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UPDATE ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2022 FOR U.S. MANAGEMENT IN 2022-2023

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Introduction

The Pacific sardine northern subpopulation (NSP) resource is assessed annually in support of the Pacific Fishery Management Council's (PFMC) process of specifying annual catch levels for the U.S. fishery. The following update assessment was conducted to provide a biomass estimate for harvest specifications during the 2022-2023 fishing year. This model contains updated data through model year-semester 2021-1 (July-December of calendar year 2021). Similar to the 2021 catch-only projection, catches from Ensenada, Mexico remained high. Additionally, observations from the acoustic-trawl survey indicated continued low biomass levels.

Methods

The following update assessment for 2022 management is based on data and methods described by Kuriyama et al. (2020), as reviewed by a Stock Assessment Review Panel in February 2020 and the Scientific and Statistical Committee in April 2020. The assessment update was conducted using Stock Synthesis (SS v.3.30.14).

The projection model included sardine NSP landings (metric tons) from six major fishing regions: Ensenada, Mexico (ENS), southern California (SCA), central California (CCA), Oregon (OR), Washington (WA), and British Columbia, Canada (BC). Catch data for the fisheries off ENS, SCA, and CCA were pooled into a single "MexCal" fleet, and catch data from OR, WA, and BC were combined and treated as a single "PacNW" fleet in the model. The sardine model is based on a July-June model year, with two semester-based seasons per year (S1-July to December and S2-January to June).

The 2020 benchmark assessment used *F* values (yr^{-1}; as opposed to catch) to forecast for 2021. This update assessment used this approach and used similar assumptions to forecast for 2022. The updated data values are shown in the following section.

Data

Catch values were updated through model year-semester 2021-1 (Tables 1a and 1b). The model year-semester 2020-2 catch value of 48,312 mt was assumed to be constant for 2021-2, consistent with the assumptions made in the 2020 base model.

Table 1a: Pacific sardine landings (mt) for major fishing regions off northern Ensenada, Mexico, the United States, and British Columbia, Canada. Ensenada (ENS) and Southern California (SCA) landings are presented as totals and northern subpopulation values. Time periods shown are calendar year-semester and model year-semester.

Calendar Y-S	Model Y-S	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2015-1	2014-2	16,496.60	-	1,543.20	-	727.70	2,131.30	62.60	-
2015-2	2015-1	20,971.90	-	1,420.90	-	6.10	0.10	66.10	-
2016-1	2015-2	23,536.70	-	423.40	184.80	1.10	1.30	-	-
2016-2	2016-1	42,532.10	-	964.50	49.40	234.10	2.70	170.40	-
2017-1	2016-2	28,211.90	6,935.80	513.10	144.70	0.10	0.10	-	-
2017-2	2017-1	99,966.60	-	1,205.40	-	170.40	1.20	-	-
2018-1	2017-2	25,720.60	9,736.30	395.30	197.80	-	2.20	-	-
2018-2	2018-1	38,049.30	-	1,424.20	-	35.30	5.80	2.00	-
2019-1	2018-2	30,118.90	11,634.30	749.70	546.80	58.10	2.50	-	-
2019-2	2019-1	64,295.20	-	869.50	49.30	174.30	7.70	0.50	-
2020-1	2019-2	74,817.30	29,555.30	681.40	144.20	328.50	0.10	-	-
2020-2	2020-1	74,686.80	-	1,203.70	113.50	428.80	0.40	-	-
2021-1	2020-2	56,274.10	48,005.40	601.70	269.60	37.30	2.90	-	-
2021-2	2021-1	86,643.20	-	1,093.00	89.90	2.90	8.60	2.70	-

Table 1b: Finalized catch values for fleet by model year-semester (bolded columns). Preliminary values used in the 2021 catch-only projection are adjacent to the bolded columns. The values in bolded columns show up-to-date values used in the 2022 update assessment. Catch is assumed to be the same for model year-semester 2021-2 for the MexCal S2 fleet.

