UPDATE ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2025 FOR U.S. MANAGEMENT IN 2025-2026

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Introduction

The Pacific sardine (*Sardinops sagax*) northern subpopulation (NSP) resource is assessed annually in support of the Pacific Fishery Management Council's process of specifying annual catch levels for the U.S. fishery (PFMC, 2024a). The following update assessment was conducted to provide a biomass estimate for setting harvest specifications during the 2025-2026 fishing year. This model contains updated fishery data through model year-semester 2024-1 (July-December of calendar year 2024) and the 2024 survey data. Observations from the acoustic-trawl survey indicated continued low biomass levels in the core survey area, and ~99% of the observed biomass occurred in the nearshore area. Based on the habitat models, no catch in Ensenada was apportioned to the NSP for any month in calendar year 2024. Any catch that occurred between San Pedro, California and the southern US border in January-April 2024 was attributed to the NSP, based on the habitat model results. Recent management performance is shown in Table 1.

Table 1. U.S. Pacific sardine harvest specifications and landings (mt) since the onset of federal management. U.S. harvest limits and closures are based on total catch, regardless of subpopulation source. *2024-25 management year landings are preliminary (through Dec. 31, 2024).

Mgmt. Year	OFL	ABC	HG or ACL	Tot. Landings	NSP Landings
2000	-	-	186,791	73,766	67,691
2001	-	-	134,737	79,746	57,019
2002	-	-	118,442	103,134	82,529
2003	-	-	110,908	77,728	65,692
2004	-	-	122,747	96,513	78,430
2005	-	-	136,179	95,786	73,104
2006	-	-	118,937	107,471	86,952
2007	-	-	152,564	125,145	104,716
2008	-	-	89,093	83,797	74,424
2009	-	-	66,932	72,847	61,220
2010	-	-	72,039	60,862	49,751
2011	92,767	84,681	50,526	55,017	43,725
2012	154,781	141,289	109,409	86,230	76,410
2013	103,284	94,281	66,495	69,833	63,832
2014 (1)	59,214	54,052	6,966	6,806	6,121
2014-15	39,210	35,792	23,293	23,113	19,969
2015-16	13,227	12,074	7,000	1,919	75
2016-17	23,085	19,236	8,000	1,885	602
2017-18	16,957	15,479	8,000	1,775	351
2018-19	11,324	9,436	7,000	2,278	525
2019-20	5,816	4,514	4,000	2,062	627
2020-21	5,525	4,288	4,000	2,276	657
2021-22	5,525	3,329	3,000	1,772	298
2022-23	5,506	4,274	3,800	1,620	565
2023-24	5,506	3,953	3,600	1,774	844
2024-25*	8,312	6,005	5,500	*772*	*267*

Data

Fishery-dependent data

Catch values were updated through model year-semester 2024-1 (through Dec. 31, 2024 from the PacFIN database) and historical catch values were reviewed and validated by State representatives from California, Oregon, and Washington (Tables 2-6). Age composition and weight-at-age (WAA) data were updated from the California EFP fishery for model year 2023 for the MexCal S2 fishery and minor corrections to the MexCal S1 fishery. The fishery weights-at-age were estimated in this 2025 update assessment using conditional variance weight-at-age for the fishery data consistent with the methods applied in the 2024 benchmark assessment (Kuriyama et al. 2024) and described in Cheng et al. (2023). Results from all model years were updated for the assessment weight-at-age, though there were only new values added to the MexCal S2 fishery for model year-semester 2023-2 and minor corrections to the MexCal S1 fishery data (*see* Appendix C, Tables C.1-4). The methods by Cheng et al. (2023) allow for the simultaneous estimation of autocorrelation for time, age, and cohort. The STAT applied AIC model selection to choose a correlation structure for each fleet independently, as was done in the 2024 benchmark assessment, and the same model configurations were selected for each fleet (Tables C.1-3).

Based on the AIC values:

- The MexCal S1 (Fleet 1) used year and age correlation parameters (Table C.1). The 2024 benchmark also used year and age correlation parameters, though this final configuration was mis-reported in the 2024 benchmark report.
- The MexCal S2 (Fleet 2) used year and cohort correlation parameters (Table C.2). This same model was selected in the benchmark.
- The PNW (Fleet 3) used year and age correlation parameters (Table C.3). This same model was selected in the benchmark.

The new weight-at-age matrices for each fleet were compared with the 2024 benchmark values (Appendix Table C.4), and the updated model output from all years and fleets was used.

Table 2. Pacific sardine landings (mt) for major fishing regions off northern Baja California (ENS – Ensenada, Mexico), the United States (SCA – Southern California, CCA – Central California, OR – Oregon, WA – Washington), and British Columbia (BC – Canada). ENS and SCA landings are presented as totals and northern subpopulation (NSP) portions. Y-S stands for year-semester for calendar and model time periods.

Calendar Y-S	Model Y-S	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2005-2	2005-1	38,000	4,397	16,615	1,581	7,825	44,418	6,395	3,231
2006-1	2005-2	17,601	2,710	18,290	10,643	2,033	102	0	0
2006-2	2006-1	39,636	0	18,556	5,016	15,710	35,565	4,364	1,575
2007-1	2006-2	13,981	5,800	27,546	20,567	6,013	2102	0	0
2007-2	2007-1	22,866	11,928	22,047	5,531	28,769	40,041	4,662	1,522
2008-1	2007-2	23,488	0	25,099	21,186	2,515	0	0	0
2008-2	2008-1	43,378	5,930	8,980	124	24,196	22,949	6,032	10,425
2009-1	2008-2	25,783	5,339	10,167	9,650	11,080	0	0	0
2009-2	2009-1	30,128	0	5,214	109	13,936	21,481	8,009	15,334
2010-1	2009-2	12,989	2,781	20,334	13,812	2,909	437	0	422
2010-2	2010-1	43,832	0	11,261	384	1,404	20,415	12,389	21,801
2011-1	2010-2	18,514	0	13,192	12,959	2,720	0	0	0
2011-2	2011-1	51,823	17,330	6,499	0	7,359	11,023	8,009	20,719
2012-1	2011-2	10,534	3,166	12,649	7,856	3,673	2,874	2,981	0
2012-2	2012-1	48,535	0	8,621	930	598	39,792	32,758	19,172
2013-1	2012-2	13,609	0	3,102	973	84	149	1,423	0

2013-2	2013-1	37,804	0	4,997	0	811	26,139	29,064	0
2014-1	2013-2	12,930	0	1,495	491	4,403	0	908	0
2014-2	2014-1	77,466	0	1,601	0	1,831	7,788	6,876	0
2015-1	2014-2	16,497	0	1,543	0	728	2,131	31	0
2015-2	2015-1	20,972	0	1,421	0	6	0	66	0
2016-1	2015-2	23,537	0	423	0	1	1	0	0
2016-2	2016-1	42,532	0	964	49	234	3	85	0
2017-1	2016-2	30,496	0	513	145	0	0	0	0
2017-2	2017-1	99,967	0	1,205	0	170	1	0	0
2018-1	2017-2	25,721	0	395	177	0	2	0	0
2018-2	2018-1	38,049	0	1,424	0	35	7	2	0
2019-1	2018-2	30,119	0	750	421	58	4	0	0
2019-2	2019-1	64,295	0	870	49	174	9	1	0
2020-1	2019-2	74,817	0	681	67	328	0	0	0
2020-2	2020-1	74,687	0	1,204	0	429	0	0	0
2021-1	2020-2	48,988	0	603	187	37	3	0	0
2021-2	2021-1	74,710	0	1,093	90	3	9	3	0
2022-1	2021-2	73,385	0	663	192	2	0	0	0
2022-2	2022-1	79,533	0	988	52	116	7	2	0
2023-1	2022-2	39,810	0	493	374	14	0	0	0
2023-2	2023-1	96,556	0	1,053	292	152	1	0	0
2024-1	2023-2	114,368	0	493	324	75	0	0	0
2024-2	2024-1	43,829	0	762	257	10	0	0	0

Table 3. Comparison of Pacific sardine landings (mt) for major fishing regions off northern Baja California (Ensenada, Mexico), the United States, and British Columbia (Canada) for calendar years 2023 and 2024 between this update assessment and the 2024 benchmark. ENS and SCA landings are presented as totals and northern subpopulation (NSP) portions. Y-S stands for year-semester for calendar and model values. Estimates in parentheses represent values reported in Kuriyama et al. (2024), if different than the values supplied for the update assessment.

Calendar Y-S	Model Y-S	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2023-1	2022-2	39,810 (46,179)	0	493	374 (326)	14 (13)	0	0	0
2023-2	2023-1	96,556 (106,035)	0	1,053 (1,052)	292 (0)	152	1	0	0
2024-1	2023-2	114,368	0	493	324	75	0	0	0
2024-2	2024-1	43,829	0	762	257	10	0	0	0

Table 4. Pacific sardine NSP landings (mt) by year-semester and fleet for the 2025 update base model.

Calendar Y-S	Model Y-S	MexCal S1	MexCal S2	PNW
2005-2	2005-1	13,803	0	54,044
2006-1	2005-2	0	15,386	102
2006-2	2006-1	20,726	0	41,504
2007-1	2006-2	0	32,381	2,102
2007-2	2007-1	46,228	0	46,225
2008-1	2007-2	0	23,701	0
2008-2	2008-1	30,249	0	39,406
2009-1	2008-2	0	26,069	0
2009-2	2009-1	14,045	0	44,824
2010-1	2009-2	0	19,502	859
2010-2	2010-1	1,787	0	54,605
2011-1	2010-2	0	15,679	0
2011-2	2011-1	24,689	0	39,751
2012-1	2011-2	0	14,694	5,855
2012-2	2012-1	1,528	0	91,722
2013-1	2012-2	0	1,057	1,572
2013-2	2013-1	811	0	55,203
2014-1	2013-2	0	4,894	908
2014-2	2014-1	1,831	0	14,664
2015-1	2014-2	0	728	2,162
2015-2	2015-1	6	0	66
2016-1	2015-2	0	1	1
2016-2	2016-1	284	0	88
2017-1	2016-2	0	145	0
2017-2	2017-1	170	0	1
2018-1	2017-2	0	177	2
2018-2	2018-1	35	0	9
2019-1	2018-2	0	479	4
2019-2	2019-1	224	0	10
2020-1	2019-2	0	395	0
2020-2	2020-1	429	0	0
2021-1	2020-2	0	224	3
2021-2	2021-1	93	0	12
2022-1	2021-2	0	193	0
2022-2	2022-1	168	0	9
2023-1	2022-2	0	387	0
2023-2	2023-1	445	0	1
2024-1	2023-2	0	399	0
2024-2	2024-1	267	0	0

Table 5. Comparison of Pacific sardine NSP landings (mt) by year-semester and fleet for calendar years 2023 and 2024 between this update assessment and the 2024 benchmark. Estimates in parentheses represent values reported in the previous benchmark, if different than the values supplied for the update assessment.

Calendar Y-S	Model Y-S	MexCal S1	MexCal S2	PNW
2023-1	2022-2	0	387 (340)	0
2023-2	2023-1	445 (152)	0	1
2024-1	2023-2	0	399 (0)	0
2024-2	2024-1	267	0	0

Fishery-independent data

The survey biomass estimate was updated from the 2024 survey data (Stierhoff et al., in prep). The survey data includes the core area survey done on the *Reuben Lasker*, and a nearshore cooperative survey with the *Lisa Marie* and *Long Beach Carnage* vessels. Observations from the acoustic-trawl survey indicated continued low biomass levels in the core survey area, and ~99% of the observed biomass occurred in the nearshore area observed by the acoustic-purse seine fishing vessels (Table 6). Nearly all of the biomass seen in the nearshore was observed in two clusters along Central California (Stierhoff et al., in prep), and these high-biomass clusters co-occurred with the highest proportion observed of Japanese sardine (*S. melanostictus*) along the West Coast (Longo et al., in prep). This update assessment does not use genetics data to separate Pacific and Japanese sardine stocks, thus total NSP biomass estimates include both wherever they co-occurred in the NSP habitat.

The survey age composition and weight-at-age data were not updated for 2024. The sample sizes were low and did not appear representative of the population. The few biologically sampled sardine for the core survey area (80 individuals) represented the core survey biomass of ~337 mt. The vast majority of the total biomass was observed in two nearshore clusters in Central California, sampled by the fishery purse seine nets, and yielded only 98 aged specimens collected from two purse seine sets in one of those clusters. Of those nearshore specimens, the ages range from 2 to 5 years old with a mode at 4. The weights-at-age from the nearshore specimens are smaller than those of sardine in the north and smaller than those in previous years (Figure 1). Considering the differences in weight-at-age, which may be due to the small sample size of Pacific sardine mixed with Japanese sardine (Longo et al., in prep), a combined age-length key was not generated. The STAT concluded that the age and weight-at-age data did not seem to be representative of the Pacific sardine subpopulation. As a result, the update assessment included only the 2024 survey biomass estimate but not the most recent age composition and weight-at-age data. All of the nearshore age samples collected by the *Lisa Marie* were single-read by WDFW. Model sensitivities to these data sources are documented in Appendix A.

Table 6. Biomass estimates from the 2024 AT core and nearshore surveys (from Stierhoff et al., in prep).

Region	Number	Area	Transects	Distance	Clusters	Individuals	Biomass estimate (mt)	CI (5%)	CI (95%)	CV
Core	3	3,877	9	392	3	61	20	5	43	51
Core	4	1,885	6	203	1	1	3	0	6	60
Core	5	8,768	18	861	4	570	314	42	865	74
Core	Total	14,530	33	1,456	8	632	**337**	64	892	69
Nearshore	1	238	14	53	4	149	34,060	5,601	48,627	32
Nearshore	2	317	12	49	3	101	43,223	4,787	126,693	76
Nearshore	3	84	3	13	1	549	129	0	270	81
Nearshore	4	103	4	16	1	1	0	0	1	84
Nearshore	5	66	4	10	1	1	0	0	1	72
Nearshore	Total	808	37	141	10	801	**77,412**	21,736	155,856	45
TOTAL		15,338	70	1597	18	1433	**77,750**	21,800	156,748	45

