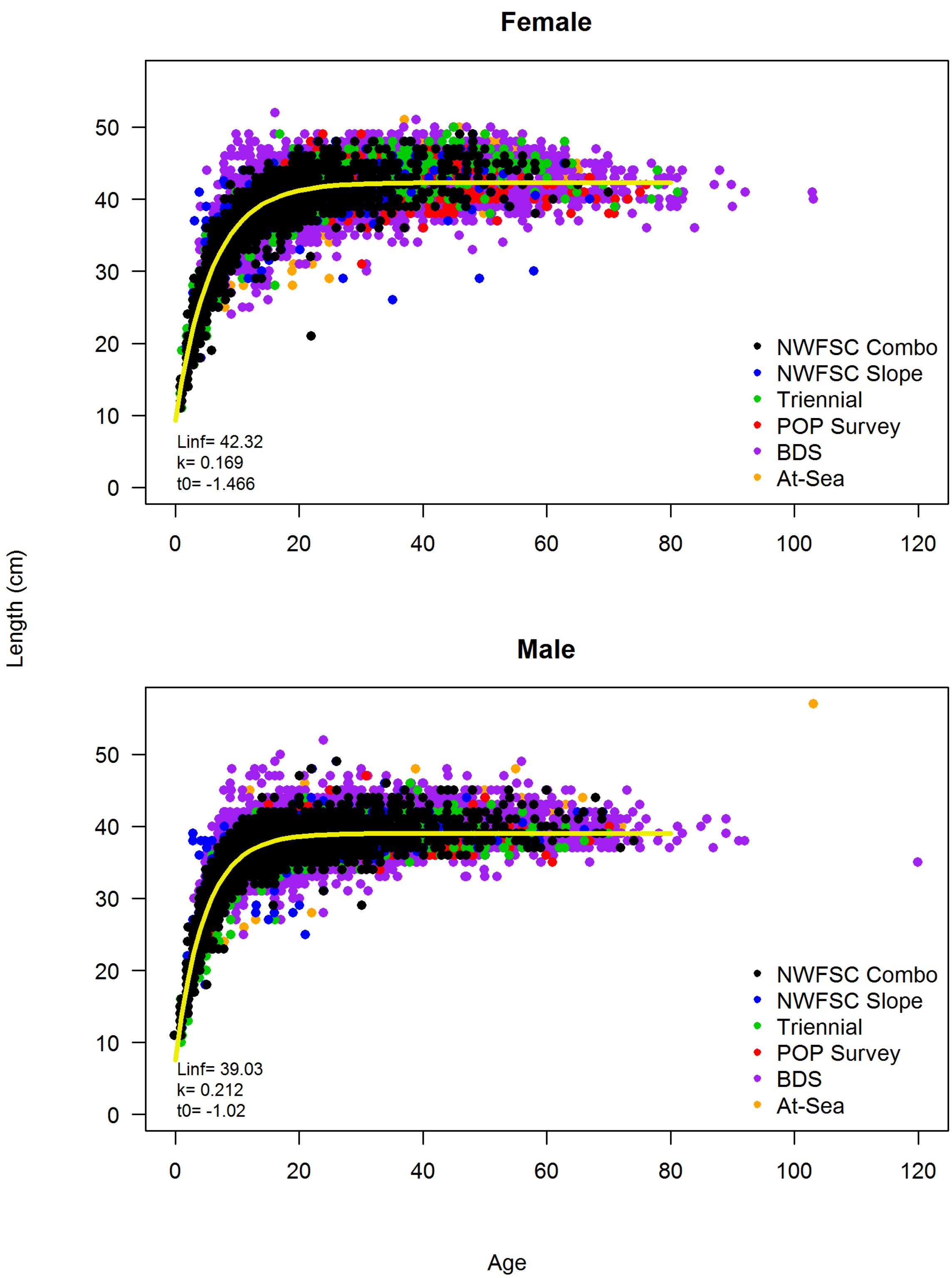

Figure 30: Estimated length-at-age for Pacific ocean perch from all data sources. fig:Len_Age

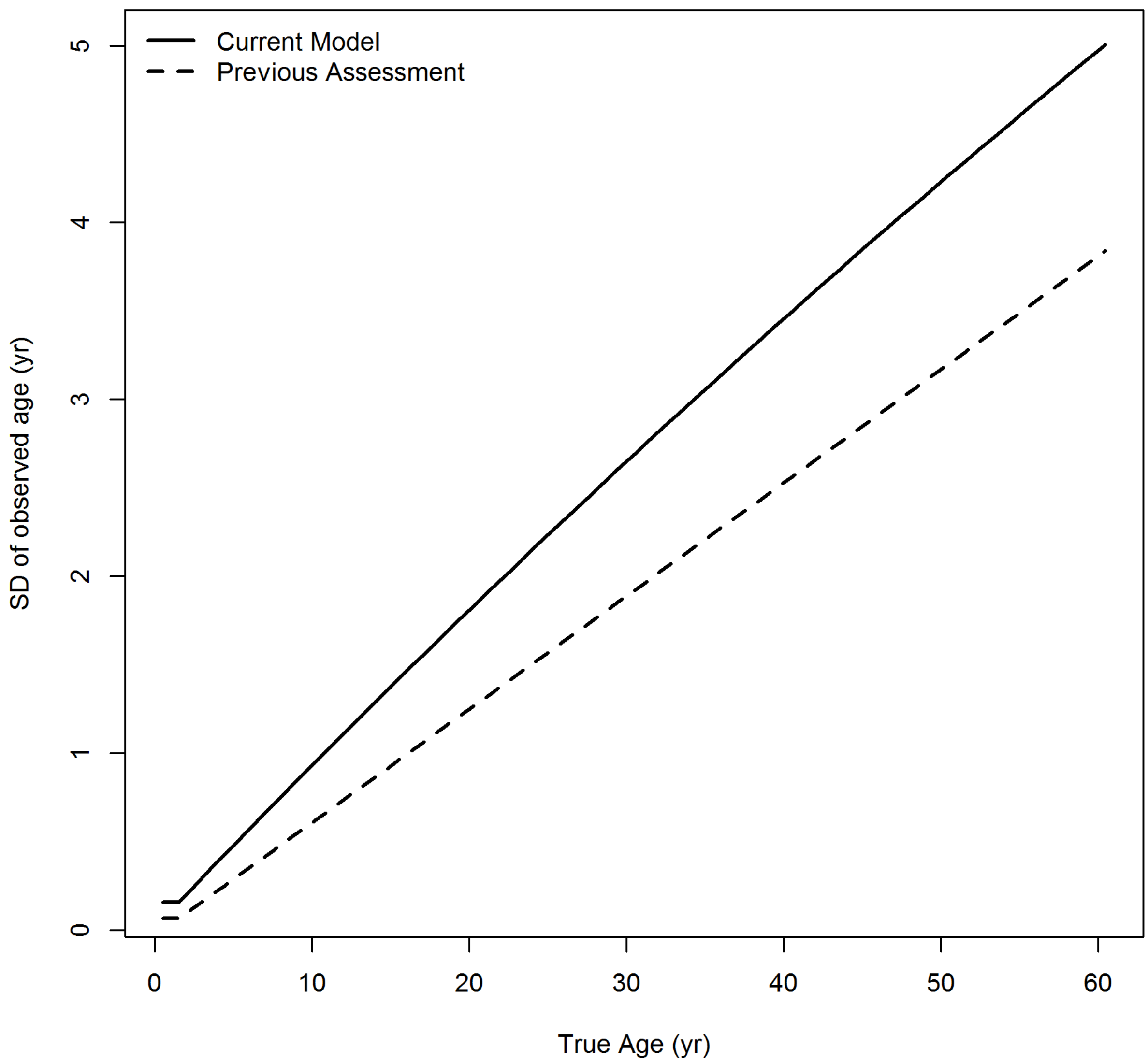

Figure 31: The estimated ageing error used in this assessment compared to the ageing error assumed in the previous assessment for Pacific ocean perch. fig:Age_Error

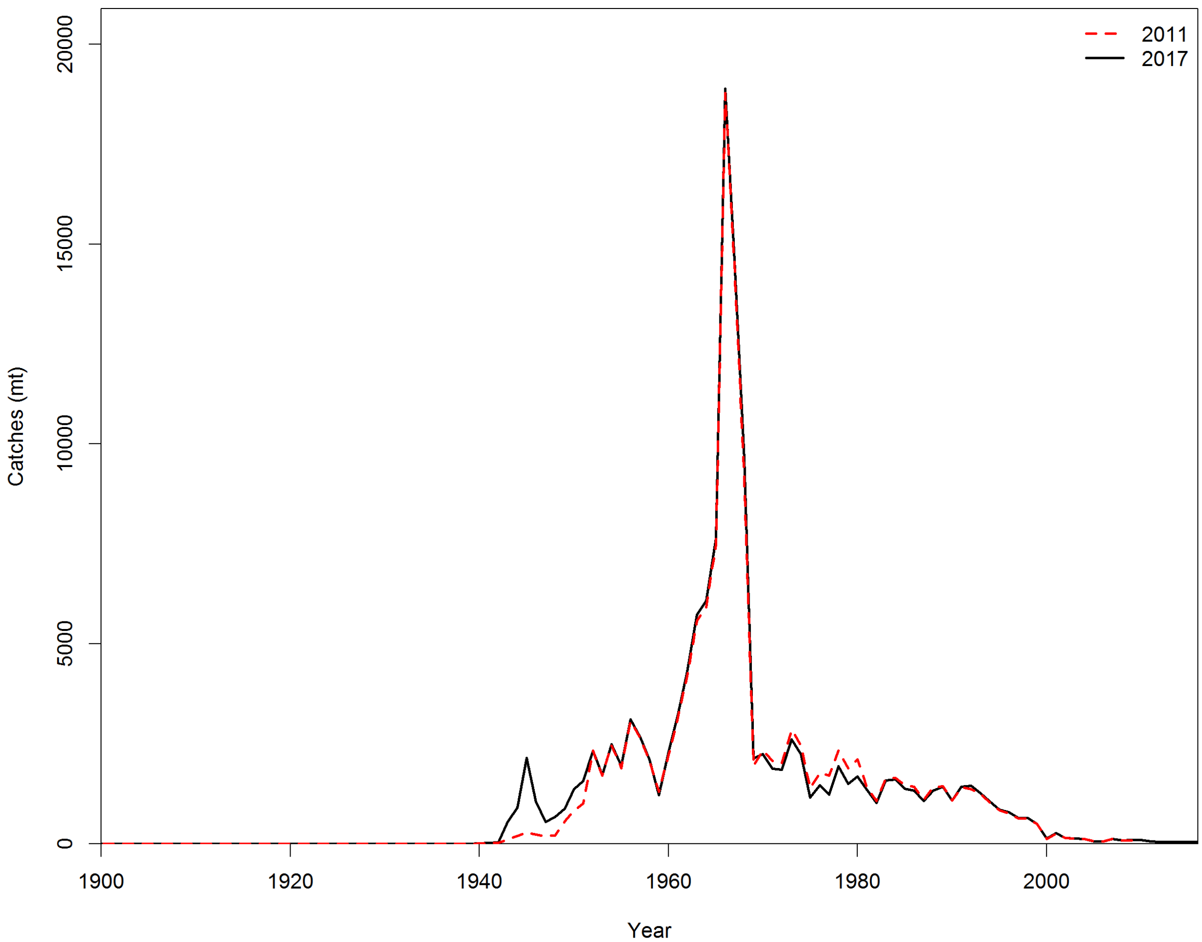

Figure 32: Comparison of the catches assumed by this assessment and the previous assessment for Pacific ocean perch. fig:Catch_Compare

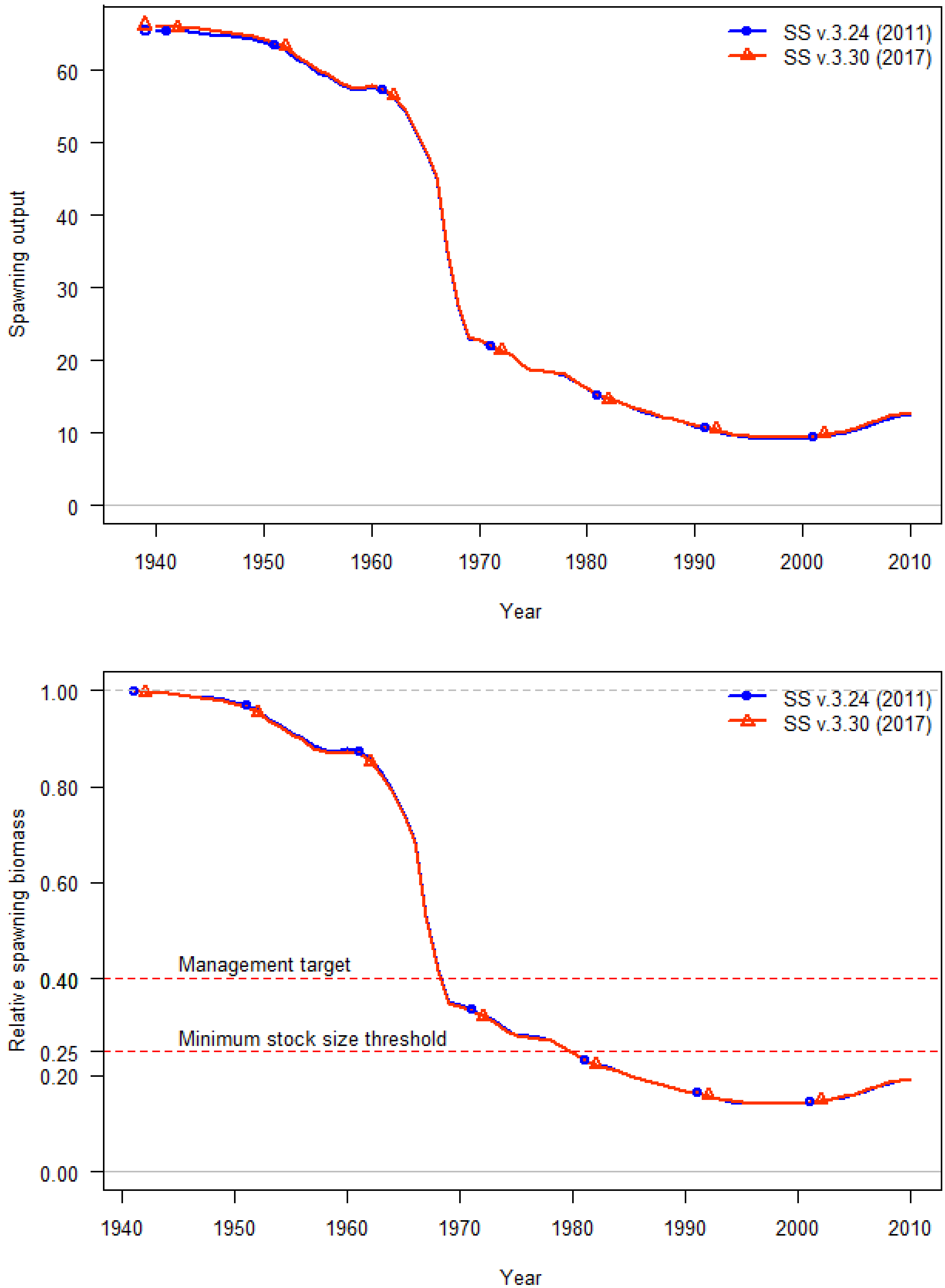

Figure 33: Comparison of estimates from Stock Synthesis version 3.30 and 3.24 for Pacific ocean perch. fig:bridge

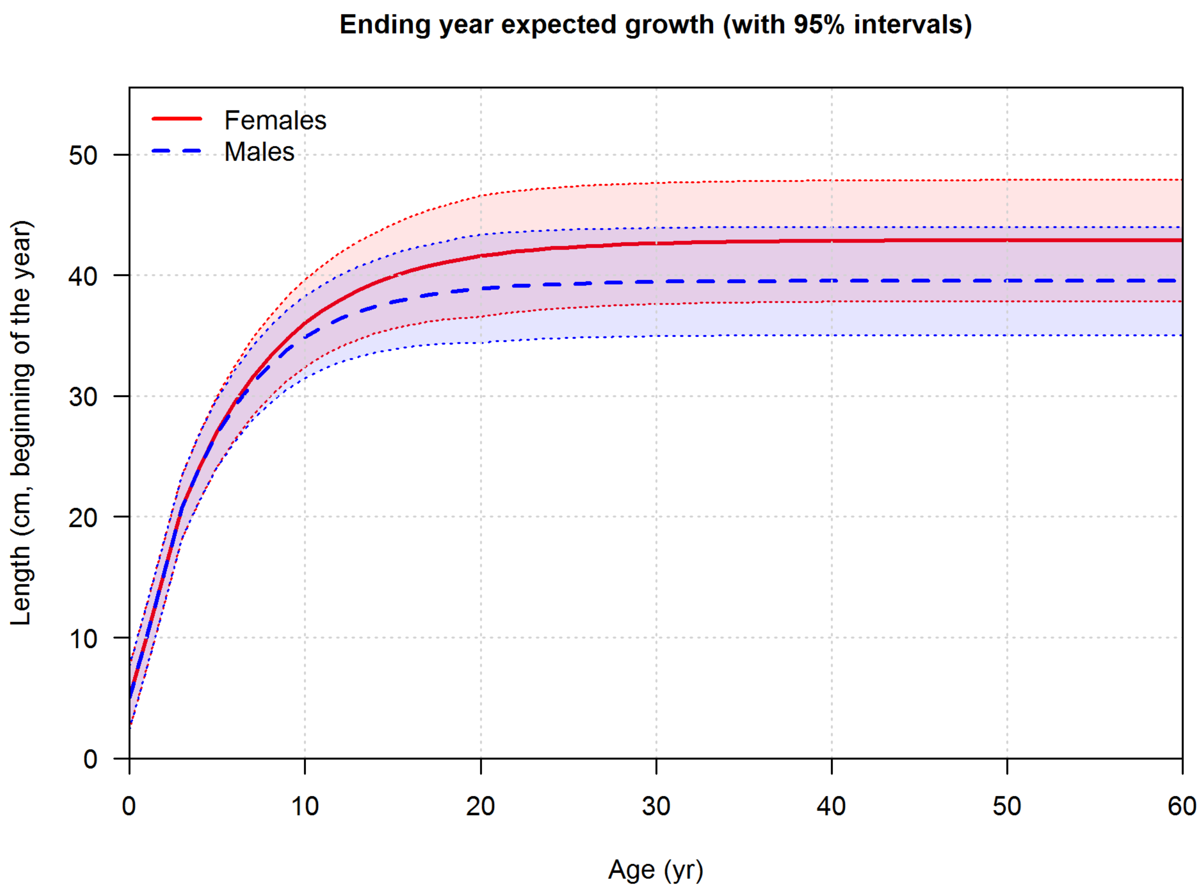

Figure 34: Estimated length-at-age for male and female for Pacific ocean perch with estimated CV. fig:sizeatage

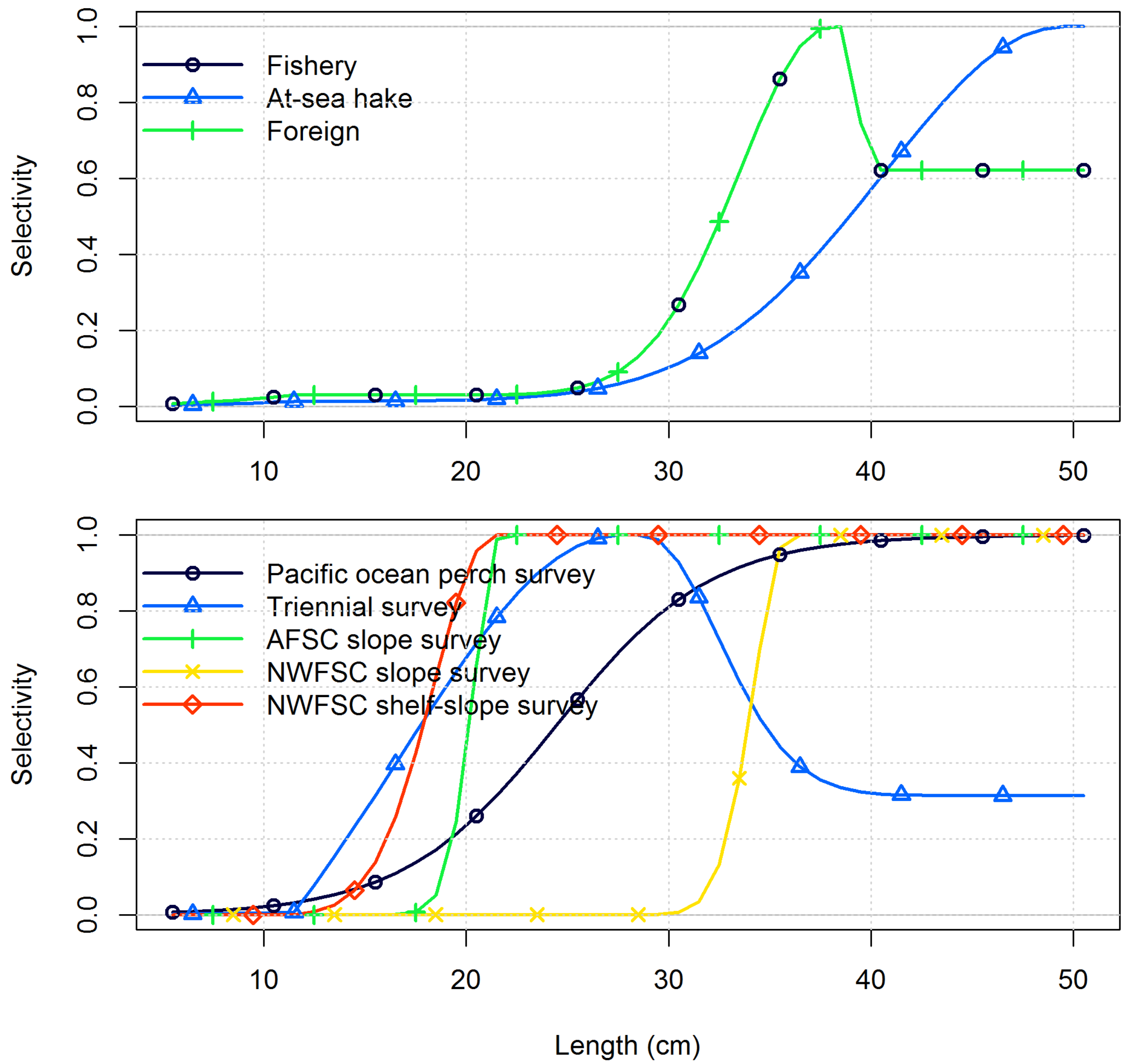

Figure 35: Estimated selectivity by length by each fishery and survey for Pacific ocean perch. fig:selex

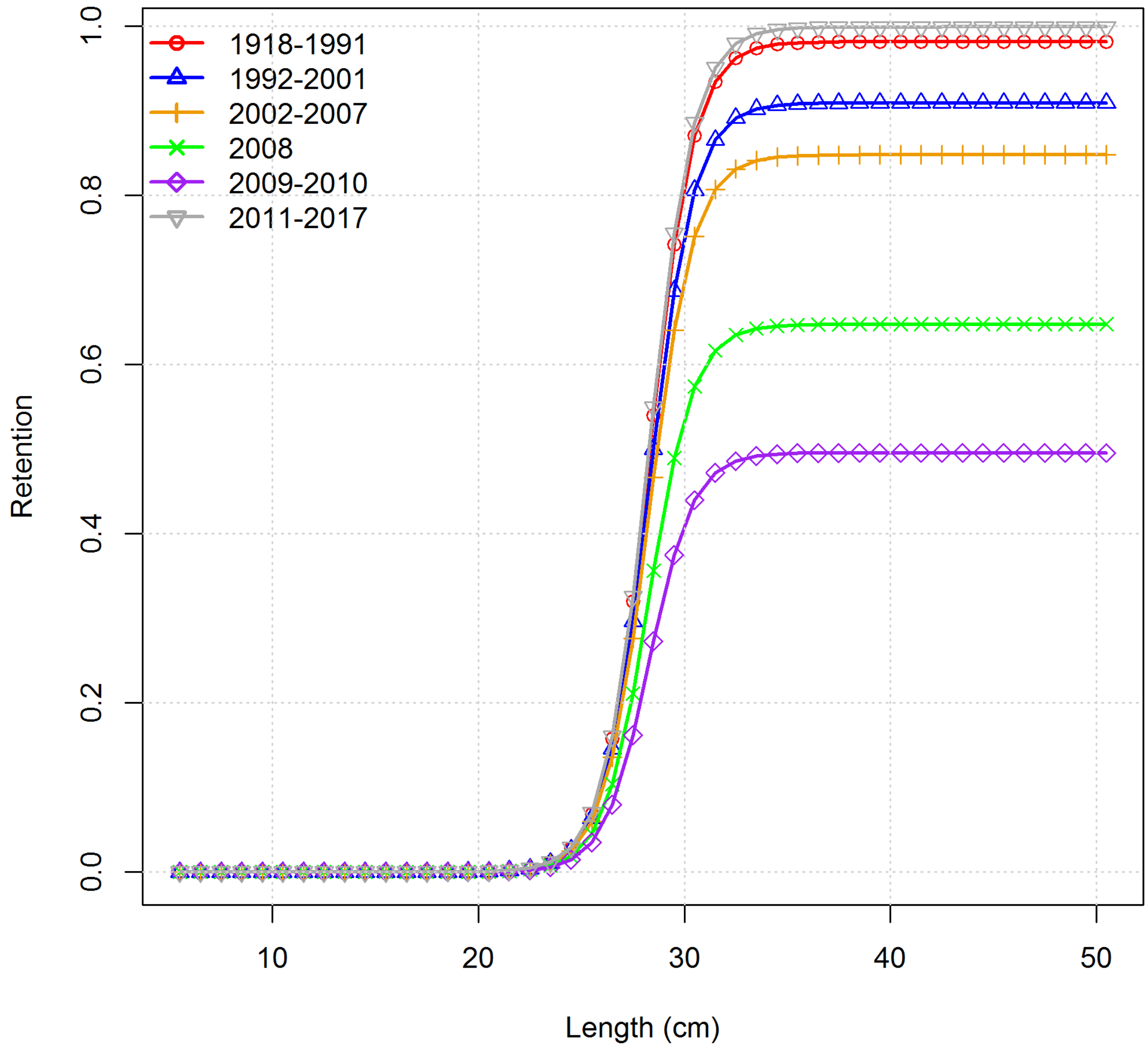

Figure 36: Estimated retention by length by the trawl fishery for Pacific ocean perch. fig:retention

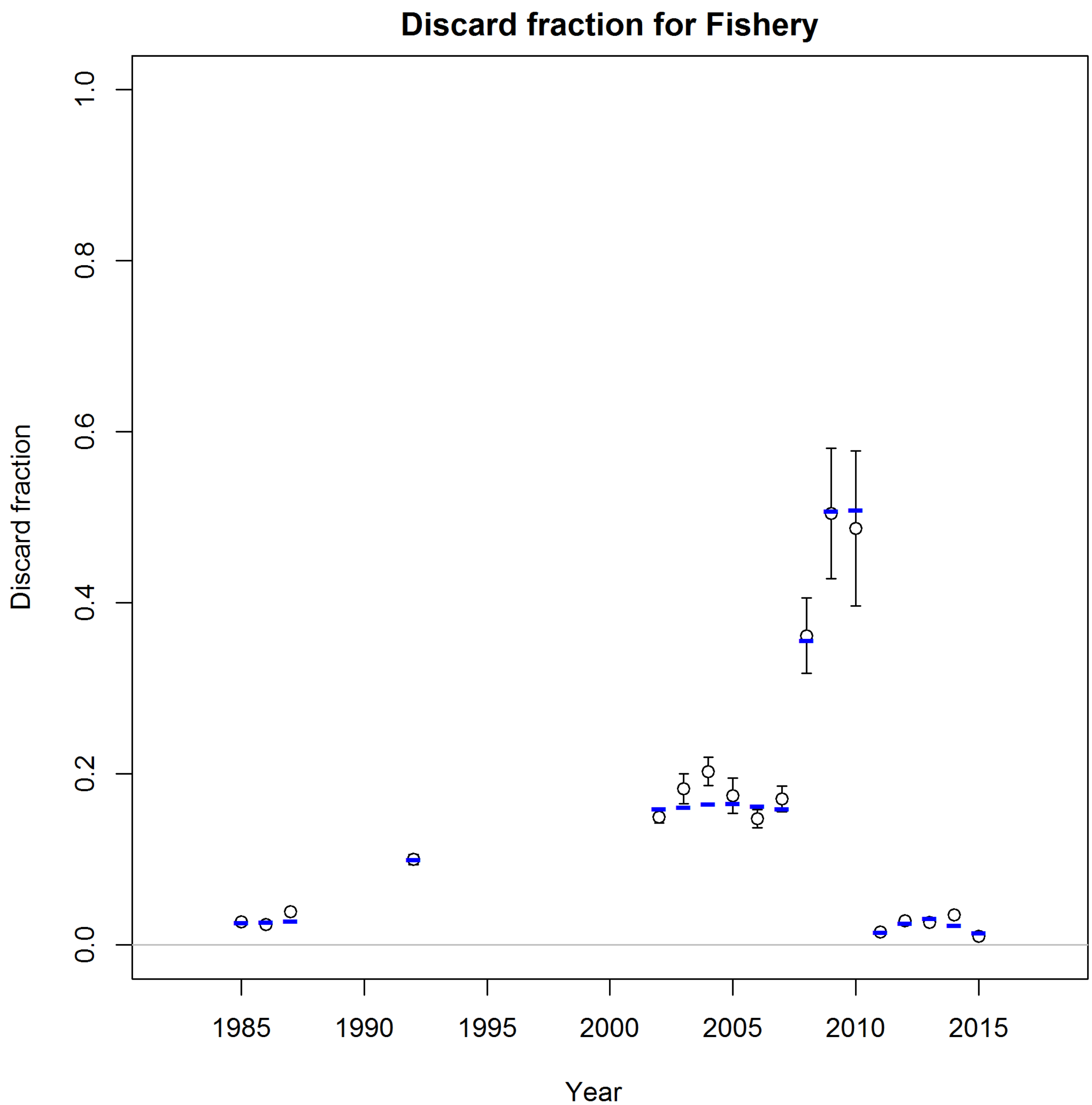

Figure 37: Estimated fits to the discard rates for Pacific ocean perch. fig:discard_fits

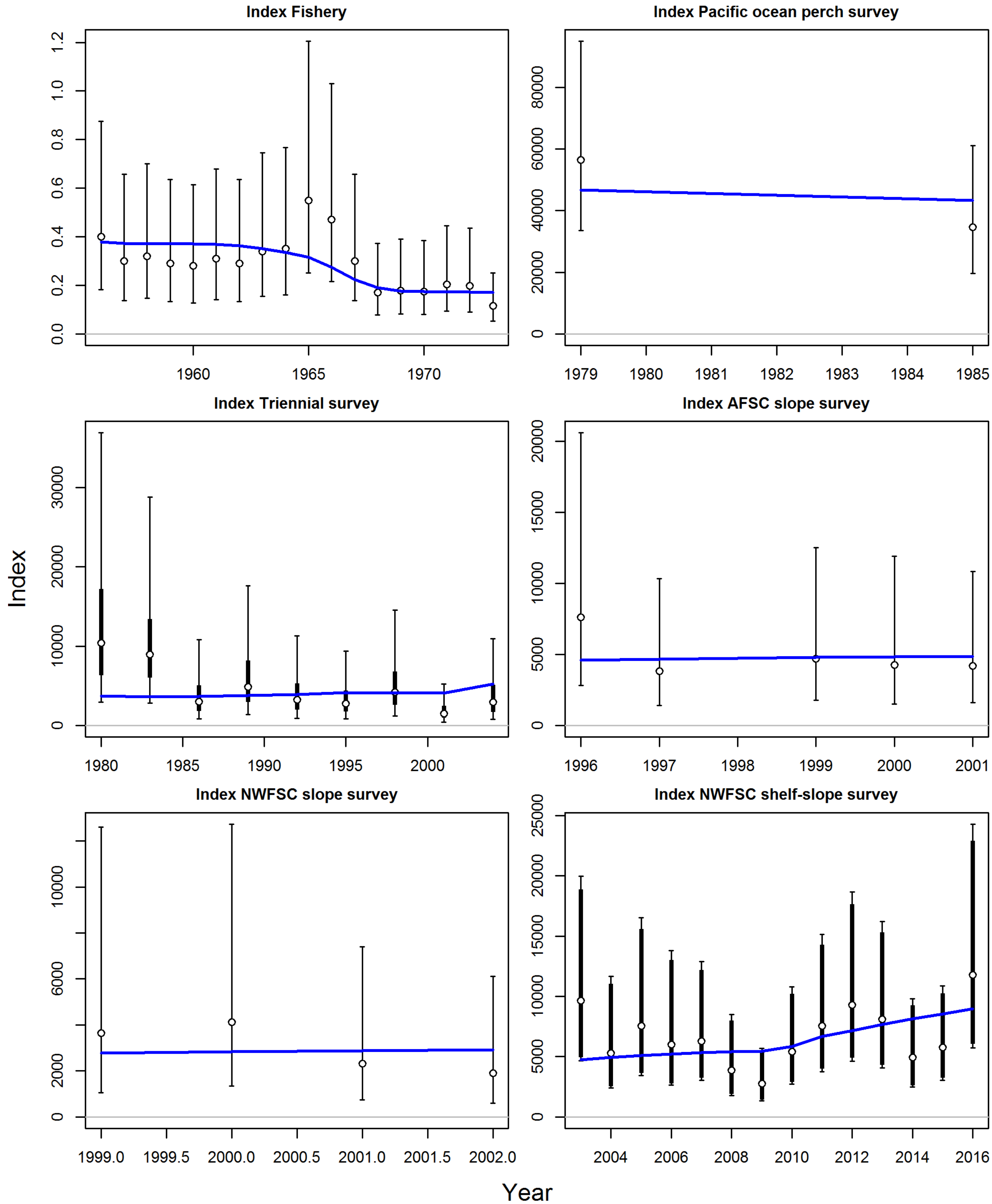

Figure 38: Estimated fits to the CPUE and survey indices for Pacific ocean perch. fig:index_fits

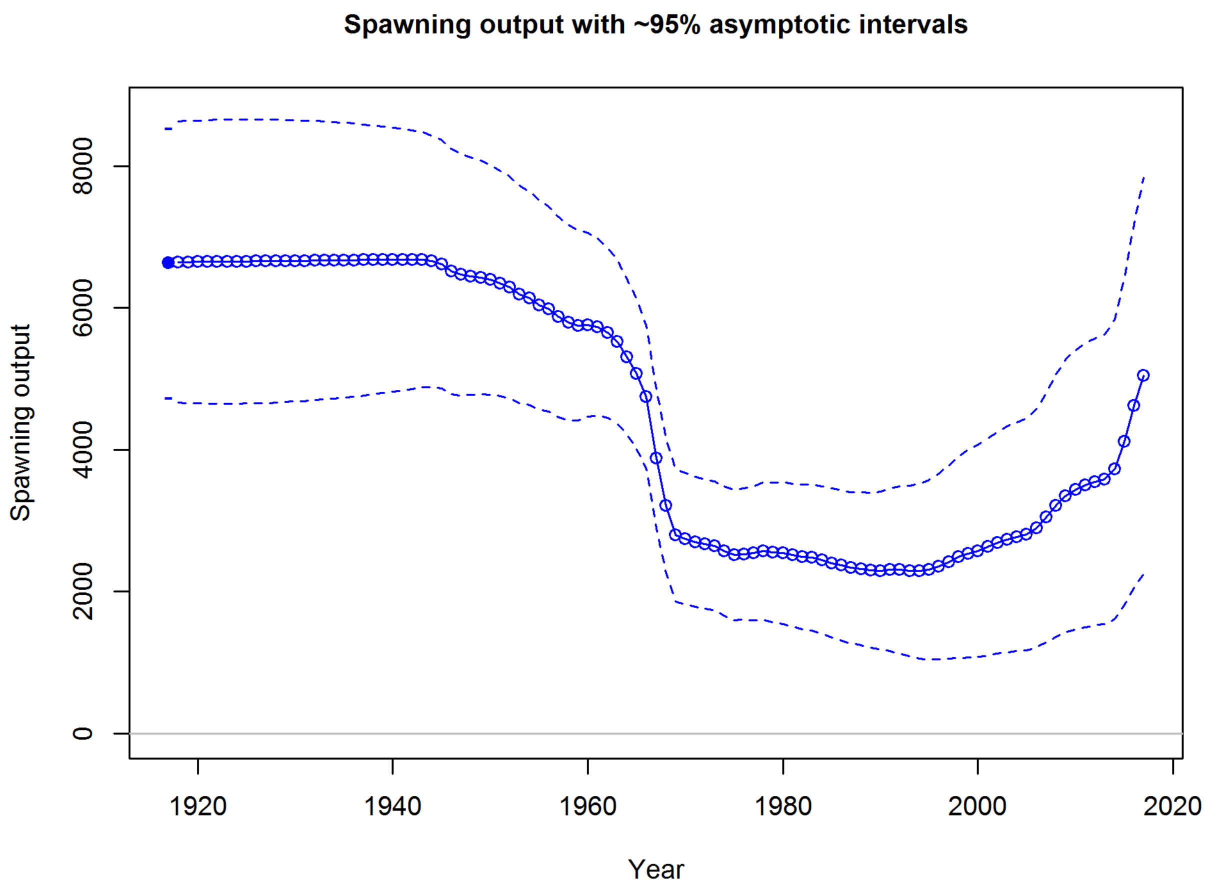

Figure 39: Estimated time-series of spawning output for Pacific ocean perch. fig:ssb

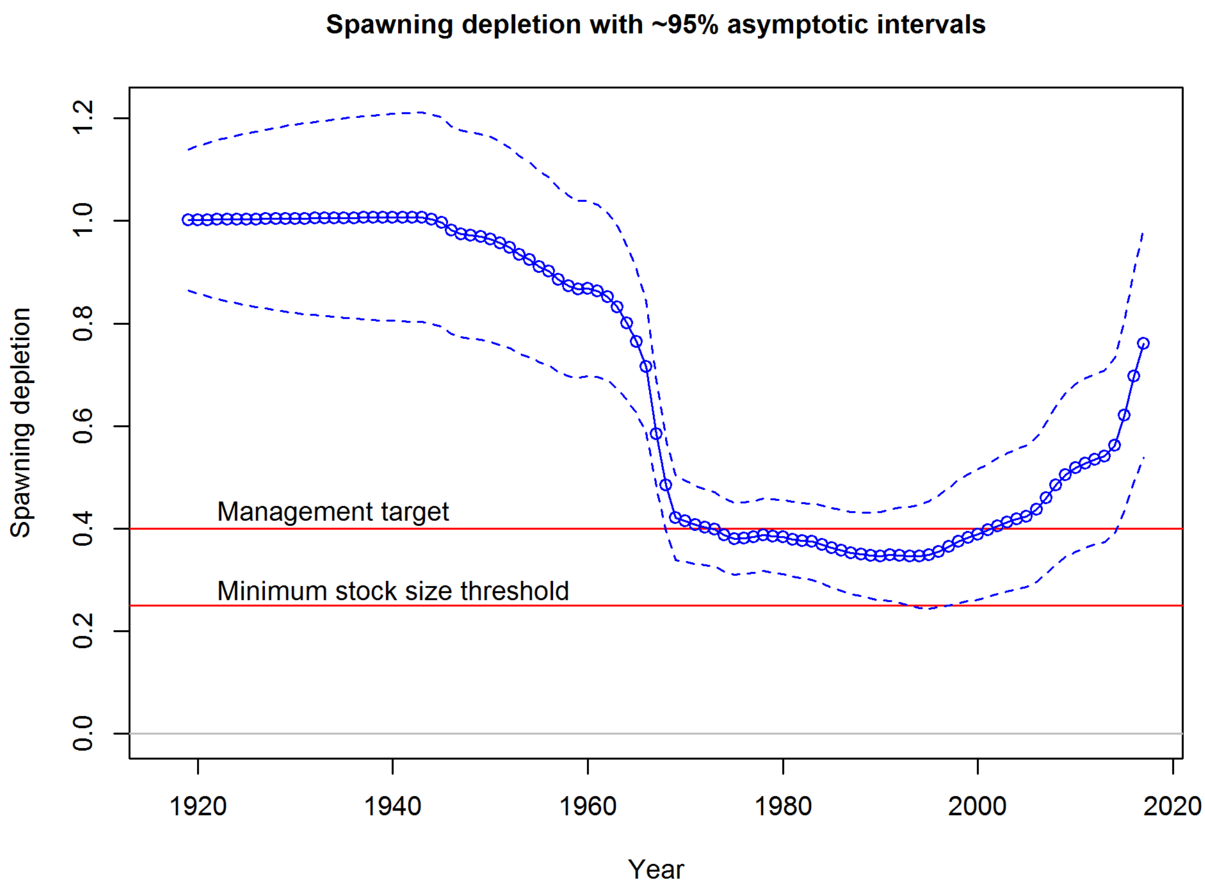

Figure 40: Estimated time-series of relative biomass for Pacific ocean perch. fig:depl