Calendar Y-S	Model Y-S	MexCal_S1	**MexCal_S1**	MexCal_S2	**MexCal_S2**	PNW	**PNW**
2019-2	2019-1	223.61	**223.61**	0	**0**	8.20	**8.198**
2020-1	2019-2	0	**0**	33,070.23	**33,070.23**	0.06	**0.06**
2020-2	2020-1	764.00	**542.27**	0	**0**	0.42	**0.42**
2021-1	2020-2	--	**0**	--	**48,312.25**	--	**2.93**
2021-2	2021-1	--	**92.84**	--	**0**	--	**11.22**
2022-1	2021-2	--	**0**	--	**48,312.25**	--	**2.93**

New age compositions from fisheries in California and the summer 2021 AT survey were included (Fig. 1). Compositions from 2020-2 were associated with the MexCal_S2 fleet, and 2021-1 with the MexCal_S1 fleet, and were sampled under exempted fishing permits. Input sample sizes were 6.8 and 1, respectively corresponding to 170 individual fish and 25 individual fish. For sampling in 2021-1, the 25 fish were attributed to northern subpopulation fish, and the rest of the samples were attributed to the southern subpopulation and not used in this update assessment. Sample sizes for the AT survey correspond to the number of positive clusters in the survey grid.

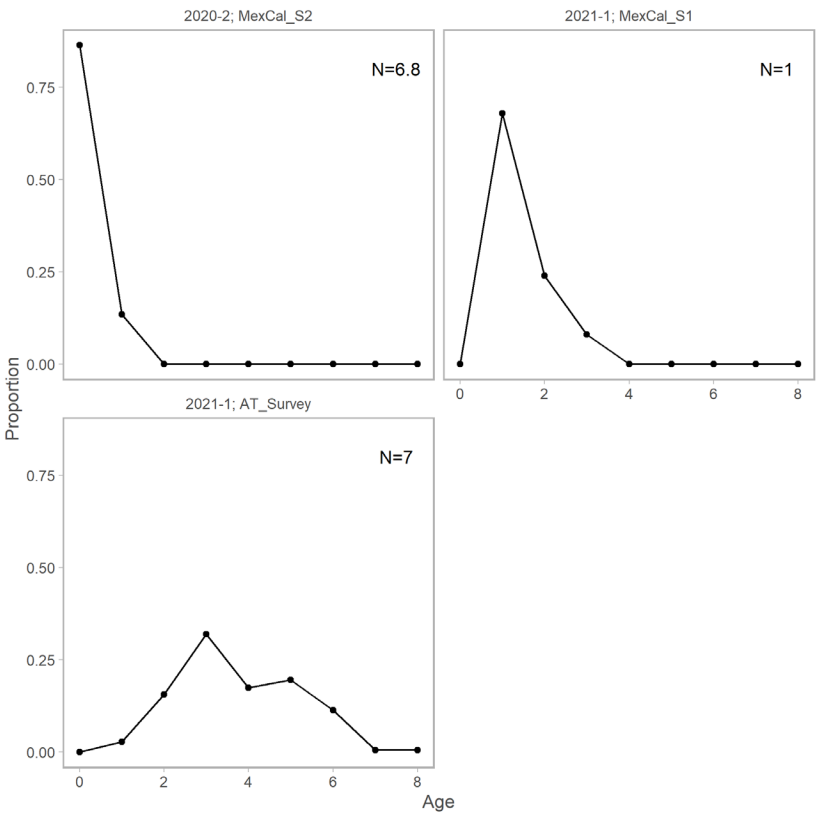

Figure 1: Age compositions for two fishing fleets and the AT survey and the model year-semesters. Input sample sizes are shown in the top right. For the fisheries, one sample corresponds to 25 individual fish, and data from the survey are weighted by the number of positive clusters in that particular survey.

Revised 2016 AT survey age readings were also included in this update assessment (new AT survey age composition for model Y-S 2016-1). The age composition for 2016-1 used in the 2020 benchmark did not seem to capture patterns of recruitment and year-class strengths observed in previous years. At the time, survey otolith samples were read by only one reader (Reader 12), and the bias associated with the readings could not be evaluated due to lack of double readings. As a result, in 2021 the SWFSC and CDFW conducted double age readings for 274 otoliths previously aged by the reader in 2016 spring and 2016 summer surveys (although only ages from the 2016 summer survey were included in this update assessment). Based on double age reading comparisons (Fig. 2), only the new reads from reader 17 were used in this update assessment. Note that Fig. 2 shows the unweighted age composition which differs from the weighted age compositions used in the assessment (Fig. 3). Additionally, ageing error vectors for the re-aged otoliths and new otoliths are shown in Fig. 4.