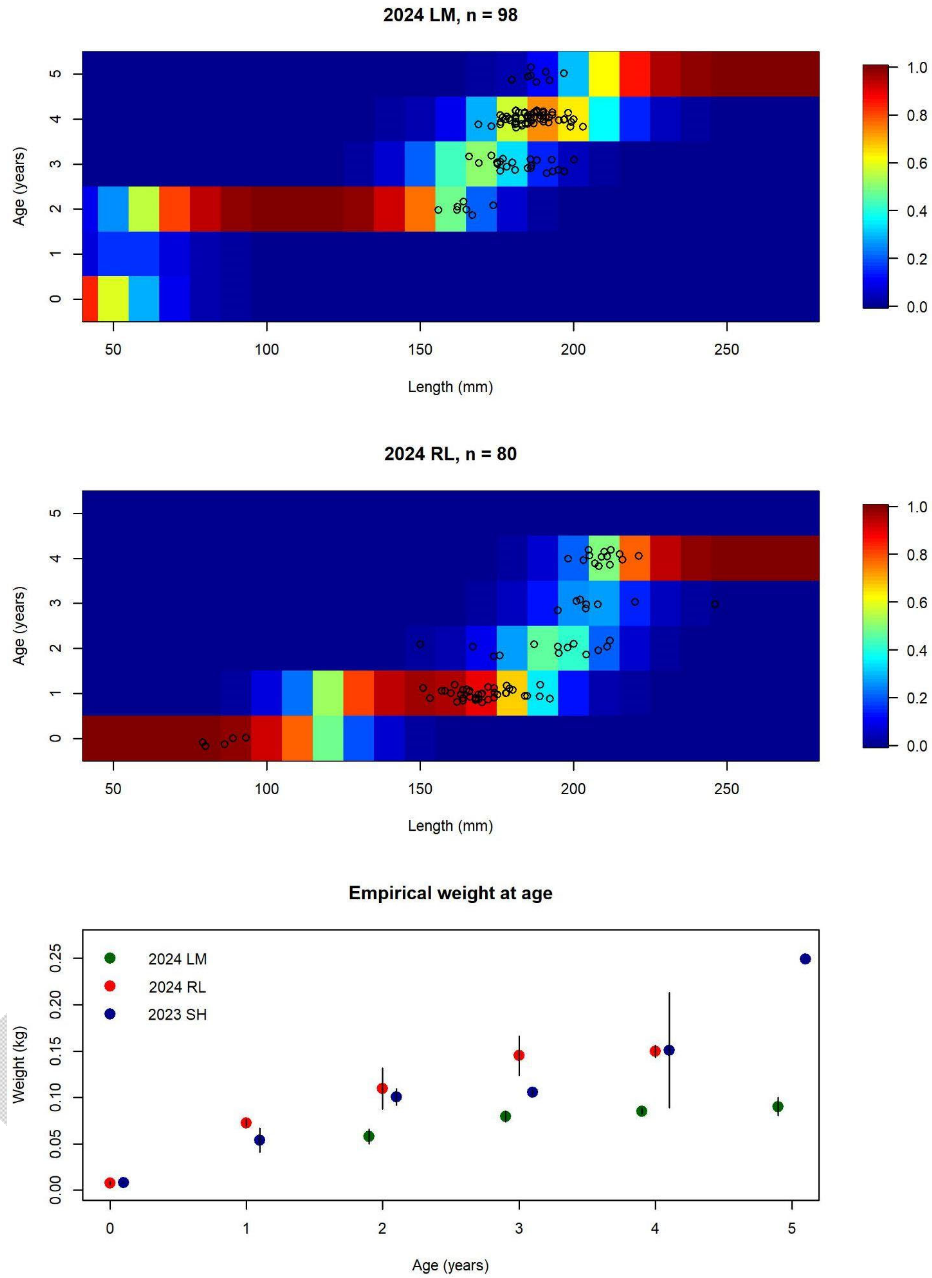

Figure 1 - Top two panels: age-length keys generated from sardine sampled in 2024 by *FV Lisa Marie* (LM) and *FSV Reuben Lasker* (RL) with pairs of length and age observations overlaid (jittered black circles). Bottom panel: Mean weights-at-age for the LM and RL 2024 data sets, with the 2023 counterparts for comparison (SH). The colored dots represent the mean weights-at-age for all the aged sardine available in the respective samples. The vertical lines cover the 95% confidence intervals for the mean.

Biological parameter data

Biological parameterization remains the same in this 2025 update assessment as the 2024 benchmark assessment (Kuriyama et al., 2024).

Ecosystem data

The CalCOFI sea surface temperature (SST) data were used to generate a mean SST for 2024, consistent with the 2024 benchmark assessment (Kuriyama et al., 2024). The 3-year running mean of SST was used to inform the E_{MSY} calculation.

Methods

The update assessment base model uses the same model parameterization as the 2024 benchmark assessment (described in Kuriyama et al., 2024), as stipulated by the Council's Terms of Reference for Update Assessments (PFMC, 2024b). However, due to the exclusion of the unrepresentative 2024 survey age composition and weight-at-age data, the model results included large recruitment forecasts without data indicating a large recruitment. The model is presented here as is required, though it includes model artifacts that the STAT caution are not accurate representations of the population. A suite of alternative models was explored and are documented in Appendix A to demonstrate this modelling problem and provide additional information intended to inform the Council of the uncertainty around the forecasted value, as well as present a range of models with more plausible population dynamics.

The update assessment was conducted using Stock Synthesis (SS v.3.30.22, consistent with the 2024 benchmark). For model tuning, the stock-recruit bias correction parameters were updated, but the last year of recruitment deviations was kept at 2023. The assumption here is that the 2024 survey age composition data would contain information on recent recruitment, but because the updated age composition data were not included the time frame of the main recruitment deviations was not extended. The forecasted fishing mortality was also updated (Table 7).

Table 7. Catch values and associated estimated F values added to the update assessment.

		MexCal S1		MexCal S2		PNW	
Calendar Y-S	Model Y-S	Catch	F (yr^{-1})	Catch	F (yr^{-1})	Catch	F (yr^{-1})
2024-1	2023-2	0.00	0.00	398.87	0.04	0.14	0.00
2024-2	2024-1	267.06	0.04	0.00	0.00	0.09	0.00

Results

Summary biomass (age 1+) for the 2025 fishing year is forecasted to be 93,972 mt (Table 8, Figure 2), and recruitment is forecasted to be 1,515,520 thousand age-0 fish (Table 8, Figure 3). However, this forecasted summary biomass estimate represents a doubling of the estimated 48,865 mt of biomass in 2024 (Table 8) due to the stock-recruit relationship reverting to a higher mean value (Figures 4-5).

Table 8. Base model estimated age-1+ biomass and age-0 recruits.

Model year	**Seas**	**1+ Biomass (mt)**	**Recruits (1,000s)**
2005	1	839,611	0
2005	2	705,196	0
2006	1	1,177,300	9,915,390
2006	2	921,799	0
2007	1	920,429	4,959,350
2007	2	842,787	0
2008	1	947,840	3,139,210
2008	2	598,720	0
2009	1	533,748	4,932,750
2009	2	461,260	0
2010	1	401,536	6,752,530
2010	2	294,924	0
2011	1	464,280	446,224
2011	2	375,219	0
2012	1	293,718	119,550
2012	2	170,264	0
2013	1	151,441	152,039
2013	2	80,980	0
2014	1	74,196	541,227
2014	2	40,314	0
2015	1	60,311	594,350
2015	2	41,530	0
2016	1	53,037	192,851
2016	2	33,020	0
2017	1	48,132	339,523
2017	2	25,931	0
2018	1	47,498	658,433
2018	2	26,402	0
2019	1	44,201	559,770
2019	2	28,638	0

2020	1	44,859	1,864,440
2020	2	29,337	0
2021	1	128,827	580,509
2021	2	48,804	0
2022	1	58,021	442,295
2022	2	48,203	0
2023	1	57,318	373,932
2023	2	50,534	0
2024	1	48,865	2,037,160
2024	2	46,481	0
2025	1	93,972	1,515,520
2025	2	61,859	0

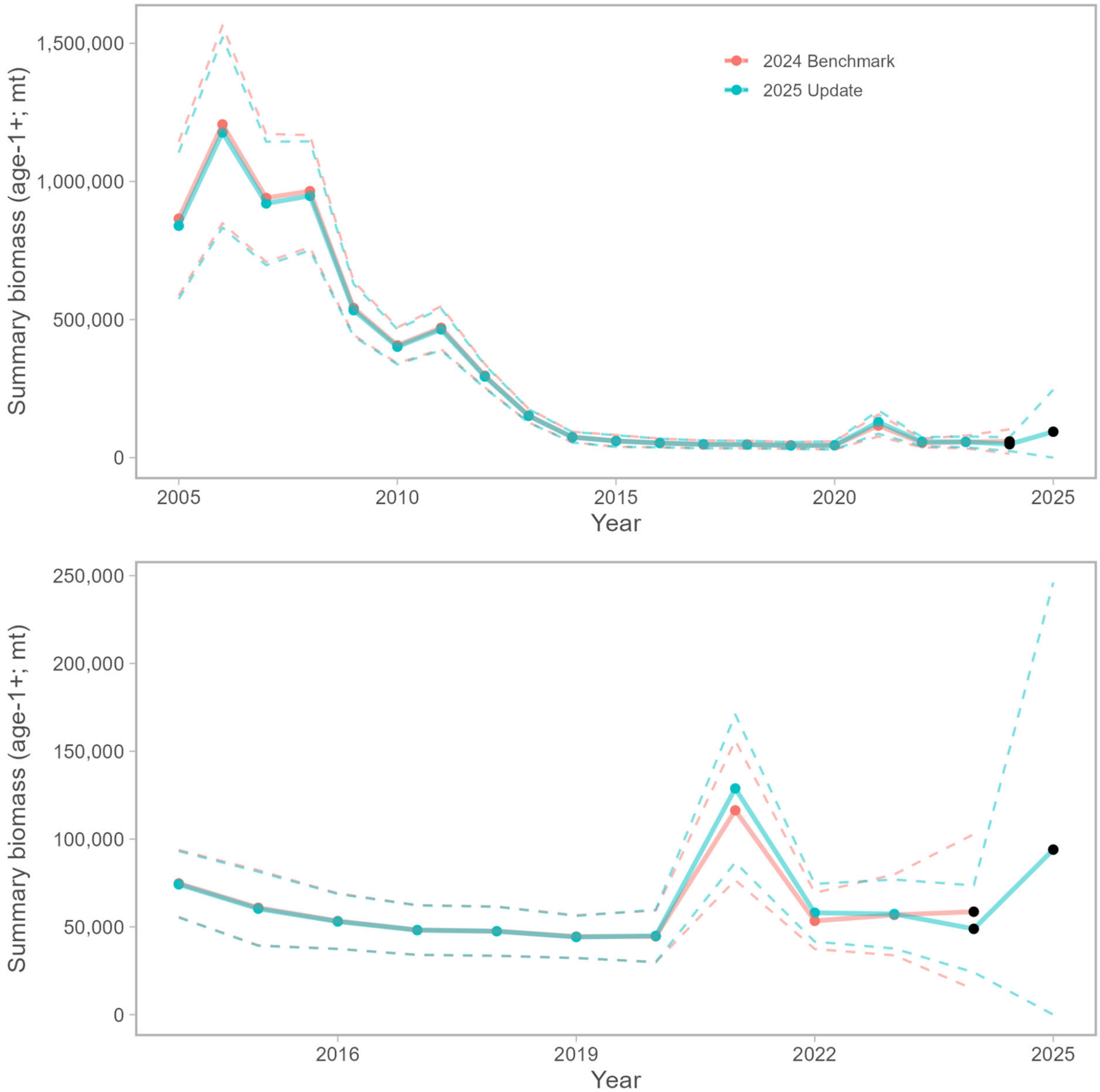

Figure 2. Time series of summary biomass (age-1+; mt) for the 2024 benchmark assessment (red) and 2025 update assessment (blue). The top panel shows values from 2005-2025, the bottom shows 2014-2025. Dotted lines represent 95% confidence intervals. Black points indicate forecasted age-1+ biomass.

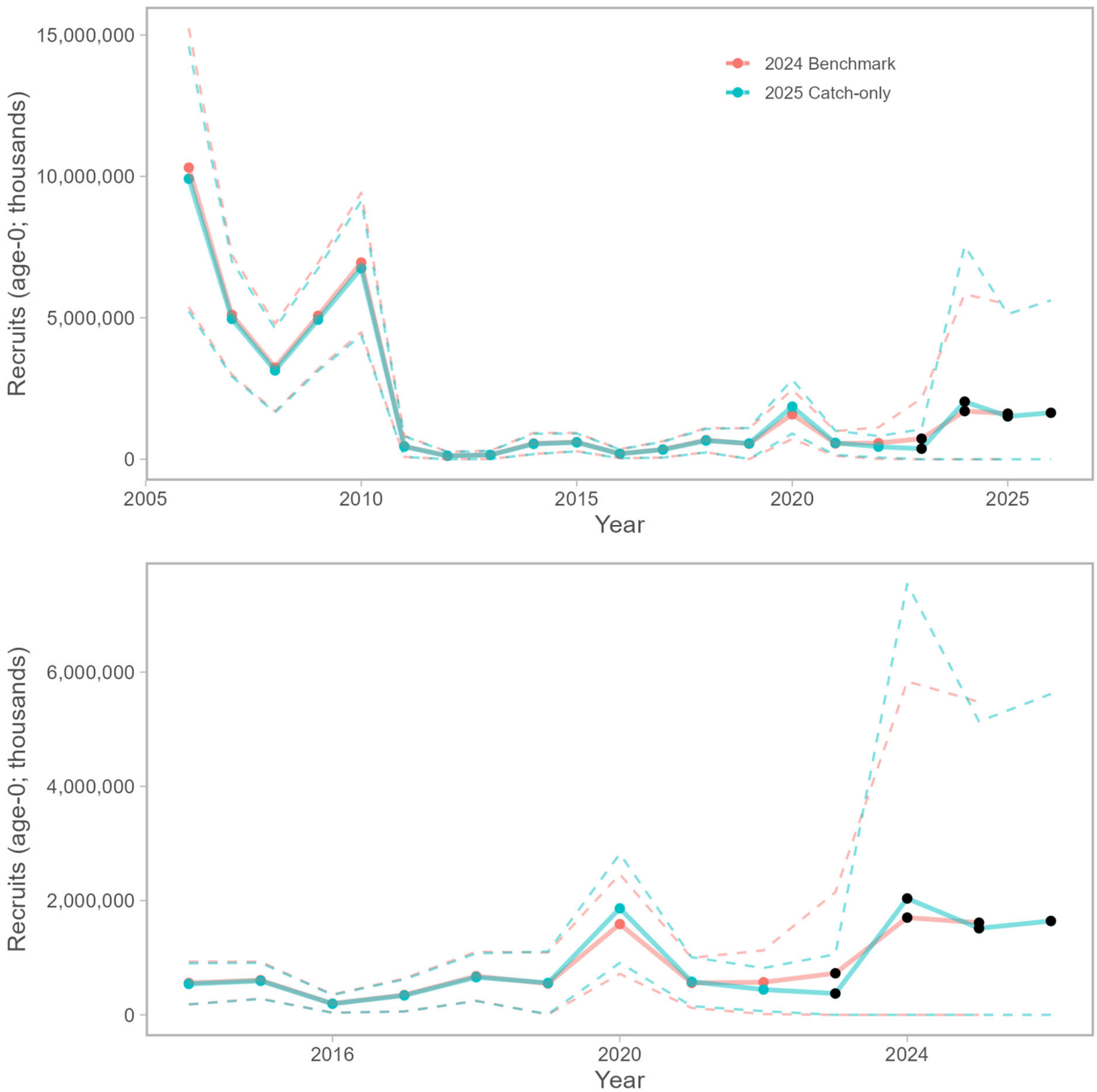

Figure 3. Time series of recruits entering the population (thousands of age-0 fish) for the 2024 benchmark assessment (red) and 2025 update assessment (blue). The top panel shows values from 2005-2026, the bottom shows 2014-2026. Dotted lines represent 95% confidence intervals. Black points indicate values based on recruitment values from the stock-recruit relationship.