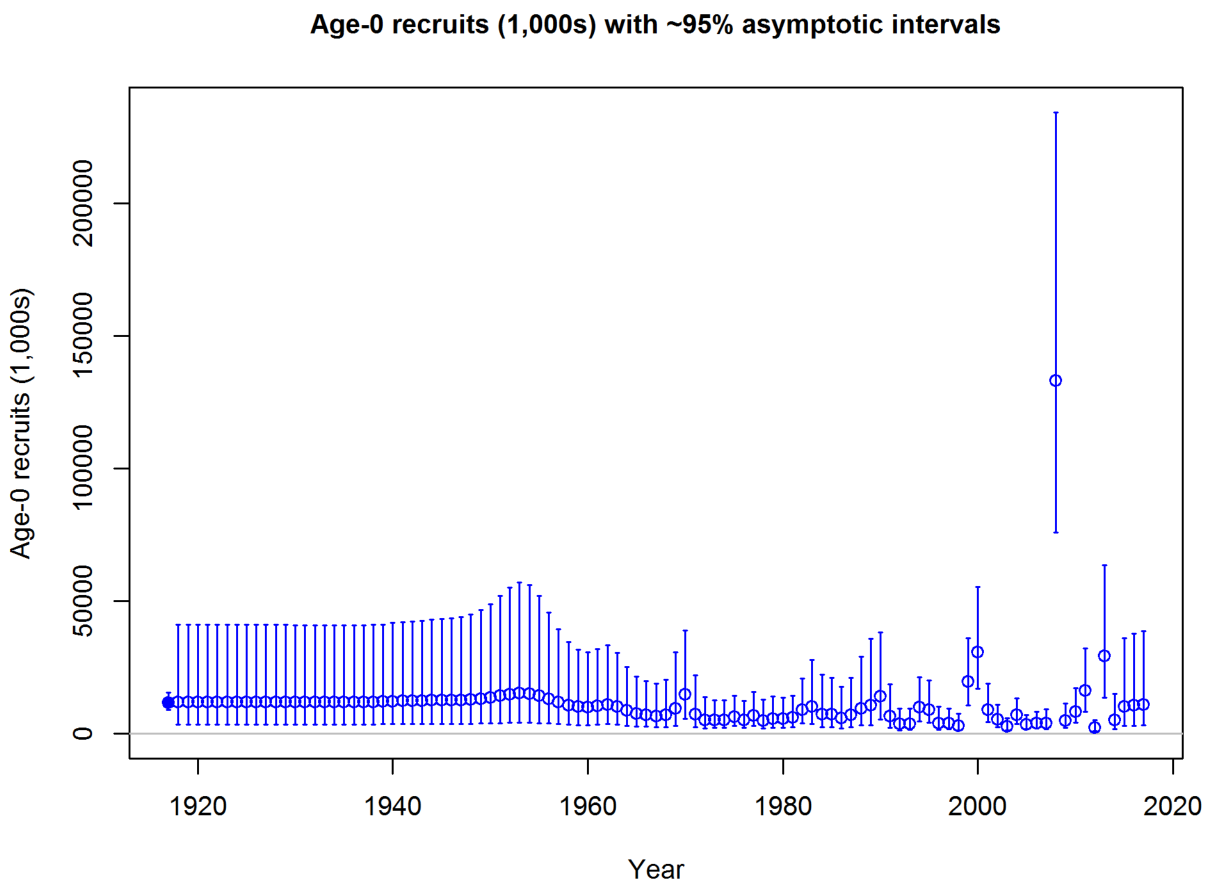

Figure 41: Estimated time-series of recruitment for Pacific ocean perch. fig:recuits

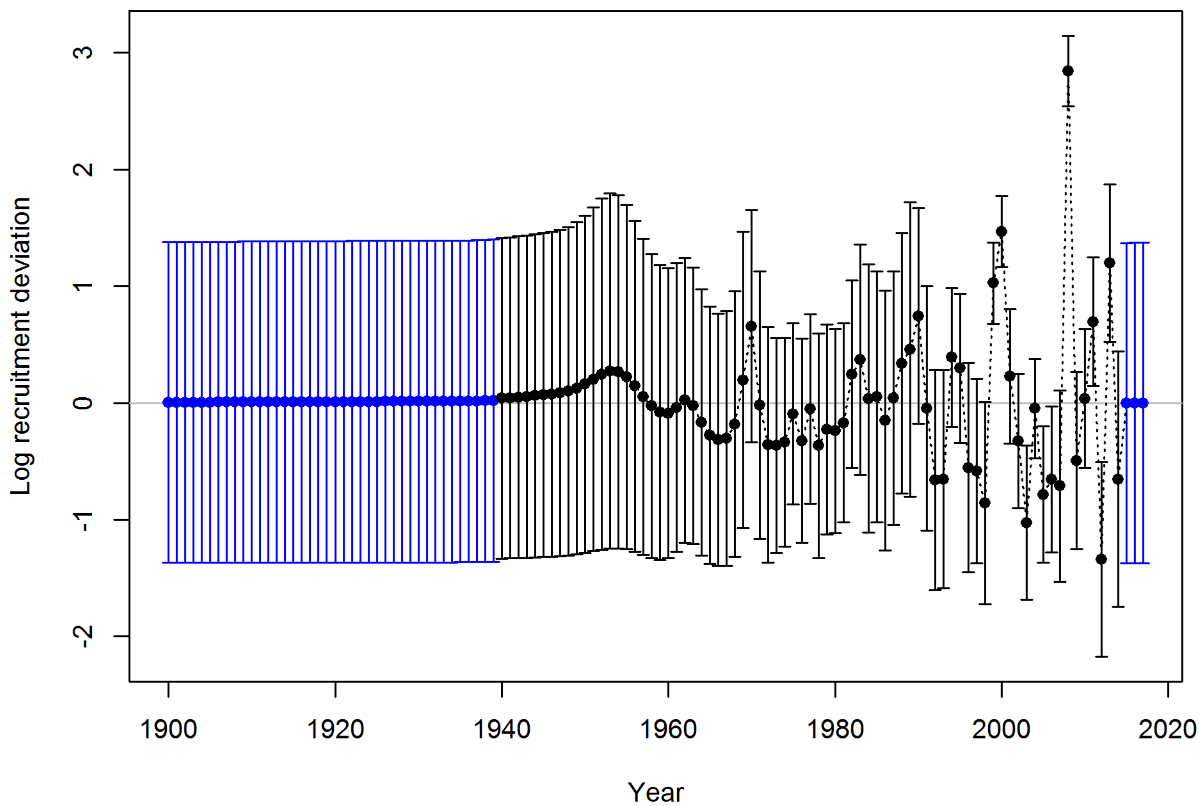

Figure 42: Estimated time-series of recruitment deviations for Pacific ocean perch. fig:recdevs

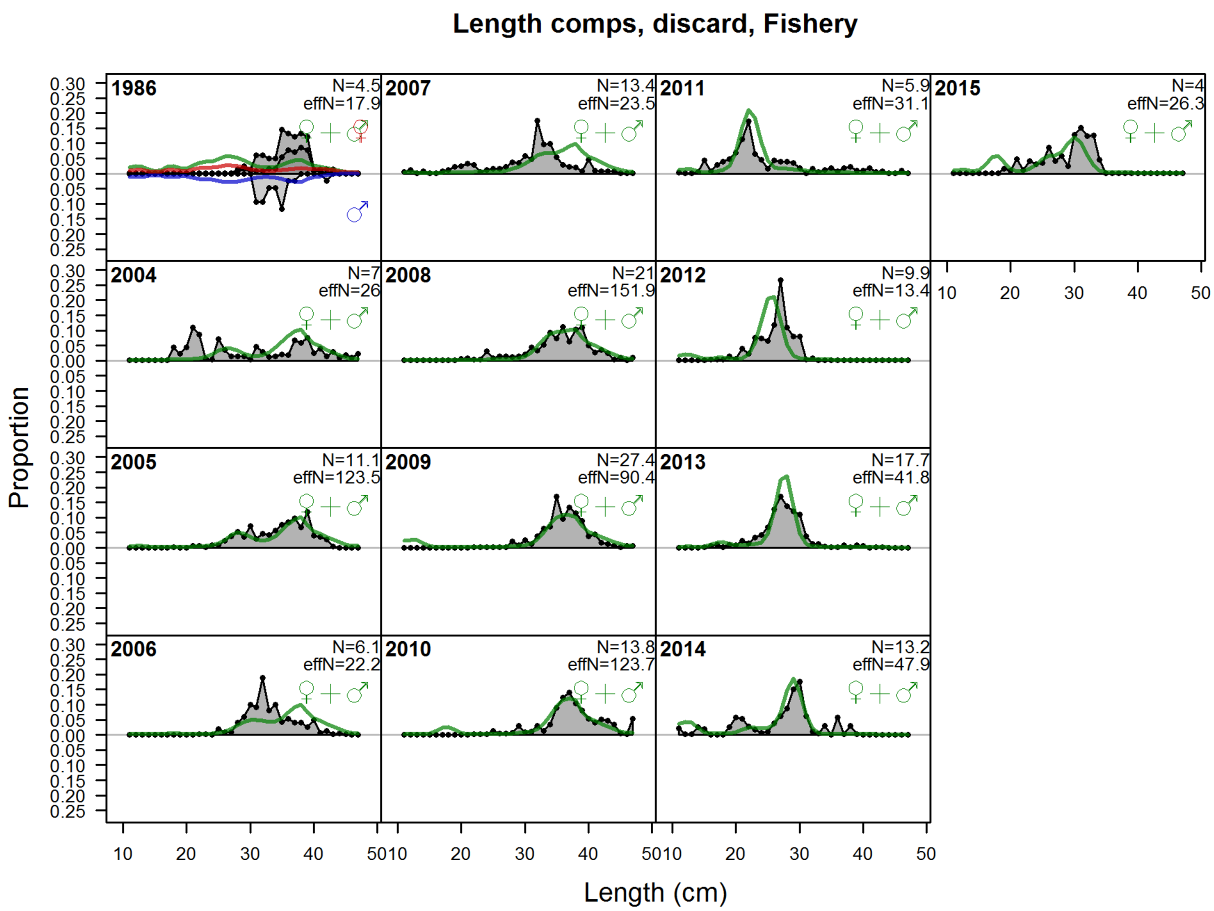

Figure 43: Length comps, discard, Fishery fig:mod1_1_comp_lenfit_flt1mkt1

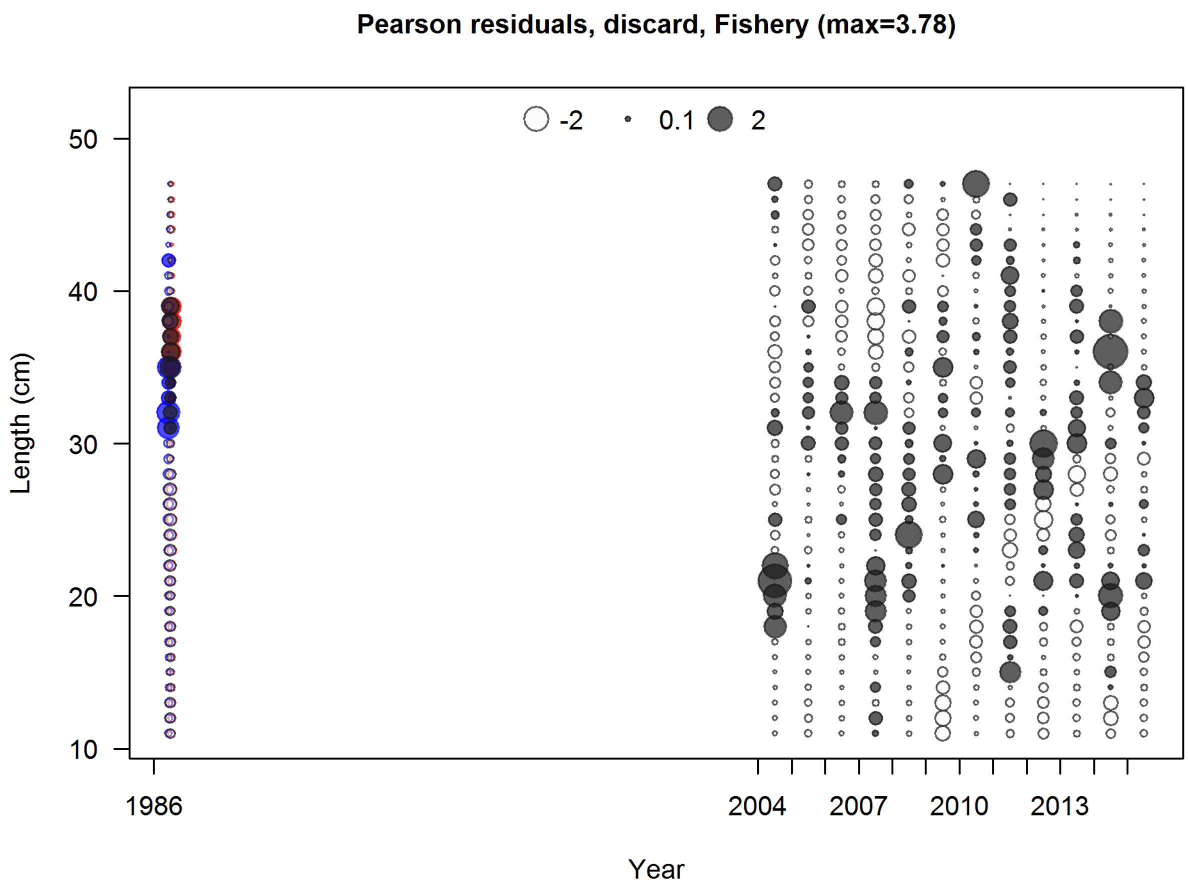

Figure 44: Pearson residuals, discard, Fishery (max=3.78)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_2_comp_lenfit_residsflt1mkt1

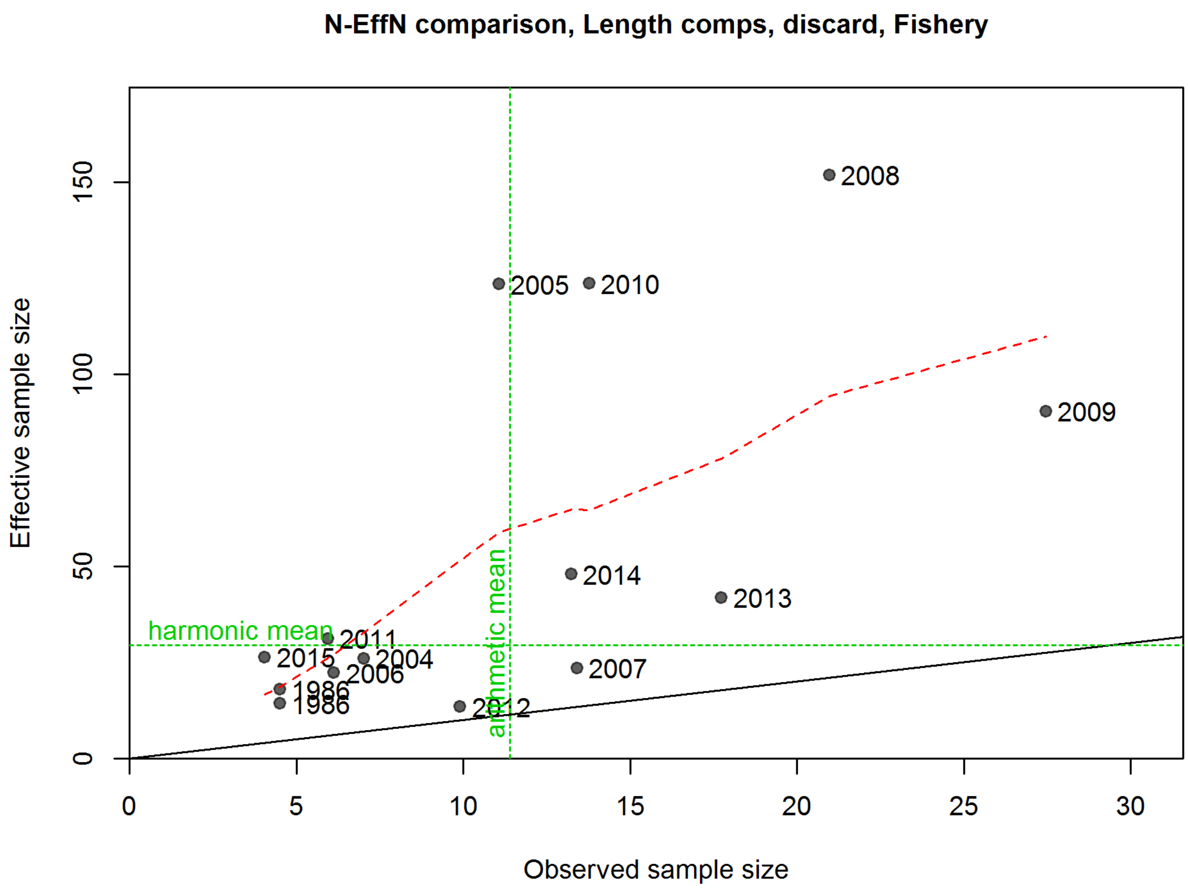

Figure 45: N_EffN comparison, Length comps, discard, Fishery fig:mod1_3_comp_lenfit_sa

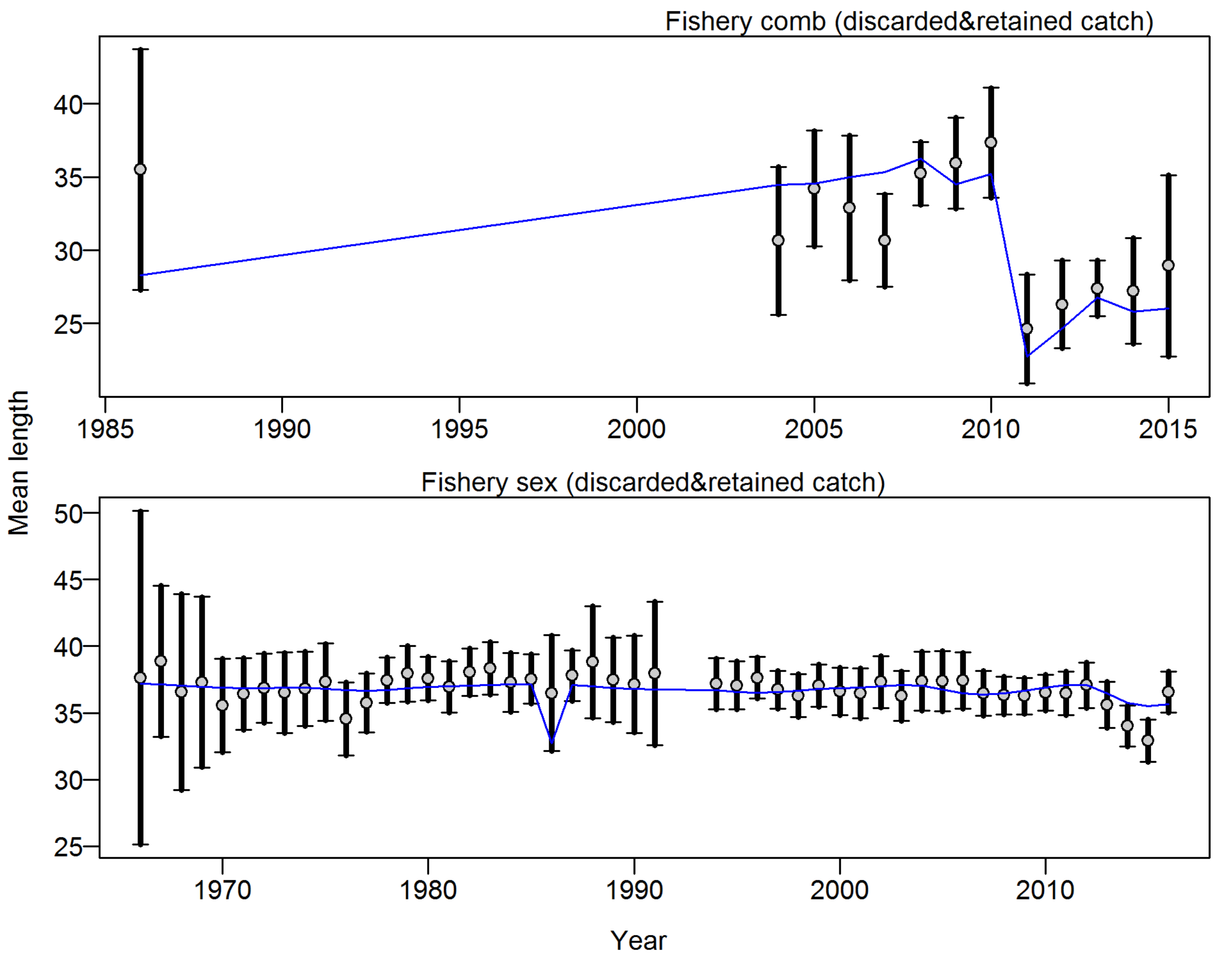

Figure 46: Francis data weighting method TA1.8: Fishery Suggested sample size adjustment (with 95% interval) for len data from Fishery: 0.9951 (0.6654_1.8149) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_4_comp_lenfit_data_weighting_TA1.8_Fishery

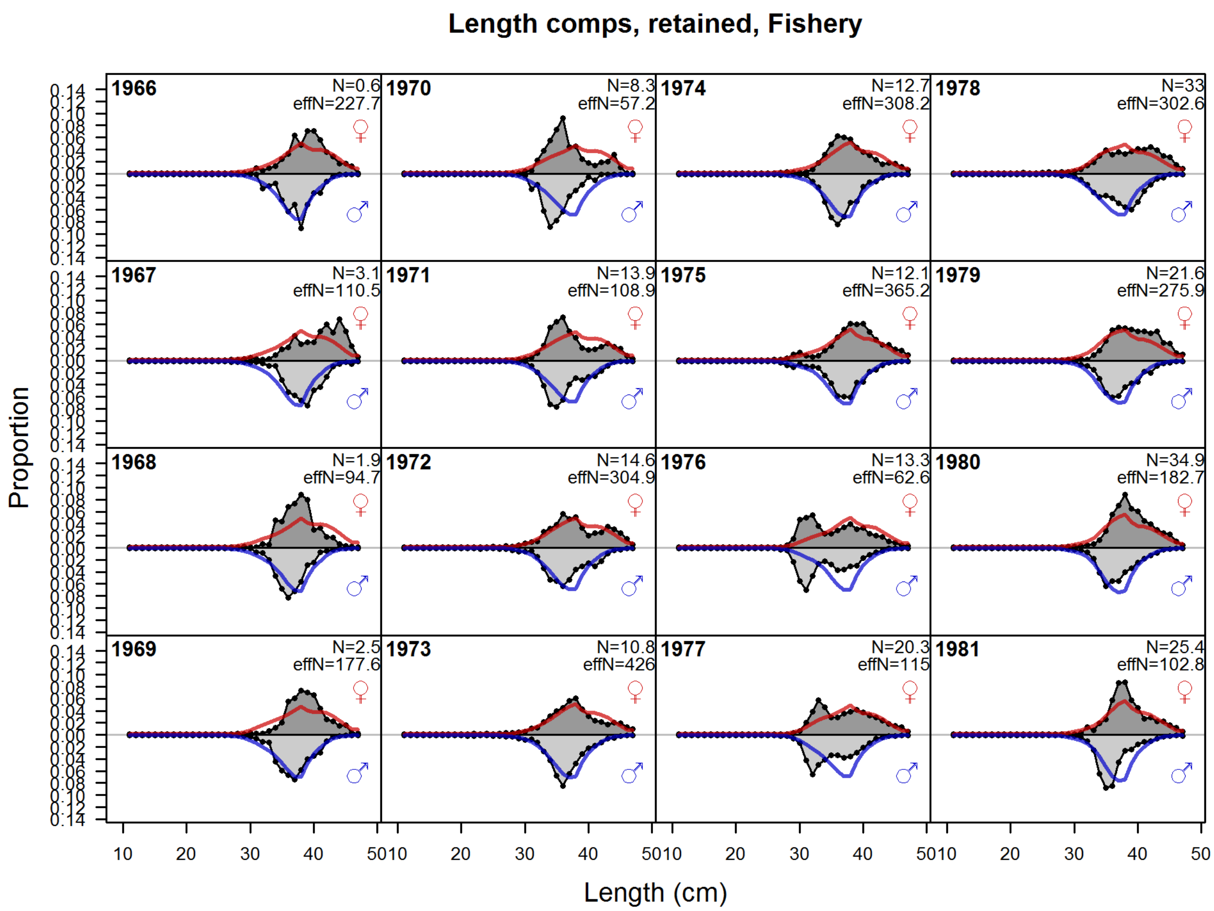

Figure 47: Length comps, retained, Fishery (plot 1 of 4) fig:mod1_5_comp_lenfit_flt1m

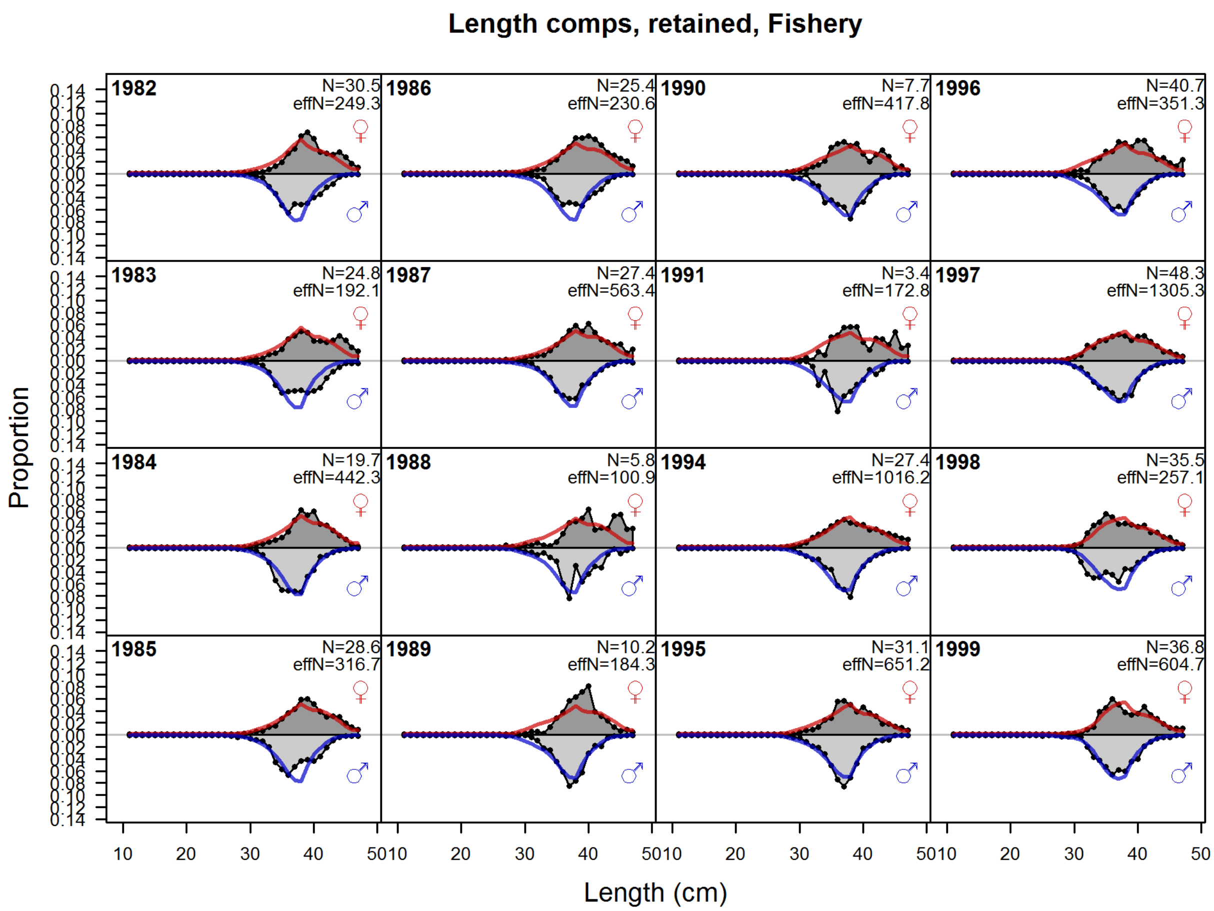

Figure 48: Length comps, retained, Fishery (plot 1 of 4) (plot 2 of 4) fig:mod1_6_comp_lenfit

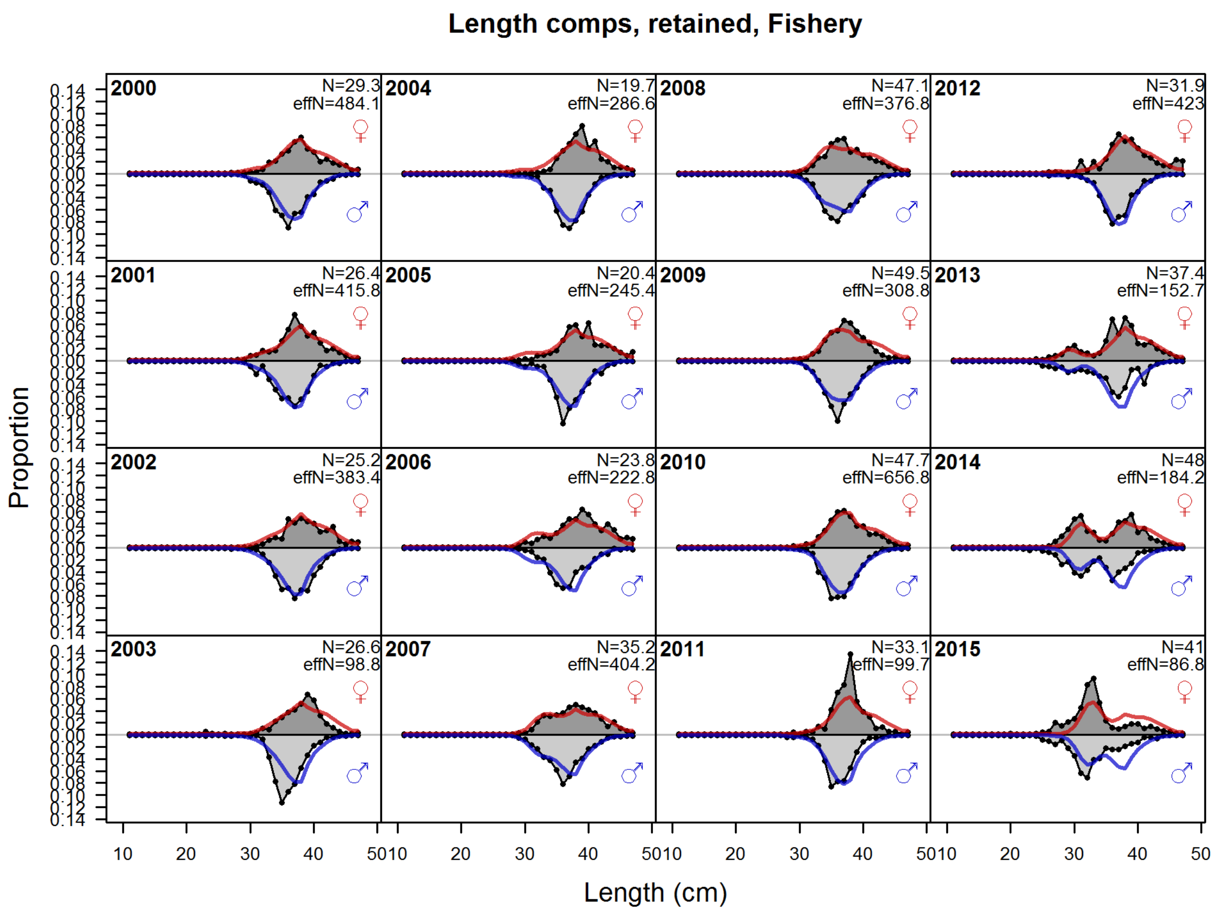

Figure 49: Length comps, retained, Fishery (plot 1 of 4) (plot 2 of 4) (plot 3 of 4) fig:mod1_7_comp_l

Length comps, retained, Fishery

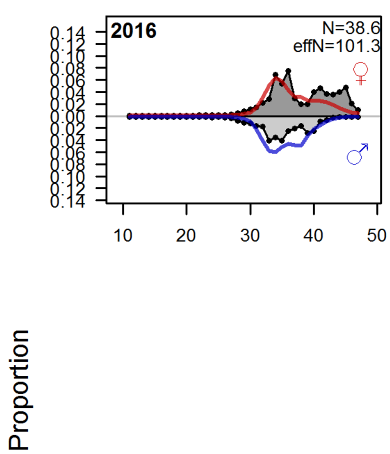

Figure 50: Length comps, retained, Fishery (plot 1 of 4) (plot 2 of 4) (plot 3 of 4) (plot 4 of 4) fig:mod1_8_comp_lenfit_flt1mkt2_page4

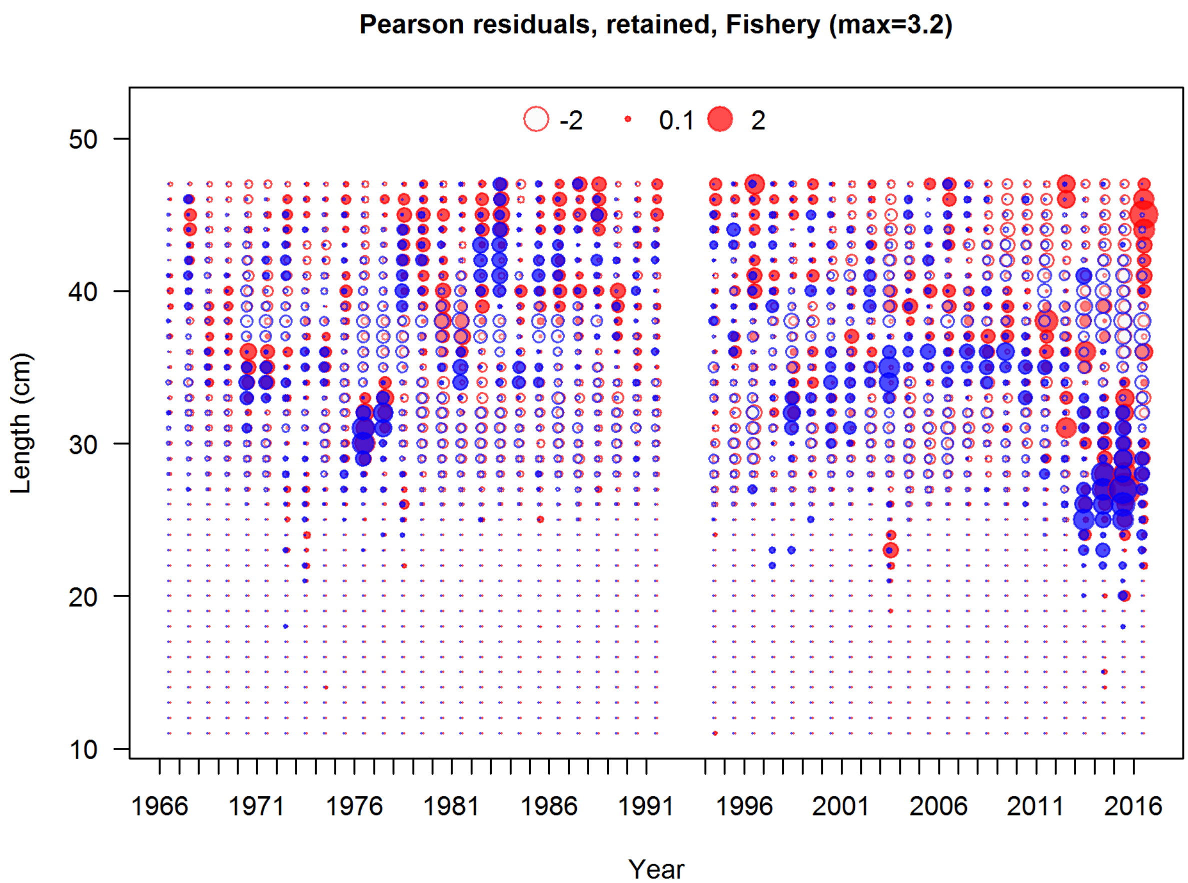

Figure 51: Pearson residuals, retained, Fishery (max=3.2) (plot 4 of 4)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_9_comp_lenfit_residsflt1mkt2_page4

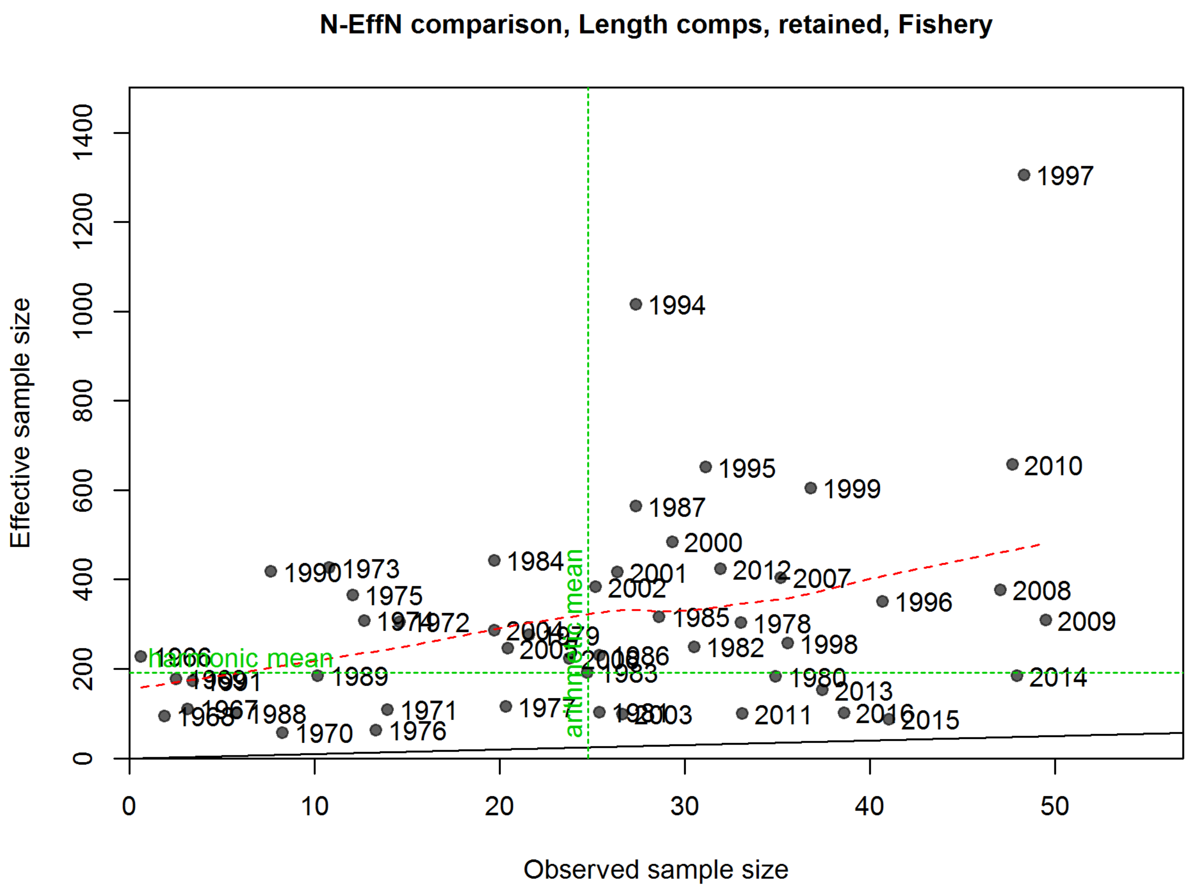

Figure 52: N_EffN comparison, Length comps, retained, Fishery [fig:mod1_10_comp_lenfit_s