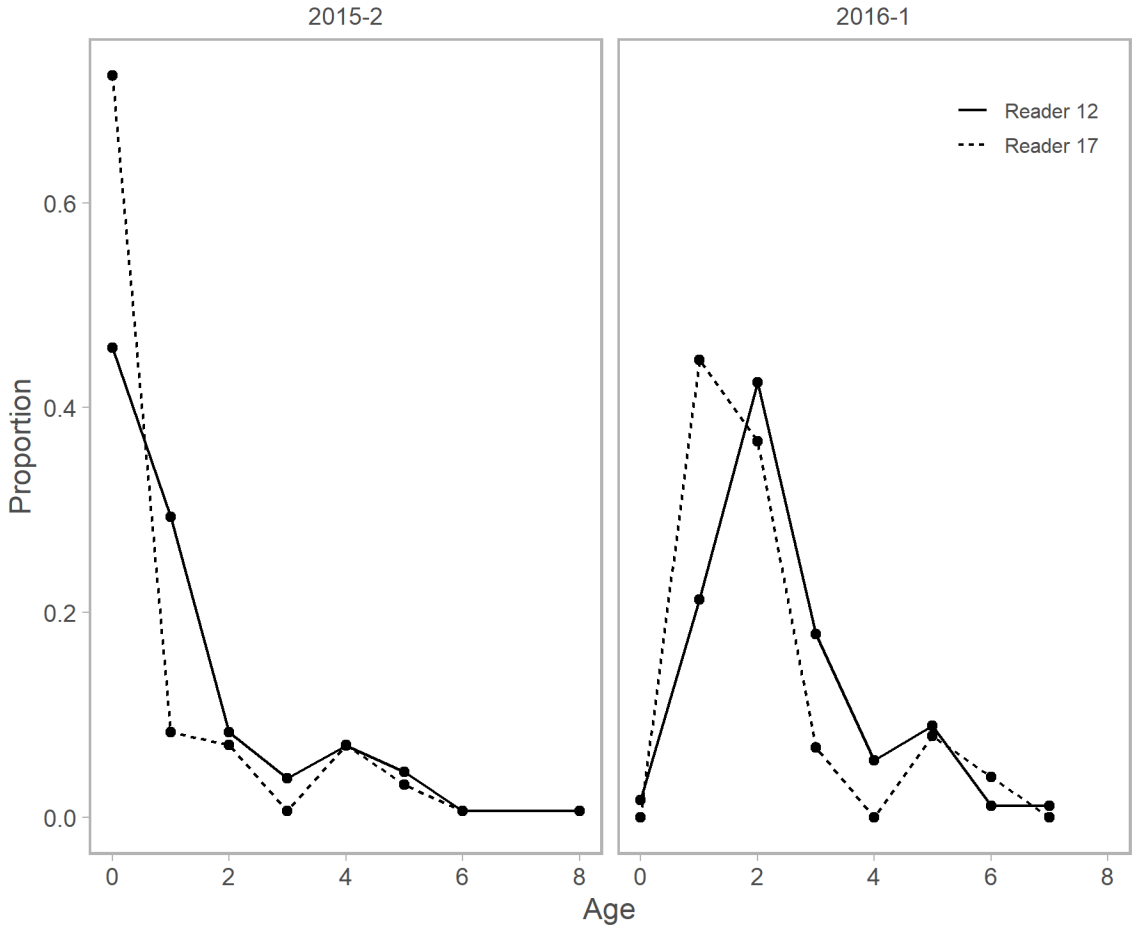

Figure 2: Age compositions from otolith readings from Readers 12 (solid lines) and 17 (dashed lines) arranged by model year-semester. Only the 2016-1 (collected on the Summer 2016 AT survey) readings from Reader 17 were used in the update assessment. These age compositions are unweighted and differ from the weighted age compositions used in the assessment.

The spring 2021 (model year-semester 2020-2) and summer 2021 (model year-semester 2021-1) AT survey observations were included in this model (Table 2). Additionally, aerial survey observations were incorporated with the calculation of Q ratios per the 2020 benchmark assessment. Note, the survey estimate from 2021-1 is preliminary, although the survey team does not anticipate the final estimate to differ by much (K. Stierhoff, pers. comm).