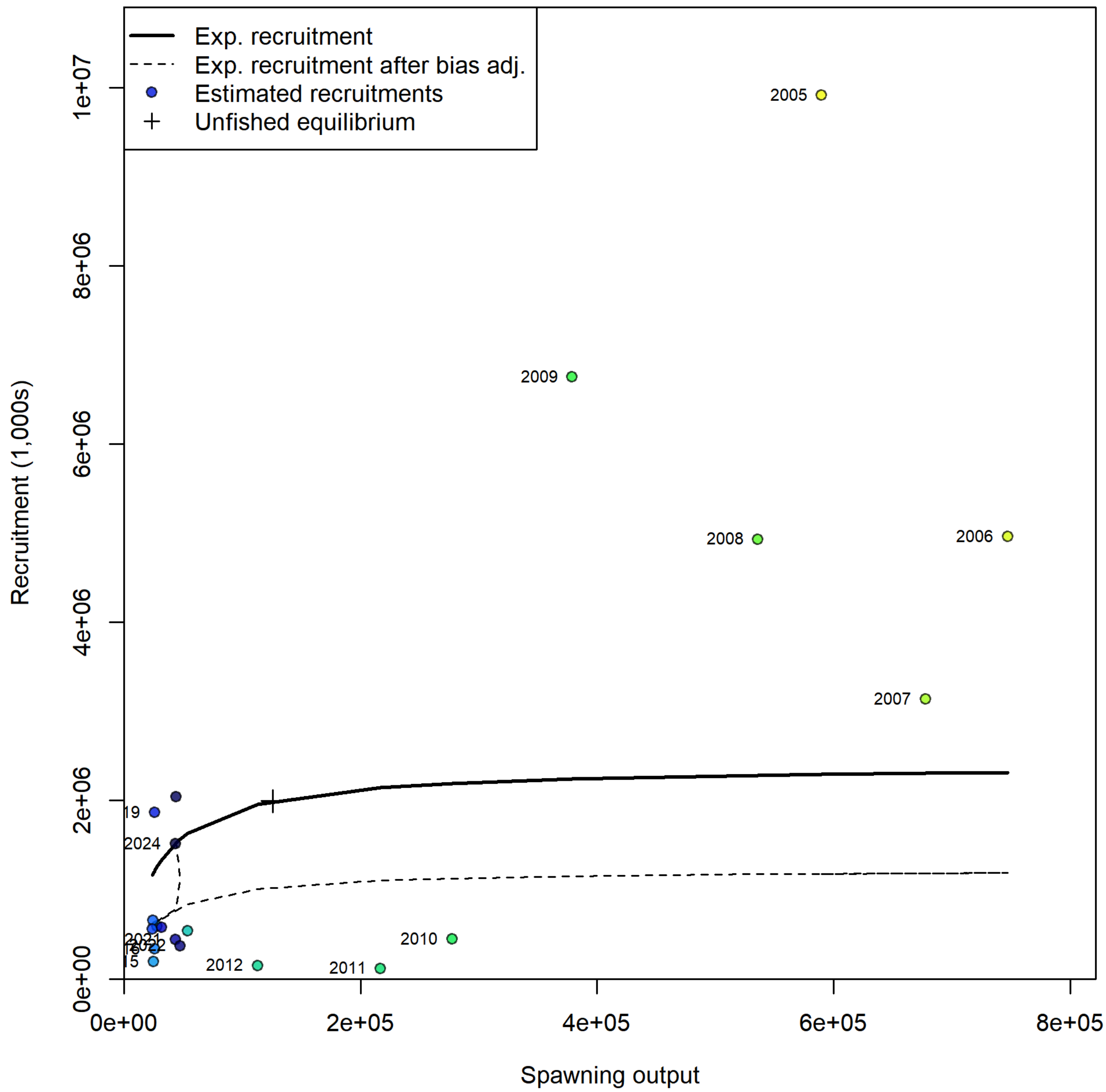

Figure 4. The stock-recruit curve with mean expected recruitment (solid curve), expected recruitment after bias adjustment (dashed line), and annual stock-recruit data (labeled points).

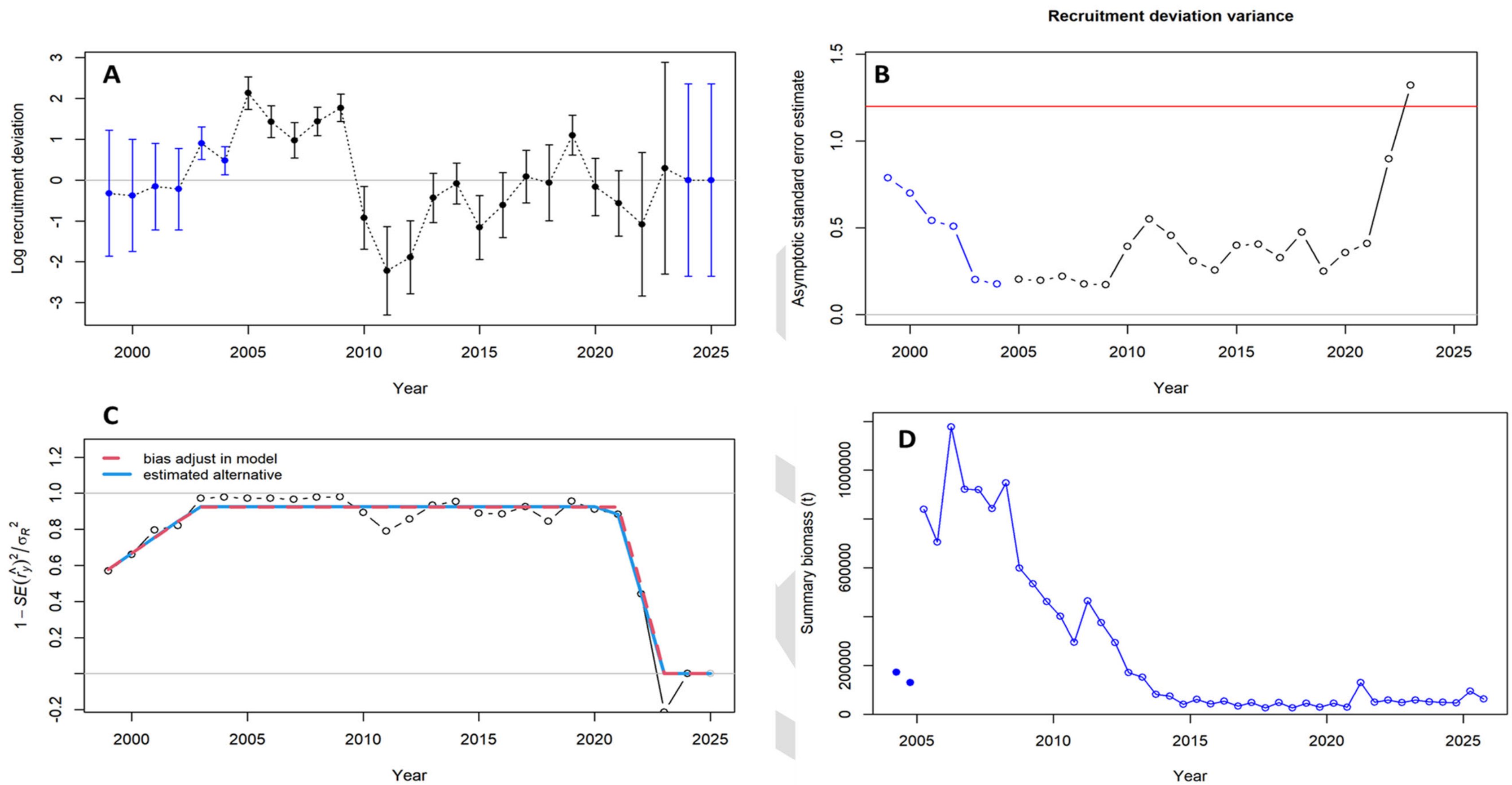

Figure 5. While the recruitment deviations (A) follow an expected pattern, the recruitment deviation variance (B, C) falls outside the expected range, resulting in a doubling of biomass in the forecast year (2025) that is driven by the model creating a large recruitment event in the current year due to the exclusion of 2024 biological survey data.

Exploitation status

Exploitation rate is defined as the calendar year catch divided by the total mid-year biomass (July-1, ages 0+). Based on the latest model and historic catches, the U.S. exploitation rate was about 1% in 2024 (Table 9, Figure 6). Mexico and Canada had an annual exploitation rate of 0%, thus the total exploitation rate for Mexico, USA, and Canada was about 1% of the total biomass. These exploitation rates are similar to those reported in the 2024 benchmark assessment (0.8% in 2023).

Table 9. Annual exploitation rate (calendar year landings / July total biomass) of the NSP by country and calendar year.

Calendar Year	Mexico	USA	Canada	Total
2005	0.004	0.052	0.003	0.058
2006	0.002	0.056	0.001	0.060
2007	0.018	0.110	0.002	0.129
2008	0.006	0.077	0.010	0.094
2009	0.009	0.108	0.026	0.143
2010	0.006	0.106	0.046	0.158
2011	0.037	0.089	0.044	0.170
2012	0.011	0.310	0.065	0.385
2013	0.000	0.382	0.000	0.382
2014	0.000	0.281	0.000	0.281
2015	0.000	0.047	0.000	0.047
2016	0.000	0.006	0.000	0.006
2017	0.000	0.006	0.000	0.006
2018	0.000	0.004	0.000	0.004
2019	0.000	0.010	0.000	0.010
2020	0.000	0.007	0.000	0.007
2021	0.000	0.002	0.000	0.002
2022	0.000	0.005	0.000	0.005
2023	0.000	0.014	0.000	0.014
2024	0.000	0.010	0.000	0.010

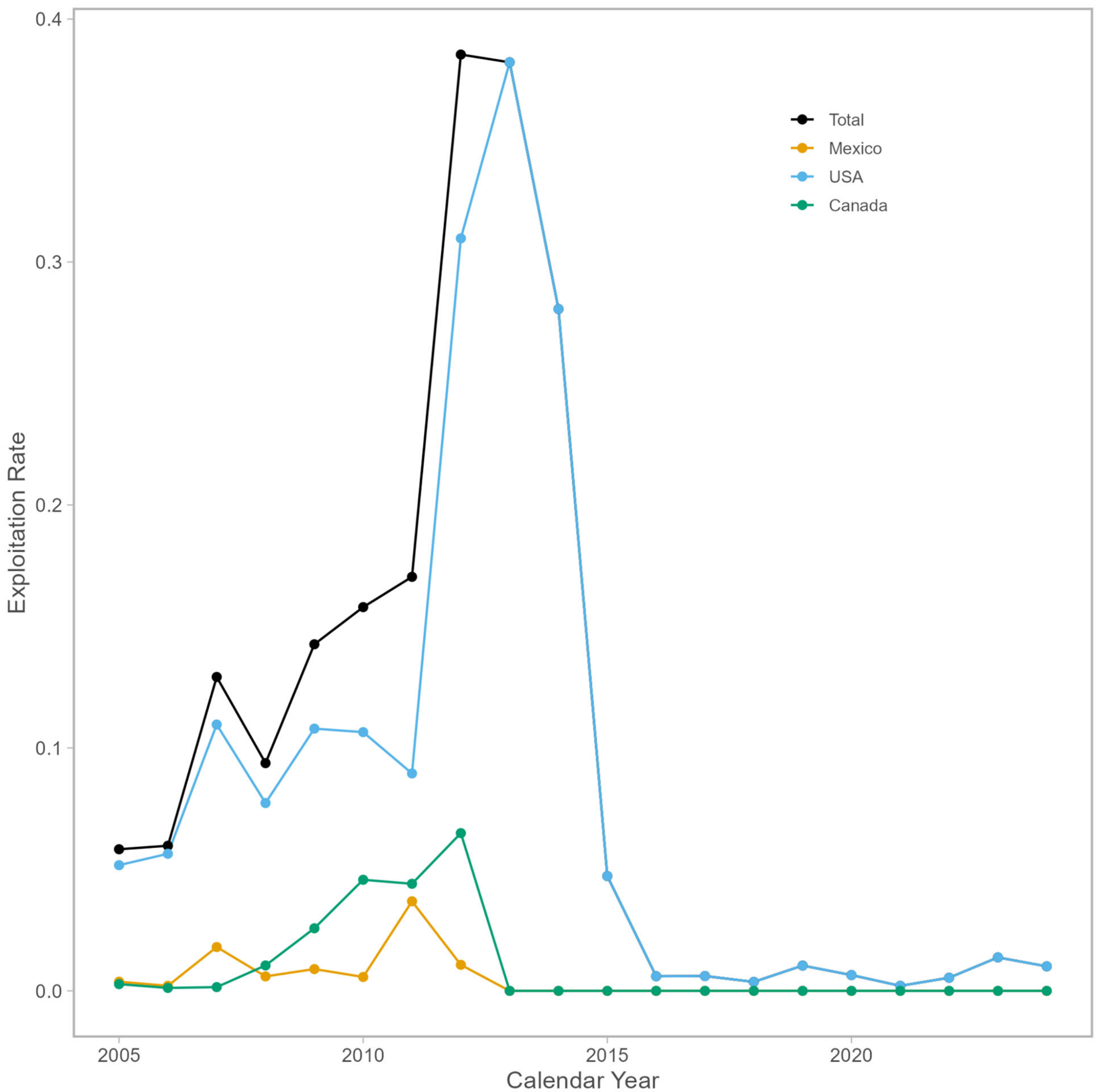

Figure 6. Annual exploitation rates (calendar year landings / July total biomass) for NSP in the base model. (Note that since Canada and Mexico exploitation rates are zero after 2013, the total exploitation rate is equal to the US exploitation rate.)

Harvest control rules

The harvest guidelines are shown in Table 10, based on a CalCOFI sea-surface temperature (SST) of 15.69 (average for 2022-2024), resulting in an EMSY of 0.1771, and forecast age 1+ biomass of 93,972 mt; however, this biomass value is likely elevated due to excluding biological survey data for 2024, leading to a model artifact inflating 2024 recruitment. Regardless, the stock is below the 150,000 mt management threshold. For the current base model, the OFL is 14,475 mt, and the harvest guideline is 0 mt for 2025. Acceptable biological catches for a range of P-star values and assessment tiers are shown in Table 10, though additional information addressing the model and data uncertainties is available in Appendix A to assist in selecting a sigma value for the ABC Buffer. A re-evaluation of the relationship between CalCOFI SST and recruits-per-spawner is examined in Appendix B.

Table 10. Pacific sardine harvest control rules for fishing year 2025-2026.

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS – CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Guideline Parameters									
BIOMASS (ages 1+, mt)	**93,972**								
P-star	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.8756	0.765	0.6654	0.5744	0.4901	0.4107	0.3343	0.258	0.1757
ABC $Buffer_{Tier\ 2}$	0.8514	0.723	0.6106	0.511	0.4216	0.3404	0.2653	0.1938	0.1217
ABC $Buffer_{Tier\ 3}$	0.7778	0.6025	0.4627	0.3504	0.2595	0.1858	0.1258	0.0771	0.0373
CalCOFI SST (2022-2024)	15.69								
E_{MSY}	0.1771								
FRACTION	0.1771								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values									
OFL =	**14,475**								
$ABC_{Tier\ 1}$ =	12,675	11,074	9,632	8,315	7,094	5,945	4,839	3,735	2,543
$ABC_{Tier\ 2}$ =	12,324	10,466	8,839	7,397	6,103	4,927	3,840	2,805	1,762
$ABC_{Tier\ 3}$ =	11,259	8,721	6,698	5,072	3,756	2,690	1,821	1,116	540
HG =	**0**								

Recent management performance

A thorough description of PFMC management actions for sardines, including HG values, may be found in the most recent CPS SAFE document (PFMC, 2024a). US landings in recent years have remained below the annual catch limits (or annual catch targets, when applicable; Table 1). The 2024-2025 annual catch target for Pacific sardine was 5,500 mt for Pacific sardine (Table 1). Landings-to-date of the northern subpopulation in the U.S. were 267 mt for 2024-2025, less than 5% of the annual catch limit, with no NSP landings in Canada or Mexico (Table 2).

Uncertainties

The high modeled 2024 recruitment and doubling of forecasted biomass for 2025 is an artifact of applying a mean stock-recruit relationship given the exclusion of biological survey data to inform the model otherwise (Fig. 4). Figure 4 shows that the assumed stock-recruit relationship reverts to the long-term mean without any additional data to inform the model otherwise, though a recruitment level that high is not common when the biomass is in a lower state. In addition, while the recruitment deviations appear normal, the recruitment deviation variance is outside the bounds of what would be expected, and results in a large recruitment assigned to 2024, resulting in a doubling of biomass in 2025 when current age-0 fish grow to age-1 size (Figure 5). Without relative abundance-at-age data for 2024, the model is driving current biomass into a large recruitment event. Given the survey biomass estimate was based primarily on age-2 to age-5 fish, there is not sufficient evidence in the data to support a large recruitment event in the environment, suggesting that the results are a model artifact. The impact of including biological data for 2024 or alternative model configurations using the regime parameter to restrict the stock-recruit relationship to specific blocks of years are shown in Appendix A.