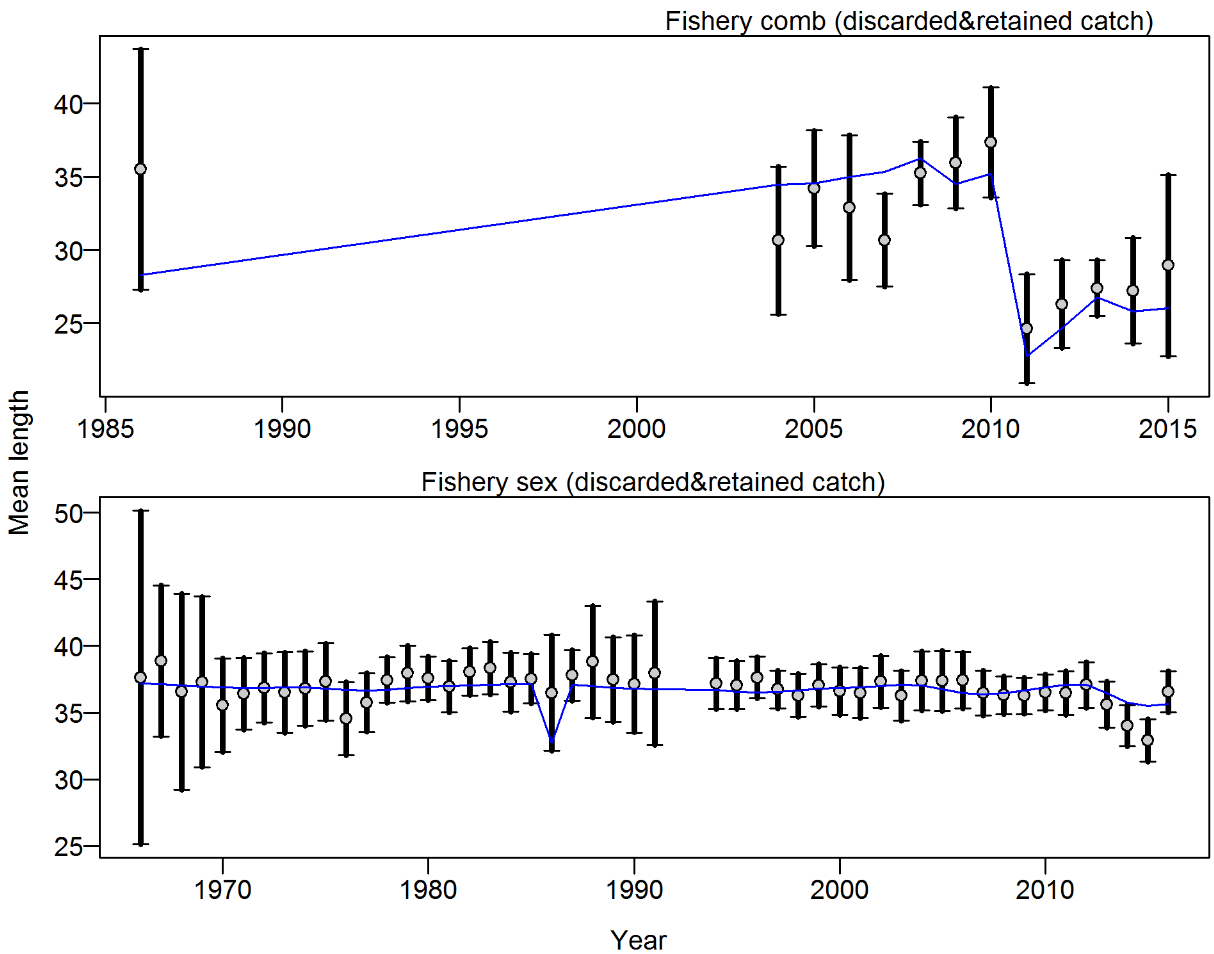

Figure 53: Francis data weighting method TA1.8: Fishery Suggested sample size adjustment (with 95% interval) for len data from Fishery: 0.9951 (0.6685_1.8165) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_11_comp_lenfit_data_weighting_TA1.8_Fishery

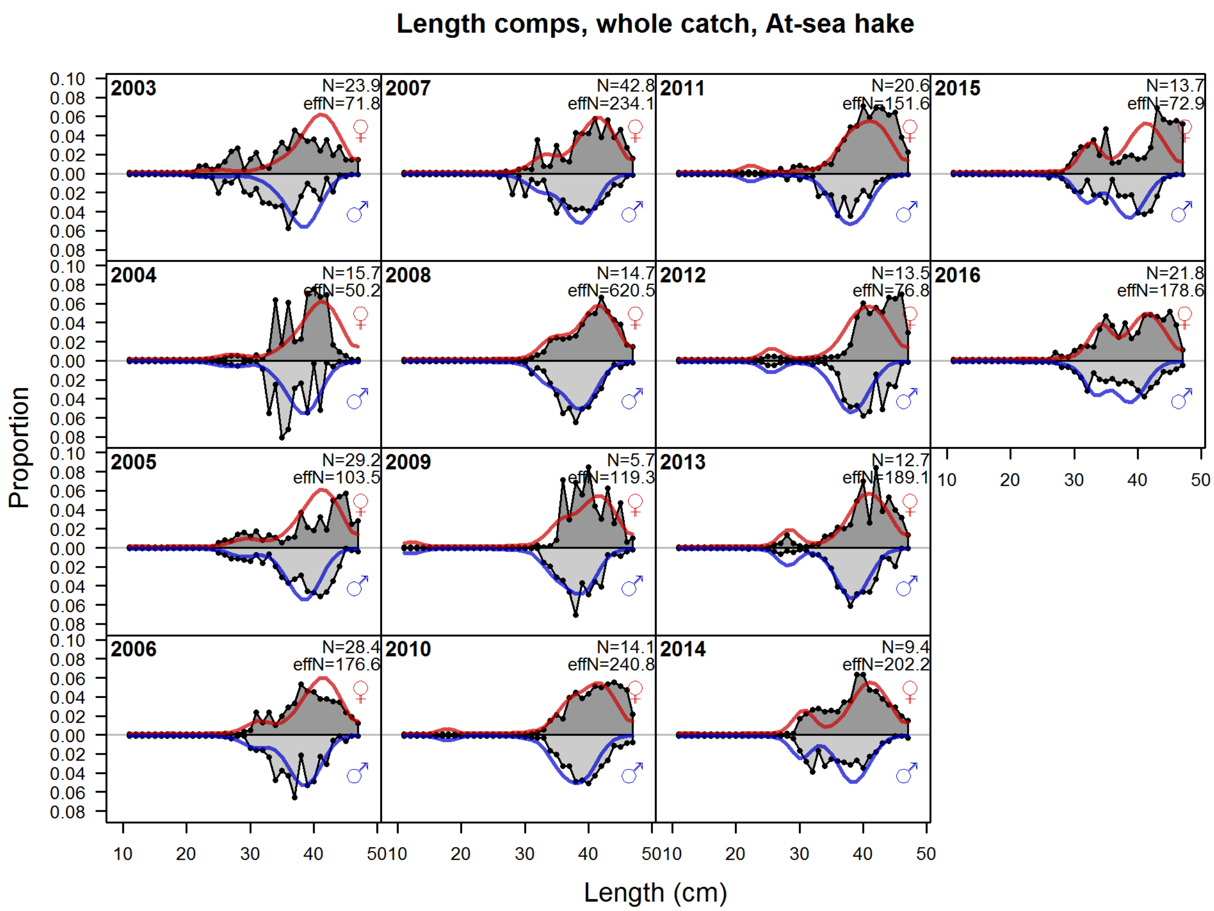

Figure 54: Length comps, whole catch, At_sea hake fig:mod1_12_comp_lenfit_flt2mk

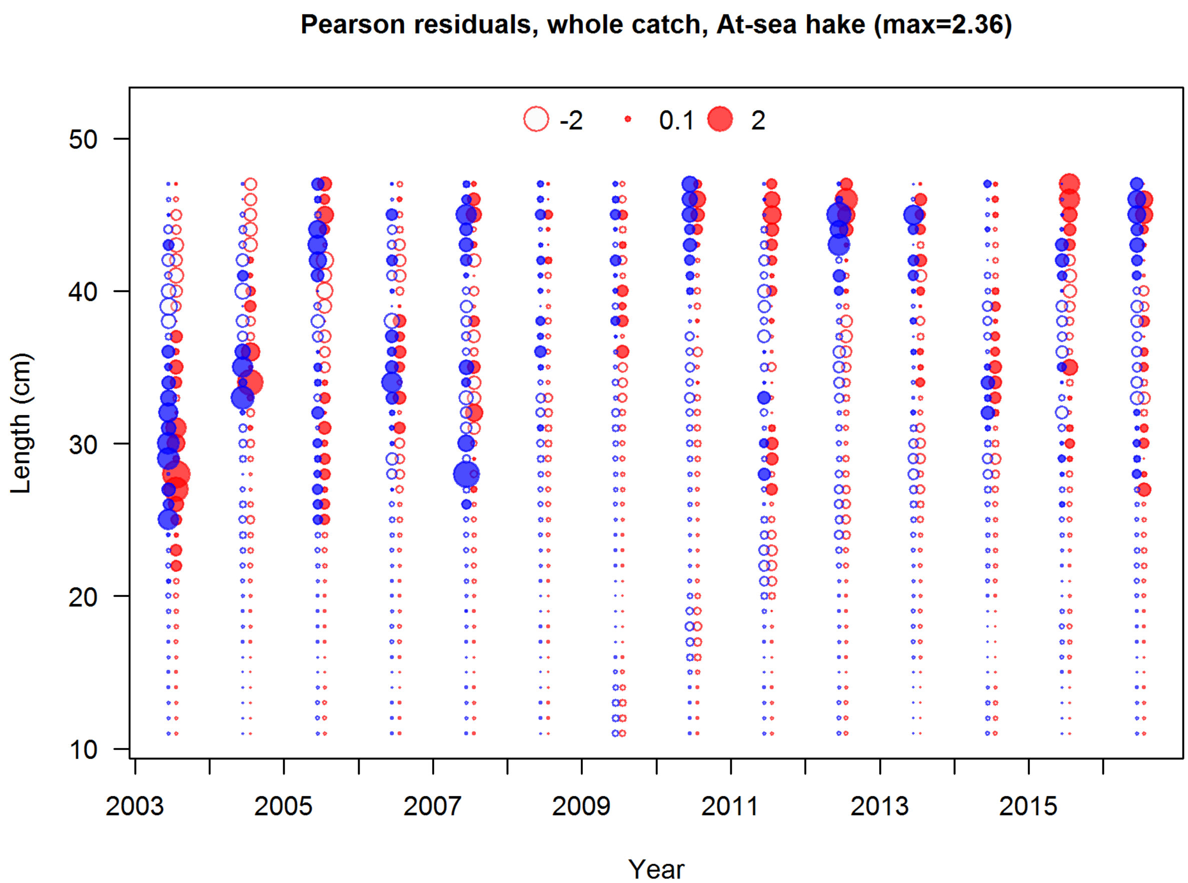

Figure 55: Pearson residuals, whole catch, At_sea hake (max=2.36)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_13_comp_lenfit_residsflt2mkt0

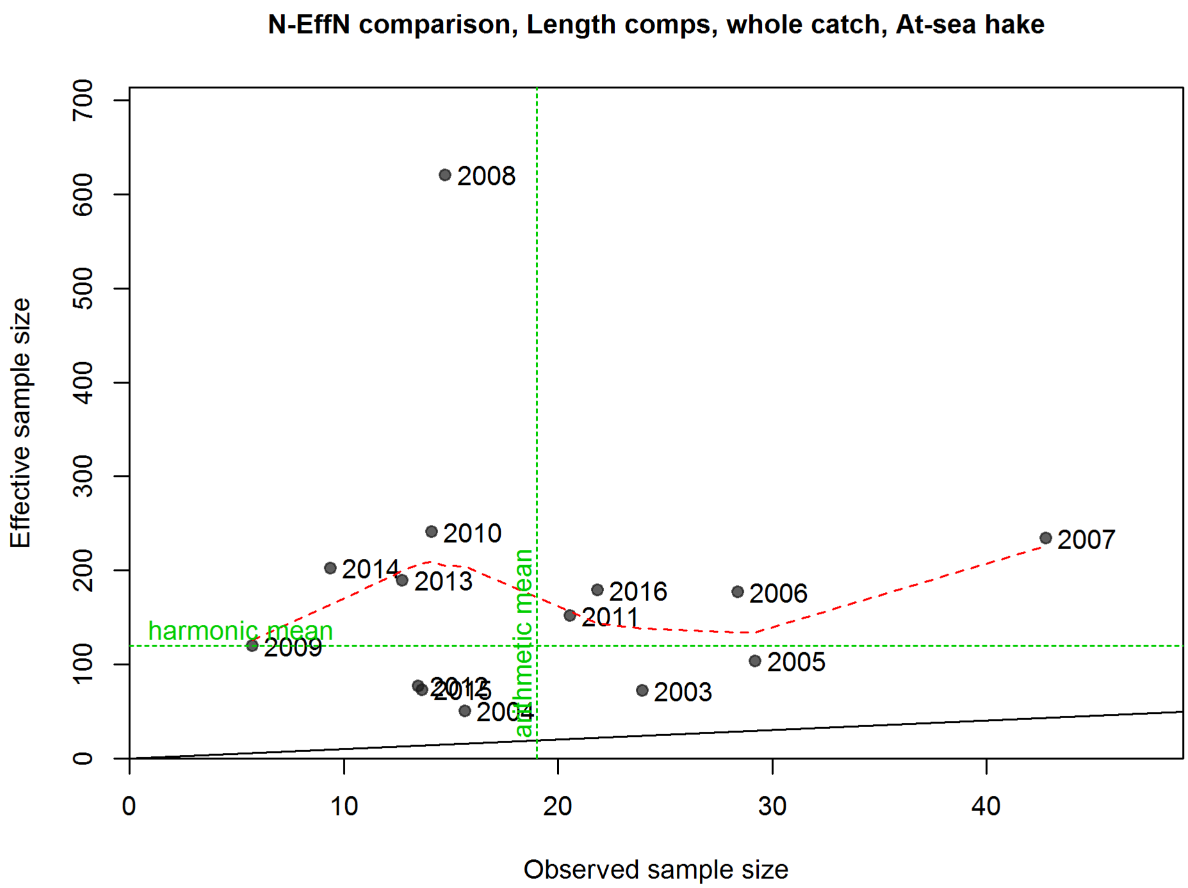

Figure 56: N_EffN comparison, Length comps, whole catch, At_sea hake fig:mod1_14_comp_lenf

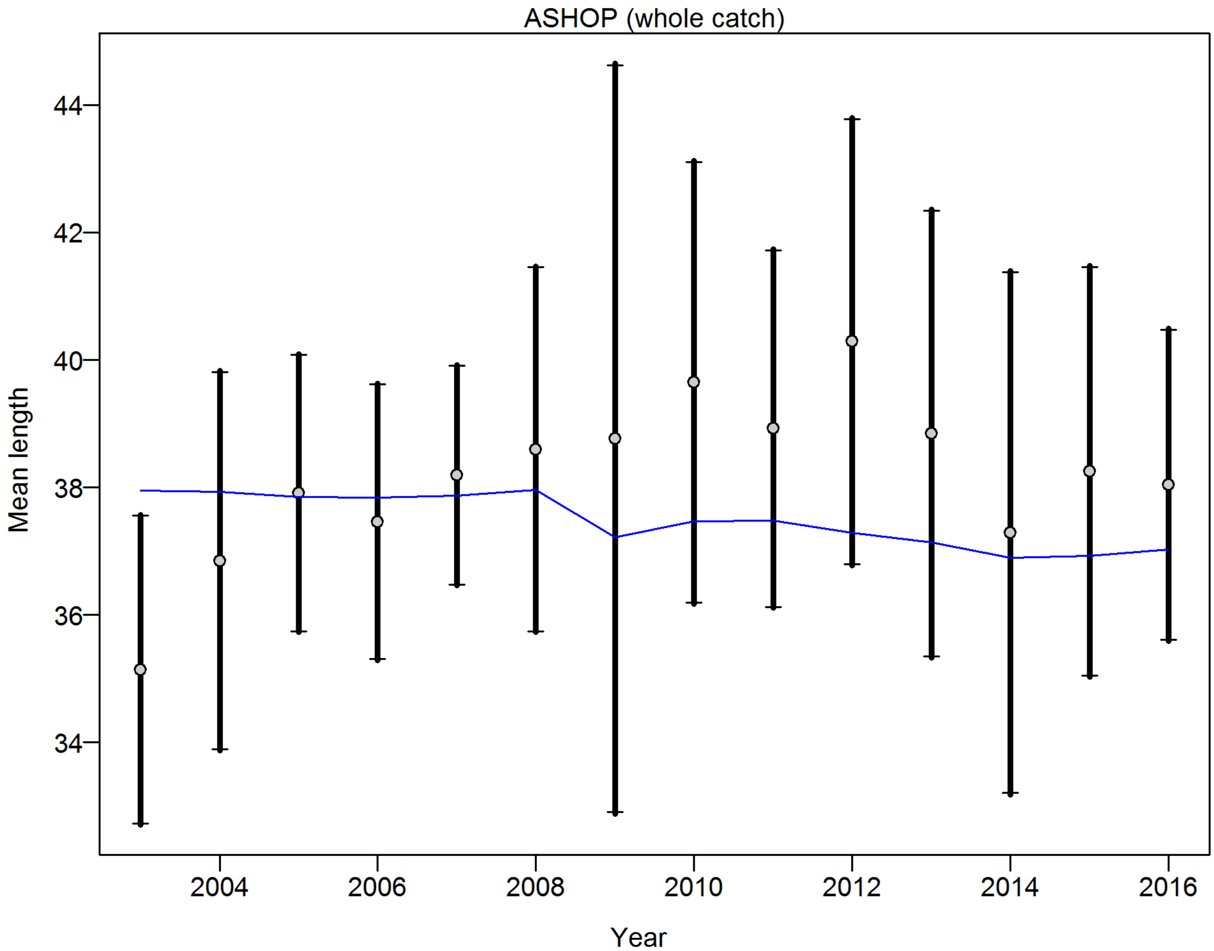

Figure 57: Francis data weighting method TA1.8: At_sea hake Suggested sample size adjustment (with 95% interval) for len data from At_sea hake: 1.0115 (0.5352_4.8582) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_15_comp_lenfit_data_weighting_TA1.8_At-s

Length comps, whole catch, Pacific ocean perch survey

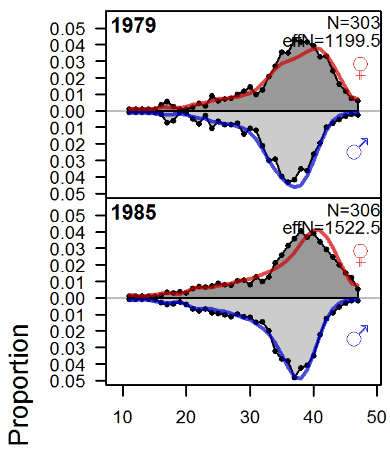

Figure 58: Length comps, whole catch, Pacific ocean perch survey fig:mod1_16_comp_lenfit_

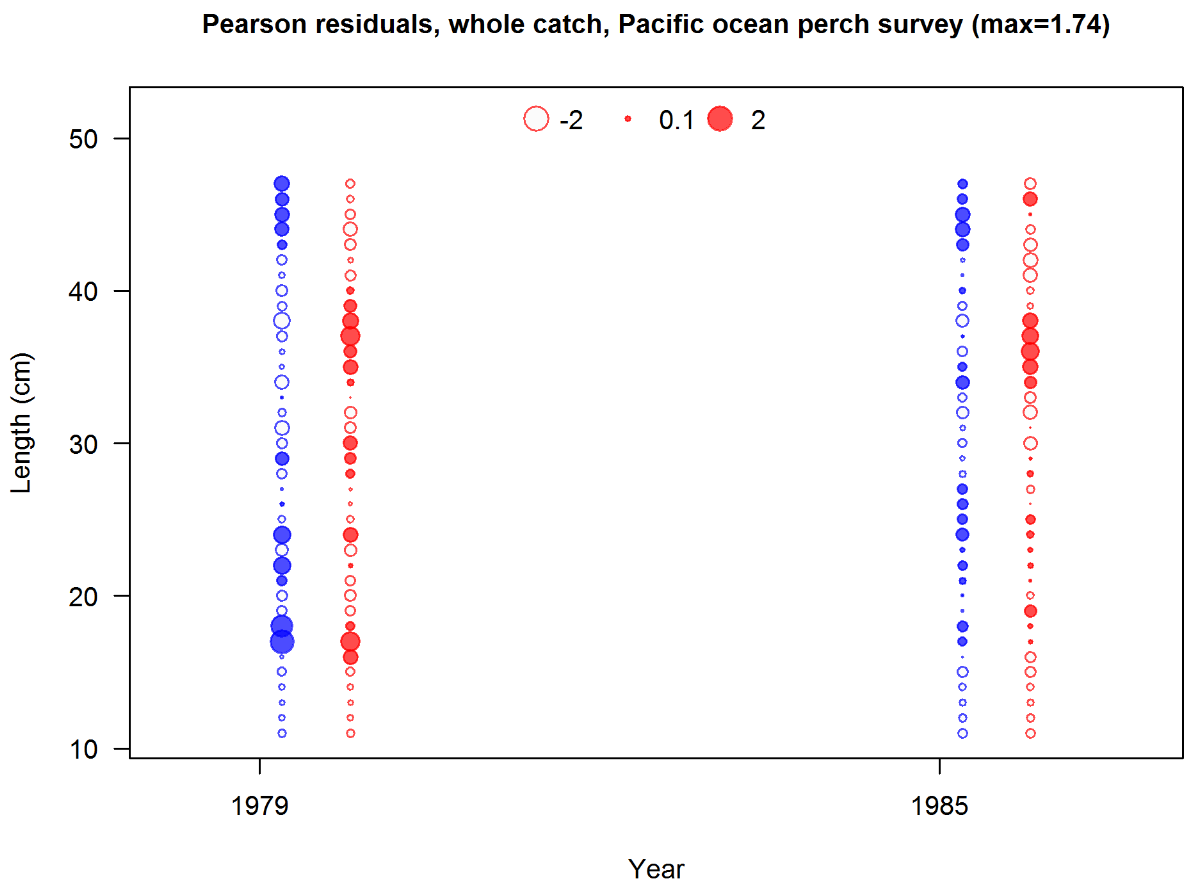

Figure 59: Pearson residuals, whole catch, Pacific ocean perch survey (max=1.74)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_17_comp_lenfit_residsflt4mkt0

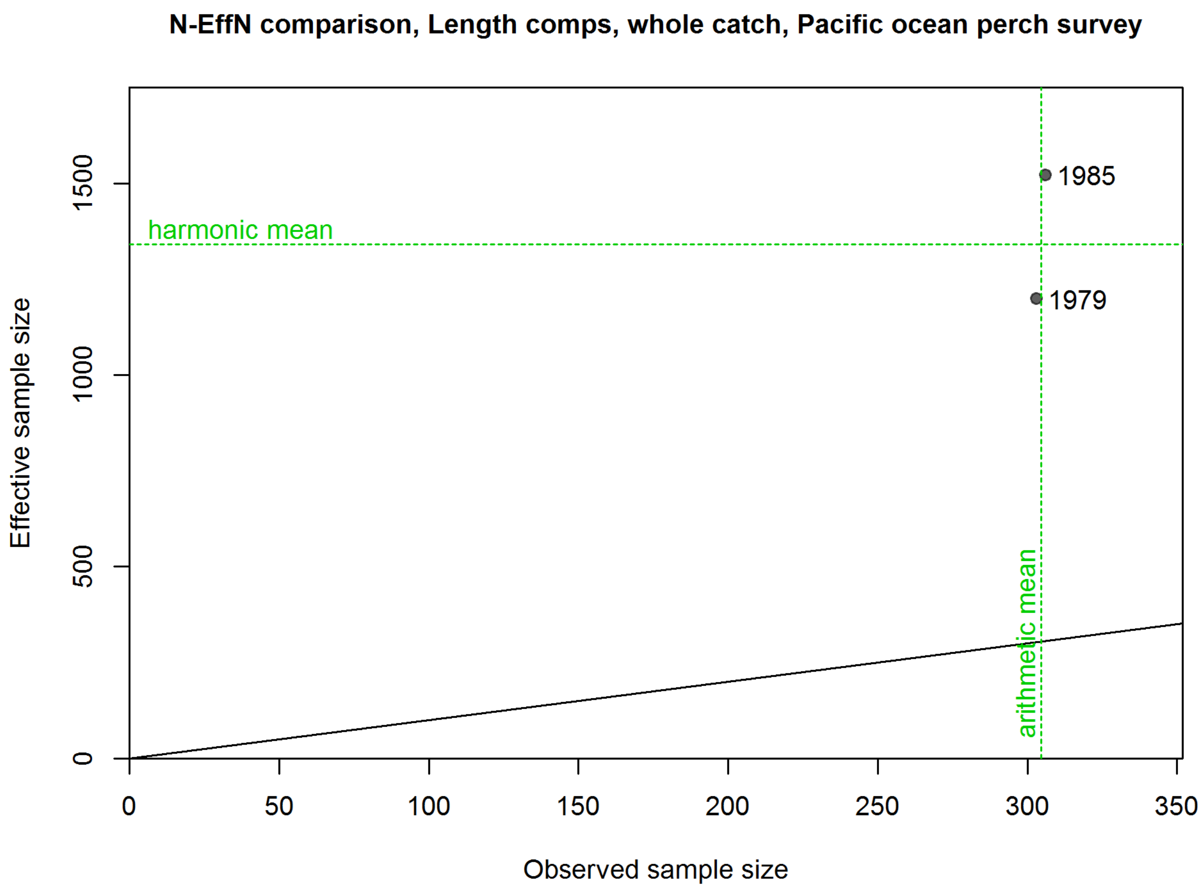

Figure 60: N_EffN comparison, Length comps, whole catch, Pacific ocean perch survey fig:mod1_18_con

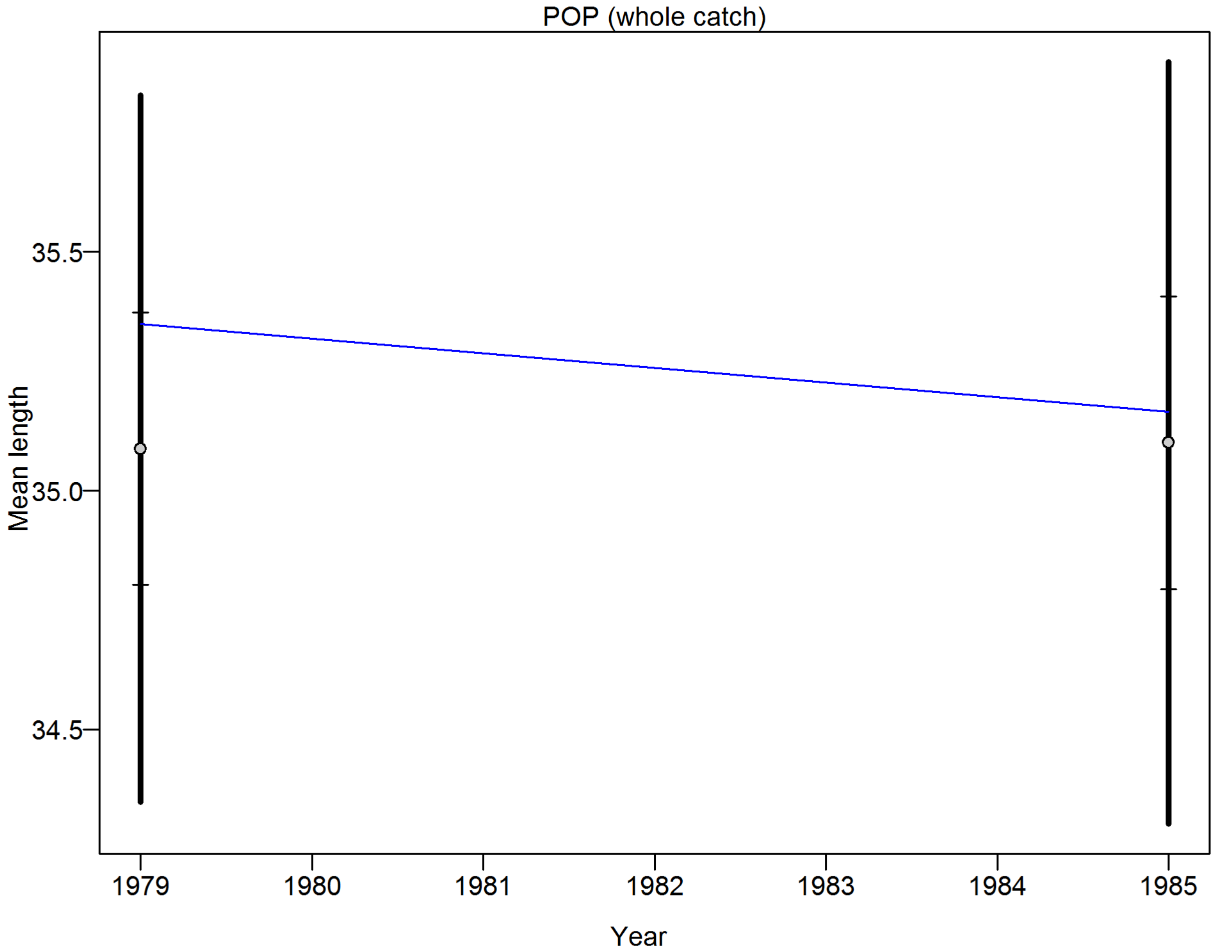

Figure 61: Francis data weighting method TA1.8: Pacific ocean perch survey Suggested sample size adjustment (with 95% interval) for len data from Pacific ocean perch survey: 6.7496 (6.7496_Inf) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_19_comp_lenfit_da

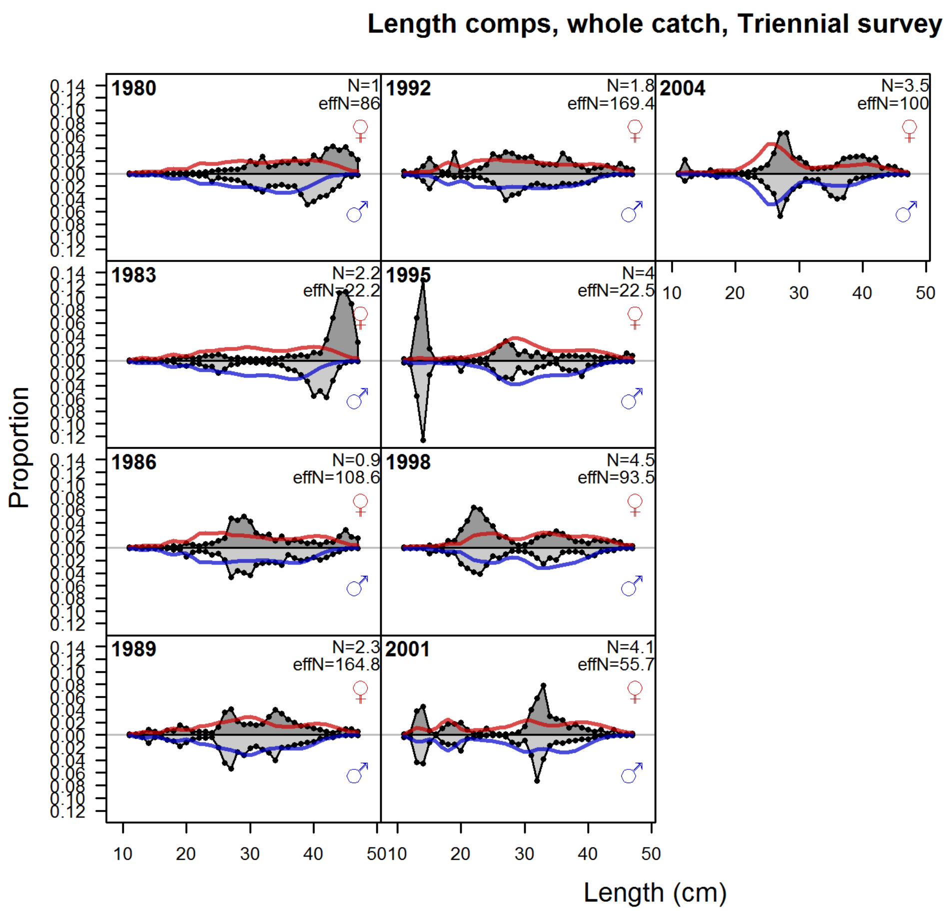

Figure 62: Length comps, whole catch, Triennial survey fig:mod1_20_comp_lenfit_flt5

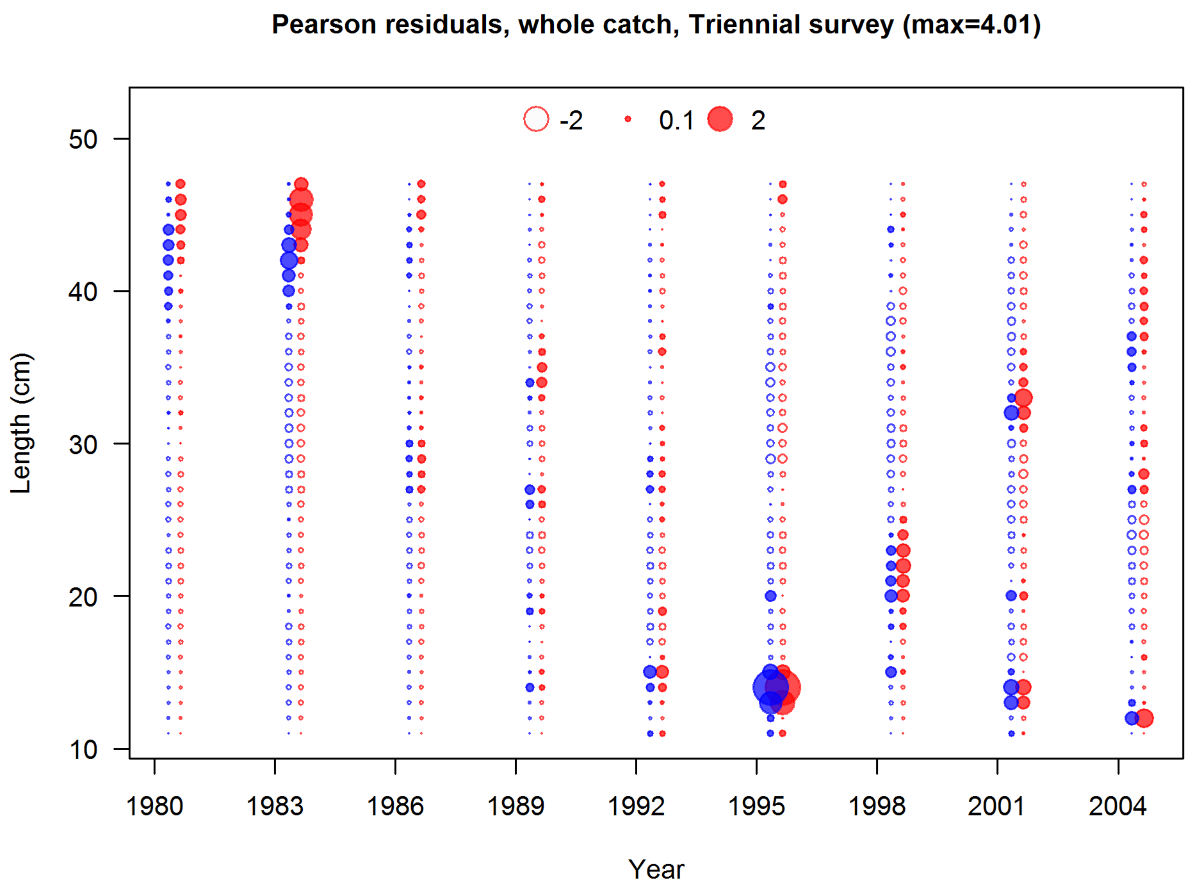

Figure 63: Pearson residuals, whole catch, Triennial survey (max=4.01)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_21_comp_lenfit_residsflt5mkt0

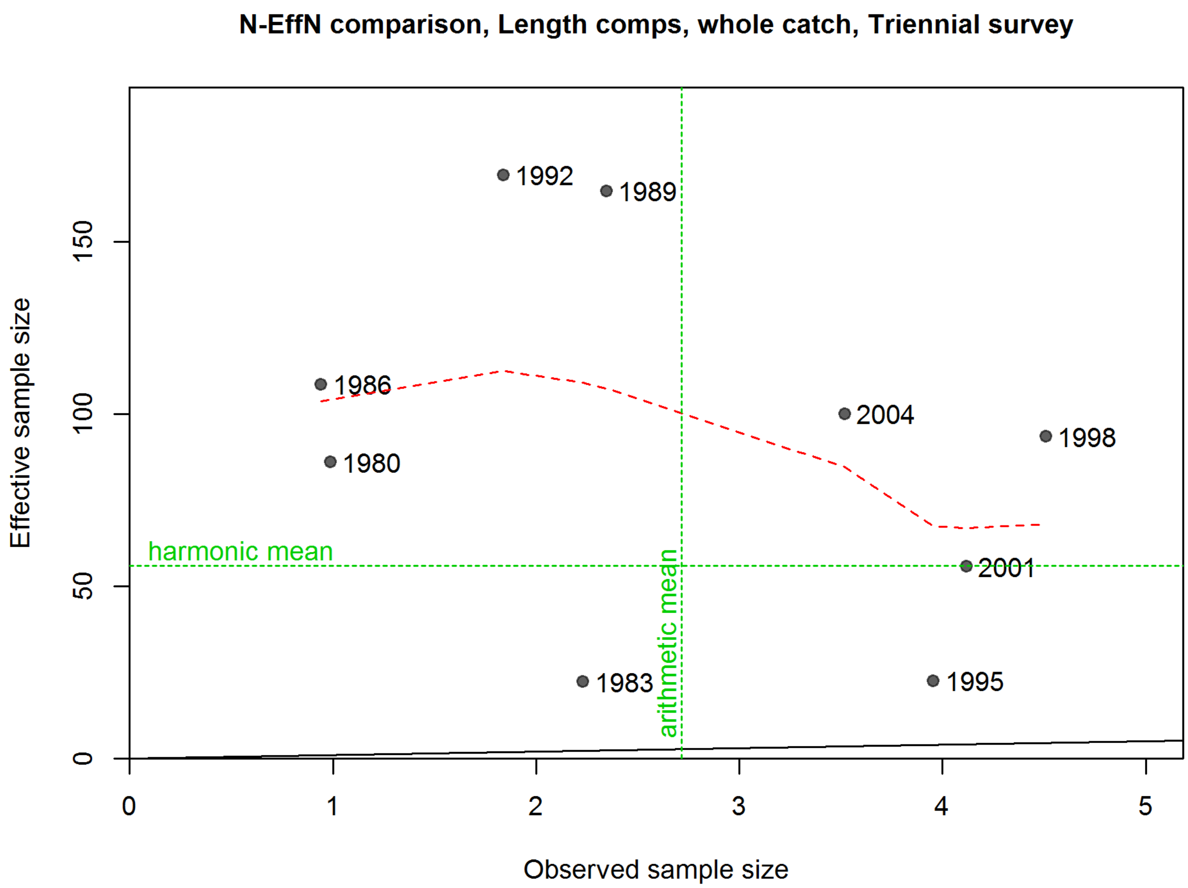

Figure 64: N_EffN comparison, Length comps, whole catch, Triennial survey fig:mod1_22_comp_le