Table 2: Survey observations and CVs beginning in 2019-1 for the AT survey and aerial survey. The nearshore observations from The Q ratios used in the assessment are also shown. Units for the survey observations are metric tons.

Model Yr-Sem	Acoustic Core	CV	Acoustic Nearshore	Acoustic CV	Acoustic Nearshore Type	Acoustic Total	Aerial	Q ratio	LnQ ratio
2019-1	33,138	0.19	494	0.28	F/V	33,632	12,279	0.733	-0.311
2019-2	-	-	-	-	-	-	-		
2020-1	-	-	-	-	-	-	8,688		
2020-2	1,409	0.4	24,960	0.29	F/V	26,369	18,409	0.589	-0.530
2021-1	40,528	0.37	455	0.79	F/V	40,983	14,942	0.733	-0.311

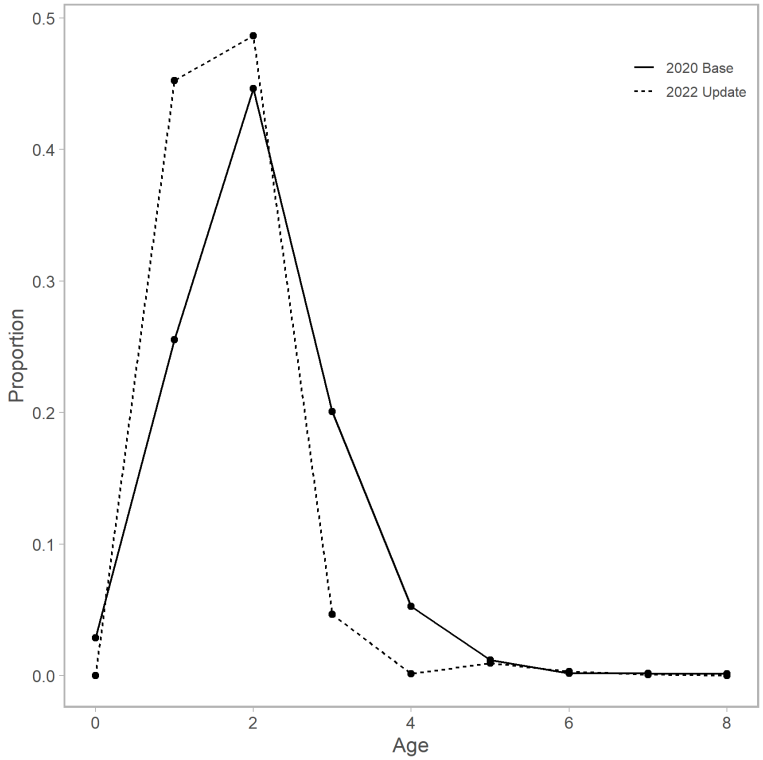

Figure 3: Updated weighted age compositions for the summer 2016 AT survey (dashed line) input to the update stock assessment. The previous weighted age composition is also shown (solid line).