The concentration of sardine biomass around a relatively small area in nearshore Central California and near absence in the core area shows a continued deviation from historical patterns of distribution, and warrants close monitoring over the next few years leading up to the 2027 benchmark. In addition, the relatively high proportion of Japanese sardine overlapping with this singular high-biomass area should continue to be monitored. Of particular importance in monitoring the results from the ongoing genetics analysis is information on the potential for hybridization between Japanese sardine and Pacific sardine populations. While successful hybridization has the potential to increase total sardine biomass on the West Coast, unsuccessful hybridization could either have no impact or a depensatory effect on both species (e.g., via cross-fertilization resulting in non-viable zygotes).

Research and data needs

The exclusion of biological data for the current year to inform the assessment highlights a source of uncertainty around the stock-recruit relationship for Pacific sardine. The STAT recommends exploring the use of the stock-recruit regime parameter for Pacific sardine in the 2027 benchmark assessment, to better characterize high and low recruitment phases for Pacific sardine.

Research on Japanese sardine potential interactions with Pacific sardine populations including spawn timing, locations, recruitment, and the results of hybridization with Pacific sardine is critical for improved understanding of the potential recruitment outcomes for these stocks in the near-term. In addition, current research regarding the high and low recruitment phases of Pacific sardine through time, including possible impacts by the environment on recruitment success would improve and strengthen our ability to more accurately forecast population biomass.

The distinction between the NSP and Southern Subpopulation (SSP) of Pacific sardine remains a continued source of investigation and research.

Given that ~99% of the sardine biomass was seen in the nearshore component of the survey, it is important to continue collecting survey data in the nearshore to assess the full scope of the US West Coast sardine populations.

Acknowledgements

[To be filled for final draft]

References

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Appendices to the update assessment

Appendix A: Alternative models to the 2025 update assessment base model

Authors: Caitlin Allen Akselrud and Alexander Jensen

Introduction

In running the 2025 Update Assessment base model, the STAT found a projected doubling in biomass for 2025. In tracing the origins of this projection, the STAT discovered that this is a model artifact of not including updated biological data for 2024, and, in particular, the survey age composition data which informs the model of the relative abundance-at-age. The STAT took a two-fold approach to addressing this problem: 1) to understand what the model-derived outputs would be if some values were included for the 2024 survey age composition and weight-at-age inputs (data-driven), and 2) to attempt to correct the model artifact using what the STAT has determined to be the best available data (used in the base model) with some modeling changes (model-driven).

In the first case, the STAT tested the impacts of only adding 2024 weight-at-age data, then adding both weight-at-age and age composition data from the 2024 survey. The majority of this biological data stems from one nearshore cluster in Central California (Stierhoff et al., in prep) and overlaps with areas indicating high proportions of Japanese sardine in the overall sardine biomass (Longo et al., in prep.). In particular, the weights-at-age were smaller than expected compared with samples collected farther north and with previous years (Figure 1). The ages were estimated between 2 to 5 years old, with a mode at 4 (*pers. comm.* Juan Zwolinski). It is unlikely that the population as a whole is well-represented by these 98 individuals. Thus, the results from these configurations should not be taken as alternative biomass estimates, but more as an example of how the model behaves differently when grounded in current year survey age composition data.

To examine possible modeling artifacts, the STAT used the best available data consistent with the base model and added a regime parameter on the stock-recruit relationship. Through our model explorations, the STAT was able to diagnose the modeling artifact as an assignment of biomass to a large recruitment event in 2024 without age composition to indicate otherwise. However, in the data we do have from 2024, there is a dearth of age-0 individuals that would support a large recruitment. The large recruitment event produced by the model was a result of reverting to a mean stock-recruit relationship that produces an estimated recruitment much higher than is indicated in recent years (Figure A.1). The STAT was able to add a block of years on the estimated stock-recruit relationship, in order to restrict it to values found in recent years and supported by data. Without a deeper dive into recruitment events, the STAT constructed three possible regime blocks: 2021-2022 as the most recent years of recruitment, 2015-2022 which covers the closure period and likely a lower-recruitment regime in the environment, and the full time series 2005-2022 which applies all stock-recruit observations within the modeled period, but excludes anything that would be used to inform the stock-recruit relationship in the pre-model build-up years (1999-2004).

Alternative model configurations:

Each model configuration examined is described below and summarized in Table A.1. A note on model version syntax: the letter in the model version suffix is updated for each model with a change to the data used from the base, and the model version numeric suffix is updated for models with a change to the model structure. Model configuration 2025.1a refers to the base model described in the main body of the update assessment text.

Data differences from the base model

While the STAT thought that the 2024 biological data (age composition and weight-at-age) were not the best representation of the NSP, we did want to generate model configurations that show the impact on the model results when biological data for the current year is included and to illustrate the impact of the large recruitment model artifact discussed in the main report.

Model 2025.1b: 2024 waa only

This model configuration uses the base model (2025.1a), but includes the actual 2024 weight-at-age data.

Model 2025.1c: 2024 survey data, early recdev

This model configuration uses the 2025.1b model and adds the 2024 age composition data, keeping the last year of main recruitment deviations at 2023 instead of updating it to 2024.

Model 2025.1d: 2024 survey data update

This model configuration uses the 2025.1c model and updates the final year of main recruitment deviations to 2024, as would be done if this data were used for the update assessment.

Model configuration differences from the base model

This set of models was developed to address the issues created by not including 2024 biological survey data, and to provide a range of more plausible modeled population dynamics.

Model 2025.2a: early recdev

This model configuration uses the 2025.1a base model, but changes the last year of recruitment deviations from 2023 to 2022. The stock-recruit bias correction is updated for this and the following three model configurations (2025.3a, 2025.4a, and 2025.5a). Forecast recruitment begins in 2023 for this and the following three model configurations (2025.3a, 2025.4a, and 2025.5.a).

Model 2025.3a: recent regime

This model configuration updates model 2025.2a to use a new stock-recruit regime parameter. The blocking of this parameter calculates a stock-recruit relationship for recent years (2021-2022) and applies this stock-recruit relationship to the remaining model years and forecast year.

Model 2025.4a: closure regime

This model configuration updates model 2025.2a to use a new stock-recruit regime parameter, similarly to 2025.3a, but the block period includes the full fishery closure period: 2015-2022, which may represent a lower-recruitment regime for Pacific sardine.

Model 2025.5a: full time series (ts) regime

This model configuration updates model 2025.2a to use a new stock-recruit regime parameter, similarly to 2025.3a and 2025.4a, but the block period includes the full modelled time series: 2005-2022. This configuration excludes any influence the pre-model period (1999-2004), which builds up the model biomass, might have on the stock-recruit relationship.

Results

Data models

All of the models with age composition data entered for 2024 (2025.1c-e) do not show a forecasted doubling of biomass for 2025, and all show a 2024 estimated recruitment between about 290 million-380 million age-0 recruits, rather than the more than 2 billion estimated recruits for 2024 in the base model (Table A.2). This illustrates that the high recruitment and biomass estimates in the base model stem solely from the exclusion of age composition data for the 2024.

Model change models

Simply setting the last year of recruitment deviations to 2022 did not change the high projected recruitment for 2024 (model 2025.2a). However, when the STAT added a regime parameter to the stock recruitment settings, the 2024 recruitment did decrease though it was variable between the three regime models (2025.3-5a; Table A.2). Despite variability in the modeled recruitment for 2024, the forecasted 2025 biomass ranged from about 42,500-62,400 mt– lower than the nearly 94,000 mt forecasted in the base model.

The likelihoods and corresponding AIC values of the regime models were very similar, with the recent regime likelihood just slightly above the closure and full time series configurations (recent regime likelihood: 229.382; closure regime likelihood: 229.374; full time series likelihood: 228.249; Table A.3). The base model likelihood is included in Table A.3, but the effective degrees of freedom from a Stock Synthesis model are difficult to characterize and methodology to do so is currently under development (*see*: https://github.com/nmfs-ost/ss3-source-code/issues/651?reload=1?reload=1). Therefore, only the three models that are structurally the same (their only change is to the starting regime block year) are compared in this analysis.

Discussion

While the STAT wanted to demonstrate the range of forecasted values given different combinations of data, we felt it was more important to develop a model using the best available data (no age composition or weight-at-age from 2024). Without current age composition data to anchor the model, the stock-recruit relationship is reverting to a mean value, which results in a larger than expected recruitment in 2024 and subsequent doubling of forecasted biomass for 2025. Given there is little evidence in our current data for a large recruitment event, the STAT developed a suite of alternative models that use the regime parameter on the stock-recruit relationship to examine three plausible alternatives: 1) the stock-recruit relationship follows recent recruitment patterns seen in 2021-2022, 2) the relationship follows the mean pattern since the fishery closure (2015-2022), or 3) the relationship follows the mean pattern since the start of the modeled data (2005-2022) and excludes years prior to the model beginning that build up the stock (1999-2004). Given the similar results between the three stock-recruit regime models, the STAT finds that these models (2025.3-5a) are more biologically plausible and represent the range of uncertainty around the 2025 forecasted biomass.

Citations

Longo, G., James, K., Hinton, K., Topping, J., and Craig, M. *In prep*. Update on the presence of Japanese Sardine (Sardinops melanosticta) in the California Current Large Marine Ecosystem 2024. U.S. Dep. Commer., NOAA Tech. Memo.

Stierhoff, K. L., Renfree, J. S., and Zwolinski, J. P. *In prep.* Distribution, biomass, and demographics of coastal pelagic fishes in the California Current Ecosystem during summer 2024 based on acoustic-trawl sampling. U.S. Dep. Commer., NOAA Tech. Memo.

Tables and Figures

Table A.1. Descriptions of the base model and each alternative model configuration. All models include bias correction.

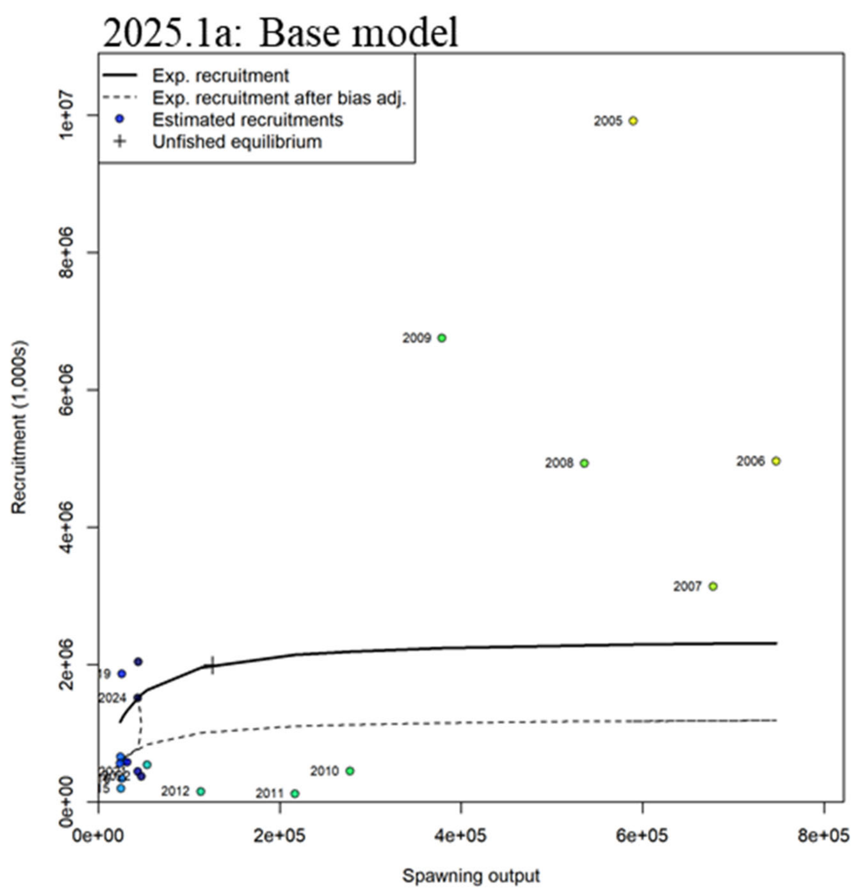
Model Names	**Change type**		**Model name**	**Previous Model**
2025 Base	**Base**	**2023 waa used for 2024, no 2024 age comp, last recdev = 2023, age0 selex = 2024**	**2025.1a**	
2024 waa only	Data	add 2024 waa, no age comp, last recdev = 2023, age0 selex = 2024	2025.1b	2025.1a
2024 survey data, early redev	Data	2024 waa, 2024 age comp, last recdev = 2023, age0 selex = 2024	2025.1c	2025.1b
2024 survey data update	Data	2024 waa, 2024 age comp, last recdev = 2024, age0 selex = 2024	2025.1d	2025.1c
early recdev	Model	base + recdev = 2022, age0 selex = 2024	2025.2a	2025.1a
recent regime	Model	early rec dev + regime = 2021-2022	2025.3a	2025.2a
closure regime	Model	early rec dev + regime = 2015-2022	2025.4a	2025.2a
full ts regime	Model	early rec dev + regime = 2005-2022	2025.5a	2025.2a

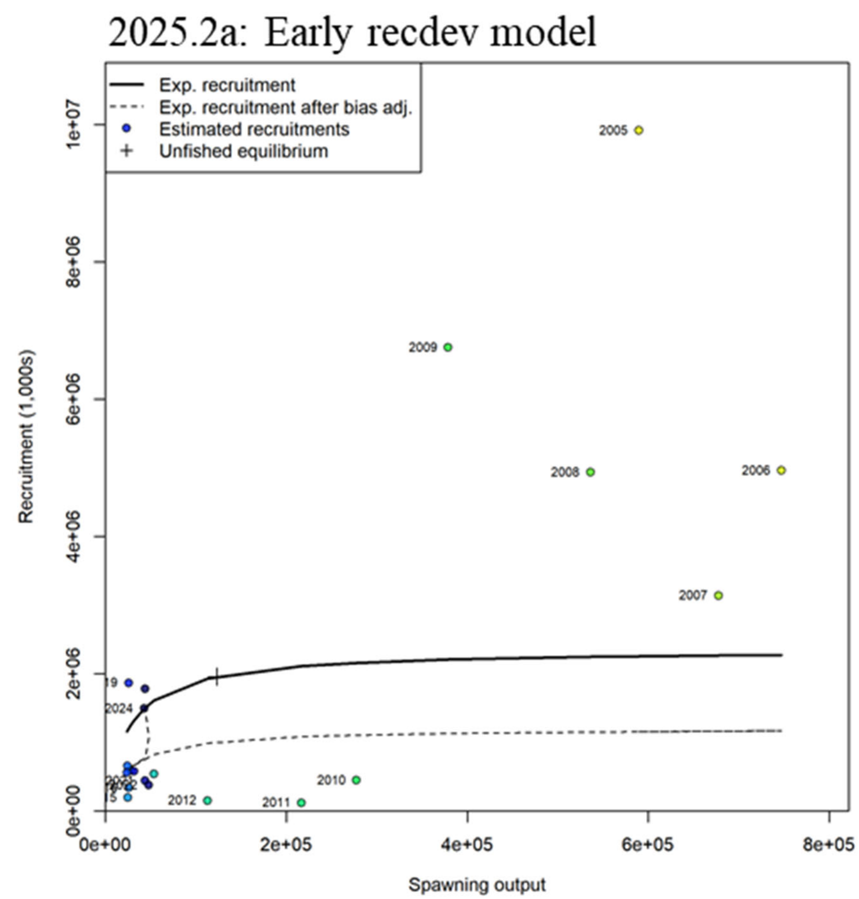
Table A.2 Model results from the base and each of the alternative model configurations. Biomass and OFL are reported in metric tons (mt) and recruitment is reported in thousands of individuals.