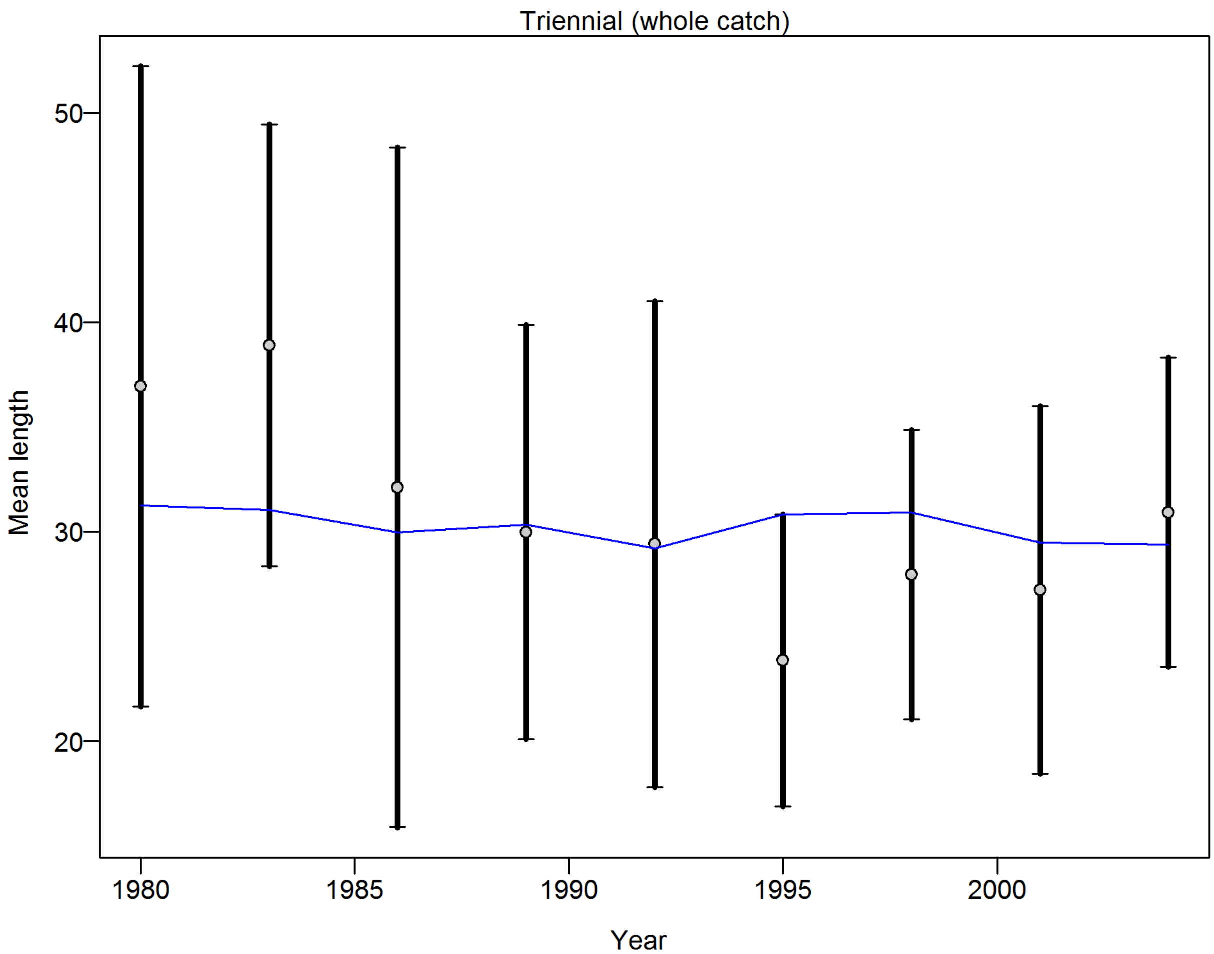

Figure 65: Francis data weighting method TA1.8: Triennial survey Suggested sample size adjustment (with 95% interval) for len data from Triennial survey: 1.0004 (0.5362_5.786) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_23_comp_lenfit_data_weighting_

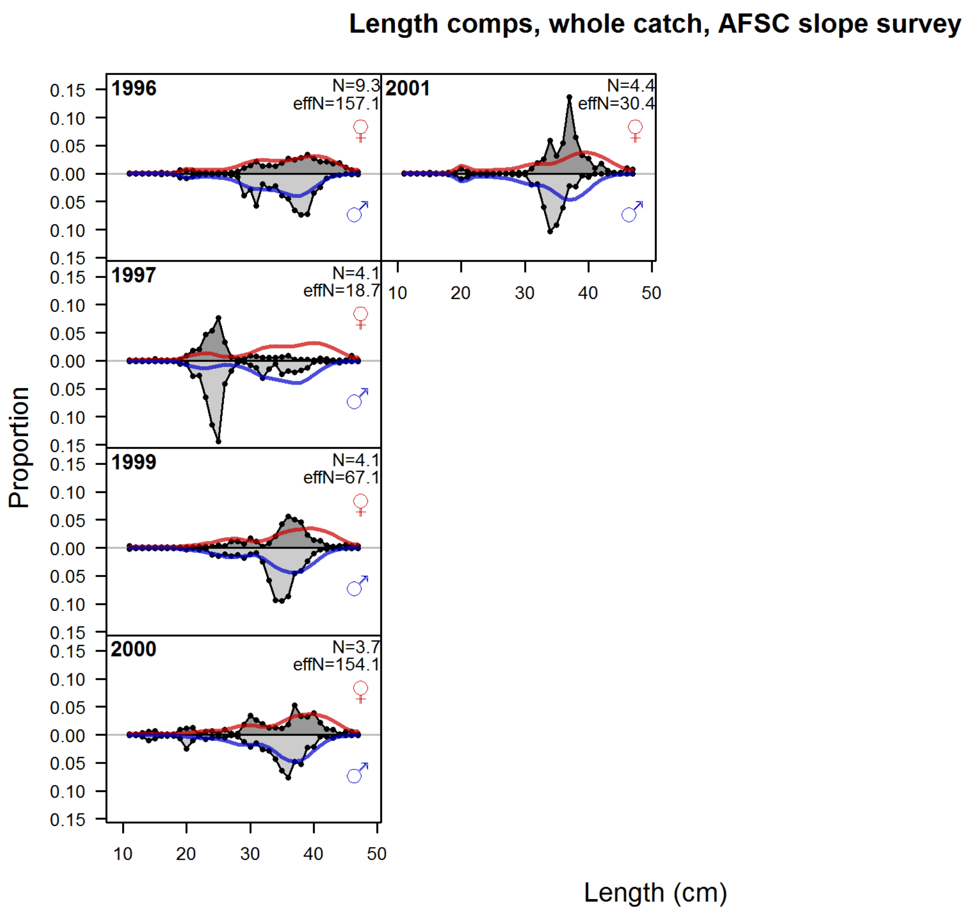

Figure 66: Length comps, whole catch, AFSC slope survey fig:mod1_24_comp_lenfit_flt

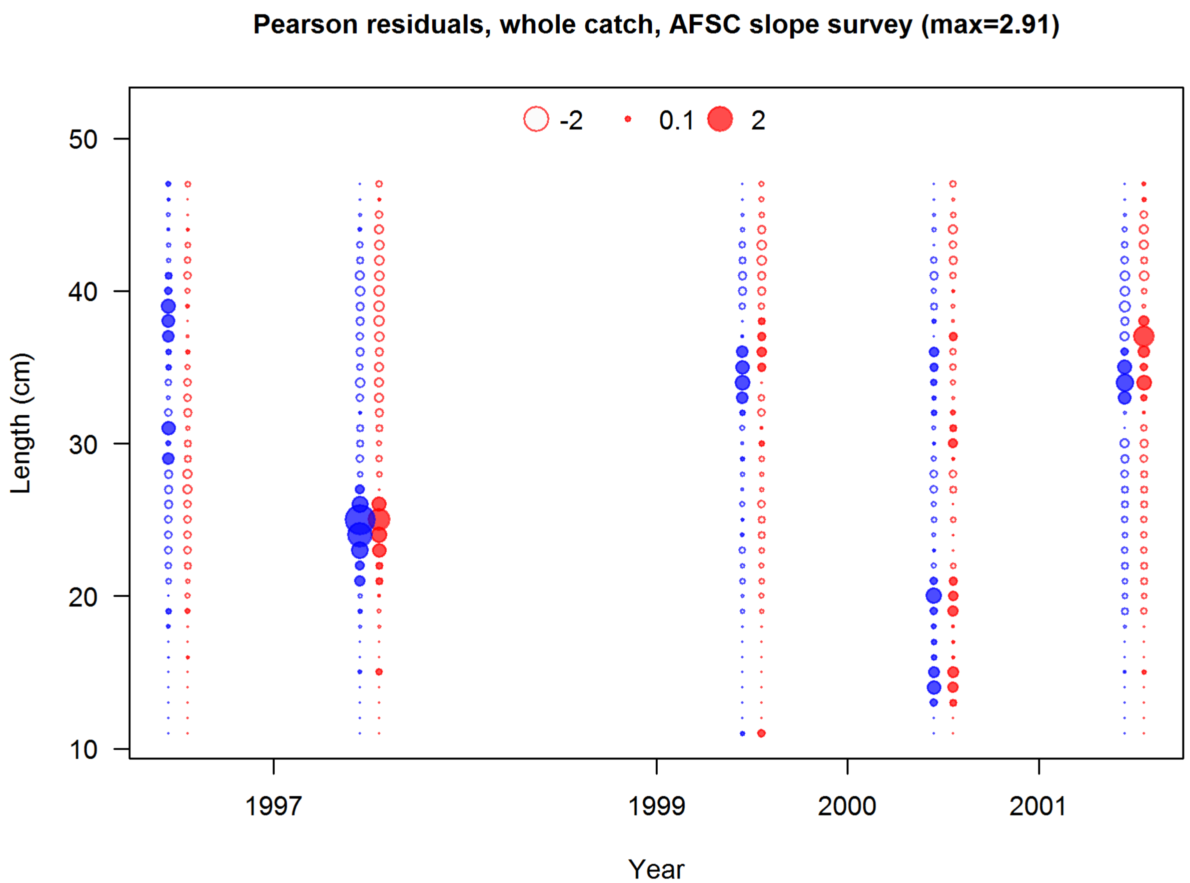

Figure 67: Pearson residuals, whole catch, AFSC slope survey (max=2.91)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_25_comp_lenfit_residsflt6mkt0

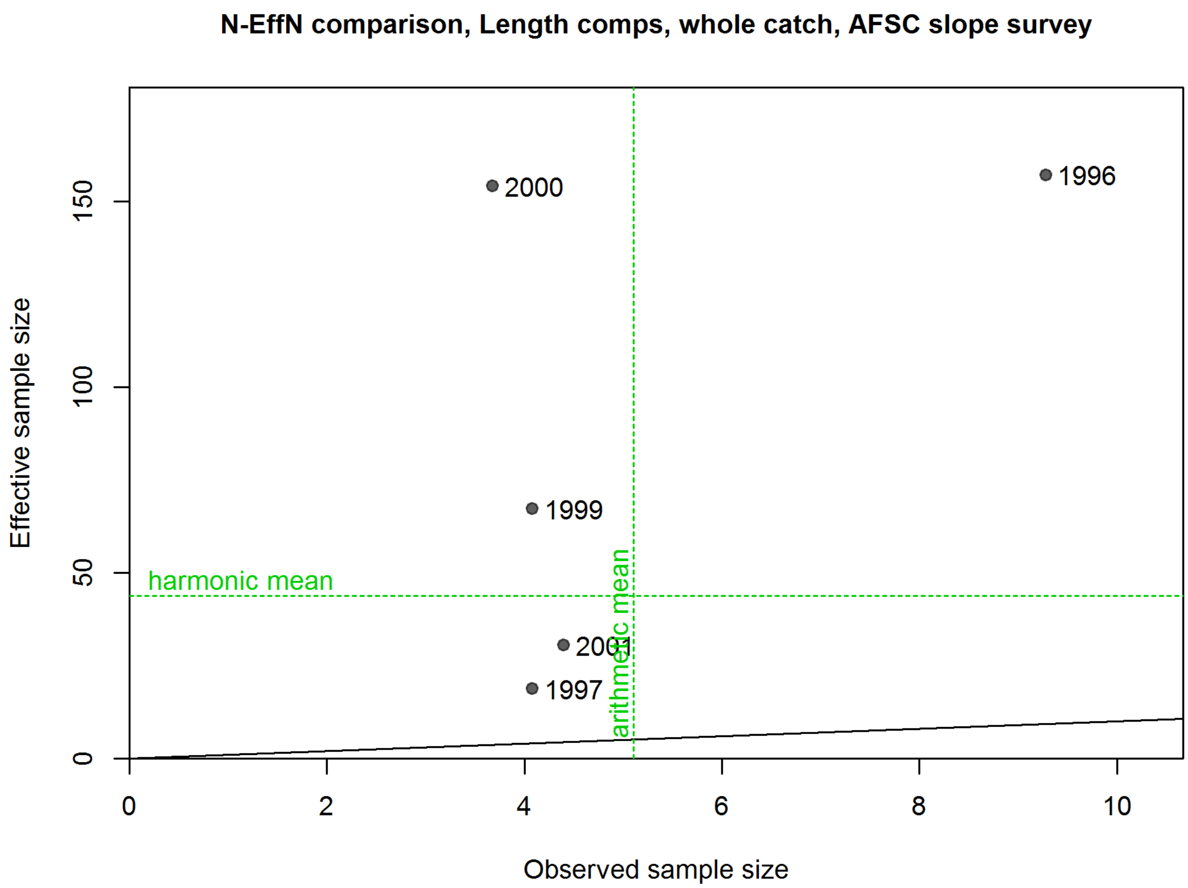

Figure 68: N_EffN comparison, Length comps, whole catch, AFSC slope survey fig:mod1_26_comp_l

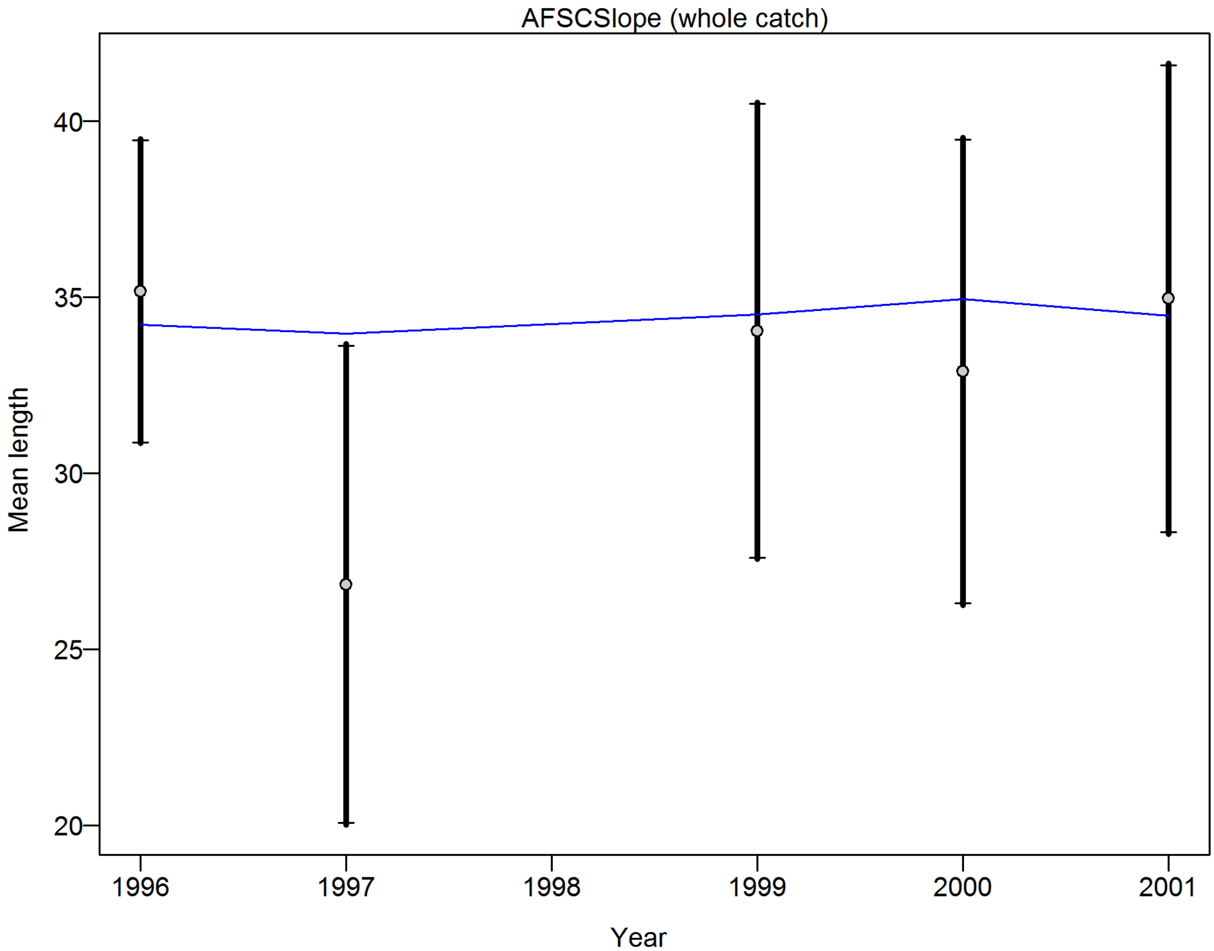

Figure 69: Francis data weighting method TA1.8: AFSC slope survey Suggested sample size adjustment (with 95% interval) for len data from AFSC slope survey: 1.0151 (0.5859_16.7225) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_27_comp_lenfit_data_weighting_

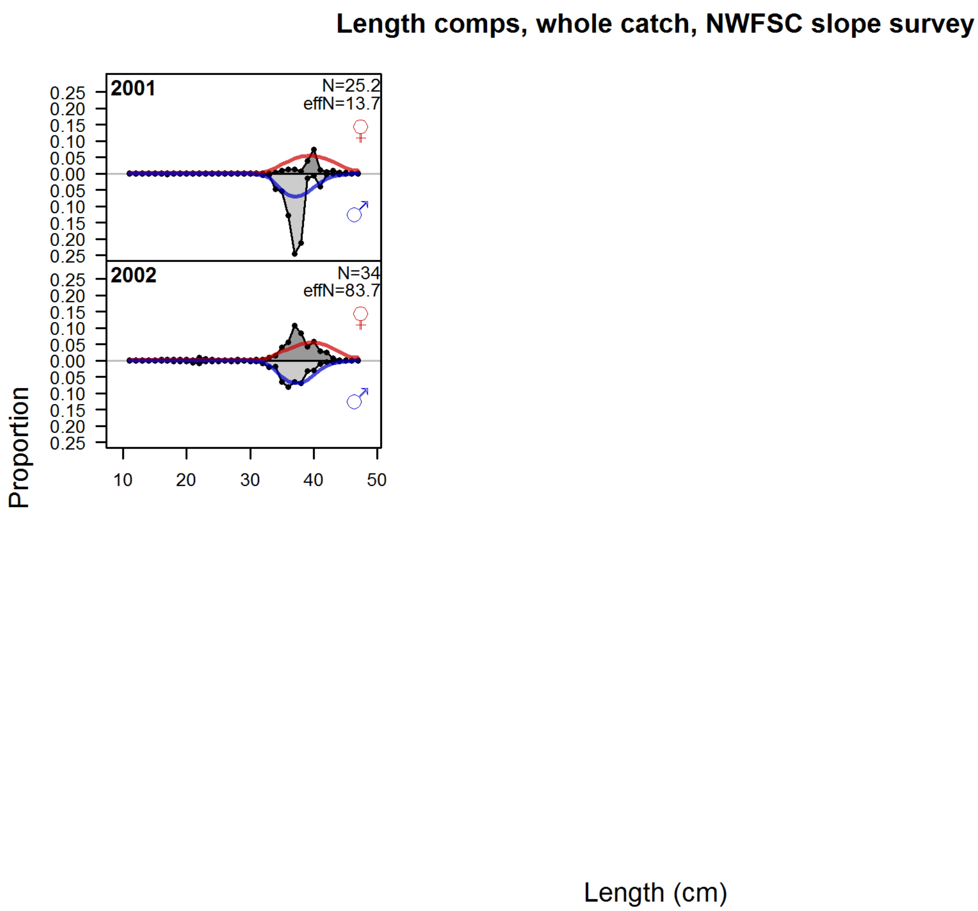

Figure 70: Length comps, whole catch, NWFSC slope survey fig:mod1_28_comp_lenfit_fl

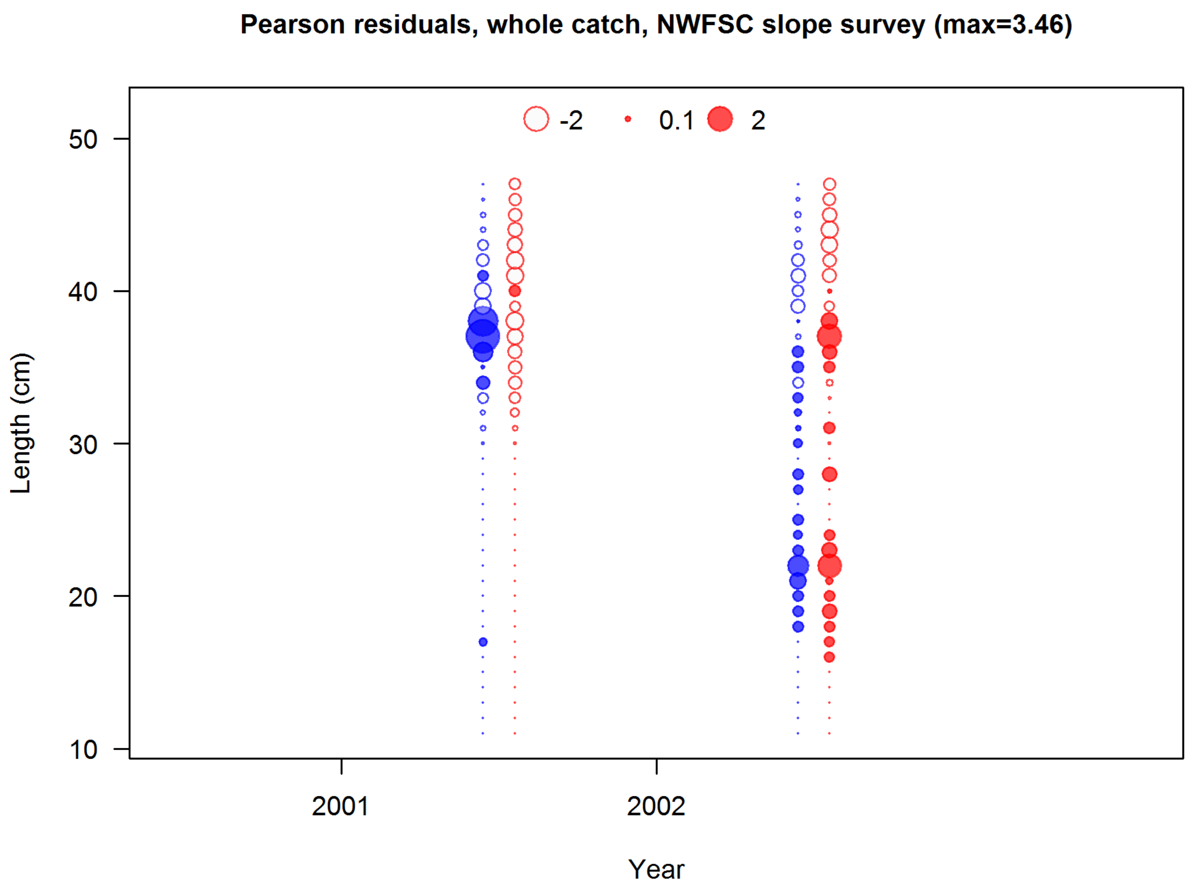

Figure 71: Pearson residuals, whole catch, NWFSC slope survey (max=3.46)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_29_comp_lenfit_residsflt7mkt0

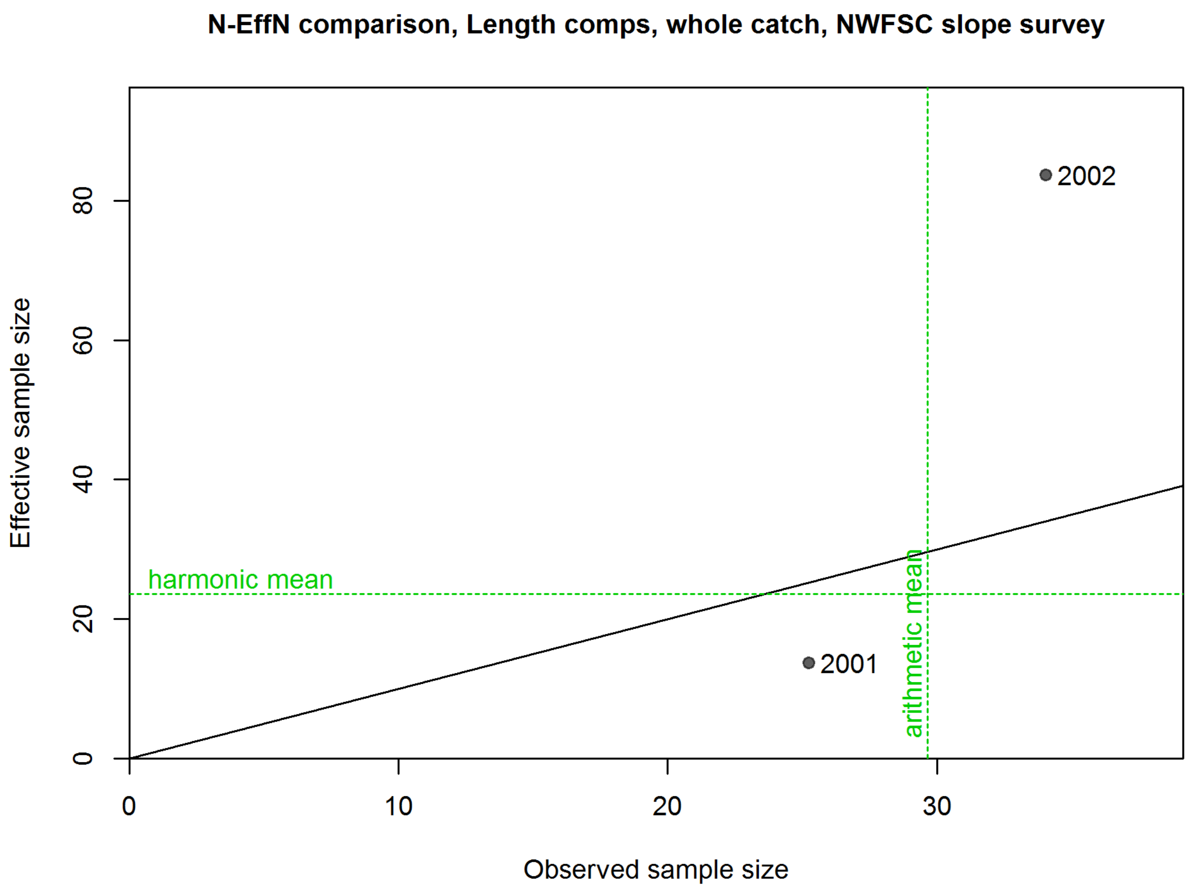

Figure 72: N_EffN comparison, Length comps, whole catch, NWFSC slope survey fig:mod1_30_comp_

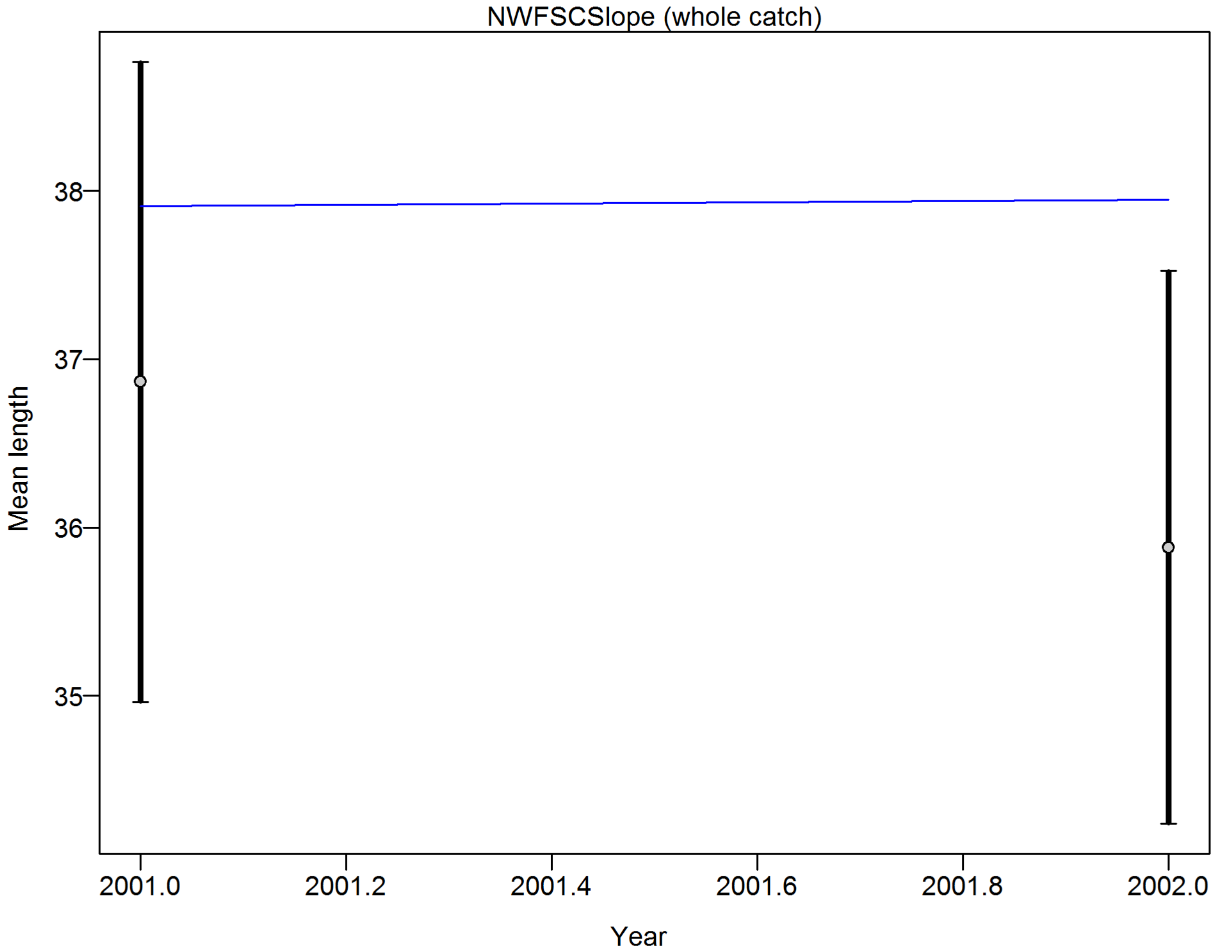

Figure 73: Francis data weighting method TA1.8: NWFSC slope survey Suggested sample size adjustment (with 95% interval) for len data from NWFSC slope survey: 0.9922 (0.9922_Inf) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_31_comp_lenfit_data_weighting_

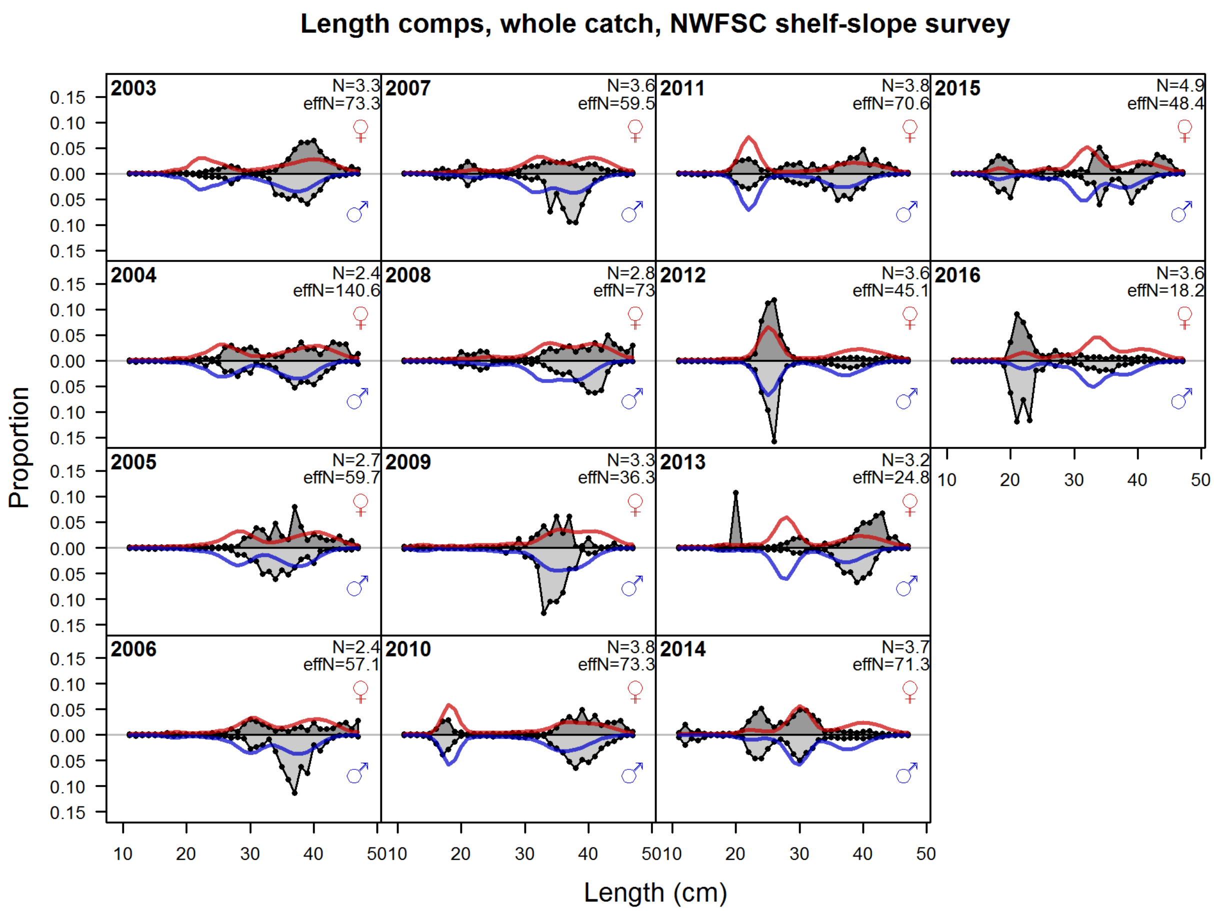

Figure 74: Length comps, whole catch, NWFSC shelf_slope survey fig:mod1_32_comp_lenfit_

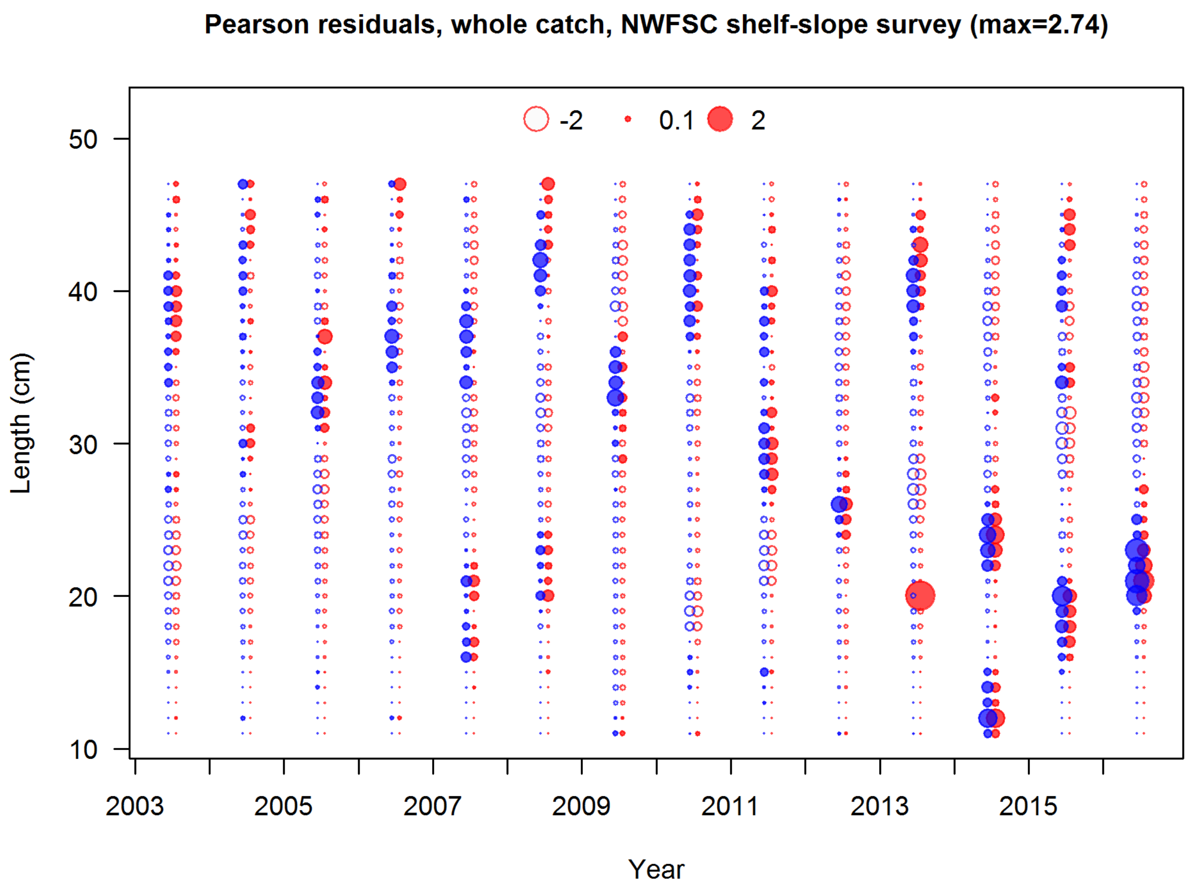

Figure 75: Pearson residuals, whole catch, NWFSC shelf_slope survey (max=2.74) Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_33_comp_lenfit_residsflt8mkt0