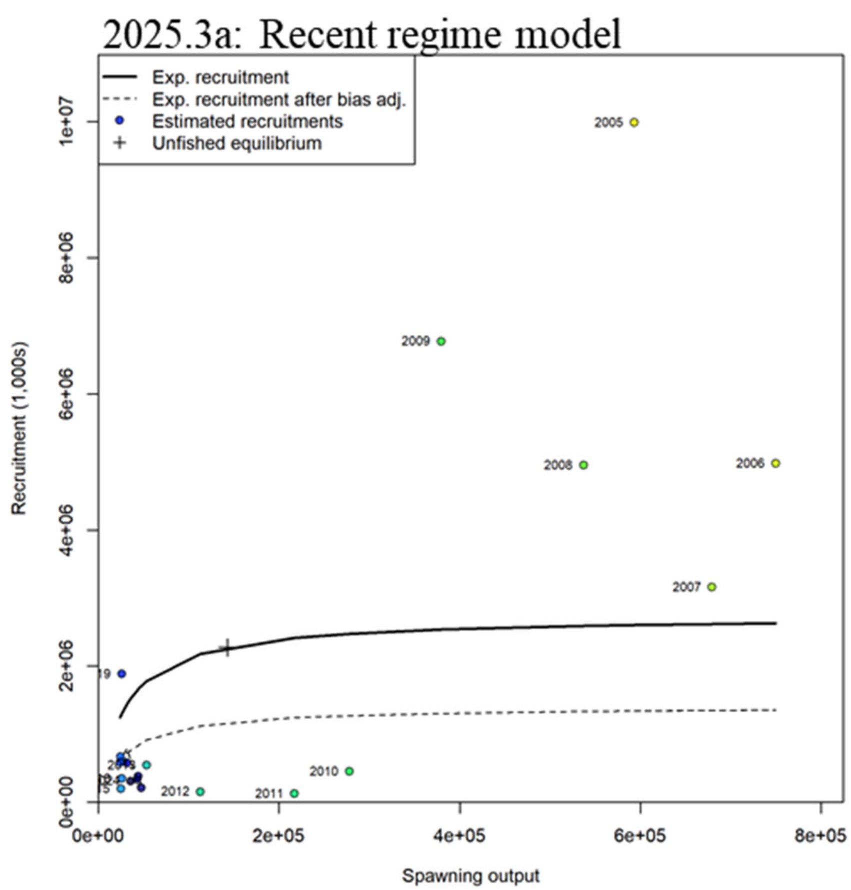
Model	**Model name**	**2023 1+bio**	**2024 1+bio**	**2025 1+bio**	**2023 recr**	**2024 recr**	**2025 recr**	**OFL**
base	2025.1a	57,318	48,865	93,972	373,932	2,037,160	1,515,520	14,475
data_2024_waa_only	2025.1b	59,381	44,205	84,562	574,699	2,094,550	1,581,900	13,026
data_2024_notuning	2025.1c	62,217	36,200	30,382	209,485	296,964	1,301,960	4,680
data_2024	2025.1d	62,214	36,190	30,158	209,191	289,283	1,391,300	4,645
early_recdev	2025.2a	57,521	49,191	77,477	380,191	1,441,230	1,481,420	13,385
regime_recent	2025.3a	55,677	43,263	42,504	212,428	334,468	310,398	6,547
regime_closure	2025.4a	55,241	44,529	62,391	274,397	1,024,460	978,206	9,611
regime_full_ts	2025.5a	53,382	45,381	57,219	355,201	830,794	759,118	8,814

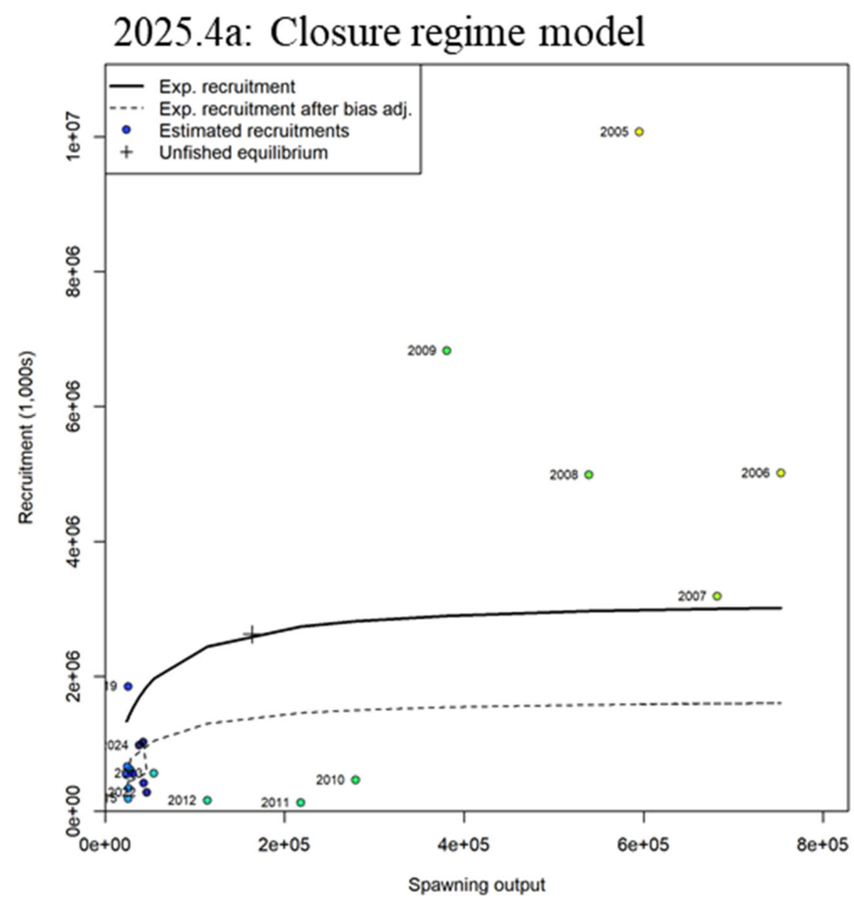
Table A.3 The number of parameters*, likelihood, and AIC reported for each of the alternative regime models, with the base model included for reference. *Note: the effective degrees of freedom from a Stock Synthesis model are difficult to characterize.

Model	**Model number**	**N params***	**Likelihood**	**AIC**
regime recent	2025.3a	155	229.38	299.13
regime closure	2025.4a	155	229.37	299.13
regime full ts	2025.5a	155	228.25	299.14
base	2025.1a	157	230.24	303.12


2025.1a: Base model
Exp. recruitment
Exp. recruitment after bias adj.
Estimated recruitments
Unfished equilibrium
Recruitment (1,000s)
Spawning output
2005
2009
2008
2006
2007
2024
2010
2012
2011


2025.2a: Early recdev model
Exp. recruitment
Exp. recruitment after bias adj.
Estimated recruitments
Unfished equilibrium
Recruitment (1,000s)
Spawning output
2005
2009
2008
2006
2007
2024
2010
2012
2011


2025.3a: Recent regime model
Exp. recruitment
Exp. recruitment after bias adj.
Estimated recruitments
Unfished equilibrium
Recruitment (1,000s)
Spawning output
2005
2009
2008
2006
2007
2010
2012
2011
0e+00
2e+05
4e+05
6e+05
8e+05
2e+06
4e+06
6e+06
8e+06
1e+07


2025.4a: Closure regime model
Exp. recruitment
Exp. recruitment after bias adj.
Estimated recruitments
Unfished equilibrium
Recruitment (1,000s)
Spawning output
2005
2009
2008
2006
2007
2010
2012
2011
0e+00
2e+05
4e+05
6e+05
8e+05
2e+06
4e+06
6e+06
8e+06
1e+07

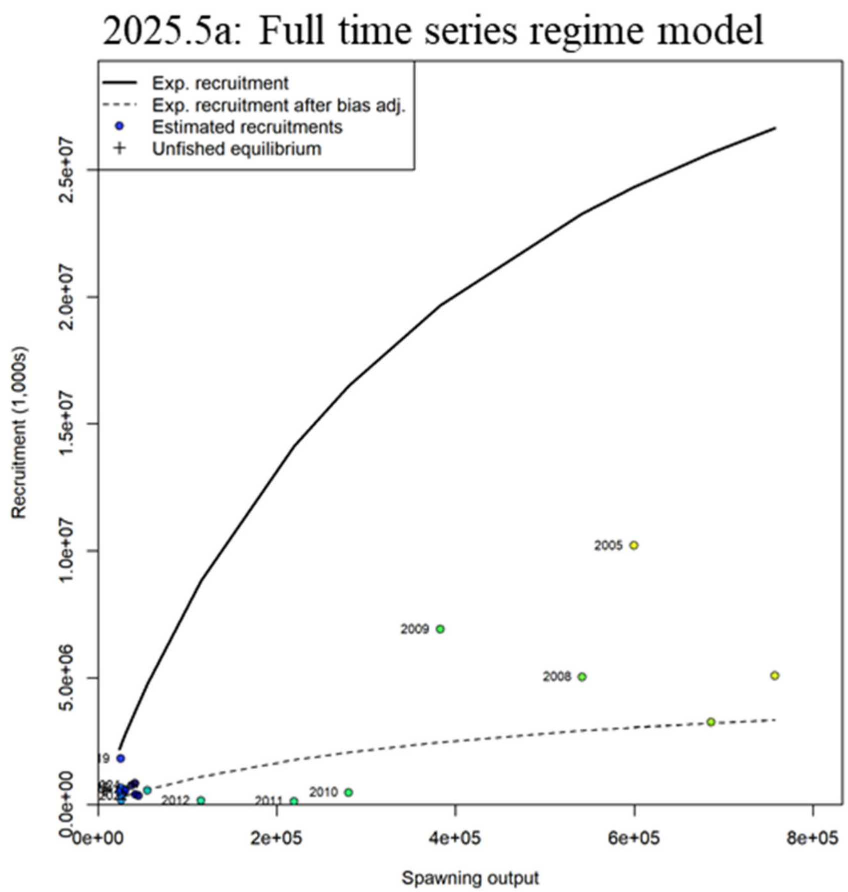


Figure A.1. Stock recruit curves for the base model (2025.1a) and the modeling-based alternative models (2025.2-5a). Each stock-recruit curve shows the mean expected recruitment (solid curve), expected recruitment after bias adjustment (dashed line), and annual stock-recruit data (labeled points).

Appendix B: Re-evaluation of the recruits-per-spawner and CalCOFI SST relationship in Pacific sardine

Authors: Caitlin Allen Akselrud, Alexander Jensen, and Kevin Hill

Background:

2013 workshop:

The 2013 Pacific sardine harvest parameters workshop selected a general additive model (GAM) to assess the relationship between the Pacific sardine recruits/spawner relationship and the smoothed (non-linear) average sea surface temperatures (SST) measured by the CalCOFI survey. This workshop used a time series of sardine age 2+ biomass (spawners) and recruits that were assembled from previous stock assessments, from 1984-2008 (Table 1; Hill et al., 2010). The results are reported in *PFMC and SWFSC (2013)*. In particular, 2013 Workshop Appendix Table E.6. includes the model results. In re-creating these models, we found the values reported as R-squared in the Appendix E.6. table are squared Pearson correlations and the reported deviance explained values are adjusted R-squared values. We have renamed those values in this report for consistency and clarity (Table B.2).

Data:

Biomass and recruitment time series:

This relationship was re-evaluated by updating the recruits/spawner and CalCOFI SST time series. Recruits/spawner data for 1984-2004 were appended with the most recent stock assessment estimates of age 2+ biomass and recruits from 2005-2023 (Kuriyama et al, 2024). The decision to supplant 2005-2008 workshop values of recruits/spawner data with more recent data produced by stock assessments is based on the rationale that the most recent stock assessment values represent the best available science.

It is worth noting that the recruits/spawner time series spans changes in stock assessment model structure, assumptions, and an update to the habitat model.

CalCOFI SST:

Values for the average annual CalCOFI SST reported in the workshop and published stock assessment reports also vary slightly. The time series of annual SST values in published stock assessments and previous SST calculations done in a consistent manner with those generated for stock assessment by SWFSC scientists were used in this re-analysis, replacing SST values from the 2013 workshop (*see* Table B.1).

Methods: 2024 model update

Model configurations:

1. Recruits/spawner time series:

    a. one time series patching together the 1984-2023 data
    b. one with only the most recent stock assessment data from 2005-2023.
2. Indicator: fitting to a log(recruits/spawner) relationship, which is consistent with the model chosen in the 2013 workshop.
3. GAM type:
    a. Configuration L models SST (Ty) as a linear covariate: $\alpha + s(Sy, k = 3) + \beta Ty + \varepsilon y$ where "α is an intercept parameter, s(x, k = 3) is a nonlinear smooth function of x, k controls smoothness by limiting the number of parameters in s(x, k = 3) , Sy is spawning biomass, β is a slope parameter, Ty is SST, and y ε is a normally distributed statistical error" (*PFMC and SWFSC*, 2013).
    b. Configuration G (consistent with the model chosen in the 2013 workshop) is the same as L, but includes a smoother on SST (non-linear covariate): $\alpha + s(Sy, k = 3) + s(\beta Ty, k=3) + \varepsilon y$.
    c. Configuration B is presented for comparison and does not include the SST covariate: $\alpha + s(Sy, k = 3) + \varepsilon y$.

Comparison of 2024 update results to 2013 workshop results:
In comparing the updated time series models to the previous workshop results, we find that the best fitting model is still the GAM with CalCOFI SST as a smoothed covariate (model G) using the extended time series (1984-2023) across metrics for AIC, adjusted-R^2, squared Pearson correlation (R^2), and deviance explained (Table B.2). While the adjusted R^2 in the best-fitting model has decreased to 0.44 from 0.74 with the addition of new data, it remains higher than the same time series with no covariate in the baseline model (B) at 0.11 (Table B.2). The squared Pearson correlation of the best-fitting model for the extended time series (0.49) is similarly lower than the previously estimated value of 0.76, but is still much higher than the squared correlation of 0.13 for the baseline extended time series model with no covariate. In addition, the likelihood ratio tests (LRT) show similar results to the 2013 workshop in rejecting the baseline (B) model in favor of one with temperature as a covariate and indicating that the smoothed covariate term provides improved fit relative to the linear term (Table B.3).

Additional discussion:
We agree with the workshop evaluation that fitting to the log(recruits/spawner) is a better choice than log(recruits) since log(recruits) will always be greater than 0 as long as temperature is greater than zero, irrespective of spawning abundance (Hurtado-Ferro and Punt, 2013). In addition, the smoothed GAM model fit to the extended time series now exhibits a dome-shaped response to SST, which is representative of a typical biological response to an optimal range of temperatures (e.g., Brewer, 1976; Figure B.1).

Table B.1. Data available for this reanalysis. Bolded data represents the data used in the full time series reanalysis, and bolded data after 2005 represents data used in the recent time series reanalysis.