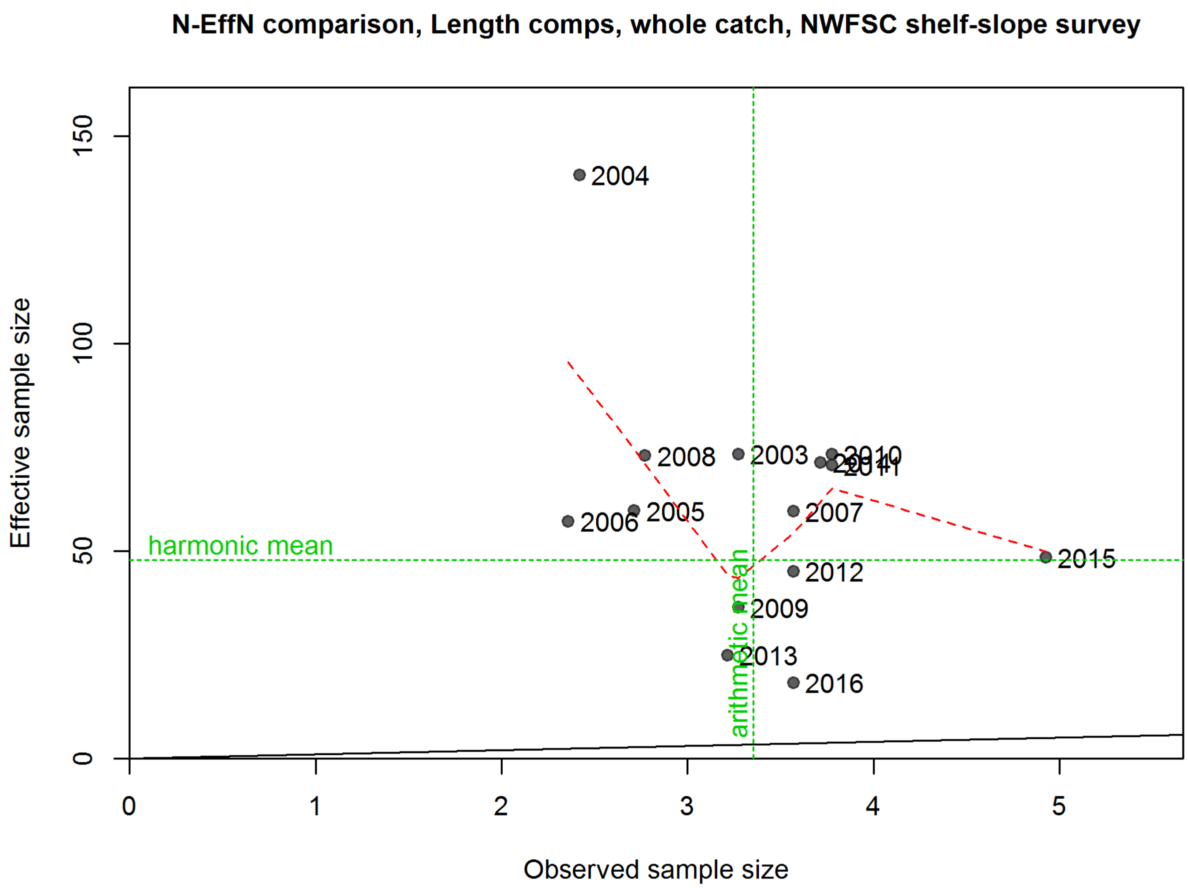

Figure 76: N_EffN comparison, Length comps, whole catch, NWFSC shelf_slope survey fig:mod1_34_co

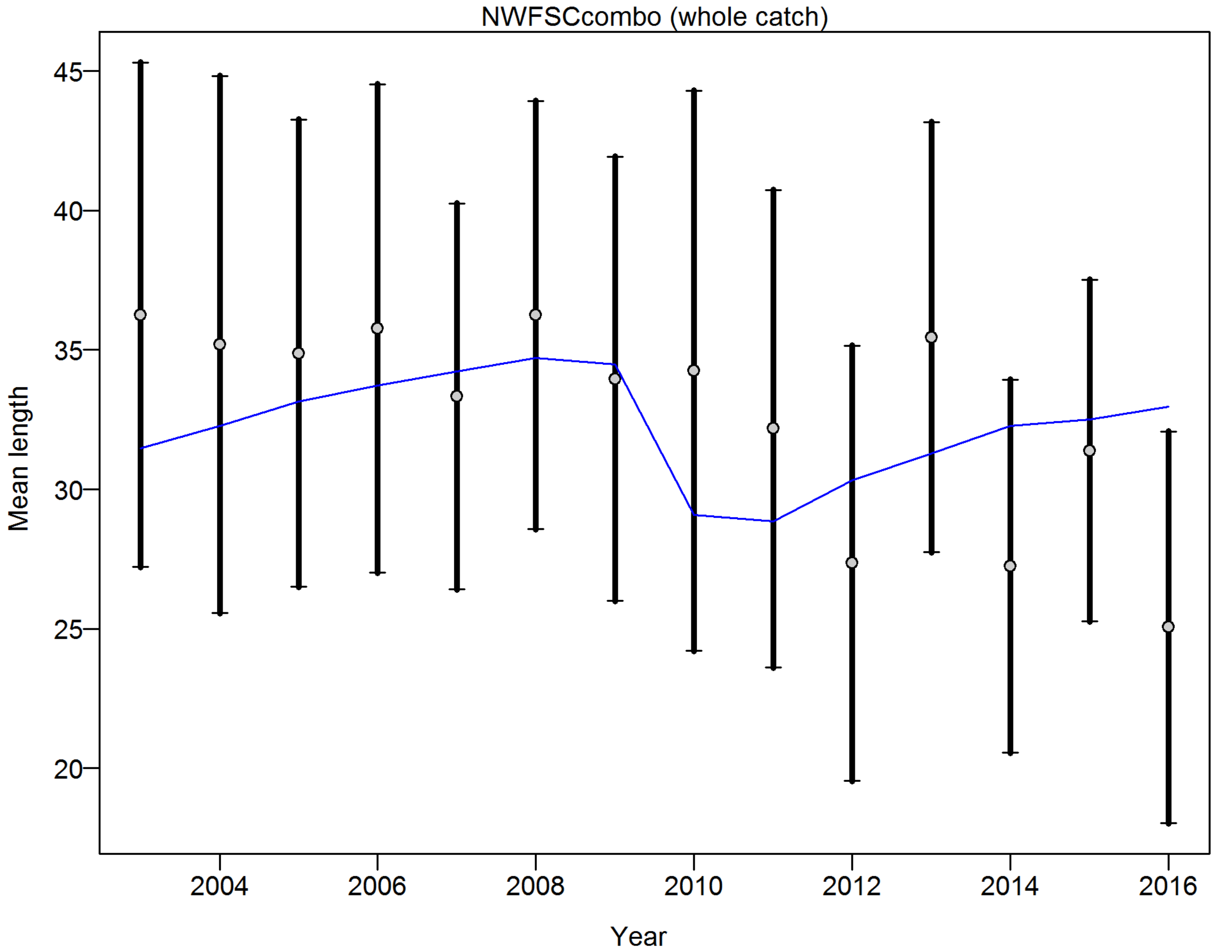

Figure 77: Francis data weighting method TA1.8: NWFSC shelf_slope survey Suggested sample size adjustment (with 95% interval) for len data from NWFSC shelf_slope survey: 1.0055 (0.6199_4.021) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_35_comp_lenfit_da

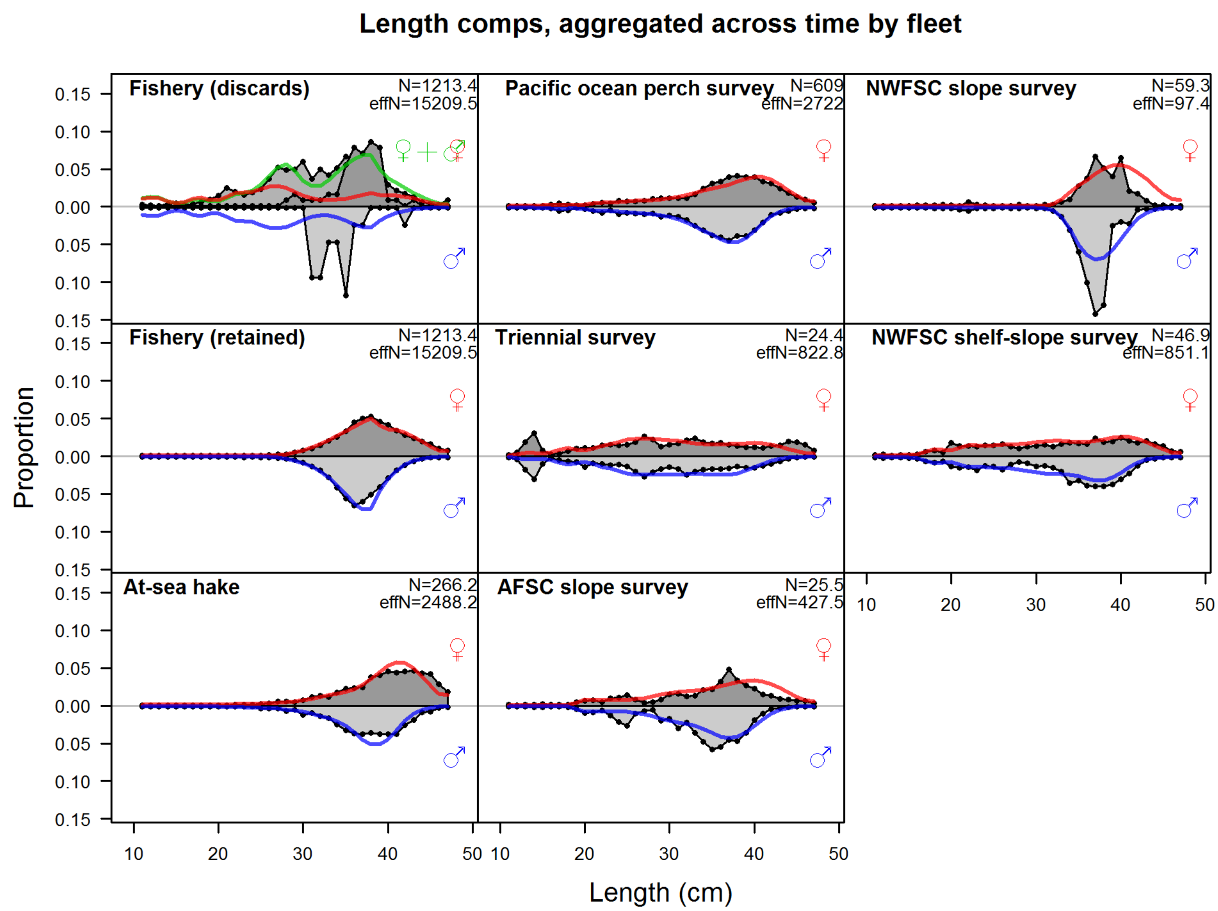

Figure 78: Length comps, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch. fig:mod1_36_comp_lenfit__aggregated_across_time

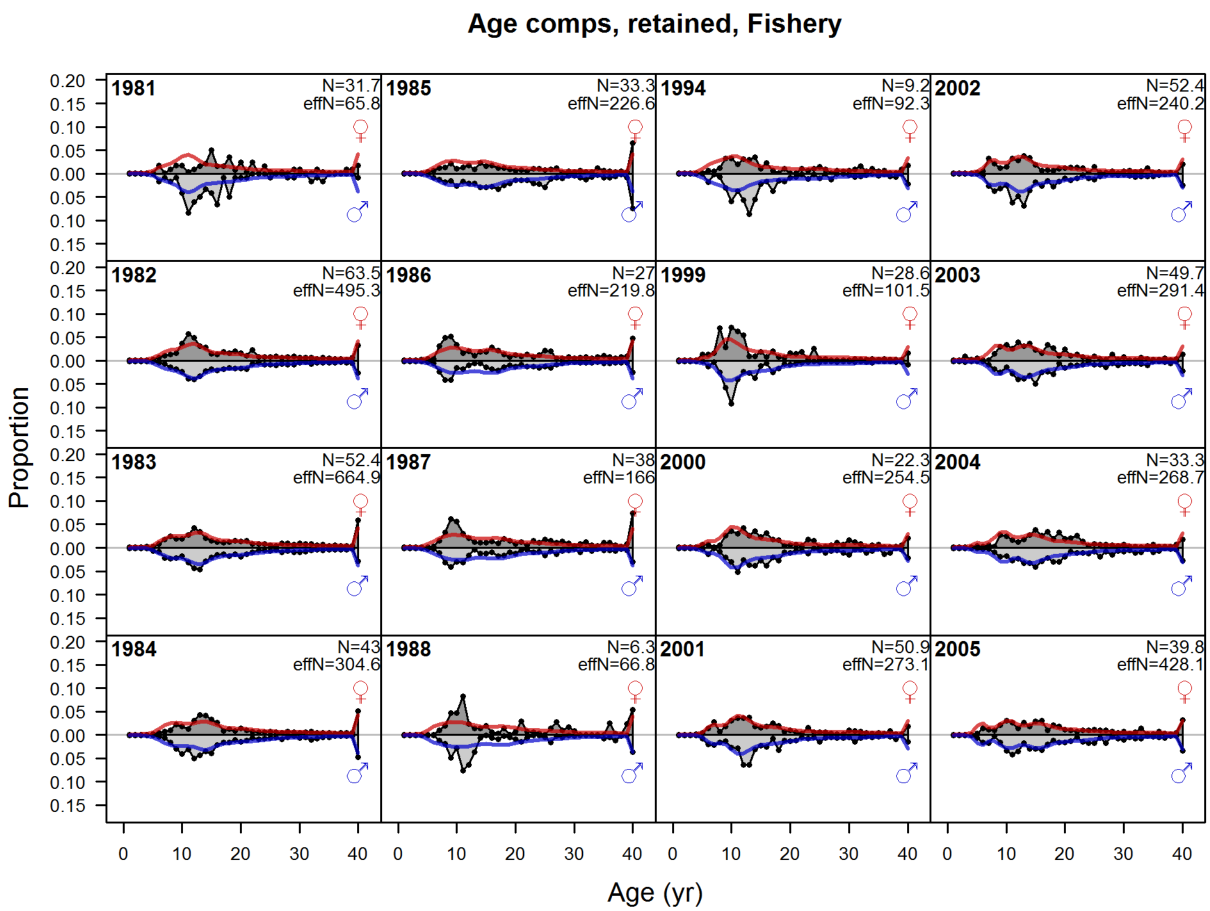

Figure 79: Age comps, retained, Fishery (plot 1 of 2) fig:mod1_1_comp_agefit_flt1mk

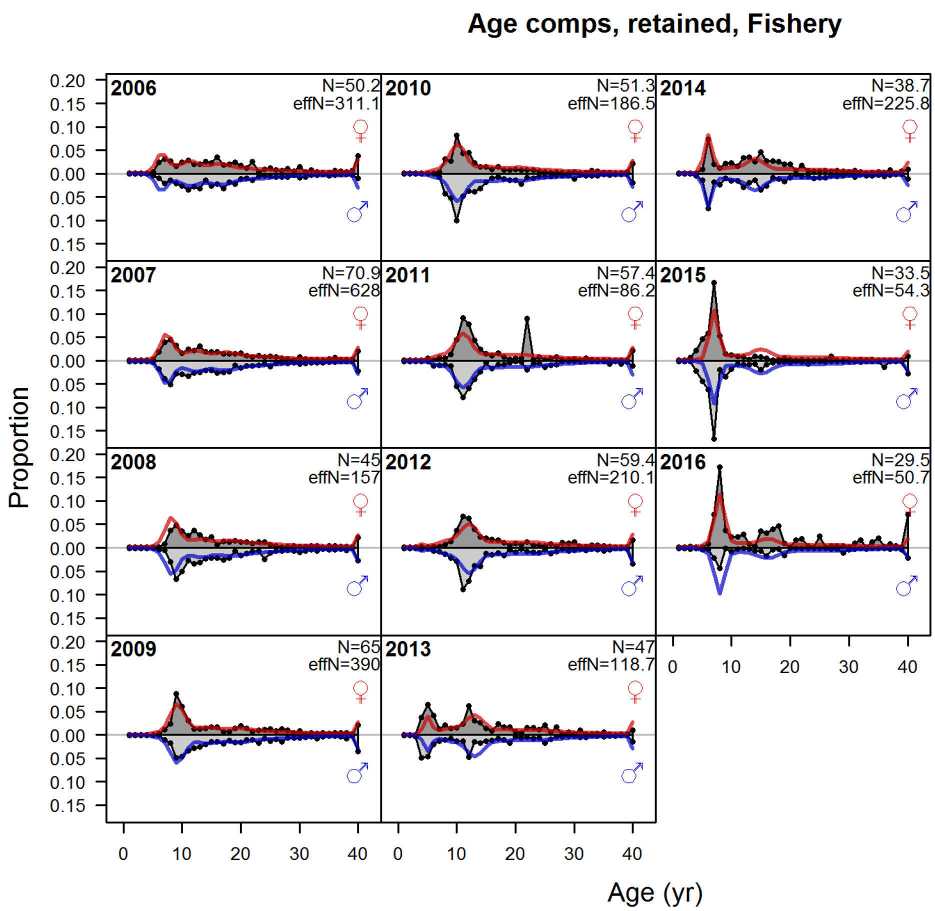

Figure 80: Age comps, retained, Fishery (plot 1 of 2) (plot 2 of 2) fig:mod1_2_comp_agefit_f

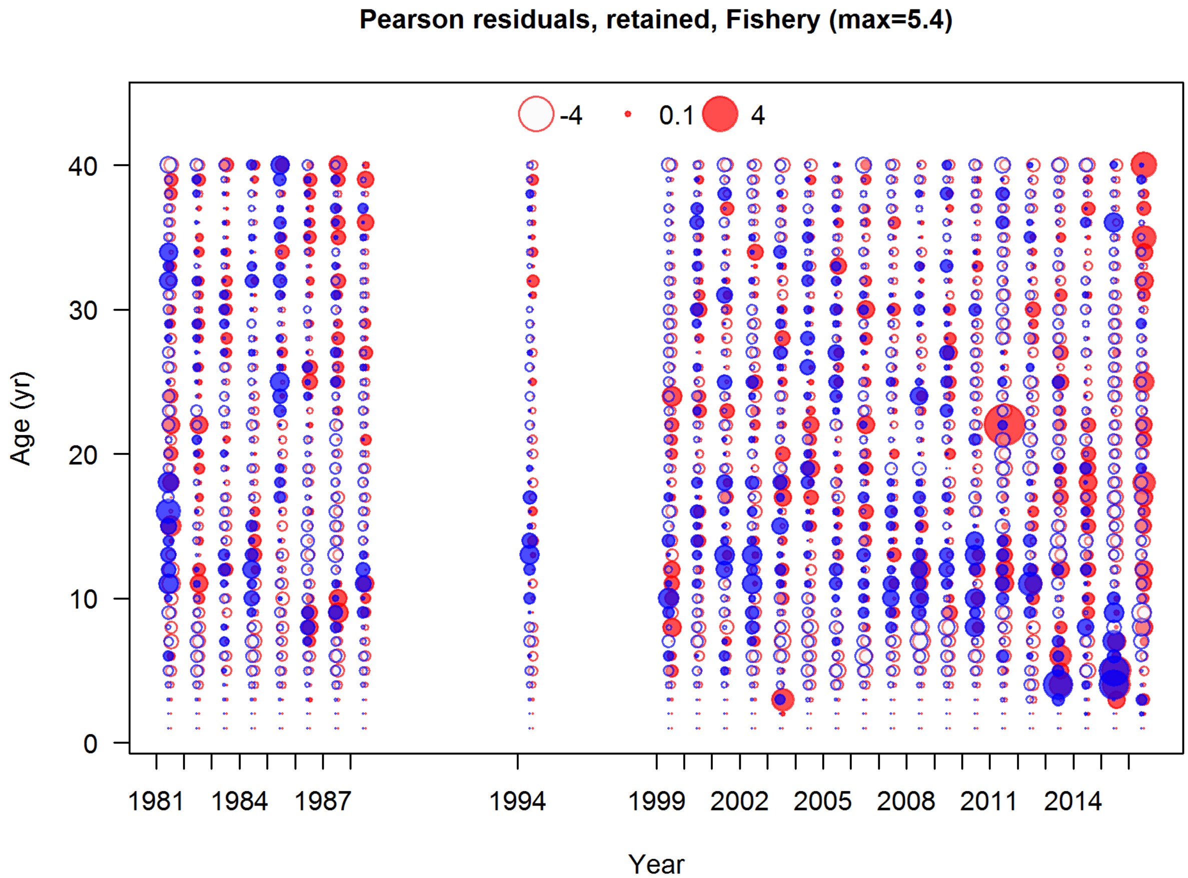

Figure 81: Pearson residuals, retained, Fishery (max=5.4) (plot 2 of 2)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_3_comp_agefit_residsflt1mkt2_page2

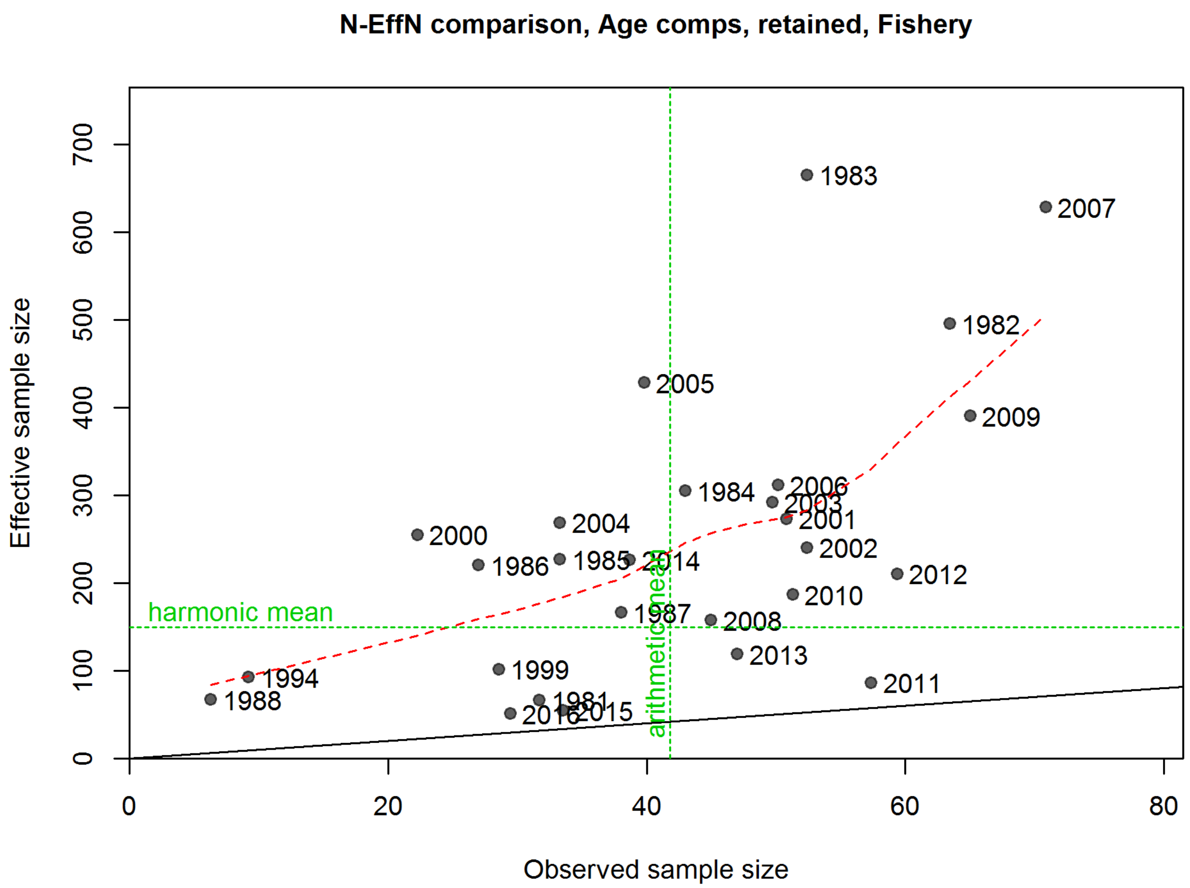

Figure 82: N_EffN comparison, Age comps, retained, Fishery fig:mod1_4_comp_agefit_sam

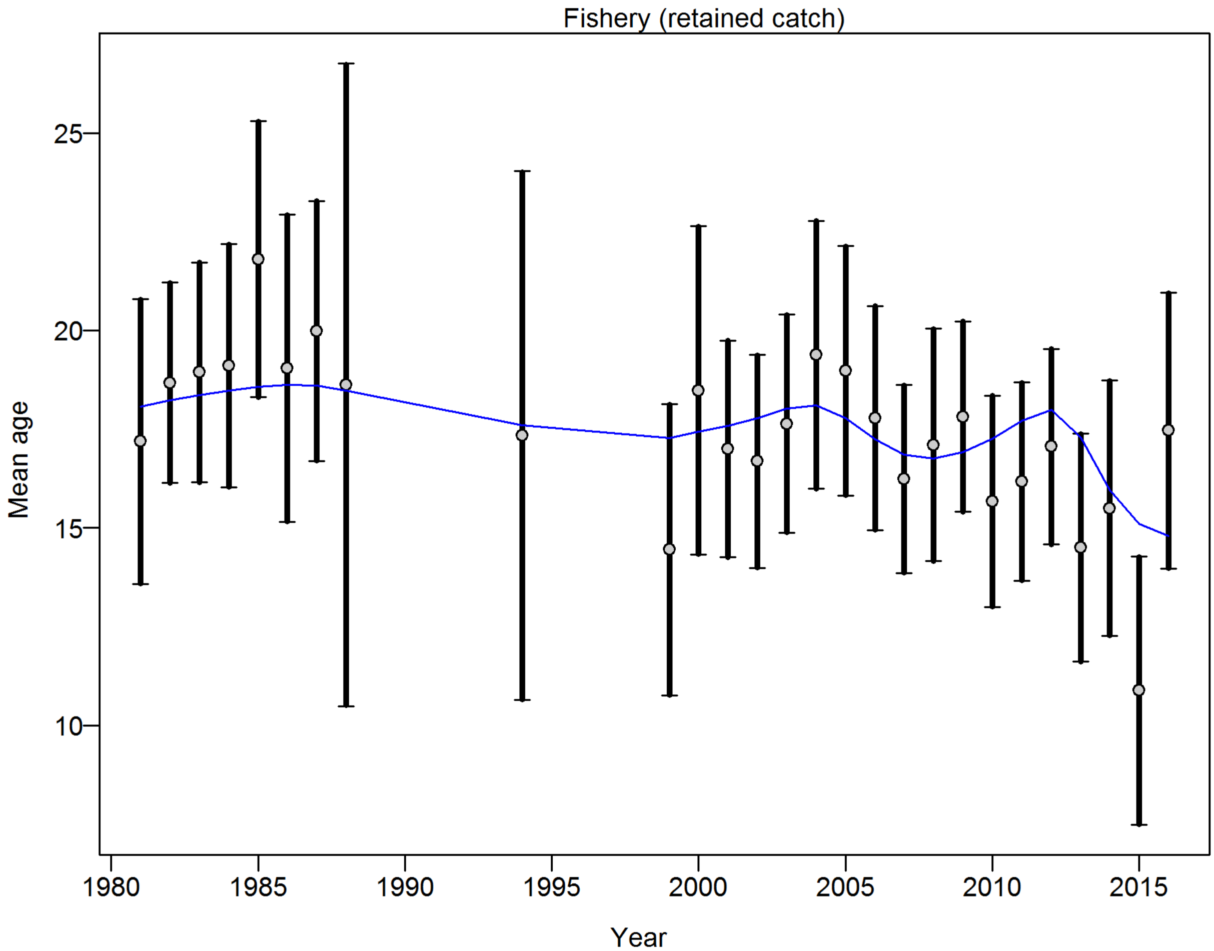

Figure 83: Francis data weighting method TA1.8: Fishery Suggested sample size adjustment (with 95% interval) for age data from Fishery: 0.9921 (0.6365_1.9959) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_5_comp_agefit_data_weighting_TA1.8_Fishery

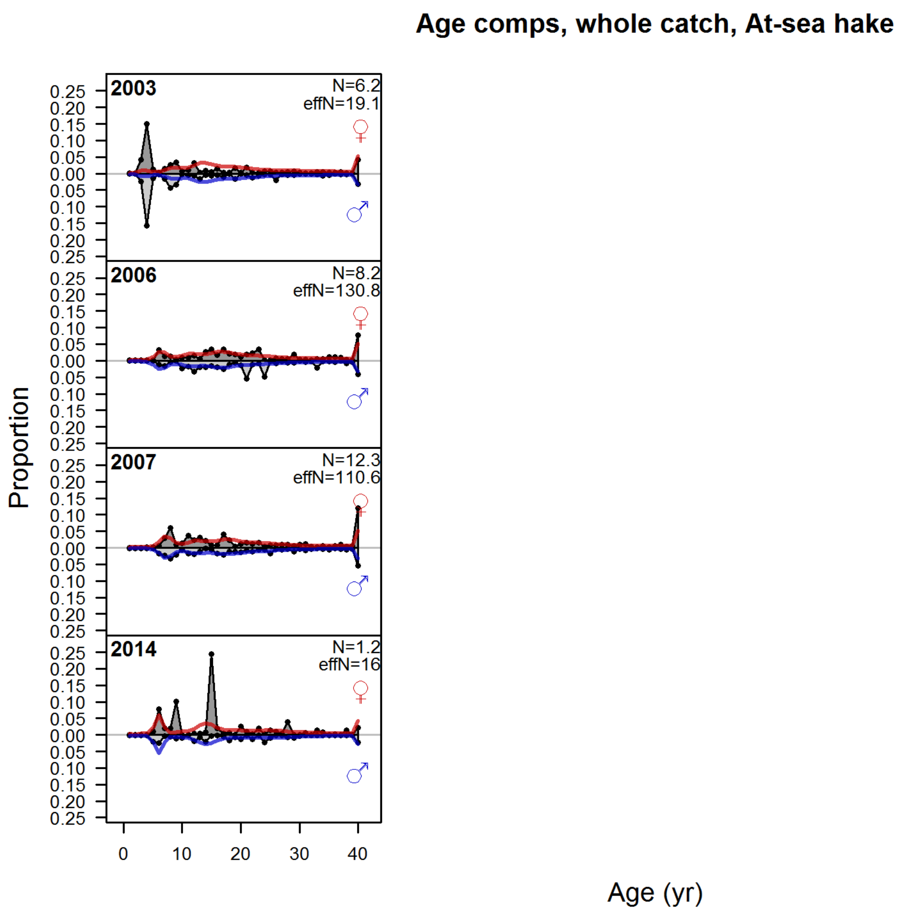

Figure 84: Age comps, whole catch, At_sea hake fig:mod1_6_comp_agefit_flt2mkt0

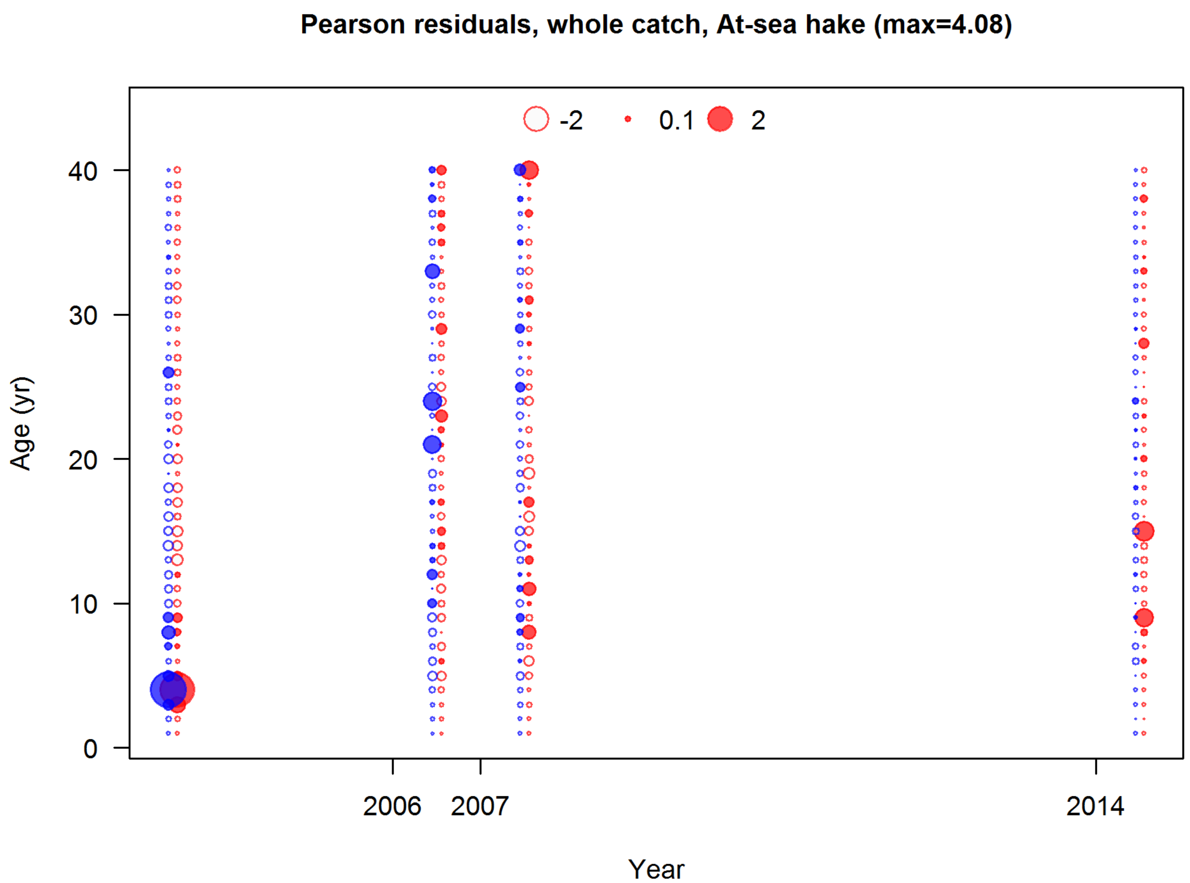

Figure 85: Pearson residuals, whole catch, At_sea hake (max=4.08)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_7_comp_agefit_residsflt2mkt0

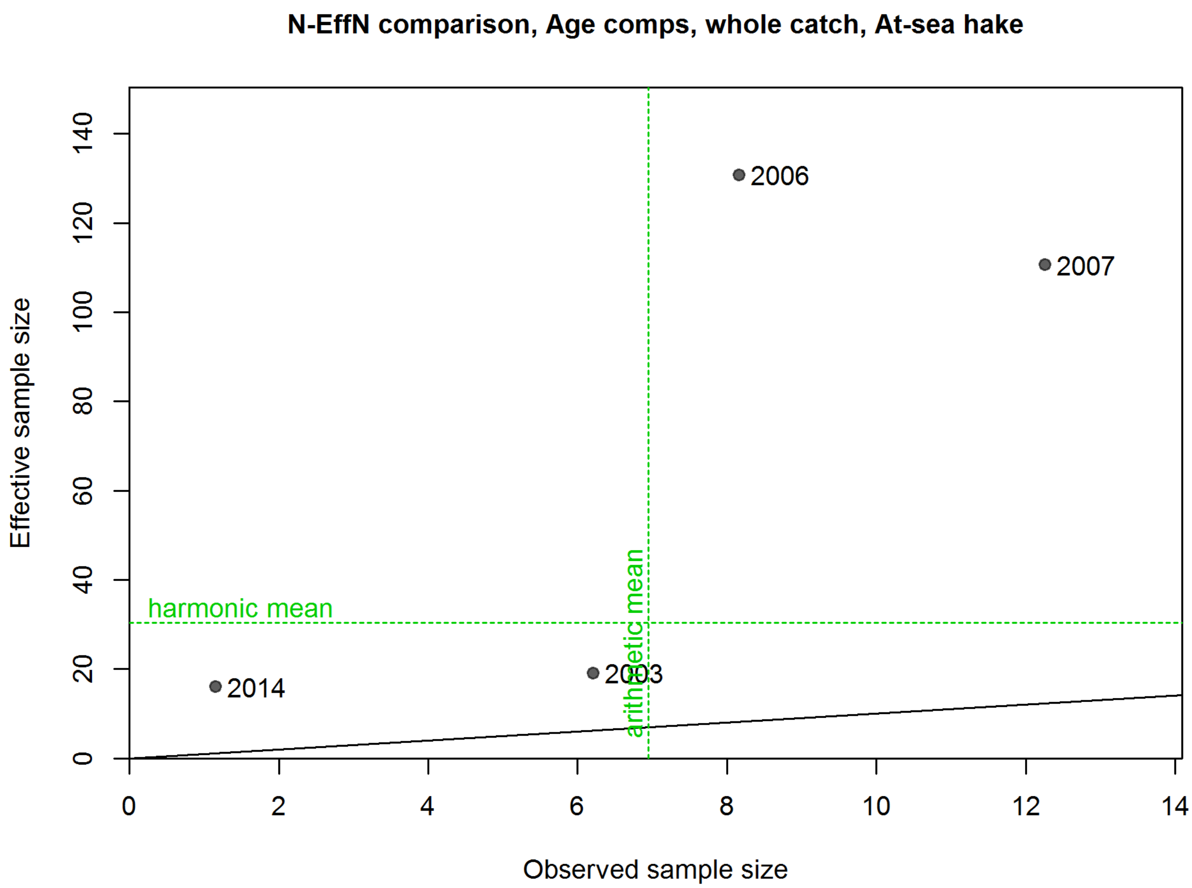

Figure 86: N_EffN comparison, Age comps, whole catch, At_sea hake fig:mod1_8_comp_agefit_

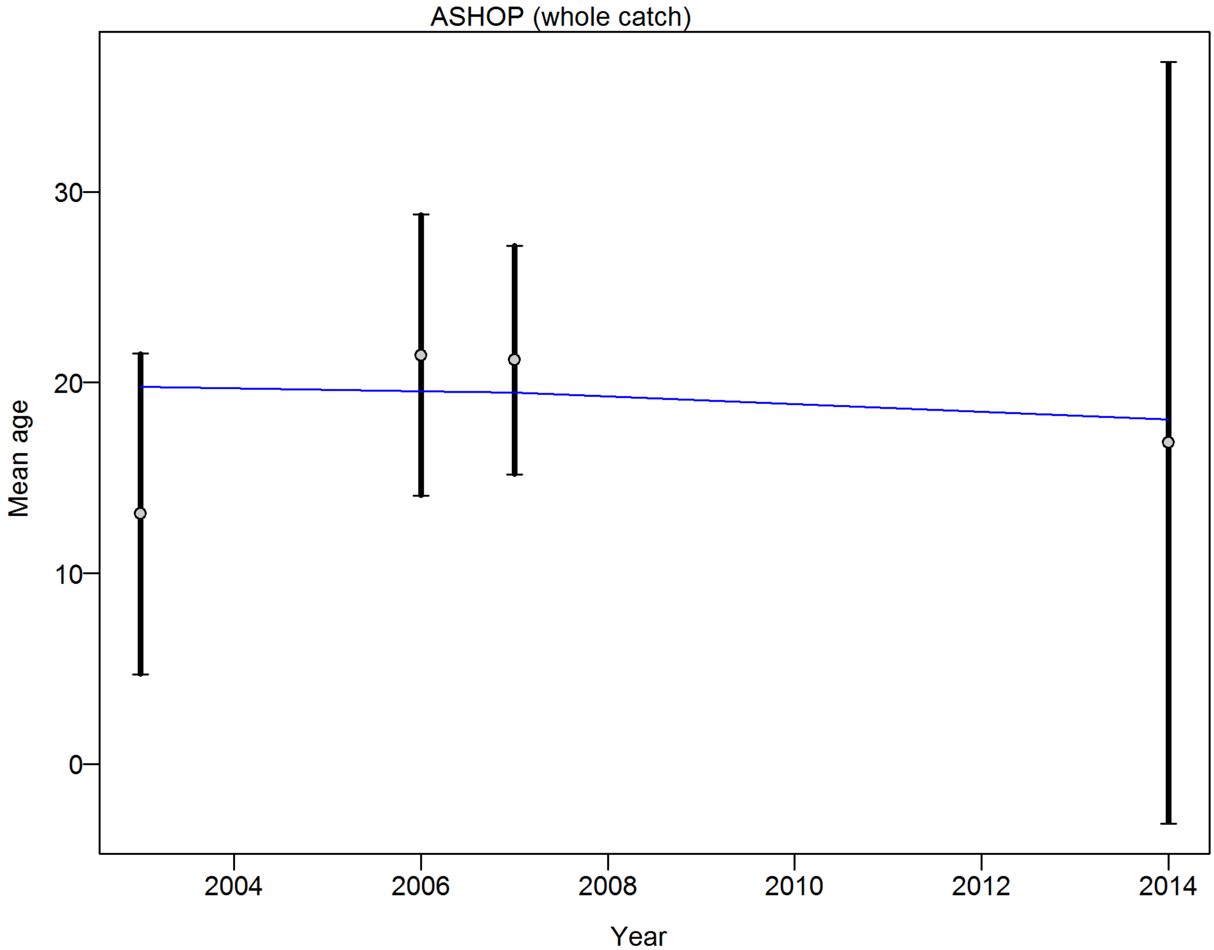

Figure 87: Francis data weighting method TA1.8: At_sea hake Suggested sample size adjustment (with 95% interval) for age data from At_sea hake: 0.9921 (0.6459_1420.3157) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_9_comp_agefit_data_weighting_T

Age comps, whole catch, Pacific ocean perch survey

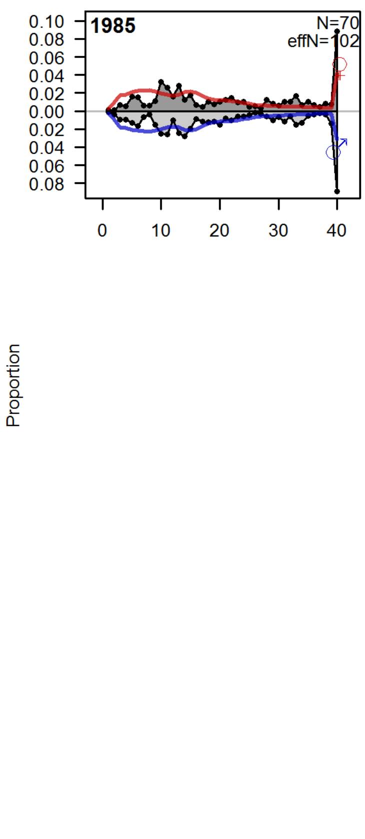

Figure 88: Age comps, whole catch, Pacific ocean perch survey fig:mod1_10_comp_agefit_f

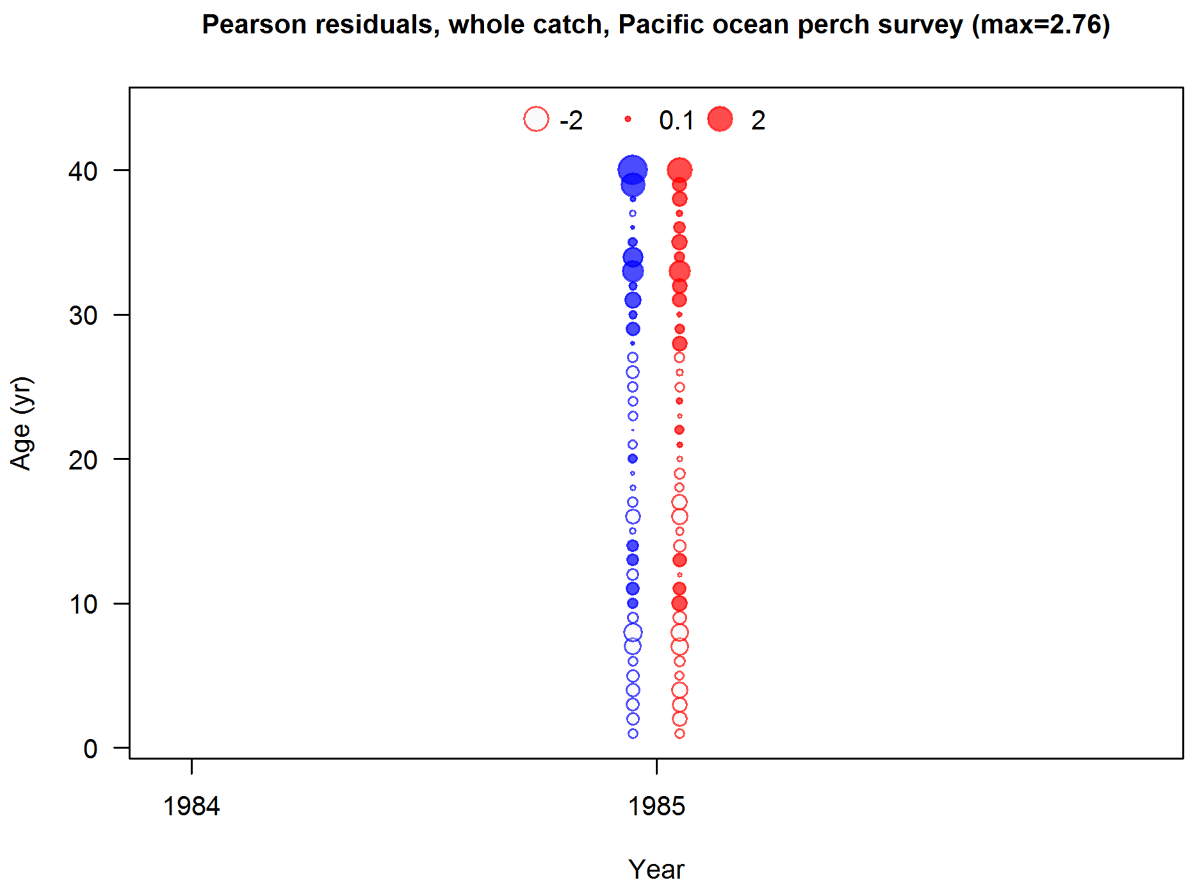

Figure 89: Pearson residuals, whole catch, Pacific ocean perch survey (max=2.76) Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_11_comp_agefit_residsflt4mkt0

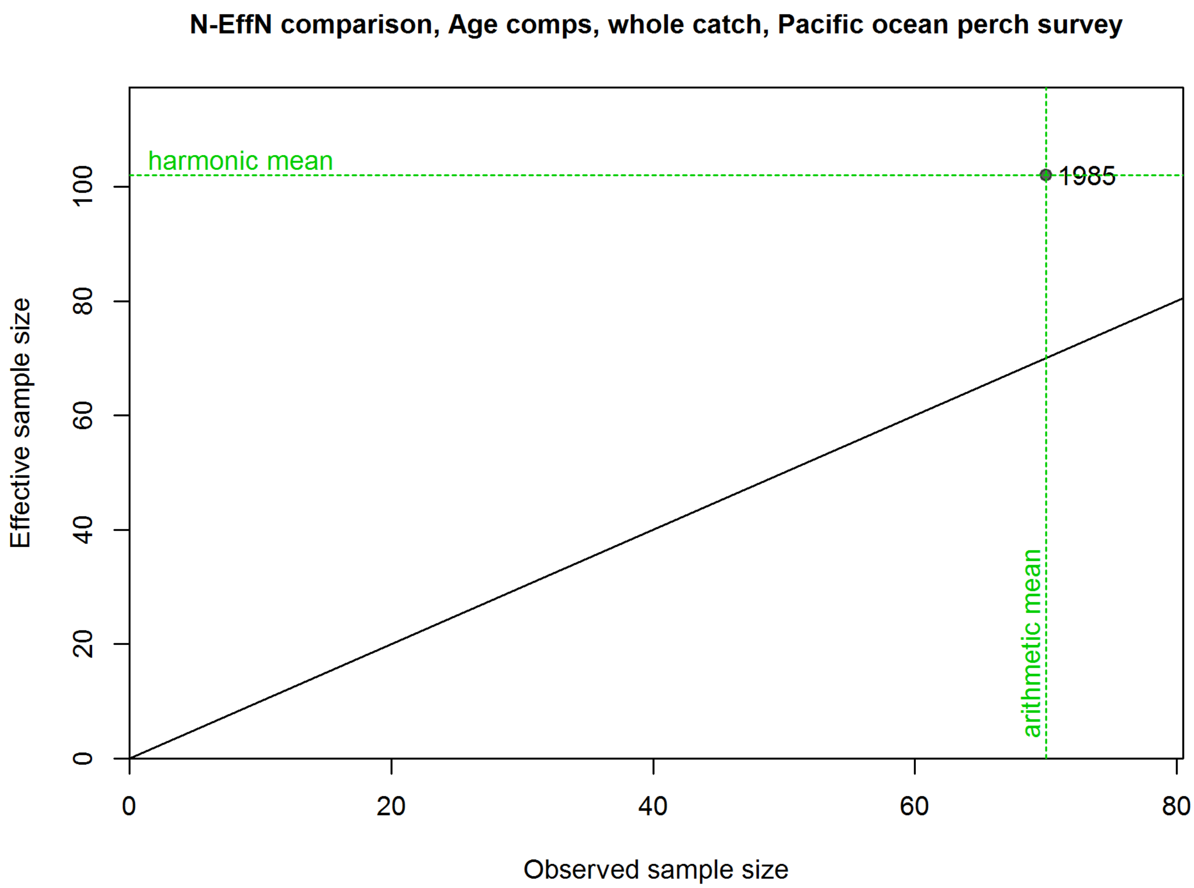

Figure 90: N_EffN comparison, Age comps, whole catch, Pacific ocean perch survey fig:mod1_12_comp

Figure 91: Francis data weighting method TA1.8: Pacific ocean perch survey Too few points to calculate adjustments For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_13_comp

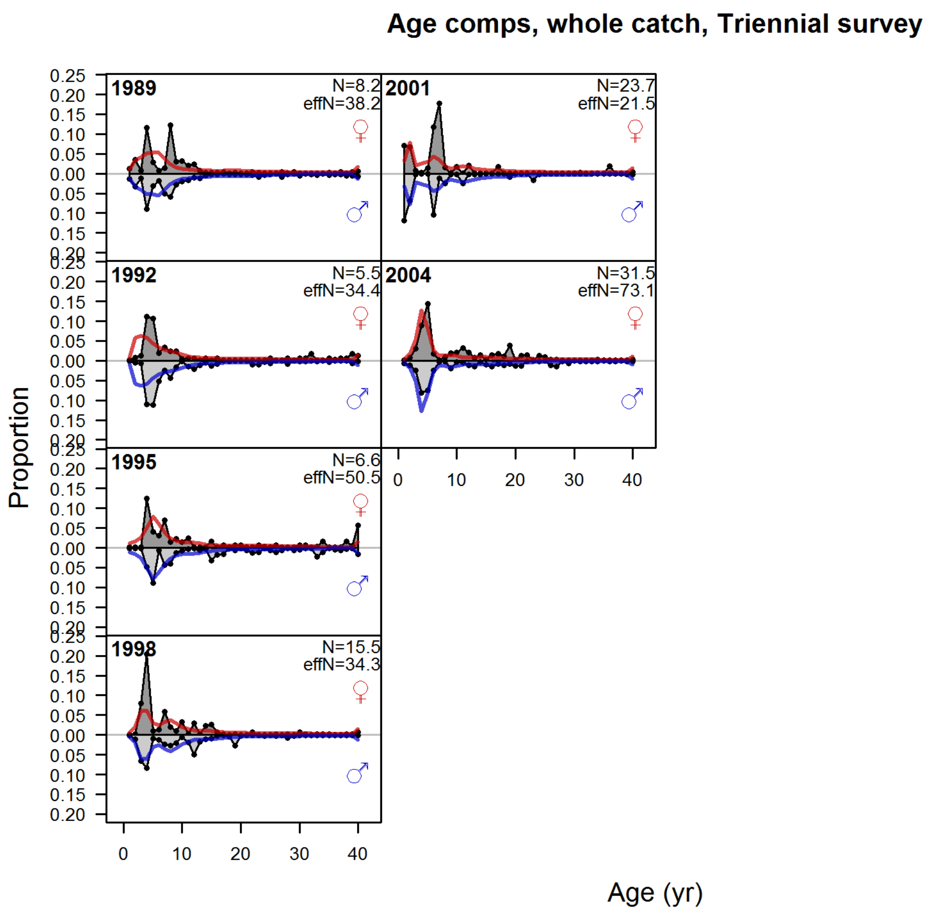

Figure 92: Age comps, whole catch, Triennial survey fig:mod1_14_comp_agefit_flt5mk

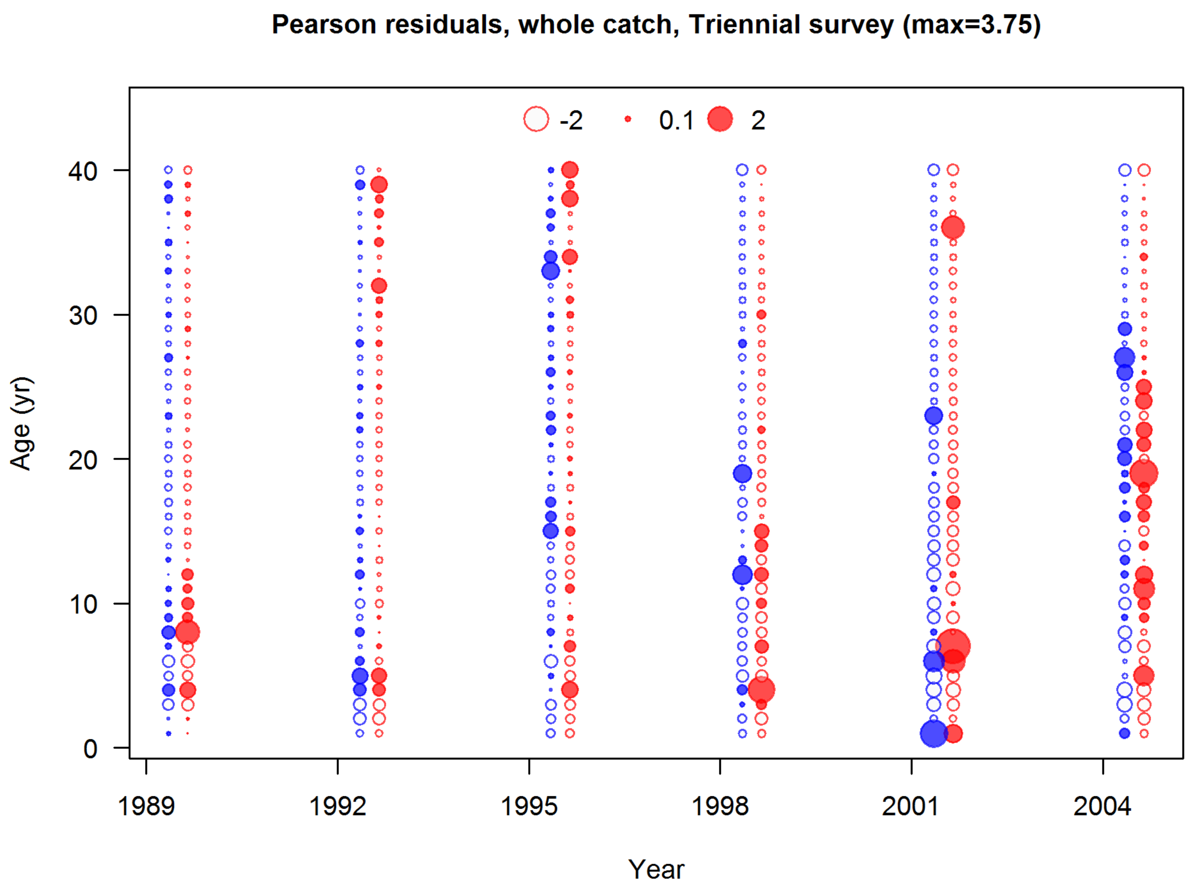

Figure 93: Pearson residuals, whole catch, Triennial survey (max=3.75)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_15_comp_agefit_residsflt5mkt0

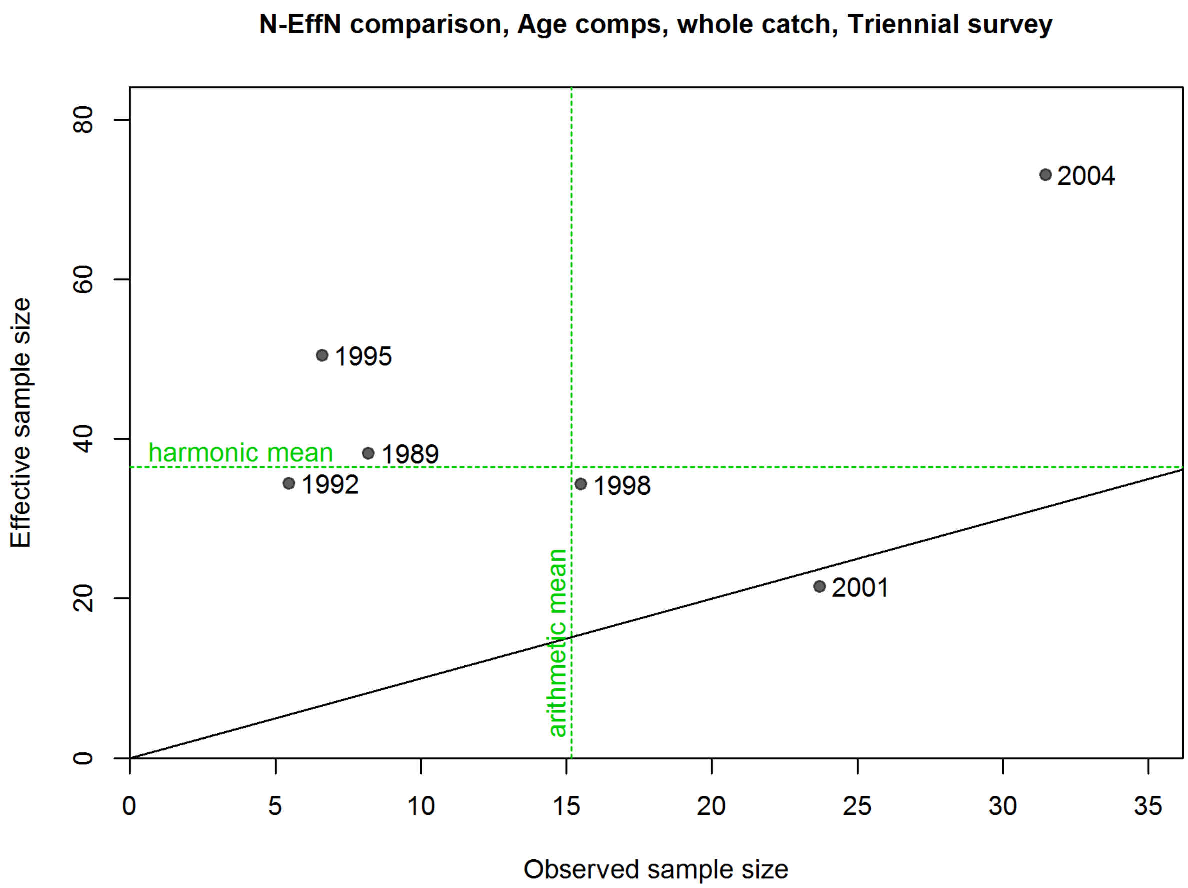

Figure 94: N_EffN comparison, Age comps, whole catch, Triennial survey fig:mod1_16_comp_age

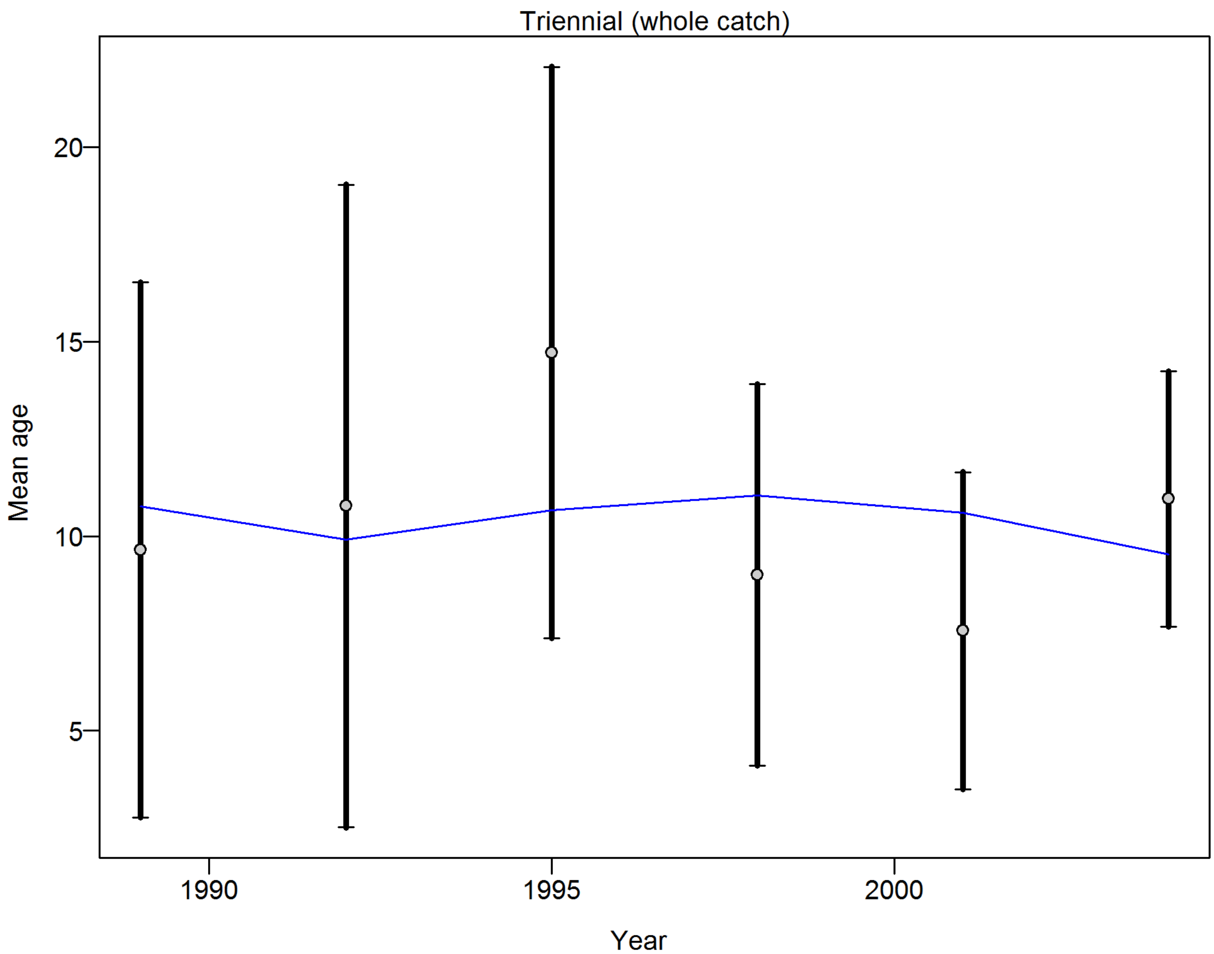

Figure 95: Francis data weighting method TA1.8: Triennial survey Suggested sample size adjustment (with 95% interval) for age data from Triennial survey: 1.0019 (0.6421_5.1354) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_17_comp_agefit_data_weighting_

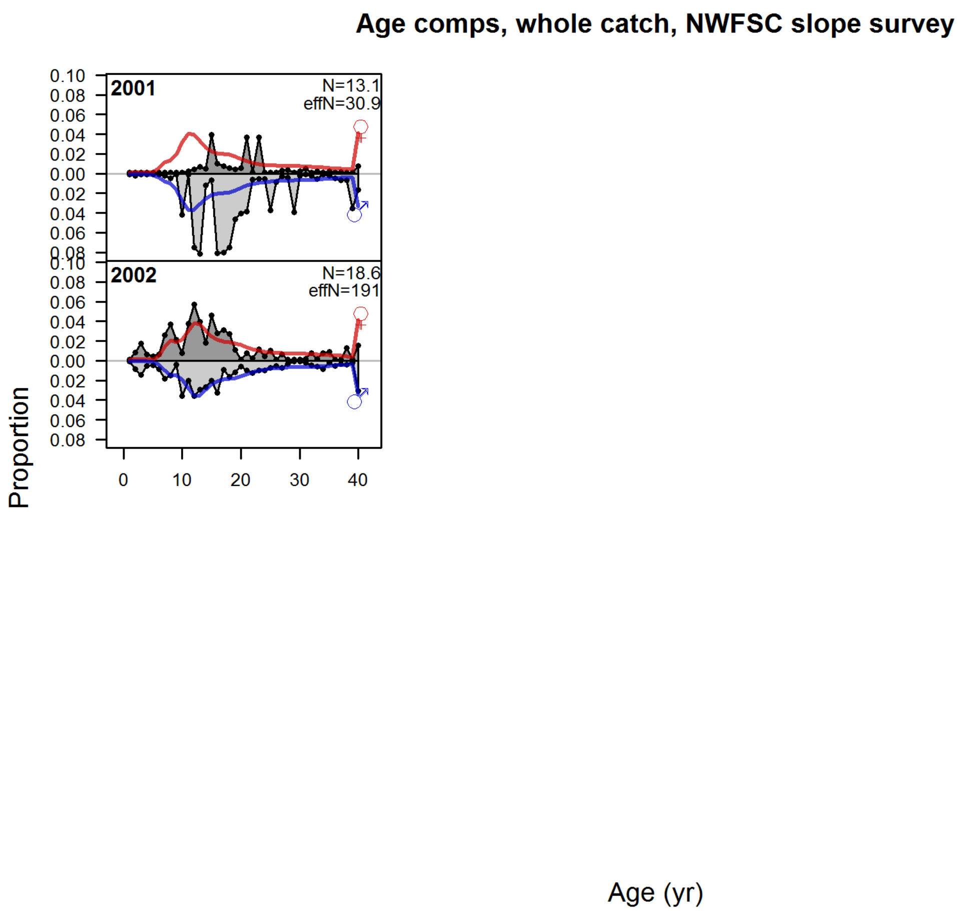

Figure 96: Age comps, whole catch, NWFSC slope survey fig:mod1_18_comp_agefit_flt

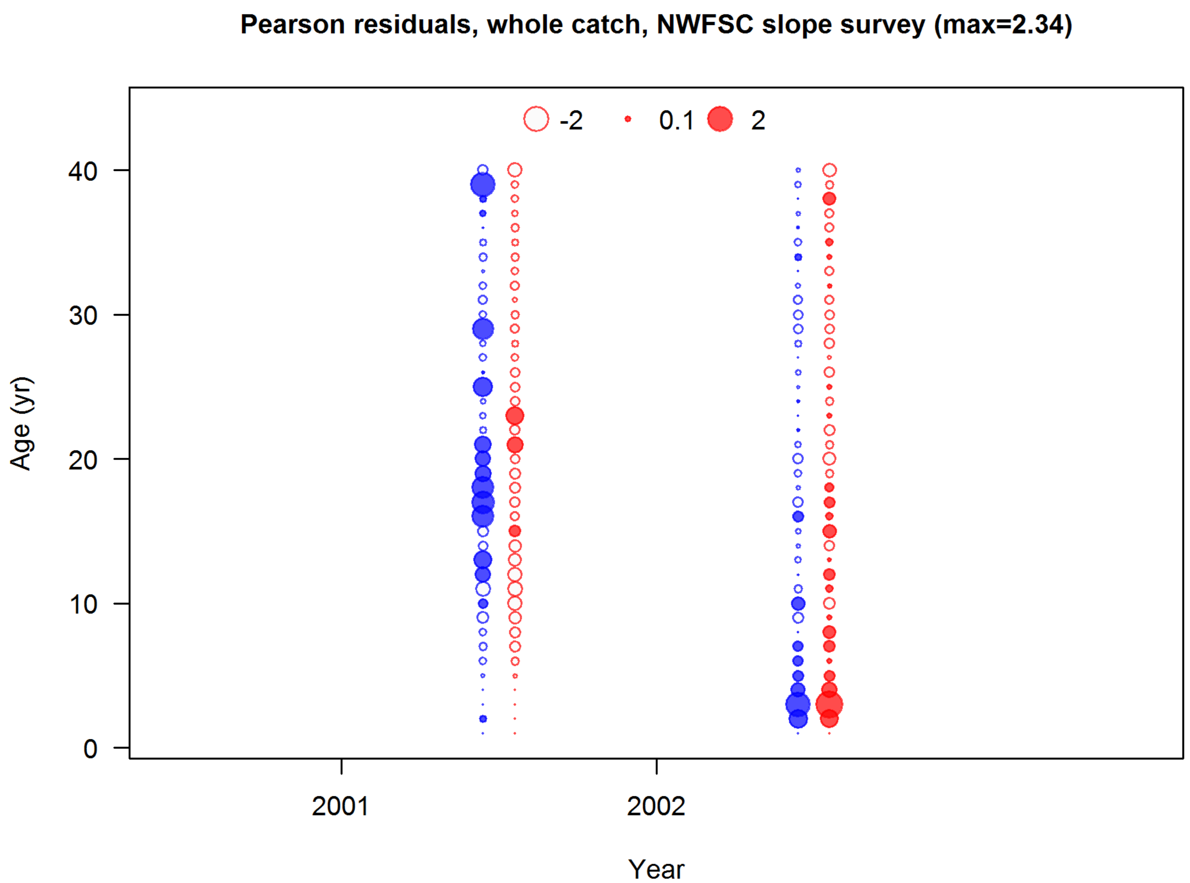

Figure 97: Pearson residuals, whole catch, NWFSC slope survey (max=2.34)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_19_comp_agefit_residsflt7mkt0

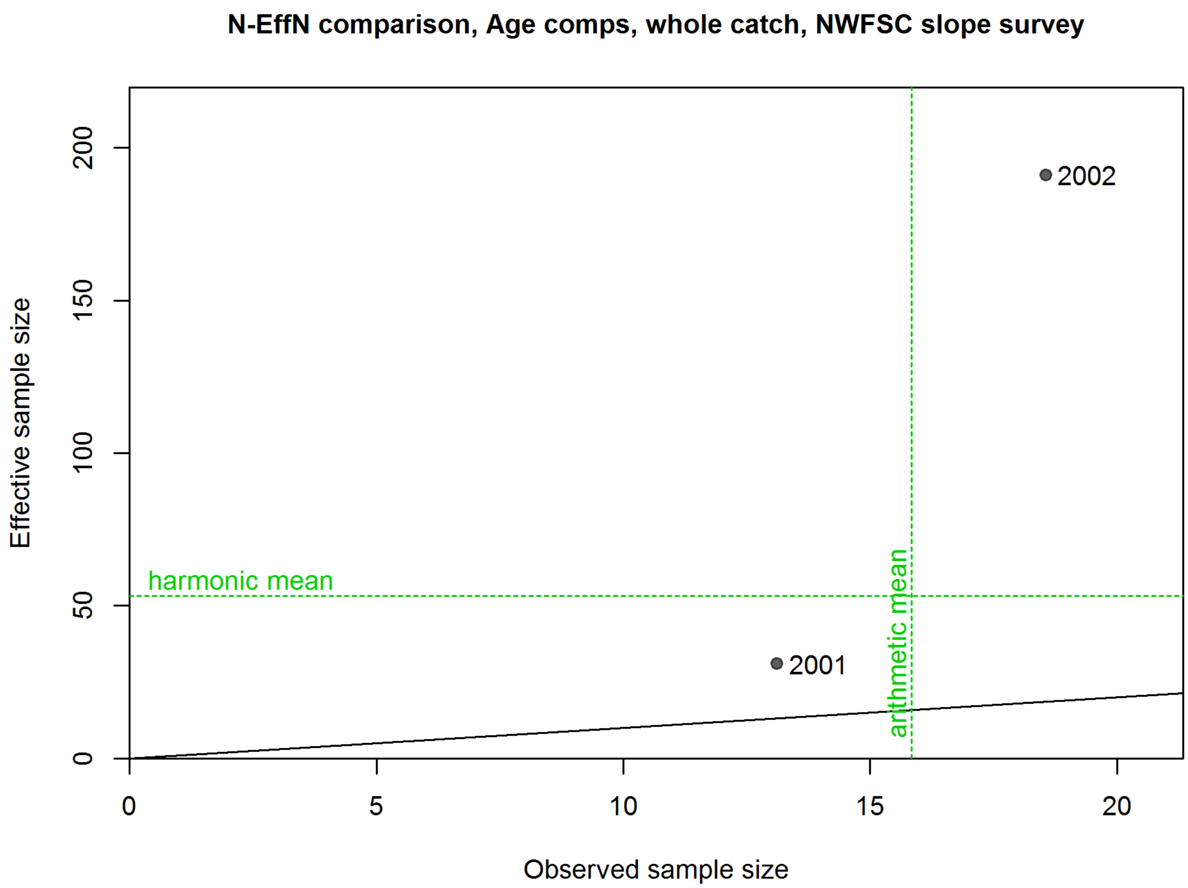

Figure 98: N_EffN comparison, Age comps, whole catch, NWFSC slope survey [fig:mod1_20_comp_a

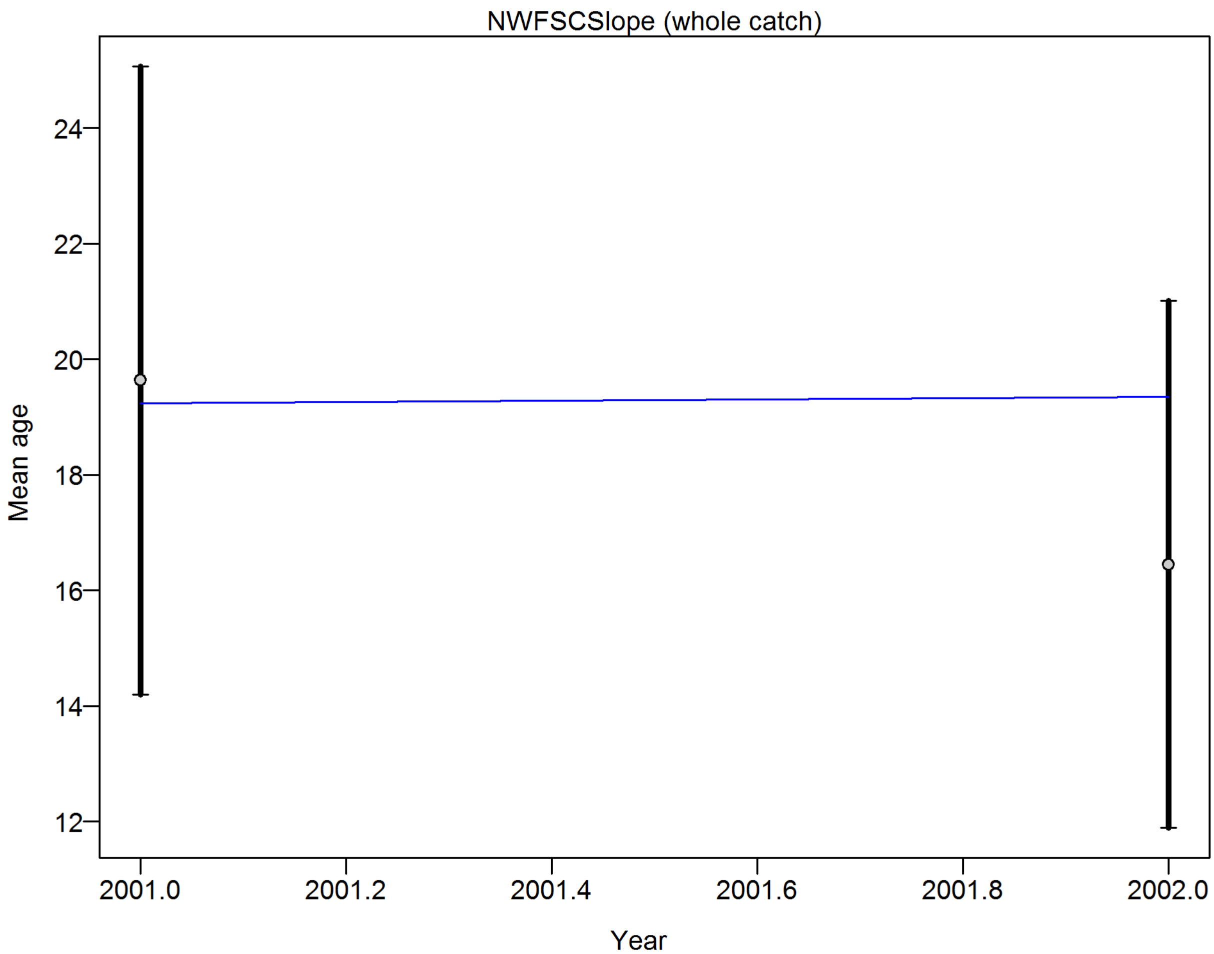

Figure 99: Francis data weighting method TA1.8: NWFSC slope survey Suggested sample size adjustment (with 95% interval) for age data from NWFSC slope survey: 0.9998 (0.9998_Inf) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_21_comp_agefit_data_weighting_

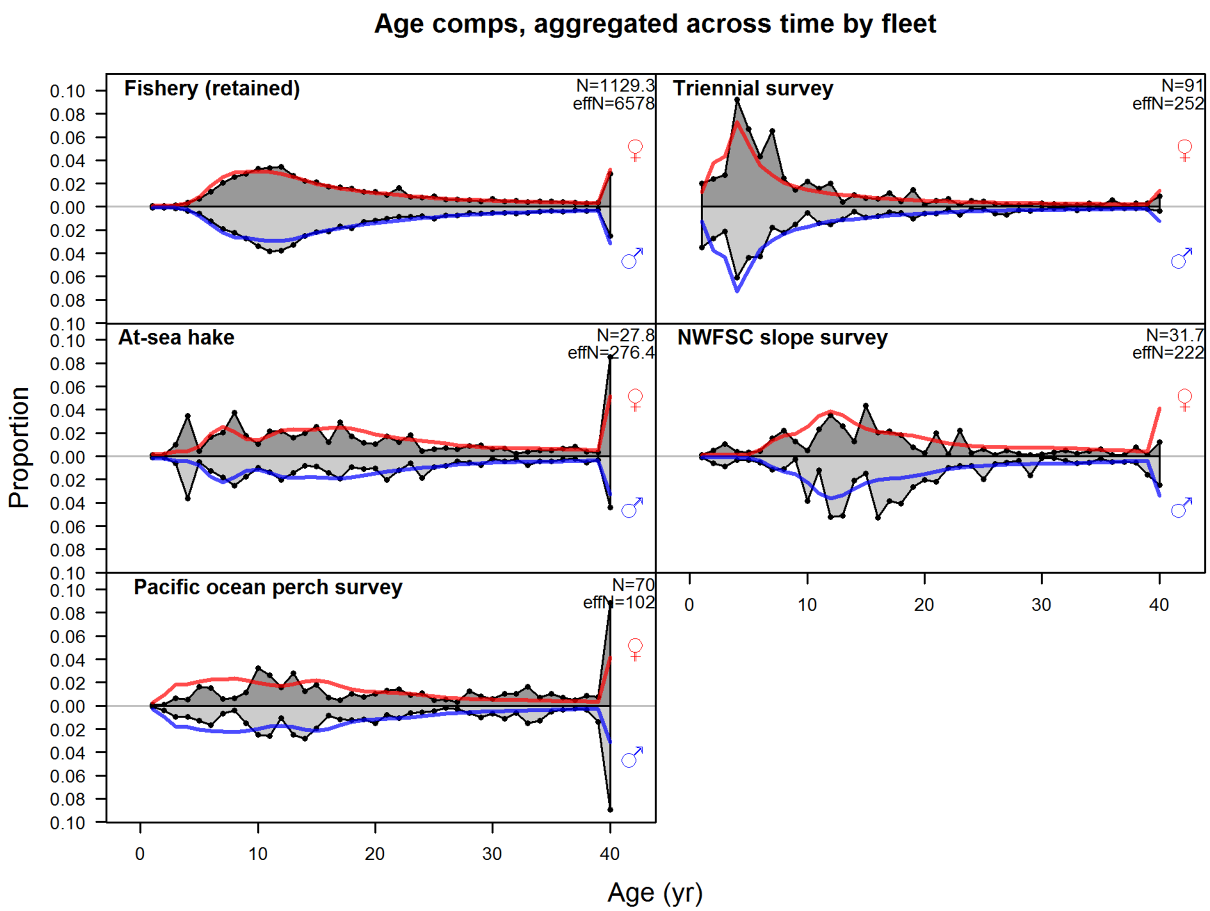

Figure 100: Age comps, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch. fig:mod1_22_comp_agefit__aggregated_across_time