Year	**BIOMASS (AGES 2+; 10^3 mt)**		**RECRUITS (AGE-0; millions)**		**Workshop Report**	**Annual SST from Stock Assessment Reports**	
	Hill et al. 2010	**Kuriyama et al. 2024**	**Hill et al. 2010**	**Kuriyama et al. 2024**	**SST_CC_ann**	**T_DegC**	**Source**
1984	**13**		**239**		15.99	**16.35**	E. Weber, *pers. comm.*
1985	**21**		**268**		15.67	**15.76**	E. Weber, *pers. comm.*
1986	**27**		**654**		15.73	**15.98**	E. Weber, *pers. comm.*
1987	**33**		**885**		16.19	**16.3**	E. Weber, *pers. comm.*
1988	**54**		**1270**		15.71	**15.79**	E. Weber, *pers. comm.*
1989	**84**		**1084**		15.65	**15.46**	E. Weber, *pers. comm.*
1990	**119**		**2261**		15.94	**15.99**	E. Weber, *pers. comm.*
1991	**134**		**5354**		15.71	**15.8**	E. Weber, *pers. comm.*
1992	**168**		**3910**		16.63	**16.7**	E. Weber, *pers. comm.*
1993	**250**		**10078**		16.33	**16.42**	E. Weber, *pers. comm.*
1994	**329**		**11130**		16.45	**16.48**	E. Weber, *pers. comm.*
1995	**562**		**4223**		15.79	**15.92**	E. Weber, *pers. comm.*
1996	**821**		**6252**		16.22	**16.33**	E. Weber, *pers. comm.*
1997	**820**		**17156**		16.8	**16.69**	E. Weber, *pers. comm.*
1998	**772**		**19743**		16.55	**16.77**	E. Weber, *pers. comm.*
1999	**1096**		**3624**		15.19	**15.28**	E. Weber, *pers. comm.*
2000	**1496**		**2928**		15.73	**15.79**	E. Weber, *pers. comm.*
2001	**1324**		**7959**		15.5	**15.55**	E. Weber, *pers. comm.*
2002	**1055**		**804**		14.91	**14.94**	E. Weber, *pers. comm.*
2003	**922**		**18578**		15.98	**16.03**	E. Weber, *pers. comm.*
2004	**670**		**9617**		15.78	**15.88**	E. Weber, *pers. comm.*
2005	967	**457**	10448	**26832**	15.36	**15.46**	E. Weber, *pers. comm.*
2006	1032	**582**	3277	**10311**	15.72	**15.92**	E. Weber, *pers. comm.*

2007	1071	**748**	3596	**5104**	15.06	**15.15**	E. Weber, *pers. comm.*
2008	848	**792**	2674	**3242**	15.13	**15.27**	E. Weber, *pers. comm.*
2009		**483**		**5072**		**15.36**	E. Weber, *pers. comm.*
2010		**313**		**6955**		**15.55**	E. Weber, *pers. comm.*
2011		**267**		**458**		**15.56**	E. Weber, *pers. comm.*
2012		**278**		**124**		**15.29**	E. Weber, *pers. comm.*
2013		**147**		**156**		**14.91**	E. Weber, *pers. comm.*
2014		**64**		**558**		**16.77**	Hill et al. 2014
2015		**32**		**608**		**17.47**	Hill et al. 2015
2016		**35**		**197**		**16.33**	Hill et al. 2016
2017		**39**		**349**		**16.12**	Hill et al. 2017
2018		**40**		**677**		**15.89**	Hill et al. 2018
2019		**28**		**548**		**15.98**	Hill et al. 2019
2020		**31**		**1589**		**16.41**	Kuriyama et al. 2020
2021		**52**		**559**		**15.48**	Kuriyama et al. 2021
2022		**42**		**571**		**15.69**	Kuriyama et al. 2022
2023		**41**		**728**		**15.62**	Kuriyama et al. 2024

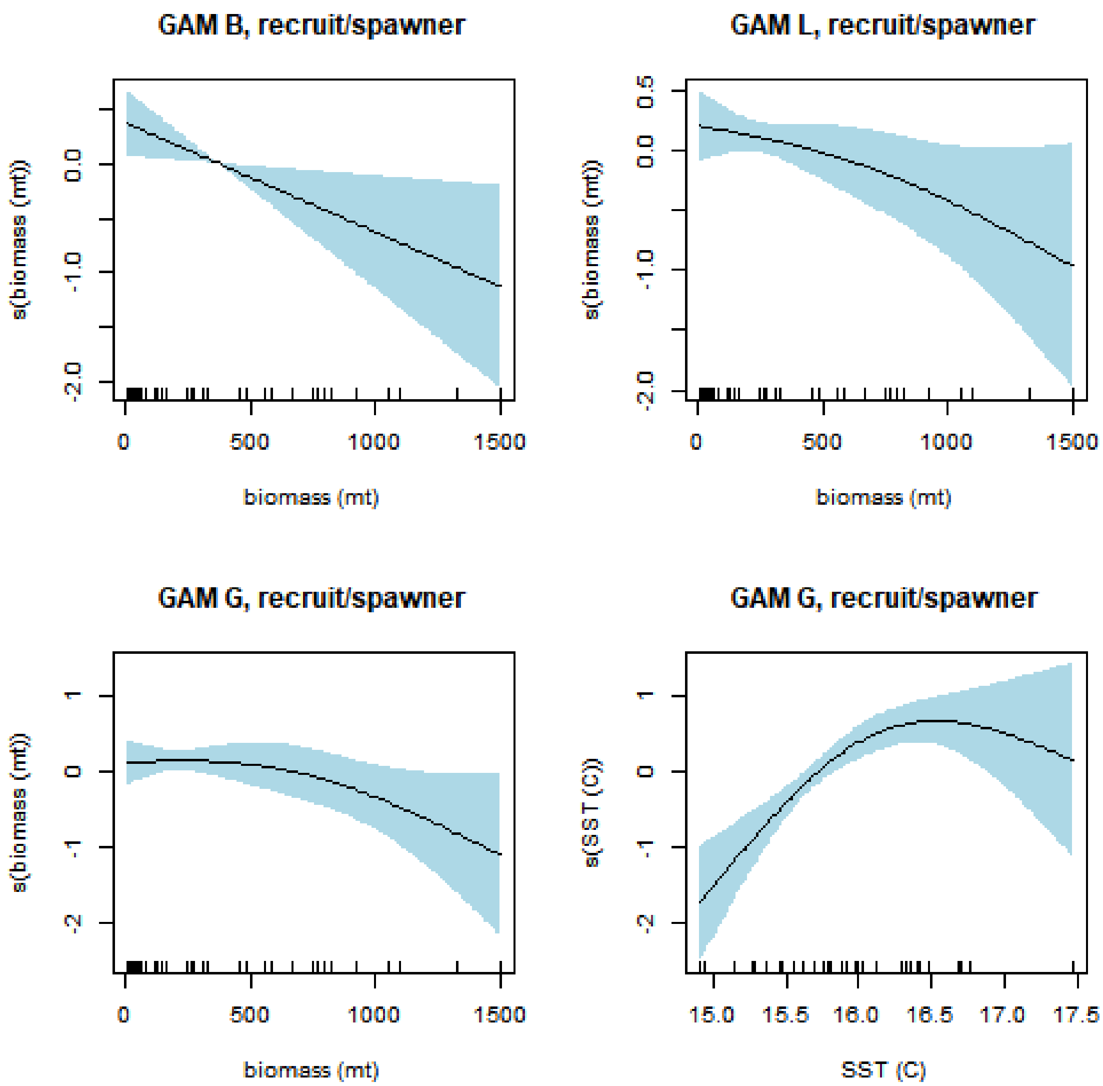
Table B.2. Output of the updated model results, with the 2013 workshop model results included in the bottom two rows of the table for comparison. [1]The workshop reported deviance explained values that are actually adjusted R-squared values, and [2]the workshop values reported as R-squared in the Appendix E.6. table are squared Pearson correlations; both have been renamed for consistency and comparability with our analysis.

Time series	GAM type	GAM	N	Resid. DF	EDF of SST	AIC	R^2 adjusted	Squared Pearson corr. (R^2)
1984-2023	B	no SST covariate	40	38.00	0.00	122.23	0.11	0.13
1984-2023	**G**	**smooth SST covariate**	**40**	**35.50**	**1.89**	**106.04**	**0.44**	**0.49**
1984-2023	L	linear SST covariate	40	36.69	0.00	112.66	0.32	0.36
2005-2023	B	no SST covariate	19	17.00	0.00	66.49	-0.04	0.02
2005-2023	G	smooth SST covariate	19	15.33	1.67	63.42	0.18	0.30
2005-2023	L	linear SST covariate	19	16.00	0.00	65.18	0.07	0.17
1984-2008	**G**	**smooth SST covariate**	**25**	**21.73**	**1.27**	**44.49**	**0.74**[1]	**0.76**[2]
1984-2008	L	linear SST covariate	25	22.00	0.00	44.68	0.73[1]	0.76[2]

Table B.3. Results of likelihood ratio tests between the different model configurations.

Model	Time series	pBG	pBL	pGL
Full timeseries	1984-2023	0	0.0007	0.0046
Short timeseries	2005-2023	0.0414	0.0806	0.0855
2013 workshop	1984-2008	0	0	0.12

A.



GAM B, recruit/spawner
s(biomass (mt))
0.0
-1.0
-2.0
0
500
1000
1500
biomass (mt)
GAM L, recruit/spawner
s(biomass (mt))
0.5
0.0
-1.0
-2.0
0
500
1000
1500
biomass (mt)
GAM G, recruit/spawner
s(biomass (mt))
1
0
-1
-2
0
500
1000
1500
biomass (mt)
GAM G, recruit/spawner
s(SST (C))
1
0
-1
-2
15.0
15.5
16.0
16.5
17.0
17.5
SST (C)

B.

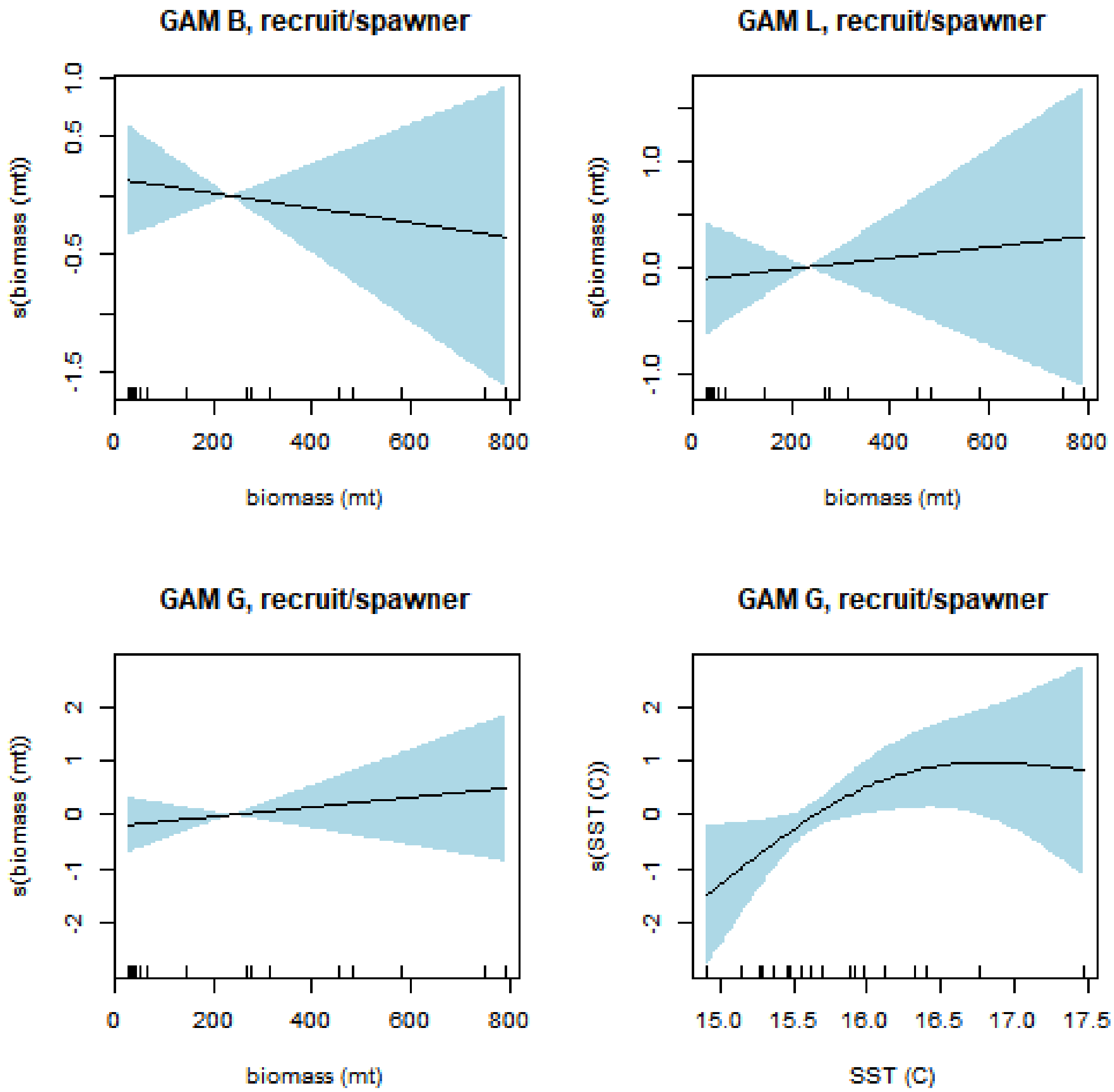


Figure B.1. Plots of GAM results for each smoothed term (s(biomass (mt)) for biomass or s(SST (C)) for temperature). The top figure (A) shows GAM results using the extended time series (1984-2023), and the bottom figure (B) shows GAM results using only the current assessment time series (2005-2023).

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Appendix C. Additional model validation and diagnostic tables and figures.

Authors: Caitlin I. Allen Akselrud, Alexander Jensen, Peter T. Kuriyama, and Kevin T. Hill

Weight-at-age model reporting and diagnostics.

Table C.1: MexCal S1 conditional weight-at-age model results.

Model	Parameter	Parameter estimate	St dev	AIC	dAIC	Pos-def Hessian
None	rho_a			-16.06	-41.1	TRUE
None	rho_c			-16.06	-41.1	TRUE
None	rho_y			-16.06	-41.1	TRUE
None	log_sigma2	0.04	0.16	-16.06	-41.1	TRUE
a	rho_a	0.2	0.14	-15.95	-41.21	TRUE
a	rho_c			-15.95	-41.21	TRUE
a	rho_y			-15.95	-41.21	TRUE
a	log_sigma2	0.04	0.16	-15.95	-41.21	TRUE
c	rho_a			-22.77	-34.39	TRUE
c	rho_c	0.43	0.13	-22.77	-34.39	TRUE
c	rho_y			-22.77	-34.39	TRUE
c	log_sigma2	0.04	0.16	-22.77	-34.39	TRUE
a_c	rho_a	0.02	0.15	-20.78	-36.38	TRUE
a_c	rho_c	0.42	0.15	-20.78	-36.38	TRUE
a_c	rho_y			-20.78	-36.38	TRUE
a_c	log_sigma2	0.04	0.16	-20.78	-36.38	TRUE
y	rho_a			-49.96	-7.2	TRUE
y	rho_c			-49.96	-7.2	TRUE
y	rho_y	0.71	0.1	-49.96	-7.2	TRUE
y	log_sigma2	0.03	0.16	-49.96	-7.2	TRUE
y_a	rho_a	0.23	0.09	-52.77	-4.39	TRUE
y_a	rho_c			-52.77	-4.39	TRUE
y_a	rho_y	0.71	0.1	-52.77	-4.39	TRUE
y_a	log_sigma2	0.03	0.16	-52.77	-4.39	TRUE
y_c	**rho_a**			**-57.16**	**0**	**TRUE**
y_c	**rho_c**	**0.32**	**0.1**	**-57.16**	**0**	**TRUE**
y_c	**rho_y**	**0.65**	**0.1**	**-57.16**	**0**	**TRUE**
y_c	**log_sigma2**	**0.02**	**0.16**	**-57.16**	**0**	**TRUE**
y_a_c	rho_a	0.04	0.12	-55.25	-1.92	TRUE
y_a_c	rho_c	0.3	0.14	-55.25	-1.92	TRUE
y_a_c	rho_y	0.65	0.1	-55.25	-1.92	TRUE
y_a_c	log_sigma2	0.02	0.16	-55.25	-1.92	TRUE

Table C.2: MexCal S2 conditional weight-at-age model results.