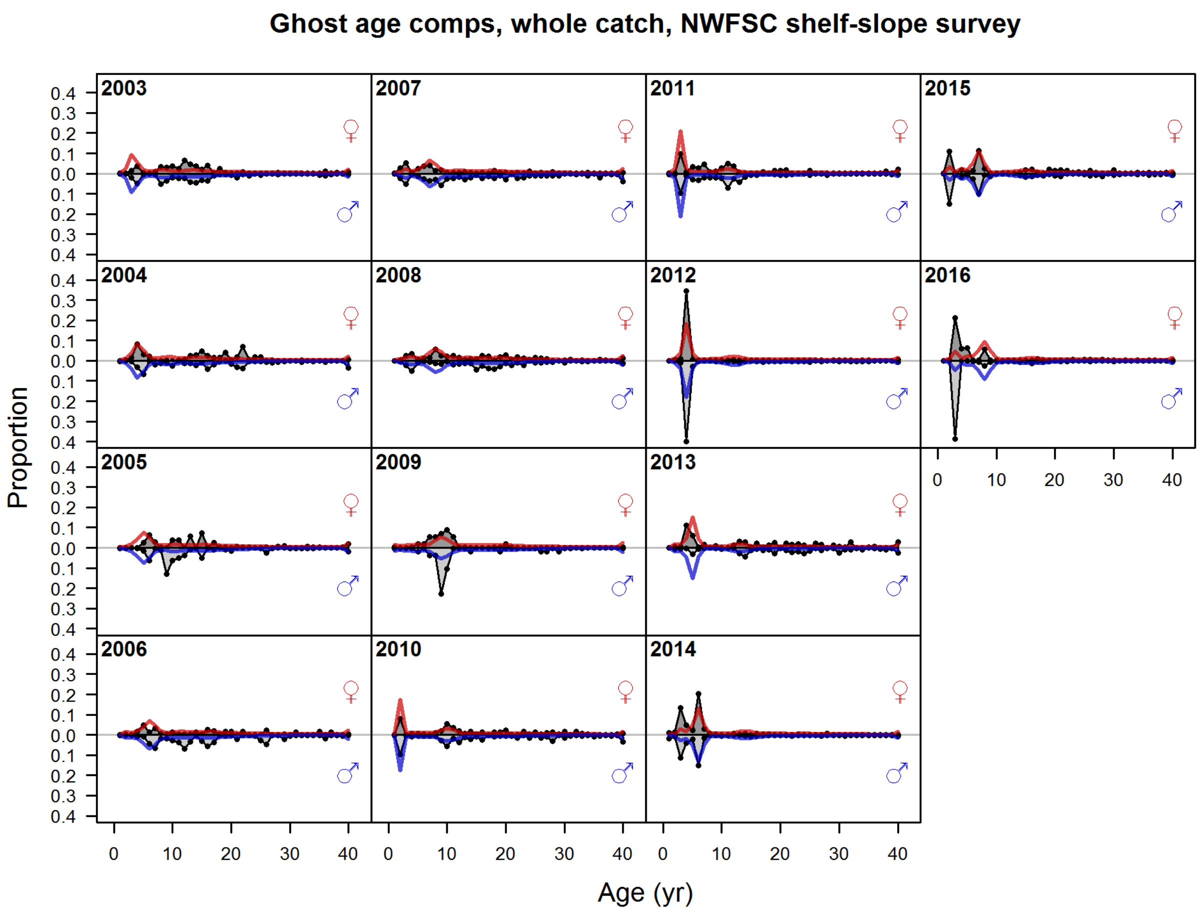

Figure 101: Ghost age comps, whole catch, NWFSC shelf_slope survey fig:mod1_23_comp_gstag

Figure 102: Pearson residuals, whole catch, NWFSC shelf_slope survey (max=NA) Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:mod1_24_comp_gstagefit_residsflt8mkt0

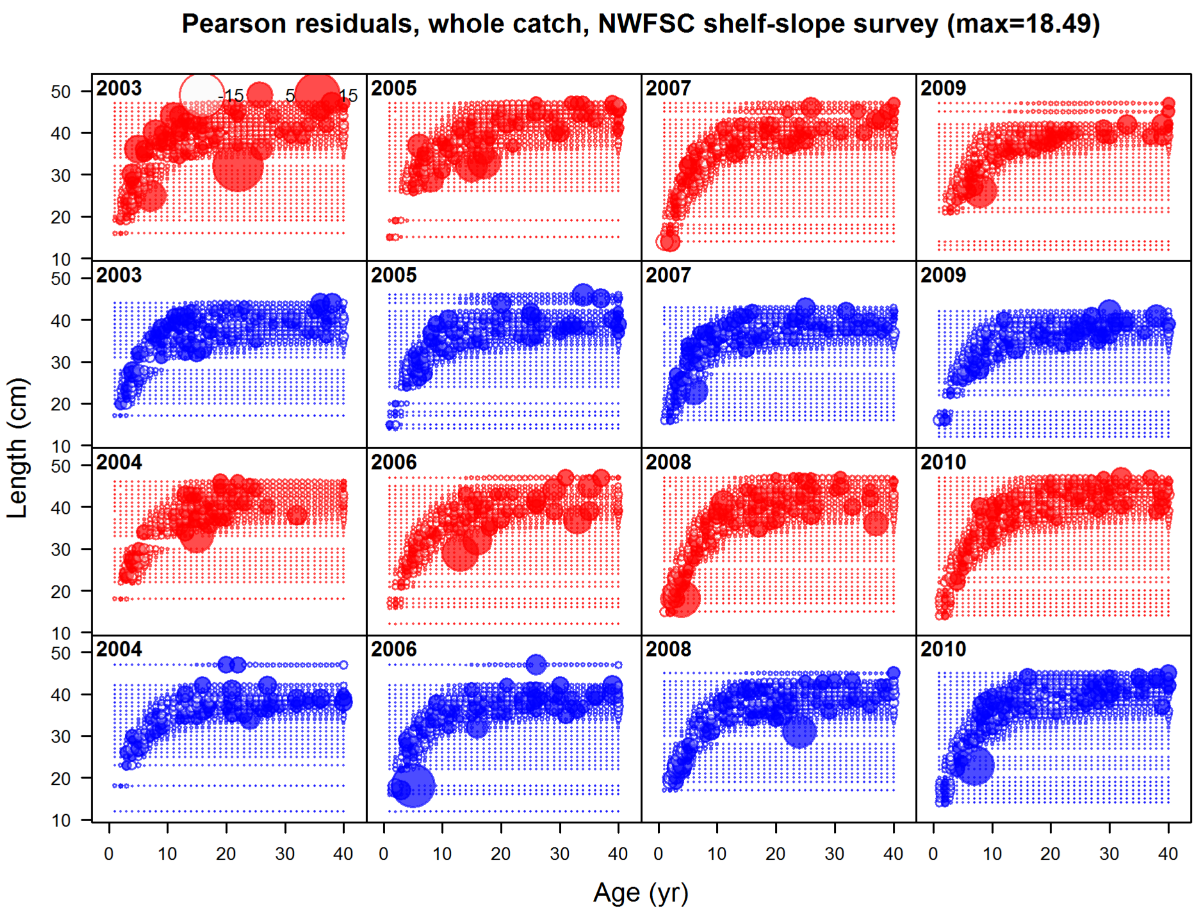

Figure 103: Pearson residuals, whole catch, NWFSC shelf-slope survey (max=18.49) (plot 1 of 2) fig:mod1_1_comp_condAALfit_residsflt8mkt0_page1

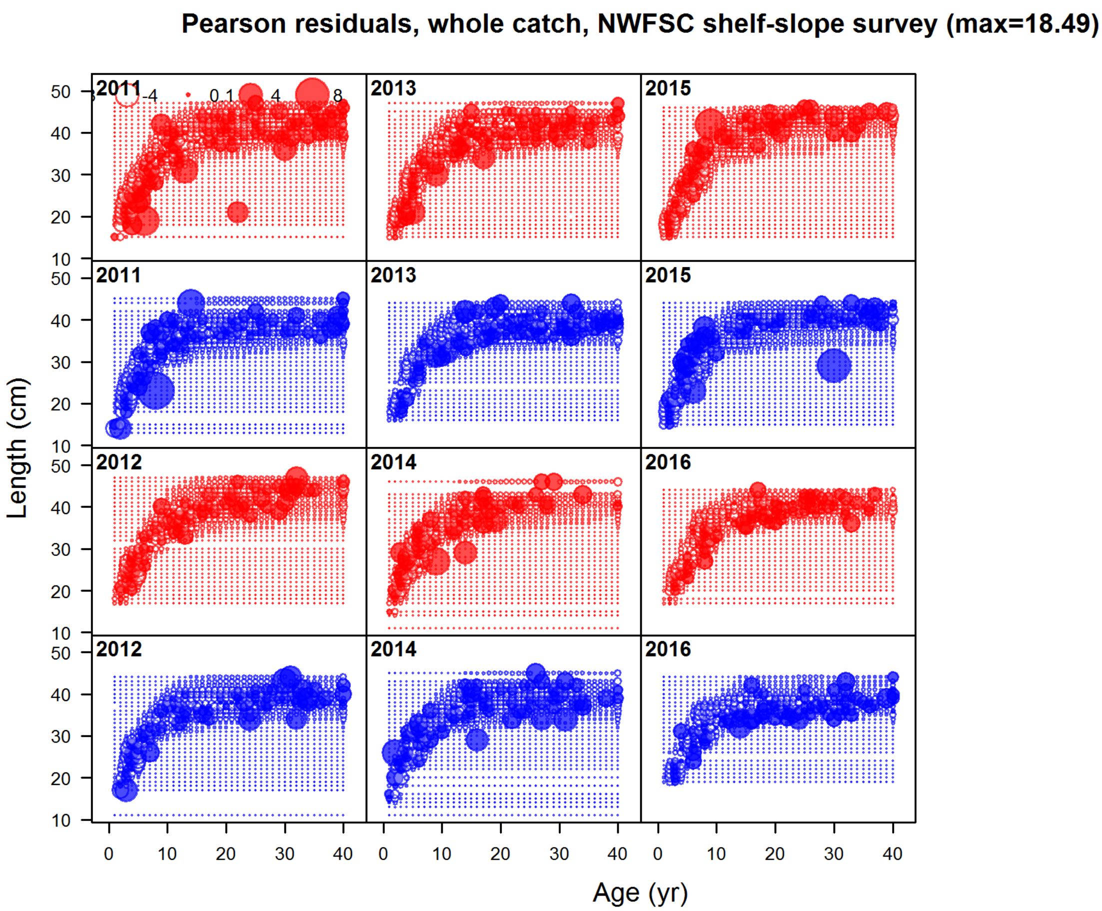

Figure 104: Pearson residuals, whole catch, NWFSC shelf-slope survey (max=18.49) (plot 1 of 2) (plot 2 of 2) fig:mod1_2_comp_condAALfit_residsflt8mkt0_page2

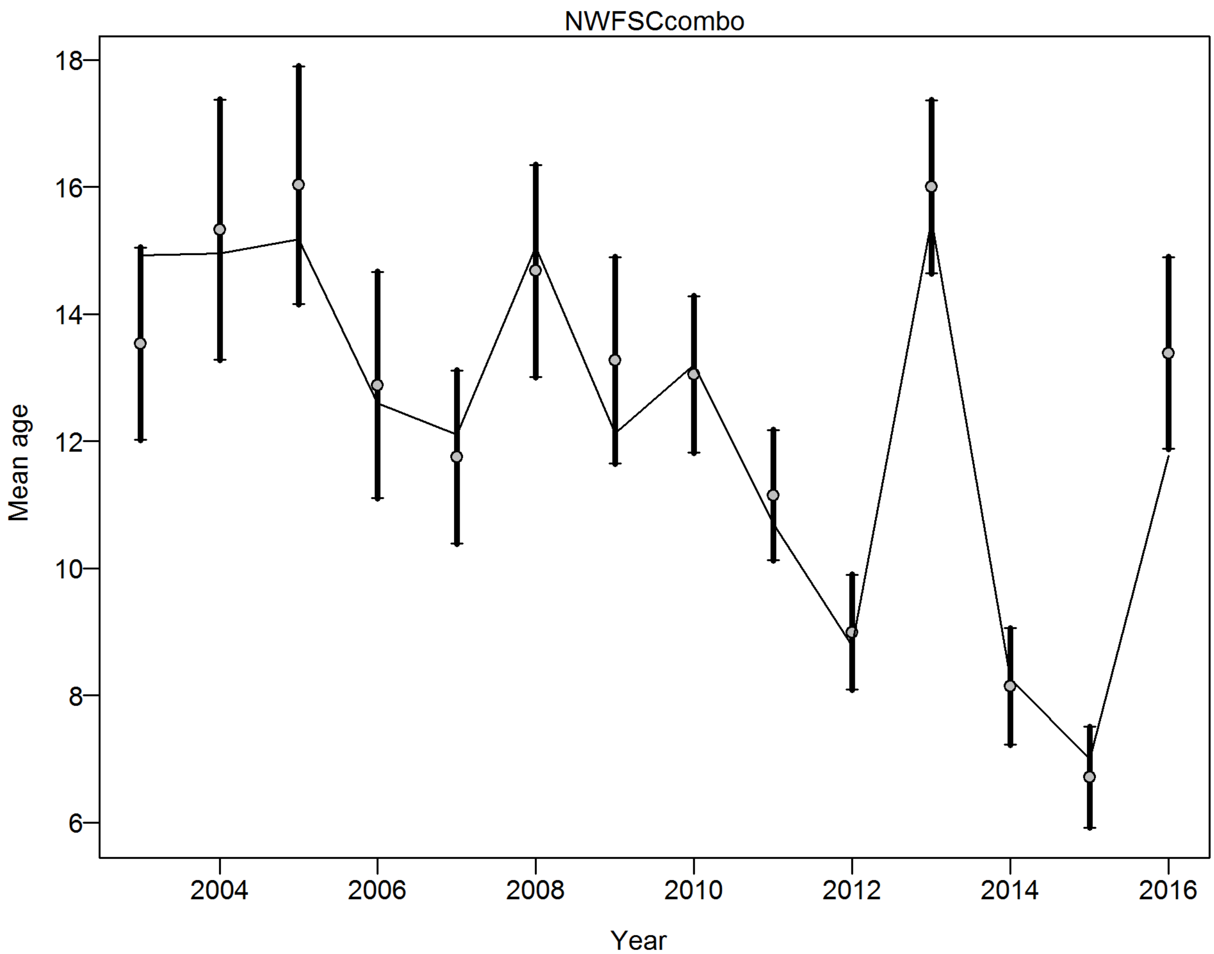

Figure 105: Francis data weighting method TA1.8 for conditional age data:NWFSC shelf_slope survey Suggested sample size adjustment(with 95% interval) forconditional age_at_length data from NWFSC shelf_slope survey: 1.0131 (0.5851_3.0487) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. fig:mod1_3_comp_condAALfit_data_weighting_TA1.8_condAgeNWFSC shelf-slo

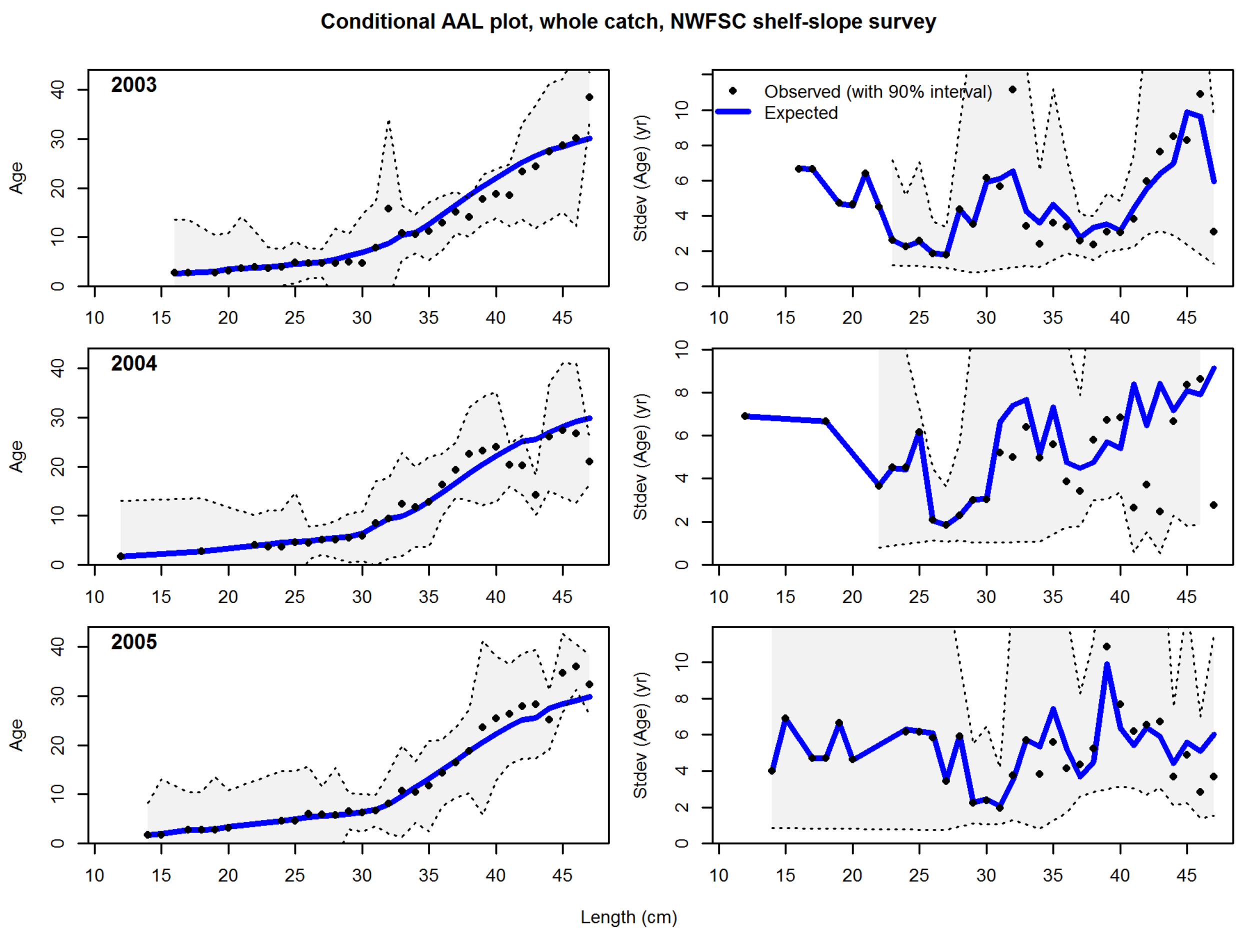

Figure 106: Conditional AAL plot, whole catch, NWFSC shelf_slope survey (plot 1 of 5) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:mod1_4_comp_condAALfit_Andre_plotsflt8mkt0_page1

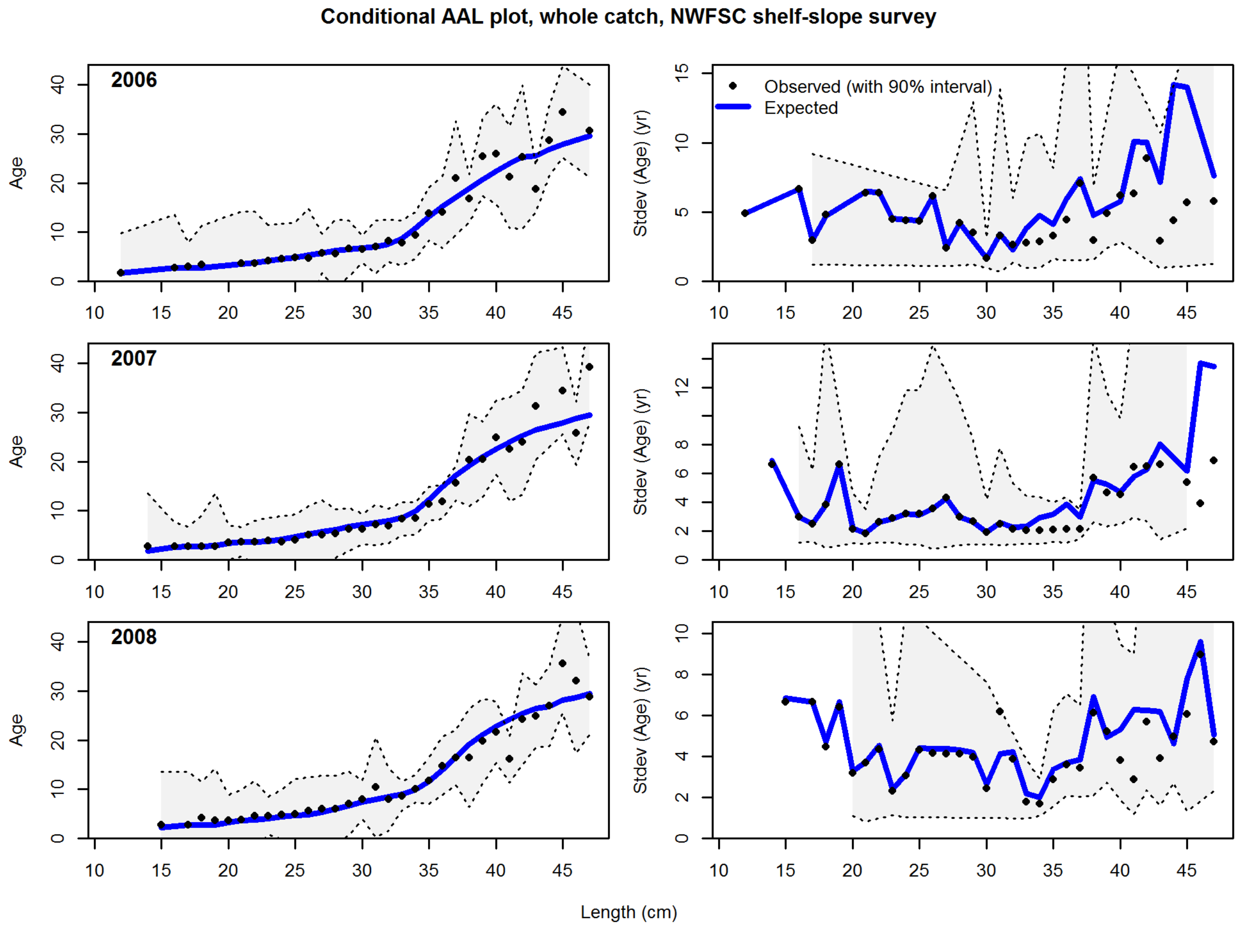

Figure 107: Conditional AAL plot, whole catch, NWFSC shelf_slope survey (plot 2 of 5) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:mod1_5_comp_condAALfit_Andre_plotsflt8mkt0_page2

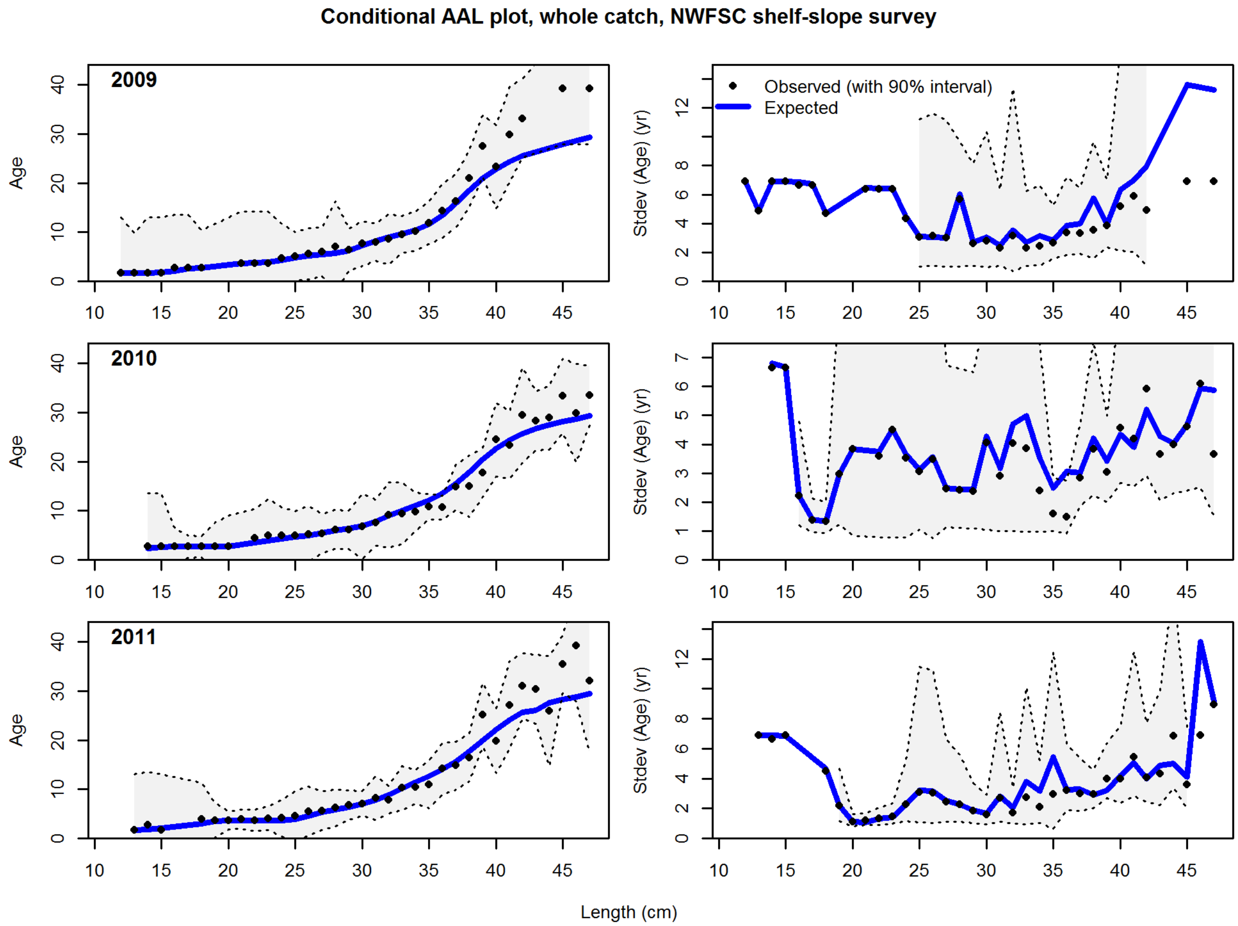

Figure 108: Conditional AAL plot, whole catch, NWFSC shelf_slope survey (plot 3 of 5) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:mod1_6_comp_condAALfit_Andre_plotsflt8mkt0_page3

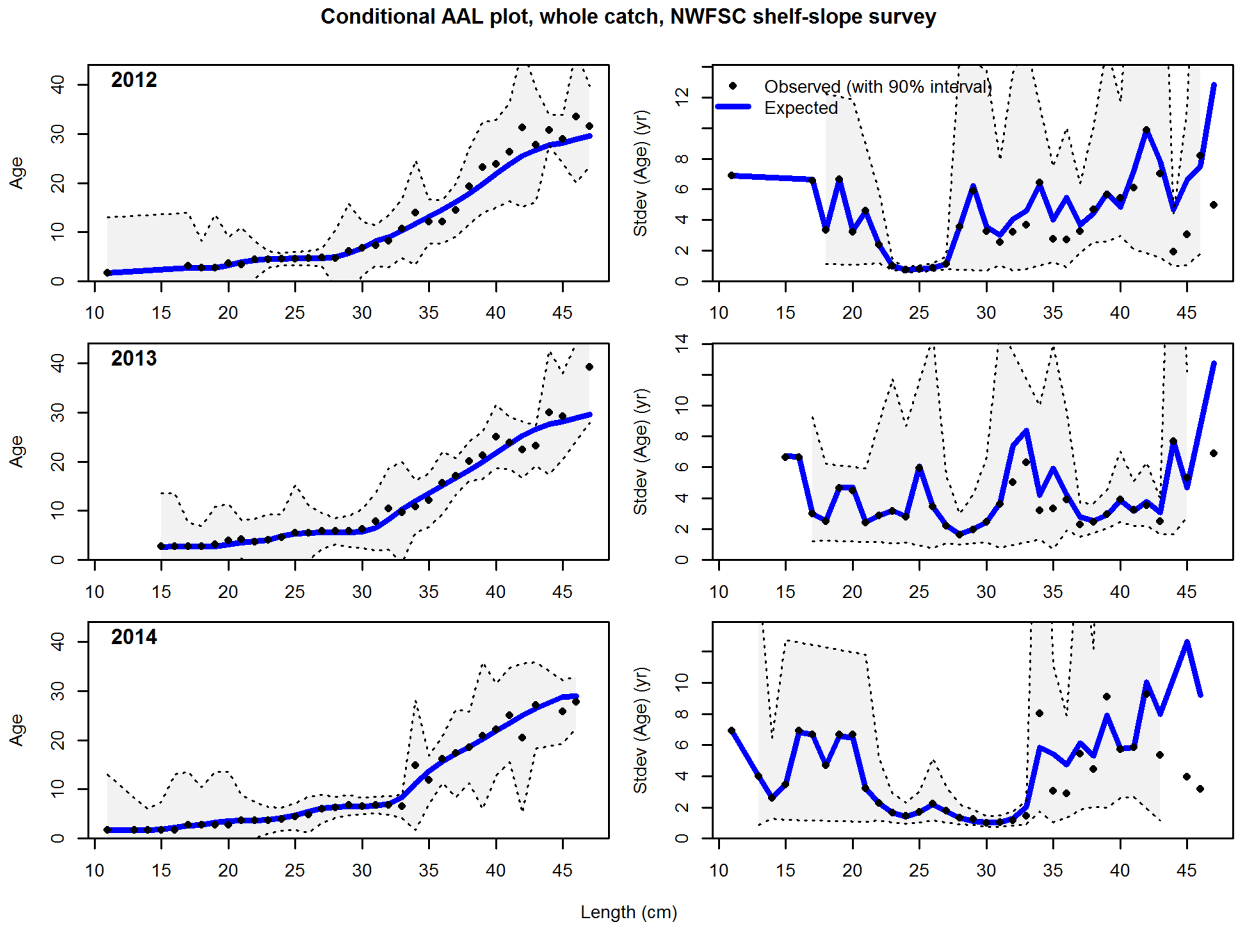

Figure 109: Conditional AAL plot, whole catch, NWFSC shelf_slope survey (plot 4 of 5) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:mod1_7_comp_condAALfit_Andre_plotsflt8mkt0_page4

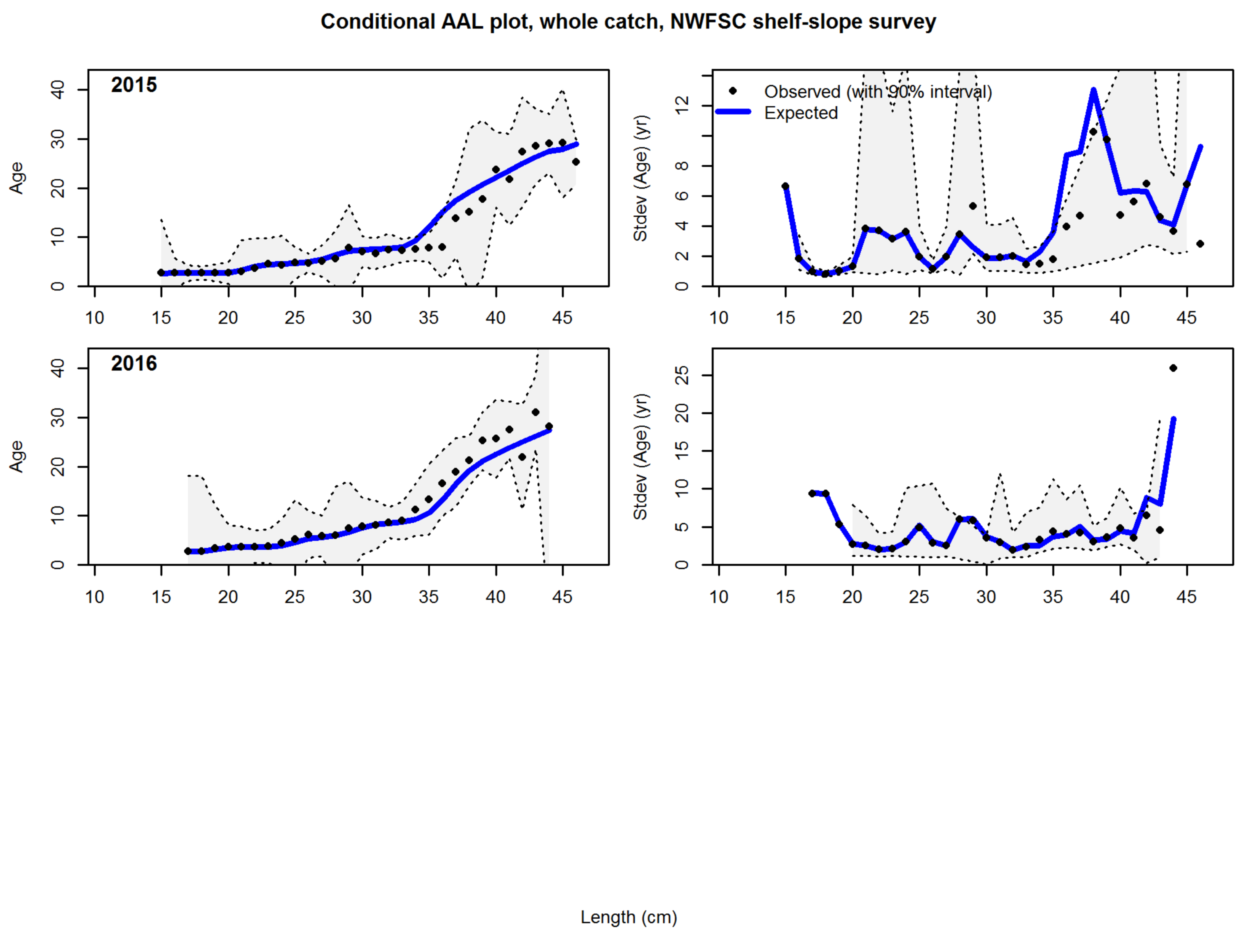

Figure 110: Conditional AAL plot, whole catch, NWFSC shelf_slope survey (plot 5 of 5) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:mod1_8_comp_condAALfit_Andre_plotsflt8mkt0_page5

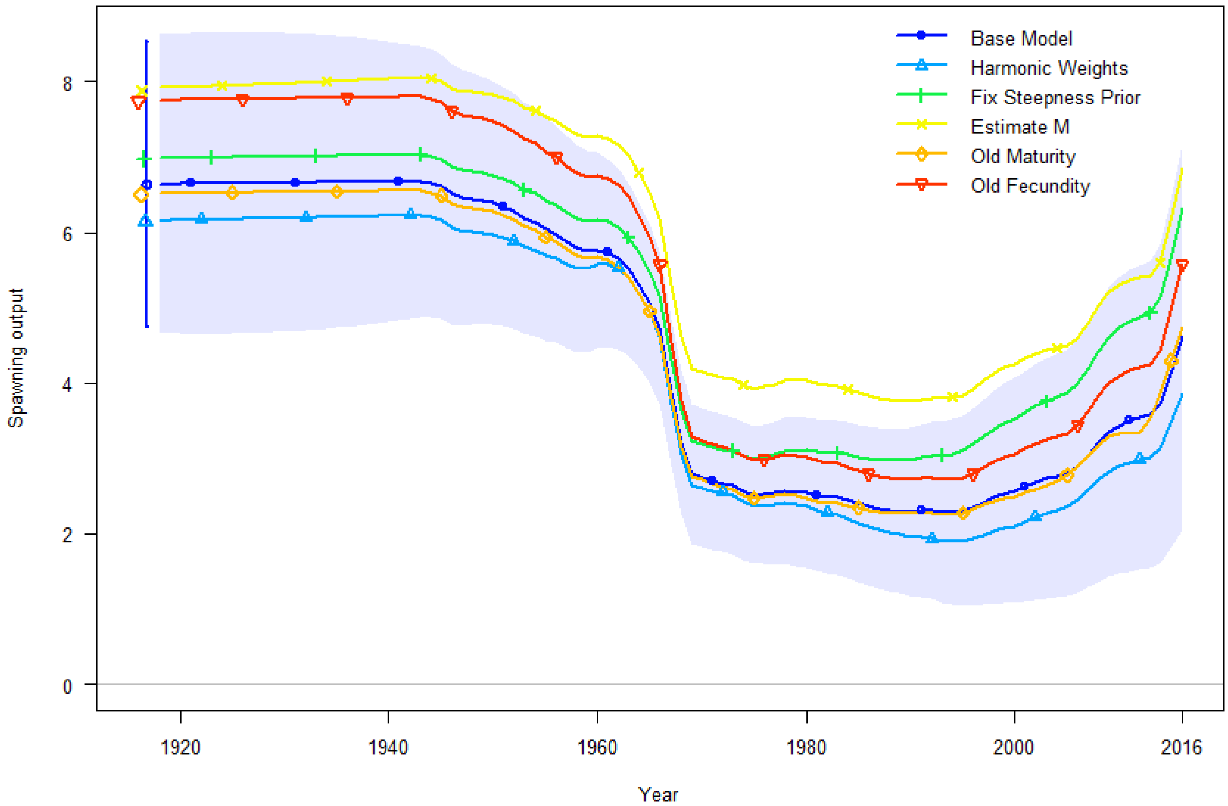

Figure 111: Time-series of spawning output for model sensitivities for Pacific ocean perch. fig:sens1_ssb

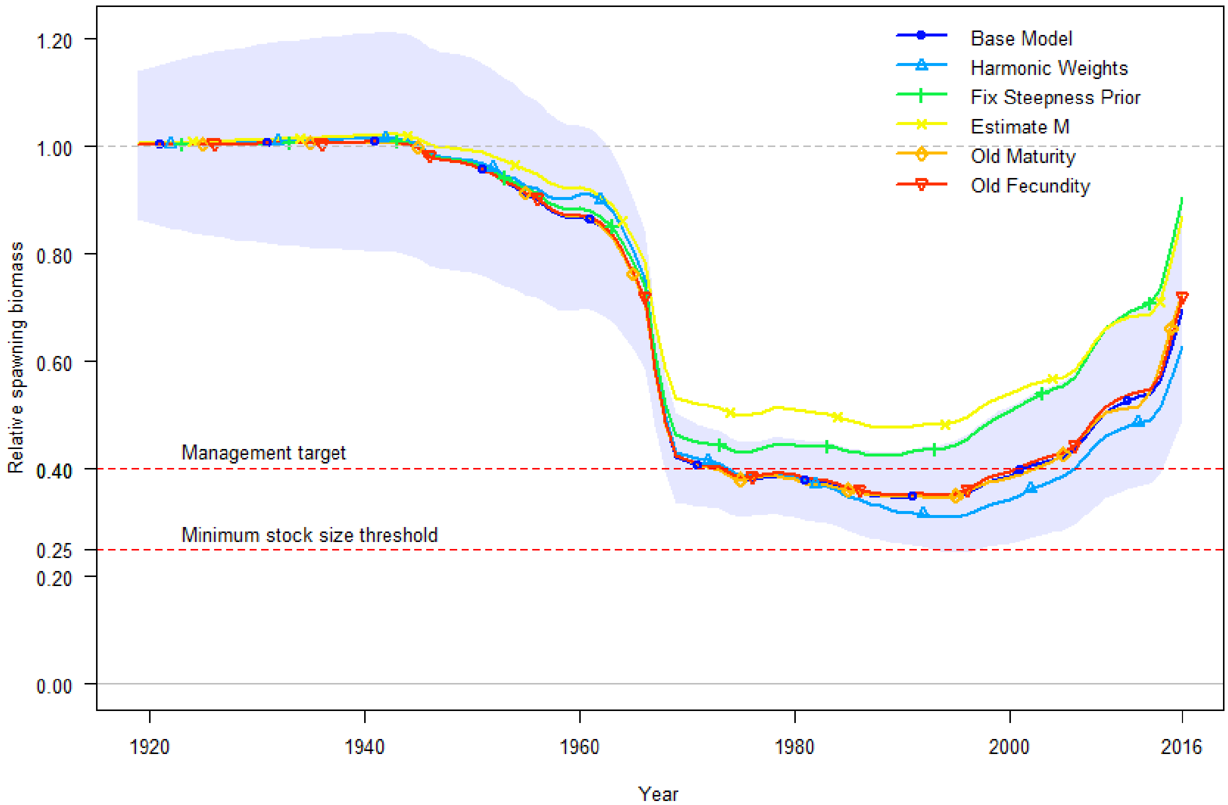

Figure 112: Time-series of relative biomass for model sensitivities for Pacific ocean perch. fig:sens1_dep