Model	Parameter	Parameter estimate	St dev	AIC	dAIC	Pos-def Hessian
None	rho_a			-16.06	-41.1	TRUE
None	rho_c			-16.06	-41.1	TRUE
None	rho_y			-16.06	-41.1	TRUE
None	log_sigma2	0.04	0.16	-16.06	-41.1	TRUE
a	rho_a	0.2	0.14	-15.95	-41.21	TRUE
a	rho_c			-15.95	-41.21	TRUE
a	rho_y			-15.95	-41.21	TRUE
a	log_sigma2	0.04	0.16	-15.95	-41.21	TRUE
c	rho_a			-22.77	-34.39	TRUE
c	rho_c	0.43	0.13	-22.77	-34.39	TRUE
c	rho_y			-22.77	-34.39	TRUE
c	log_sigma2	0.04	0.16	-22.77	-34.39	TRUE
a_c	rho_a	0.02	0.15	-20.78	-36.38	TRUE
a_c	rho_c	0.42	0.15	-20.78	-36.38	TRUE
a_c	rho_y			-20.78	-36.38	TRUE
a_c	log_sigma2	0.04	0.16	-20.78	-36.38	TRUE
y	rho_a			-49.96	-7.2	TRUE
y	rho_c			-49.96	-7.2	TRUE
y	rho_y	0.71	0.1	-49.96	-7.2	TRUE
y	log_sigma2	0.03	0.16	-49.96	-7.2	TRUE
y_a	rho_a	0.23	0.09	-52.77	-4.39	TRUE
y_a	rho_c			-52.77	-4.39	TRUE
y_a	rho_y	0.71	0.1	-52.77	-4.39	TRUE
y_a	log_sigma2	0.03	0.16	-52.77	-4.39	TRUE
y_c	**rho_a**			**-57.16**	**0**	**TRUE**
y_c	**rho_c**	**0.32**	**0.1**	**-57.16**	**0**	**TRUE**
y_c	**rho_y**	**0.65**	**0.1**	**-57.16**	**0**	**TRUE**
y_c	**log_sigma2**	**0.02**	**0.16**	**-57.16**	**0**	**TRUE**
y_a_c	rho_a	0.04	0.12	-55.25	-1.92	TRUE
y_a_c	rho_c	0.3	0.14	-55.25	-1.92	TRUE
y_a_c	rho_y	0.65	0.1	-55.25	-1.92	TRUE
y_a_c	log_sigma2	0.02	0.16	-55.25	-1.92	TRUE

Table C.3: PNW conditional weight-at-age model results.

Model	Parameter	Parameter estimate	St dev	AIC	dAIC	Pos-def Hessian
None	rho_a			-35.5	-86.23	TRUE
None	rho_c			-35.5	-86.23	TRUE
None	rho_y			-35.5	-86.23	TRUE
None	log_sigma2	0.03	0.15	-35.5	-86.23	TRUE
a	rho_a	0.67	0.11	-63.98	-57.75	TRUE
a	rho_c			-63.98	-57.75	TRUE
a	rho_y			-63.98	-57.75	TRUE
a	log_sigma2	0.02	0.15	-63.98	-57.75	TRUE
c	rho_a			-47.28	-74.46	FALSE
c	rho_c	0.88	0.08	-47.28	-74.46	FALSE
c	rho_y			-47.28	-74.46	FALSE
c	log_sigma2	0.02	0.16	-47.28	-74.46	FALSE
a_c	rho_a	0.19	0.14	-86.76	-34.97	TRUE
a_c	rho_c	0.66	0.12	-86.76	-34.97	TRUE
a_c	rho_y			-86.76	-34.97	TRUE
a_c	log_sigma2	0.02	0.15	-86.76	-34.97	TRUE
y	rho_a			-111.17	-10.56	TRUE
y	rho_c			-111.17	-10.56	TRUE
y	rho_y	0.83	0.07	-111.17	-10.56	TRUE
y	log_sigma2	0.01	0.16	-111.17	-10.56	TRUE
y_a	**rho_a**	**0.28**	**0.08**	**-121.74**	**0**	**TRUE**
y_a	**rho_c**			**-121.74**	**0**	**TRUE**
y_a	**rho_y**	**0.7**	**0.07**	**-121.74**	**0**	**TRUE**
y_a	**log_sigma2**	**0.01**	**0.16**	**-121.74**	**0**	**TRUE**
y_c	rho_a			-121.42	-0.32	TRUE
y_c	rho_c	0.33	0.1	-121.42	-0.32	TRUE
y_c	rho_y	0.63	0.09	-121.42	-0.32	TRUE
y_c	log_sigma2	0.01	0.16	-121.42	-0.32	TRUE
y_a_c	rho_a	0.16	0.12	-121.27	-0.47	TRUE
y_a_c	rho_c	0.18	0.15	-121.27	-0.47	TRUE
y_a_c	rho_y	0.64	0.09	-121.27	-0.47	TRUE
y_a_c	log_sigma2	0.01	0.16	-121.27	-0.47	TRUE

Table C.4: Comparison of the new weight-at-age values for each fishery fleet with the 2024 benchmark (A: MexCal S1 fleet; B: MexCal S2 fleet; C: PNW fleet). The numbers represent the difference between the update base model configuration and 2024 benchmark configuration (update - benchmark).

MexCal S1 Fleet

A	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
2005	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0137	0.0185	0.0223	0.0269	0.0324
2006	0.0000	0.0000	0.0000	0.0000	0.0061	0.0061	-0.0024	0.0091	0.0192	0.0266	0.0330
2007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0086	0.0087	0.0054	0.0121	0.0218	0.0307
2008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0157	0.0210	0.0205	0.0179	0.0209	0.0280
2009	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0119	0.0026	0.0166	0.0233	0.0256	0.0292
2010	0.0000	0.0000	0.0000	0.0000	-0.0052	0.0046	-0.0011	0.0071	0.0183	0.0268	0.0321
2011	0.0041	0.0000	0.0000	0.0000	0.0000	-0.0014	0.0019	0.0063	0.0133	0.0228	0.0315
2012	-0.0047	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0060	0.0123	0.0196	0.0283
2013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0109	0.0165	0.0218	0.0282
2014	0.0000	0.0106	0.0439	0.0000	0.0000	0.0000	0.0000	0.0000	0.0104	0.0201	0.0280
2015	-0.0029	-0.0109	0.0019	0.0326	0.0536	0.0587	0.0340	0.0139	0.0045	0.0068	0.0139
2016	-0.0028	-0.0048	-0.0039	0.0083	0.0258	0.0398	0.0448	0.0374	0.0260	0.0188	0.0192
2017	-0.0030	-0.0054	-0.0046	0.0007	0.0108	0.0225	0.0319	0.0388	0.0385	0.0339	0.0302
2018	-0.0036	-0.0064	-0.0084	-0.0048	0.0035	0.0127	0.0214	0.0294	0.0365	0.0398	0.0398
2019	-0.0047	-0.0074	-0.0123	-0.0124	-0.0041	0.0054	0.0144	0.0224	0.0299	0.0369	0.0420
2020	-0.0070	-0.0081	-0.0166	-0.0218	-0.0138	-0.0035	0.0070	0.0165	0.0248	0.0322	0.0393
2021	0.0000	0.0000	0.0000	0.0000	-0.0391	-0.0467	-0.0298	-0.0024	0.0127	0.0281	0.0405
2022	-0.0027	-0.0048	-0.0137	-0.0256	-0.0258	-0.0199	-0.0102	0.0010	0.0122	0.0226	0.0322
2023	0.0000	0.0000	0.0000	0.0000	0.0073	-0.0143	-0.0275	-0.0229	-0.0054	0.0102	0.0255
2024	0.0031	0.0049	0.0010	-0.0077	-0.0133	-0.0148	-0.0119	-0.0054	0.0035	0.0136	0.0238
2025	0.0006	0.0027	0.0025	-0.0015	-0.0060	-0.0085	-0.0079	-0.0040	0.0029	0.0116	0.0212

MexCal S2 Fleet

B	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
2005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0019	-0.0032
2006	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0011	0.0003	0.0028	0.0018	-0.0010	-0.0029
2007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0002	0.0004	0.0022	0.0029	0.0015
2008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0011	0.0003	0.0000	0.0001	0.0012	0.0022
2009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0021	0.0027	0.0025	0.0023	0.0024
2010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0012	0.0022	0.0027
2011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005
2012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0016	-0.0013	-0.0020	-0.0035	-0.0039
2013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0008	-0.0024
2014	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0032	0.0062	0.0050	0.0043	0.0032
2015	0.0004	-0.0030	-0.0012	0.0057	0.0258	0.0466	0.0560	0.0589	0.0583	0.0512	0.0418
2016	0.0004	-0.0002	-0.0019	-0.0027	-0.0014	0.0064	0.0188	0.0304	0.0394	0.0454	0.0471
2017	0.0003	-0.0002	-0.0009	-0.0020	-0.0030	-0.0036	-0.0014	0.0041	0.0117	0.0198	0.0272
2018	-0.0001	-0.0010	-0.0016	-0.0023	-0.0030	-0.0038	-0.0045	-0.0043	-0.0023	0.0014	0.0066
2019	0.0001	-0.0025	-0.0046	-0.0050	-0.0052	-0.0054	-0.0057	-0.0059	-0.0060	-0.0054	-0.0037
2020	0.0000	0.0000	0.0000	0.0000	-0.0102	-0.0231	-0.0300	-0.0334	-0.0350	-0.0332	-0.0300
2021	-0.0047	-0.0148	-0.0165	-0.0183	-0.0207	-0.0214	-0.0209	-0.0196	-0.0179	-0.0161	-0.0142
2022	0.0000	0.0000	0.0000	-0.0053	-0.0074	-0.0123	-0.0193	-0.0260	-0.0311	-0.0343	-0.0352
2023	0.0132	0.0131	0.0108	-0.0153	-0.0375	-0.0434	-0.0462	-0.0466	-0.0452	-0.0426	-0.0393
2024	0.0004	0.0054	0.0096	0.0116	0.0016	-0.0154	-0.0285	-0.0376	-0.0432	-0.0459	-0.0464
2025	0.0004	-0.0002	0.0015	0.0044	0.0074	0.0057	-0.0022	-0.0127	-0.0229	-0.0314	-0.0377

PNW Fleet

C	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
2005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2017	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2021	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2024	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Base model diagnostic figures

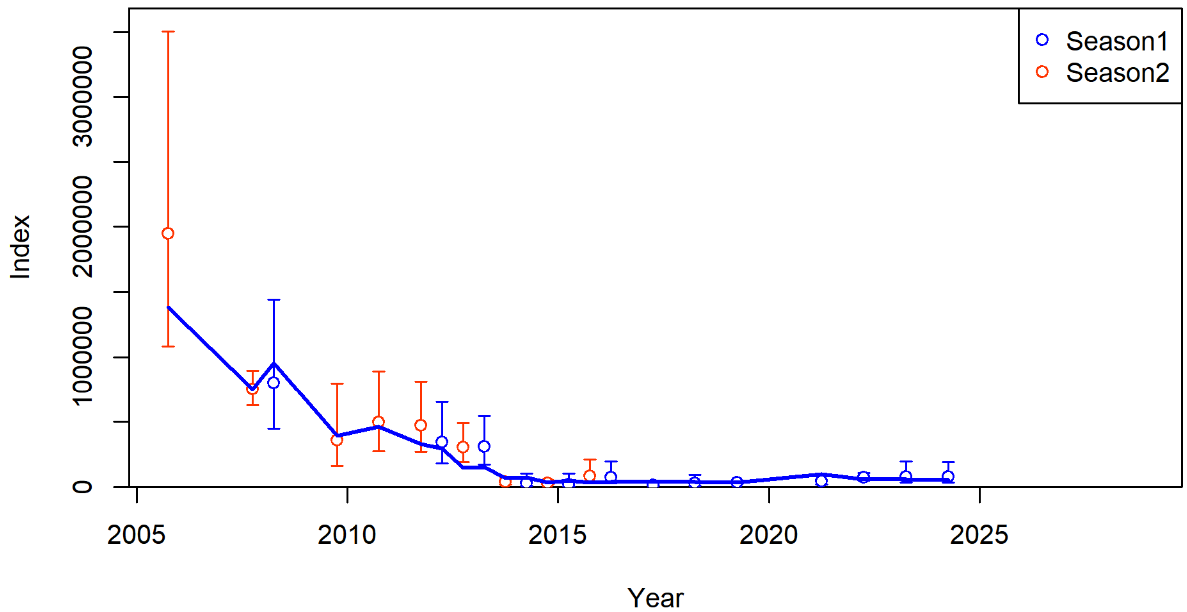

Figure C.1. Fit to index data for the AT Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

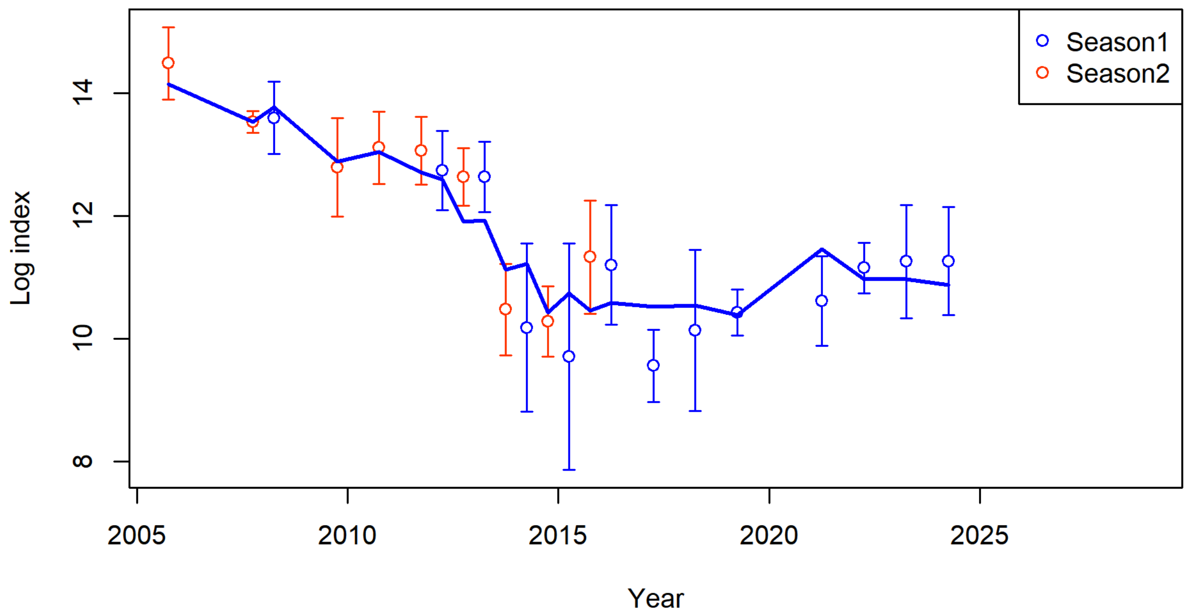

Figure C.2. Fit to log index data on log scale for AT Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