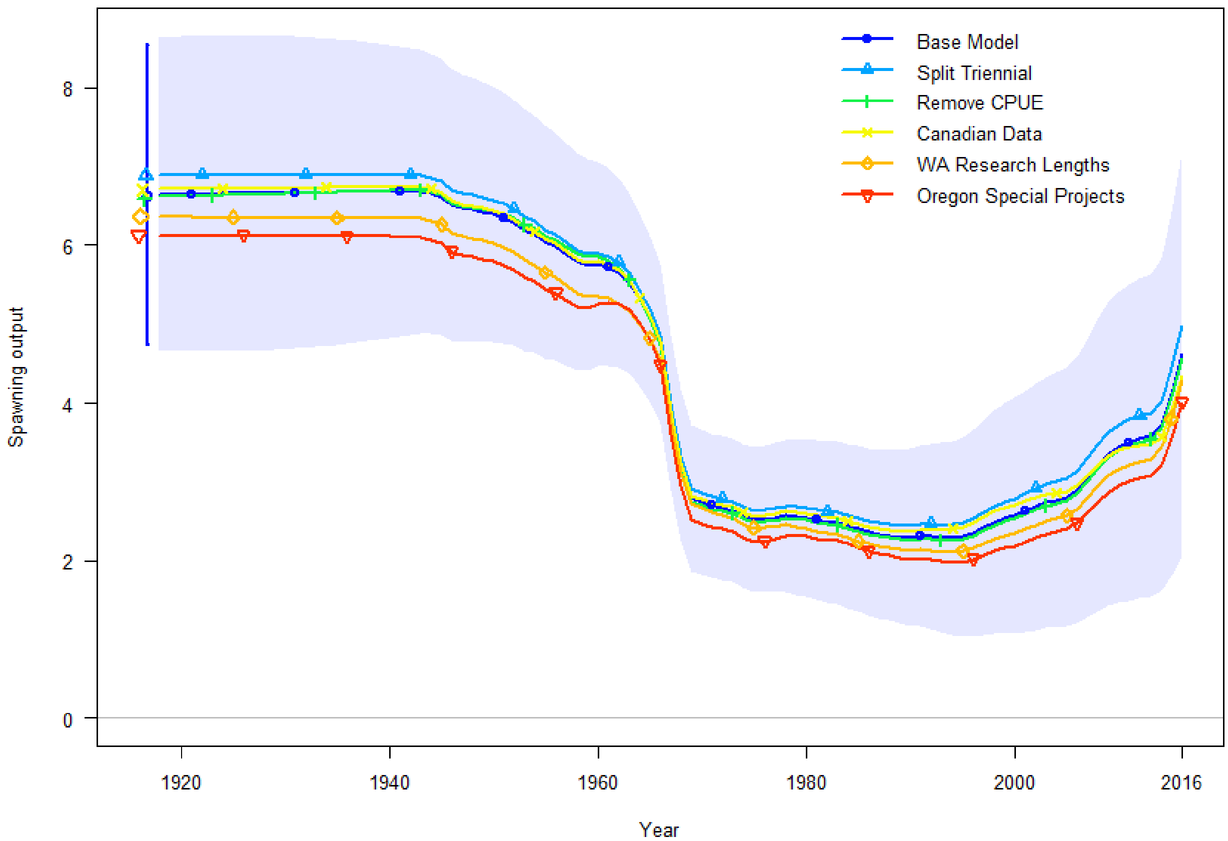

Figure 113: Time-series of spawning output for model sensitivities for Pacific ocean perch. fig:sens2_ssb

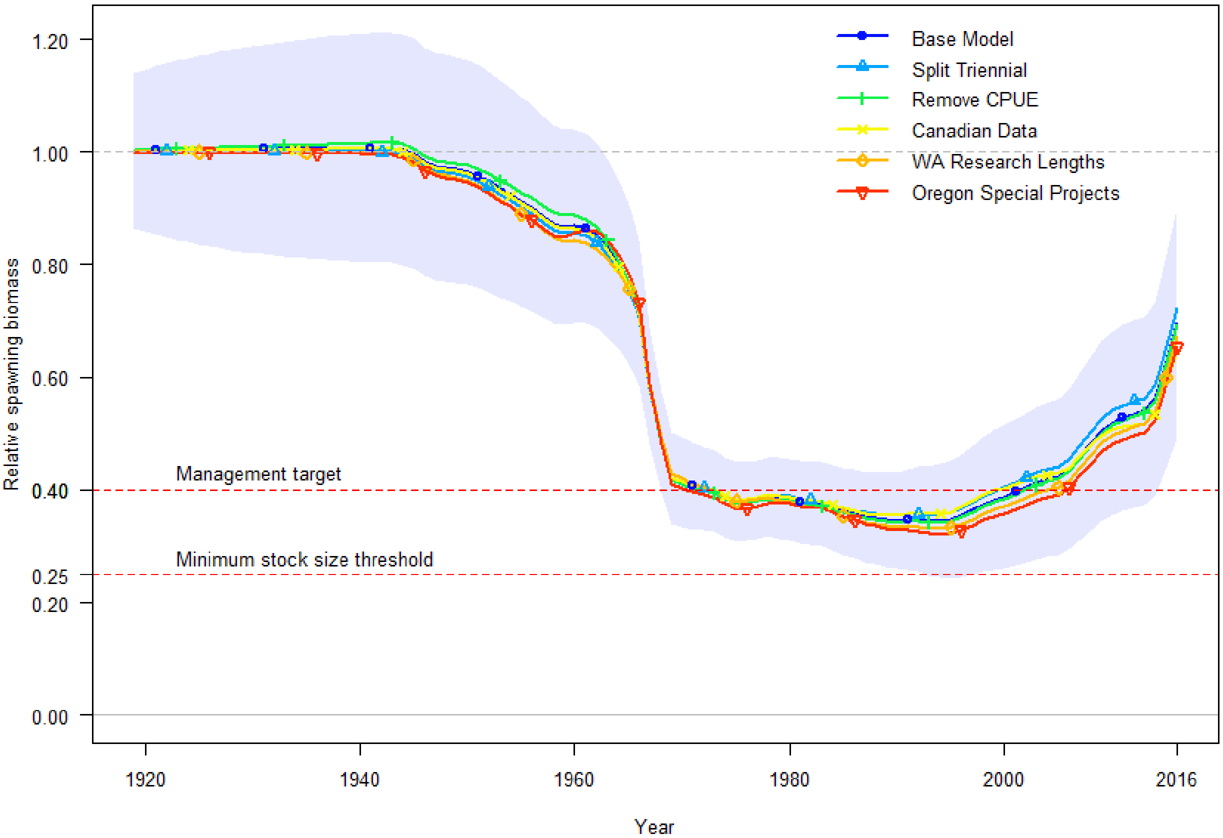

Figure 114: Time-series of relative biomass for model sensitivities for Pacific ocean perch. fig:sens2_dep

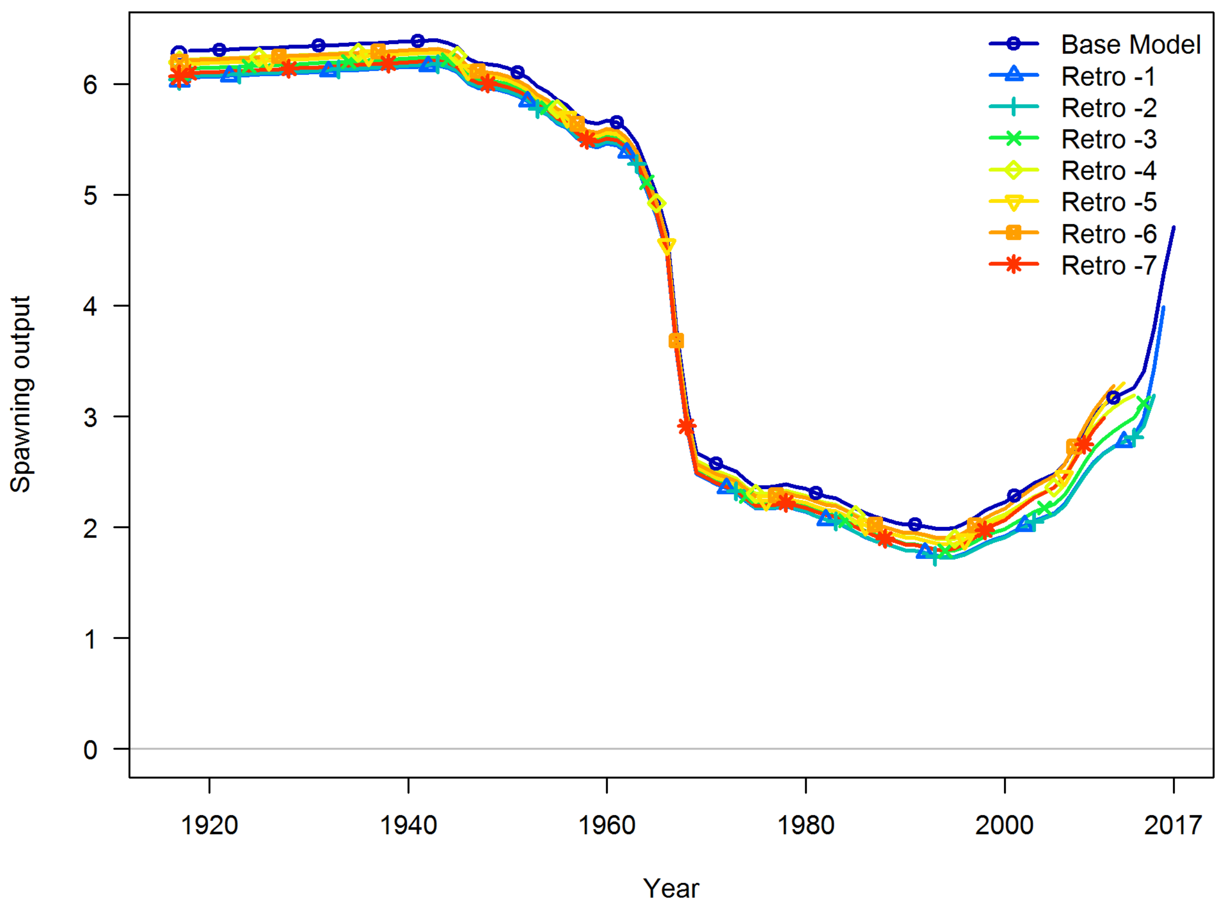

Figure 115: Retrospective pattern for spawning output. fig:retro_sb

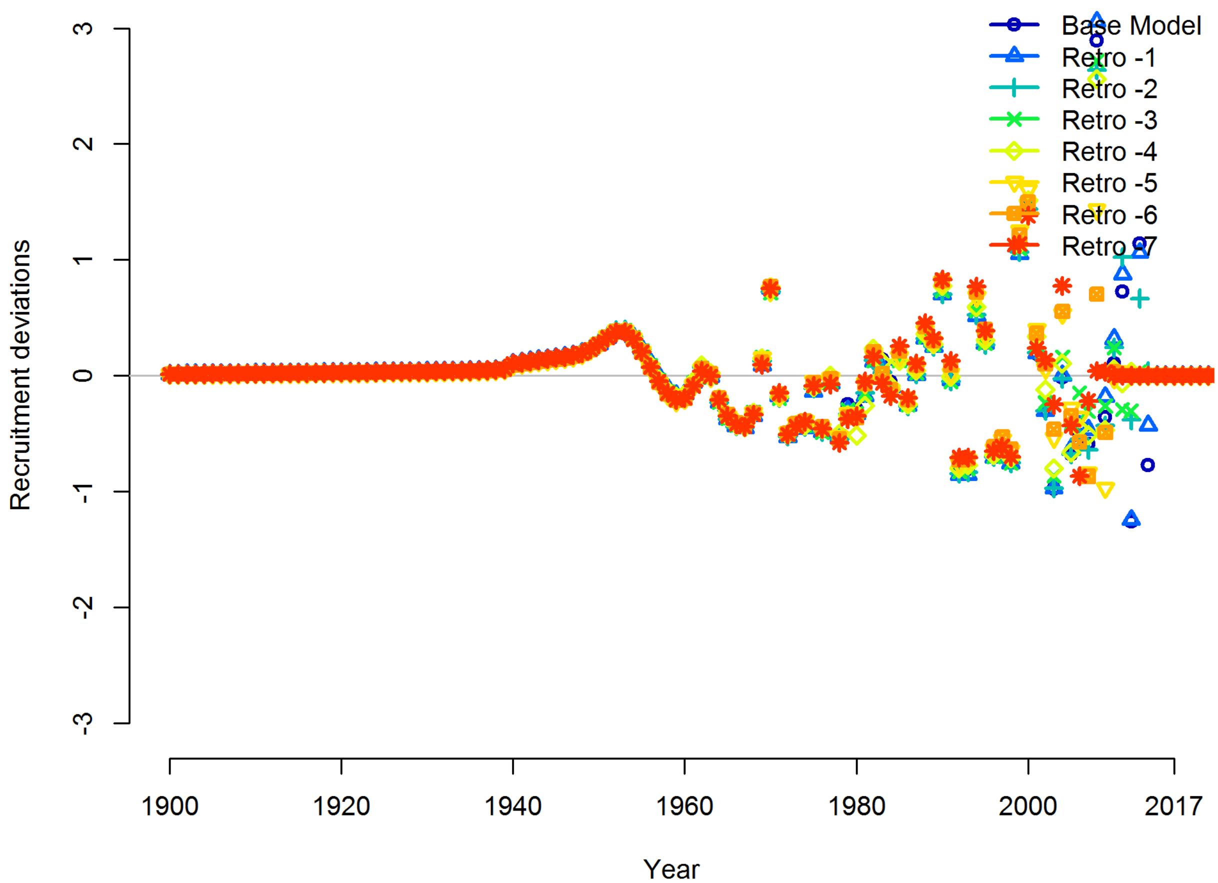

Figure 116: Retrospective pattern for estimated recruitment deviations. fig:retro_recdev

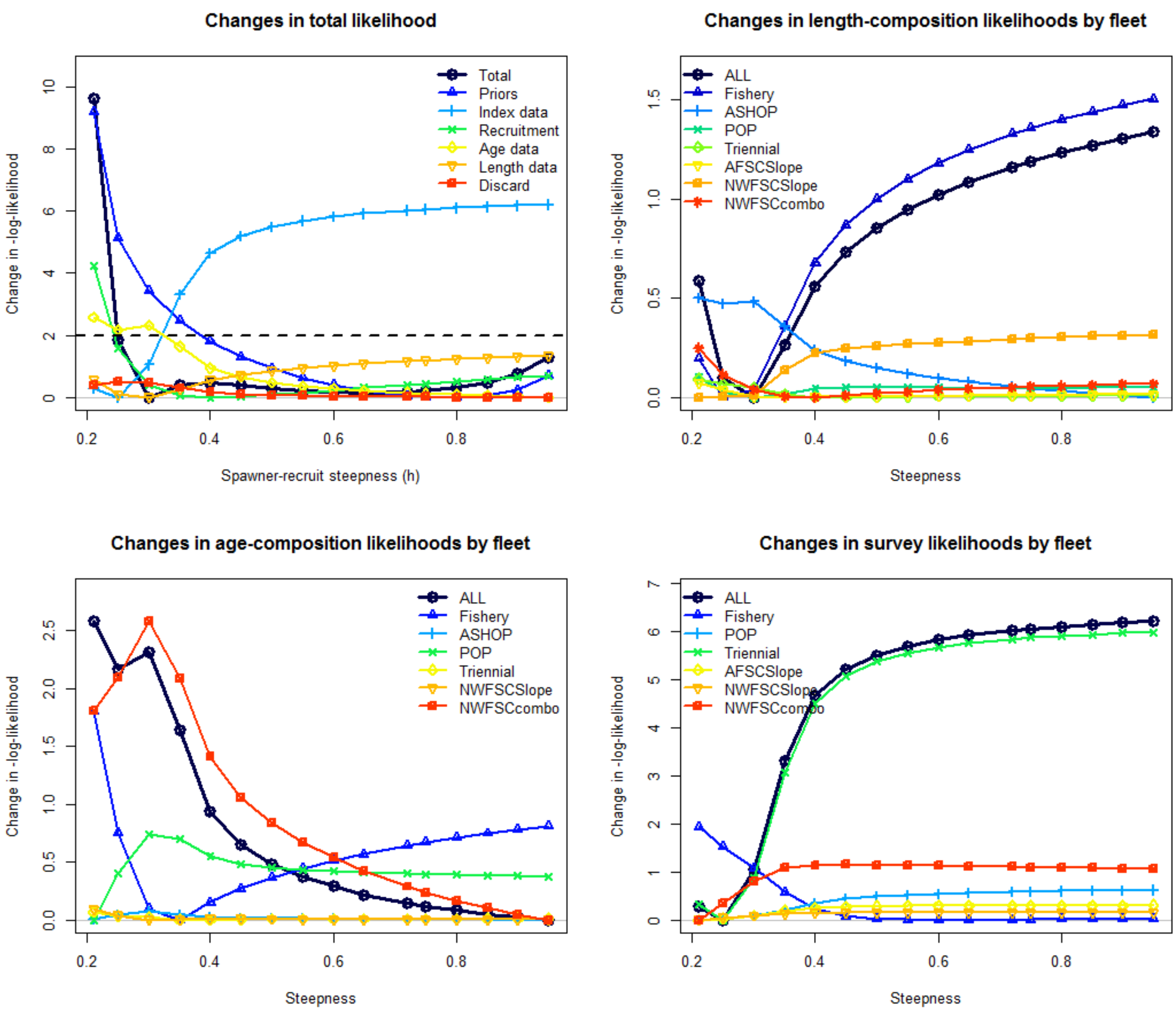

Figure 117: Likelihood profile across steepness values. fig:piner_h

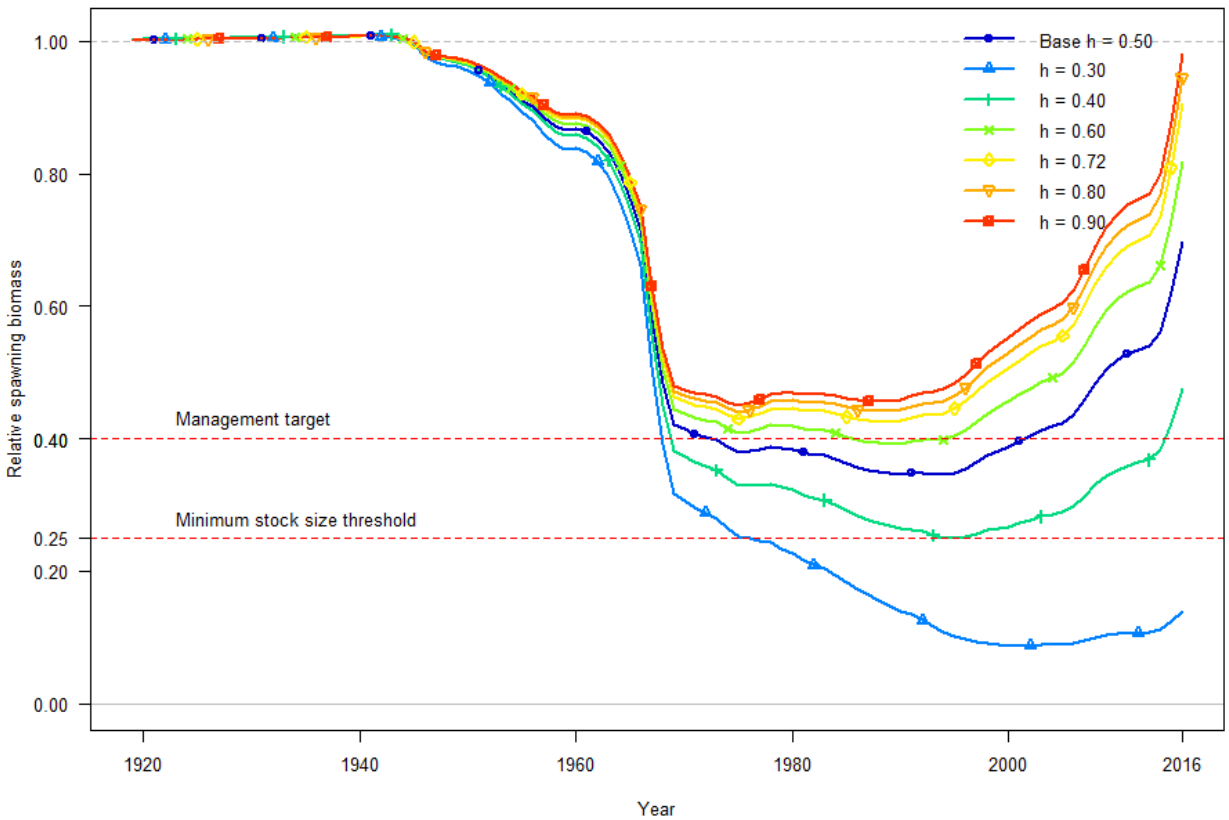

Figure 118: Trajectories of relative biomass across values of steepness. fig:h_trajectory

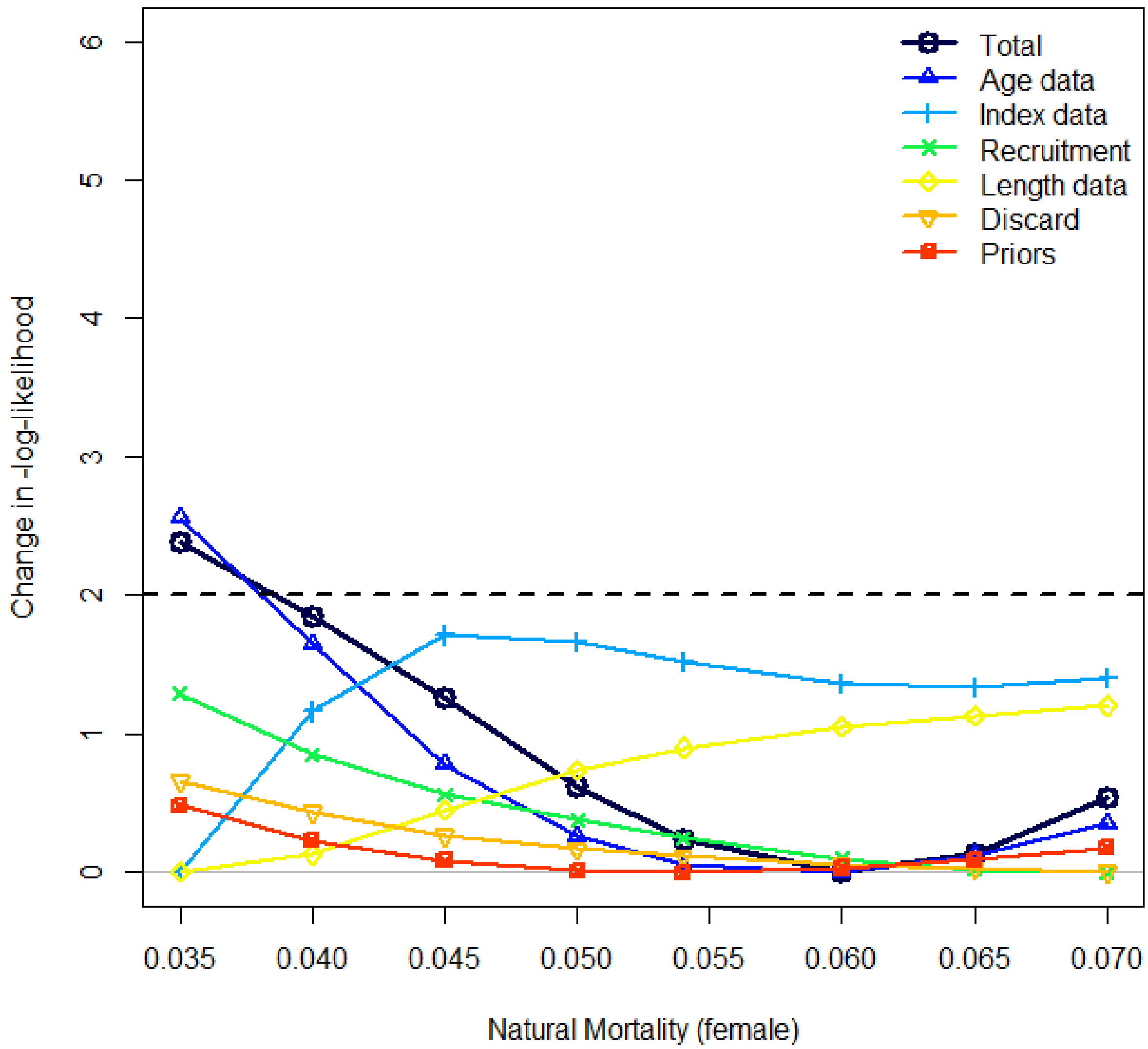

Figure 119: Likelihood profile across natural mortality values. fig:m_like

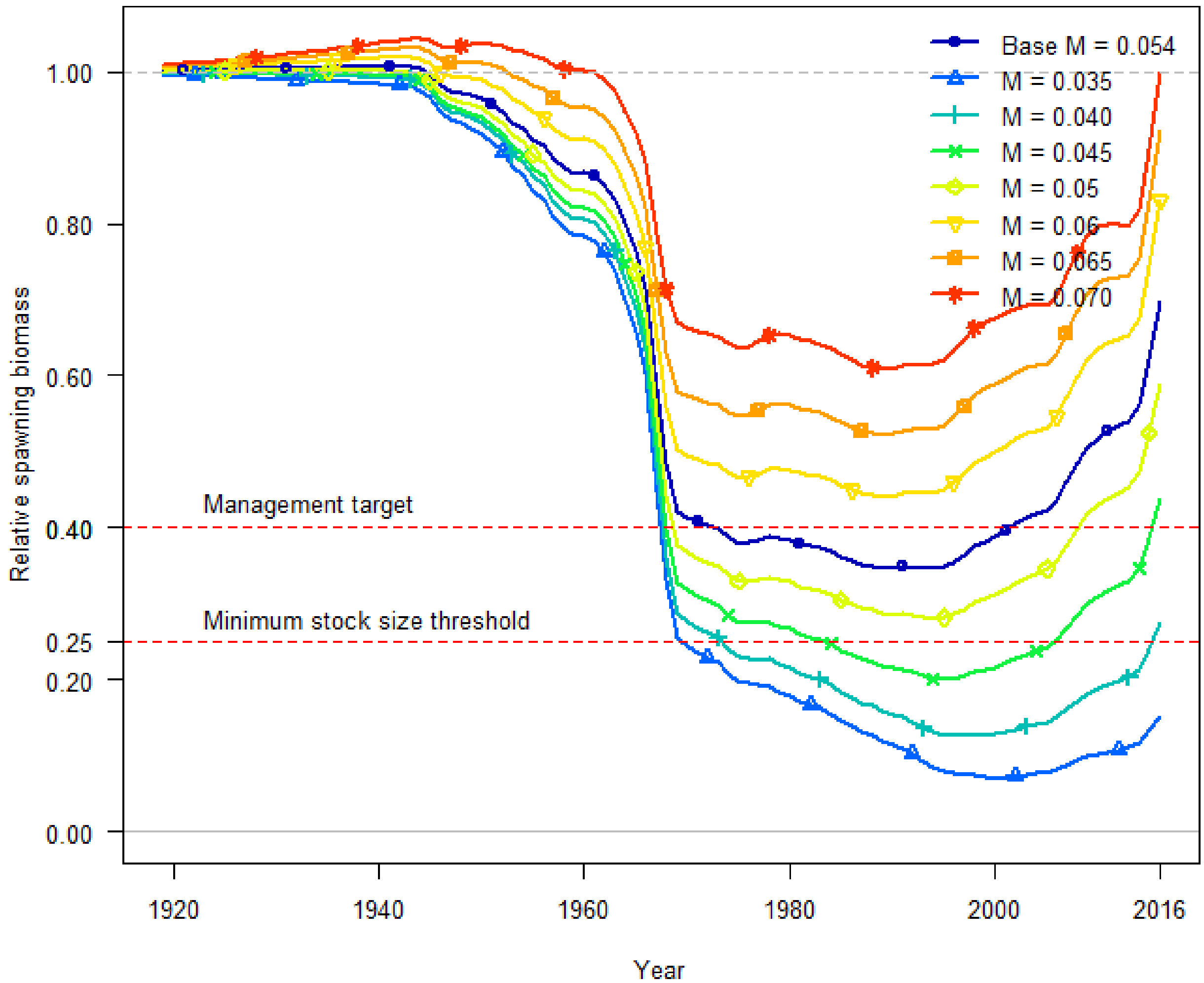

Figure 120: Trajectories of relative biomass across values of natural mortality. fig:m_trajectory

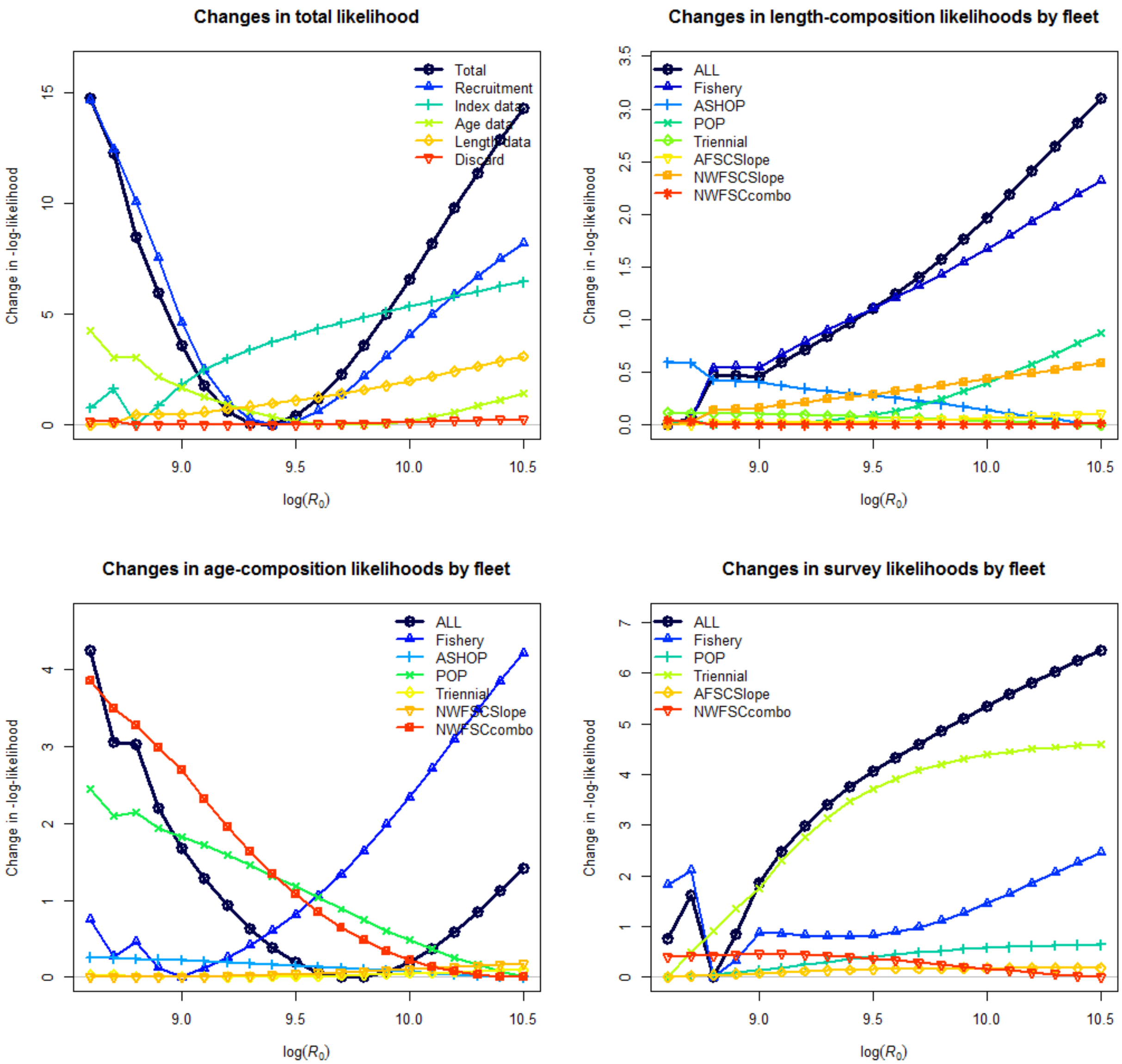

Figure 121: Likelihood profile across R_0 values. fig:piner_R0

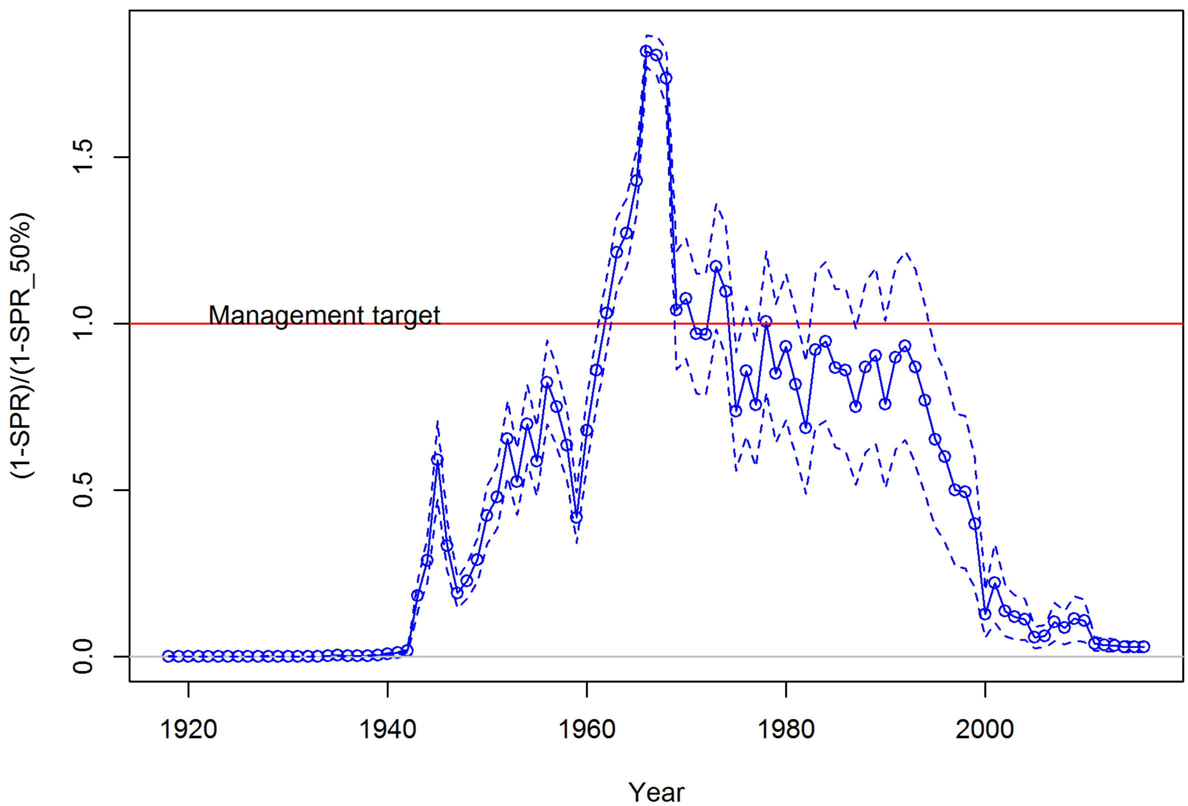

Figure 122: Estimated spawning potential ratio (1-SPR)/(1-SPR50%) for the base-case model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR50% harvest rate. The last year in the time series is 2016. fig:SPR

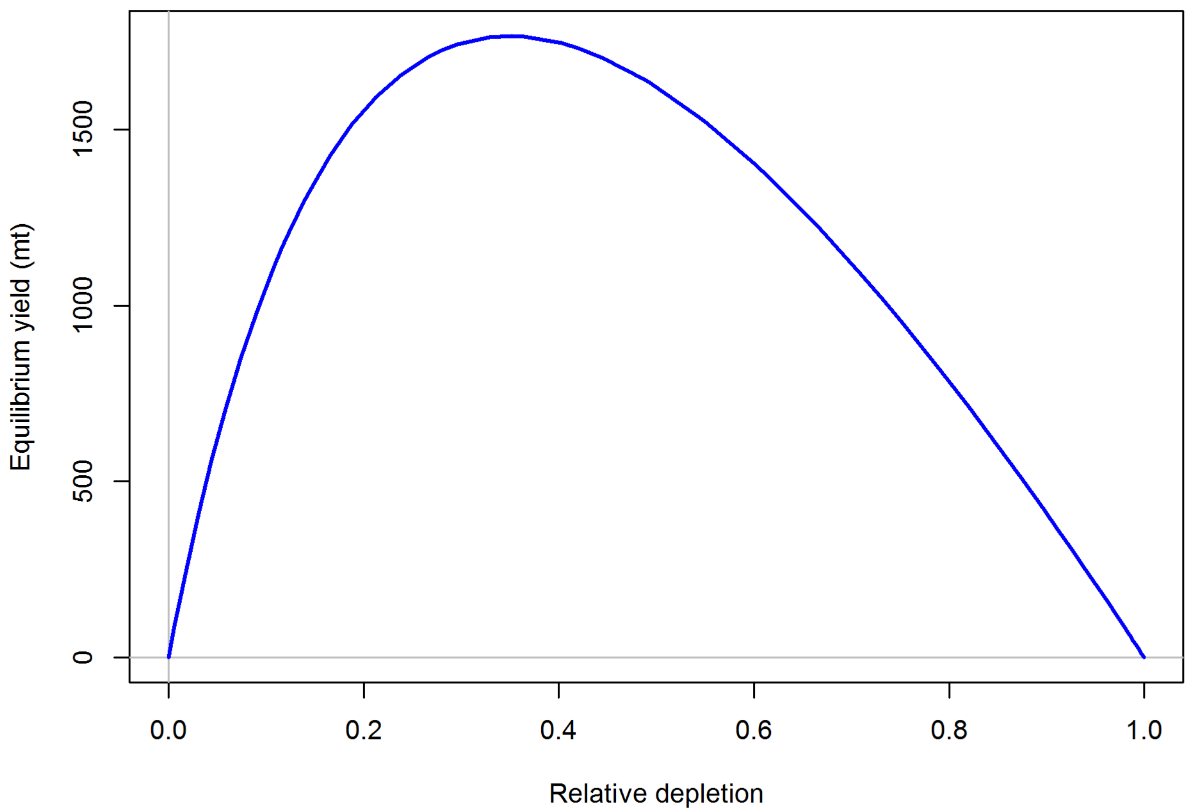

Figure 123: Equilibrium yield curve for the base case model. Values are based on the 2016 fishery selectivity and with steepness fixed at 0.50. fig:yield

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