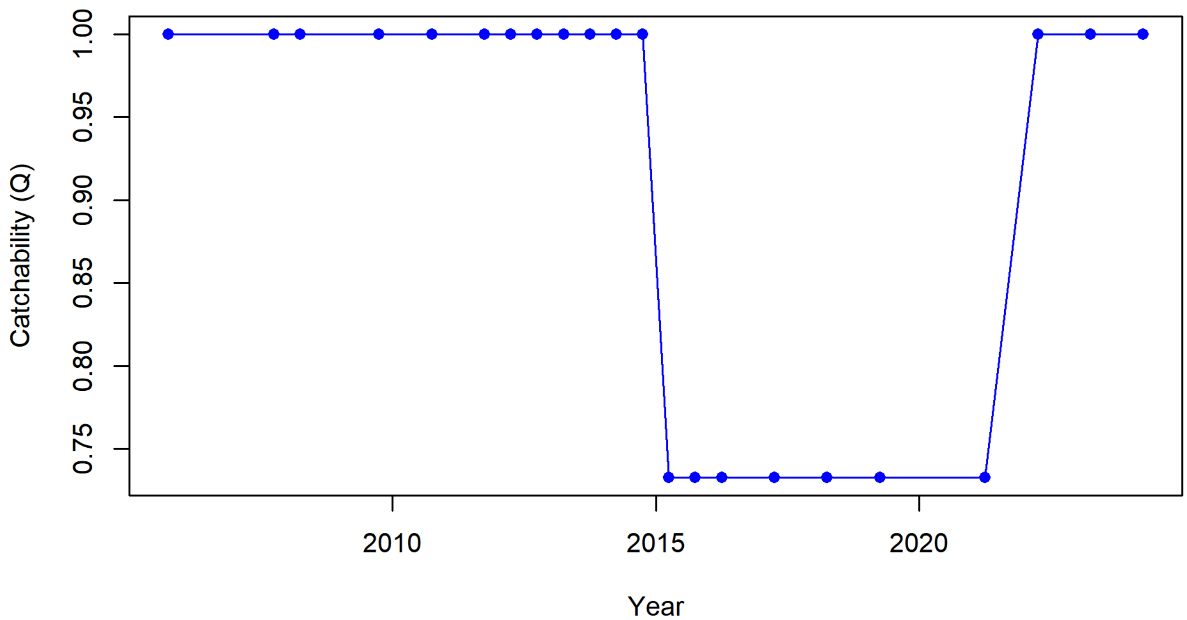

Figure C.3. Catchability (Q) values input to the assessment. Between 2015-2021, these values were calculated as a ratio of the AT survey observations and the aerial survey observations.

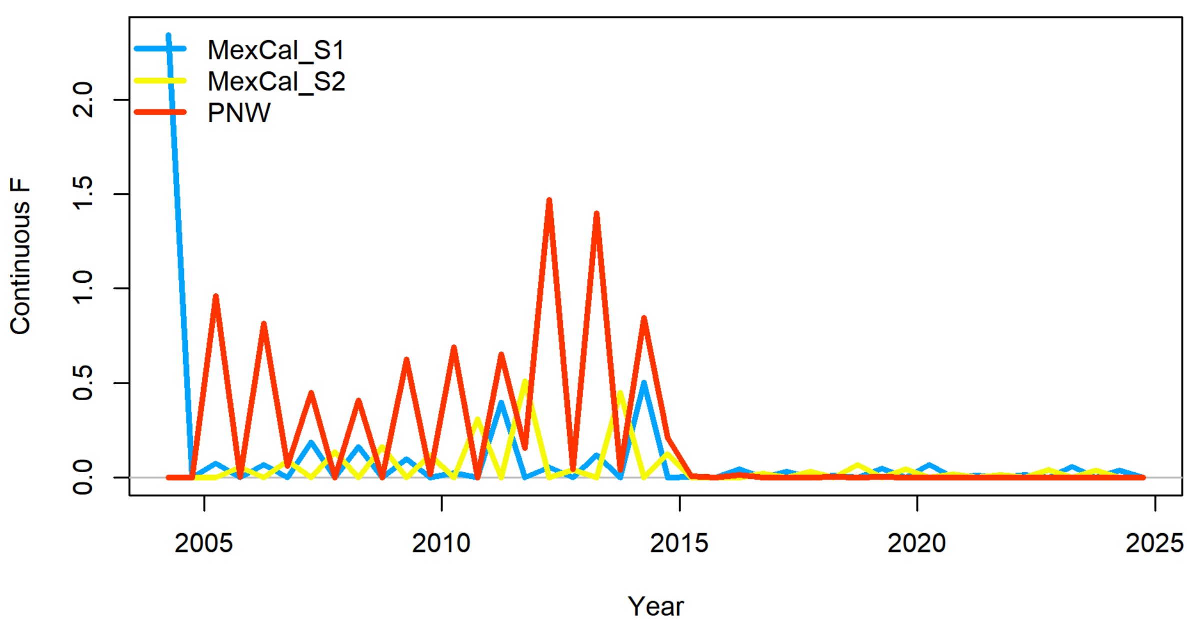

Figure C.4. Instantaneous fishing mortality time series for each fishery fleet.

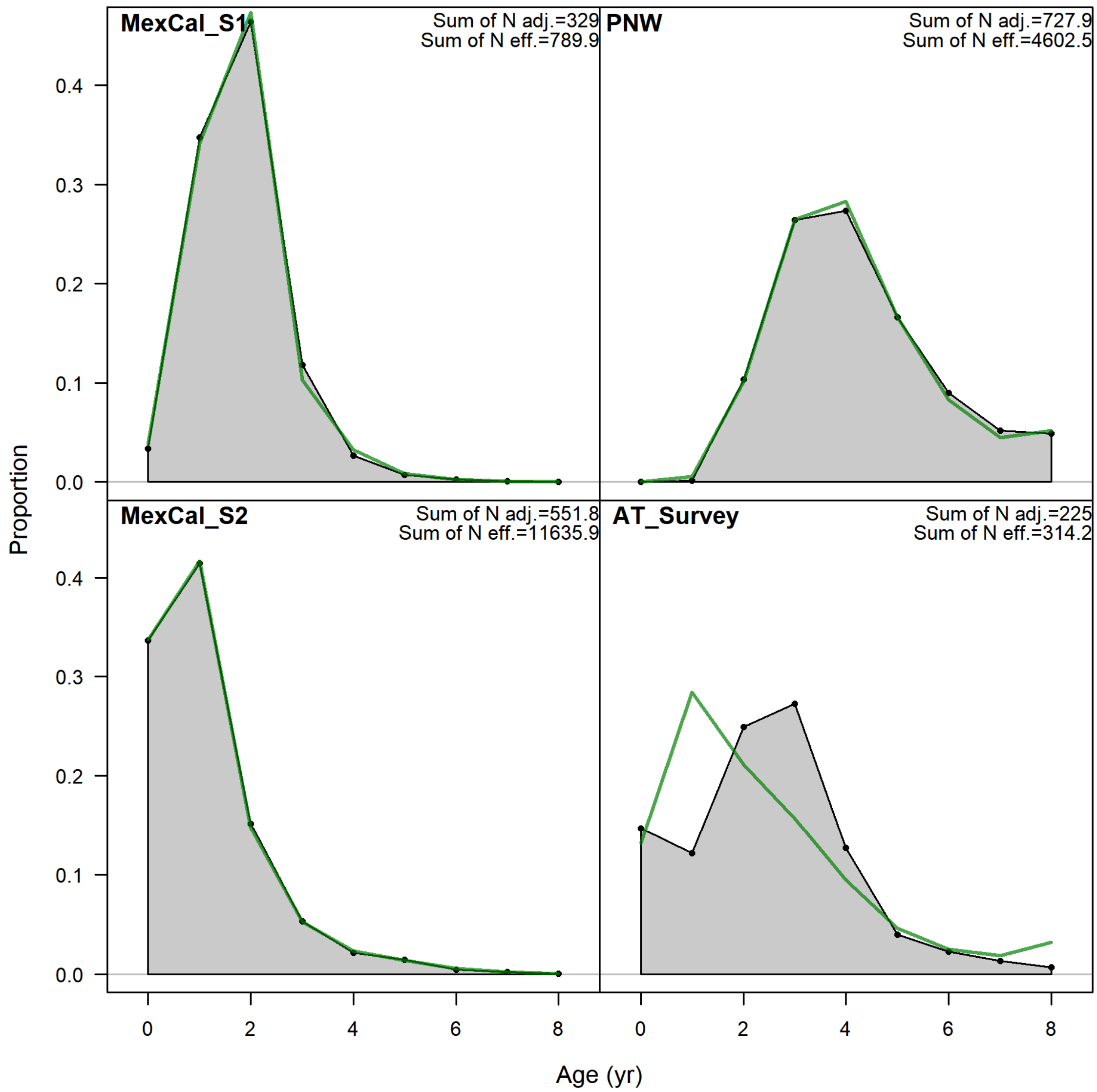

Figure C.5. Base model fits to the age composition data, aggregated across time by fleet.

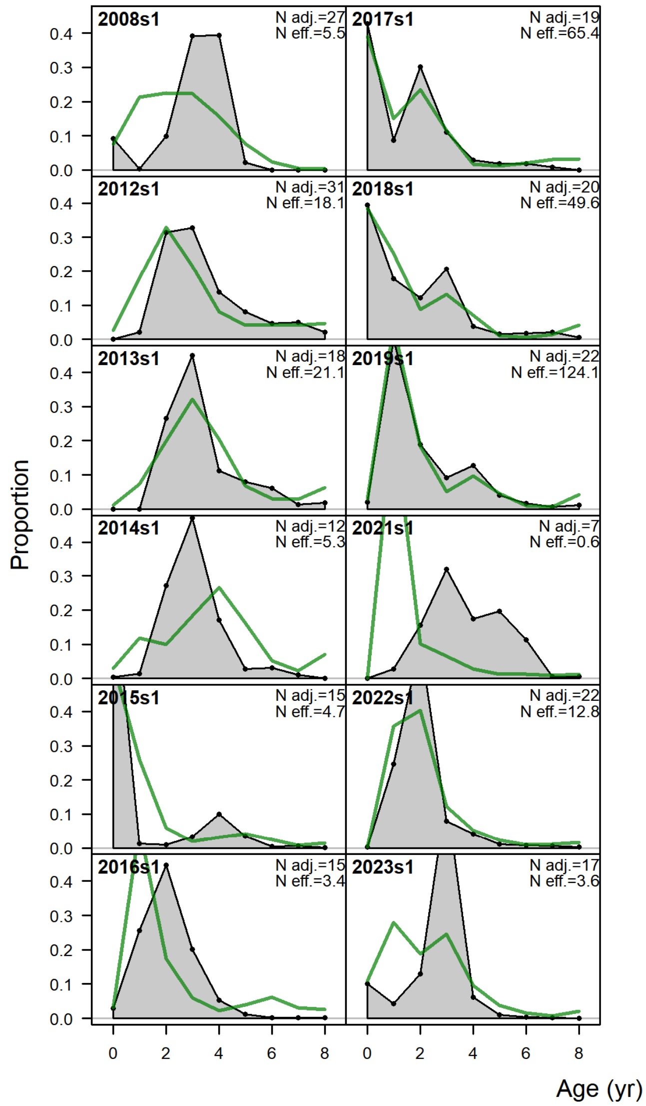

Figure C.6. Fits to the AT survey age compositions by year.

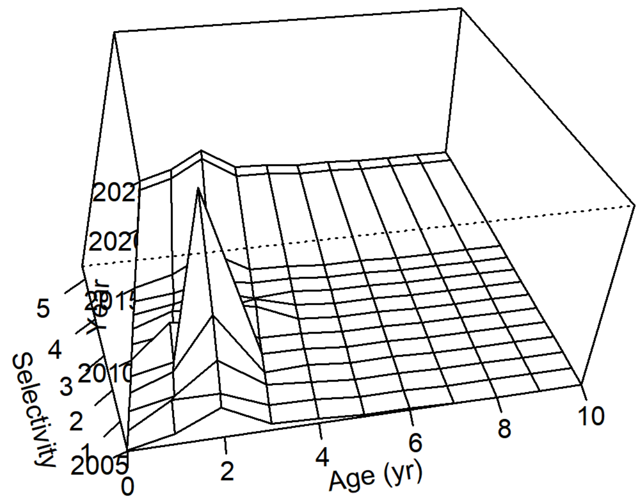

Figure C.7. Time-varying age-based selectivity patterns for the MexCal S1 fishery.

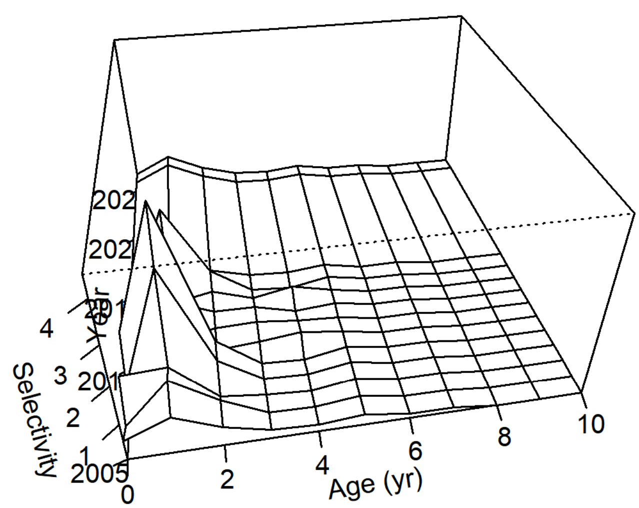

Figure C.8. Time-varying age-based selectivity patterns for the MexCal S2 fishery.

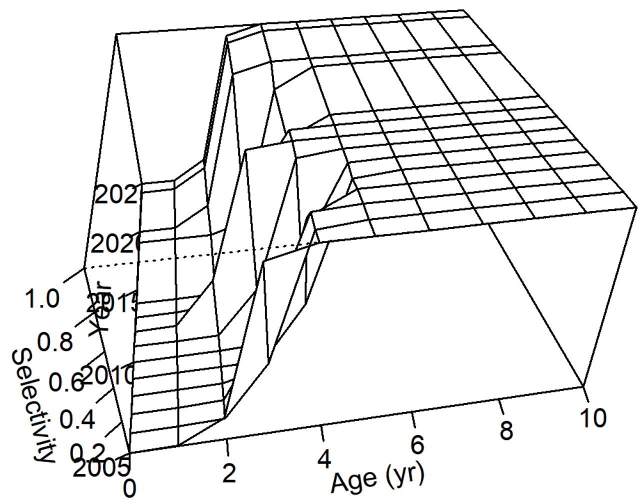

Figure C.9. Time-varying age-based selectivity patterns for the PNW fishery.

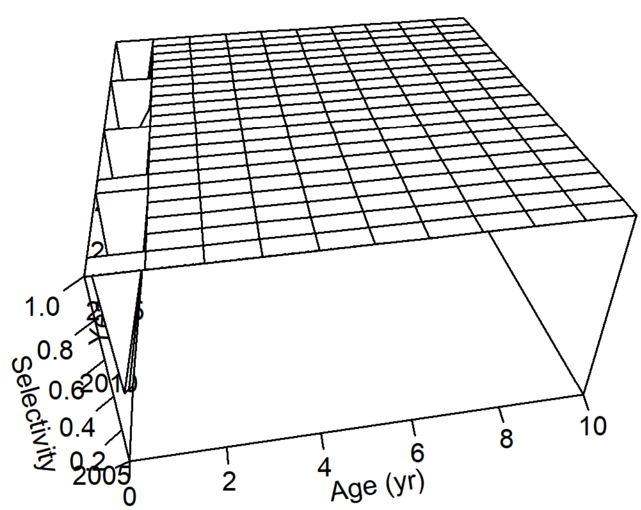

Figure C.10. Time-varying age-based selectivity patterns for the combined AT survey and nearshore survey.