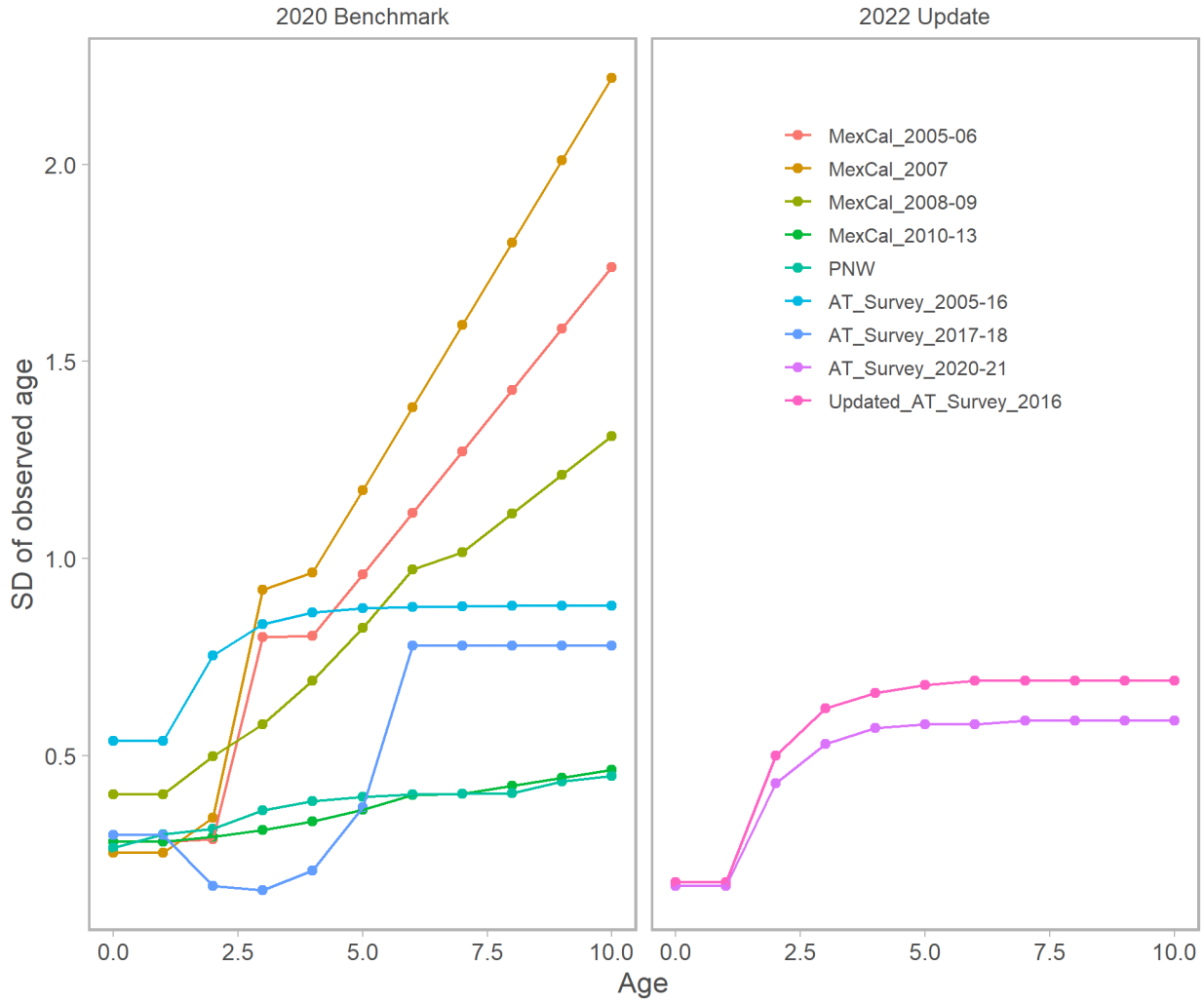

Figure 4: Ageing error vectors used in the 2020 benchmark assessment (left panel) and the new ageing error vectors used in the update assessment (right panel). The Updated_AT_Survey_2016 vector was from the re-aged 2016 otoliths, and the AT_Survey_2020-21 vector is from the new 2021 otolith reads. The 2016 vector was substituted for the relevant age composition. The remainder of the ageing error vectors were unchanged and used in this update assessment.

The 2020 benchmark assessment used *F* values (yr^{-1}; as opposed to catch) to forecast for 2021. The same approach is used for this update assessment. The *F* values from model year-semester 2021-1 and 2021-2 (Table 3) used in the forecast file. The update assessment assumed, as in the 2020 benchmark assessment, that fishing activity remained constant from the most recent observations. Note, the *F* values estimated from the MexCal_S2 catch value (48,312 mt) were estimated to be 4.0, which is the upper bound in the model.

Table 3: Catch values and associated *F* values estimated in model year 2021 in the update assessment. The *F* values were input as values for model year 2022 in the forecast file.

-	-	MexCal_S1	-	MexCal_S2	-	PNW	-
Calendar Y-S	Model Y-S	Catch	F (yr^{-1})	Catch	F (yr^{-1})	Catch	F (yr^{-1})
2021-2	2021-1	92.84	0.02	0	0	1.22	0.00
2022-1	2021-2	0	0	48,312	4	2.93	0.00

Results

Summary biomass (age 1+) for the 2022 fishing year is forecast to be 27,311 mt (Fig. 5), and recruitment is forecast to be 241 million age-0 fish (Fig. 6). The update assessment estimated higher recruitment events in 2018, 2019, and 2020 (Fig. 6), likely the result of higher catch values than previously used for both the 2021 catch-only projection (Kuriyama et al. 2021) and 2020 benchmark (Kuriyama et al. 2020).

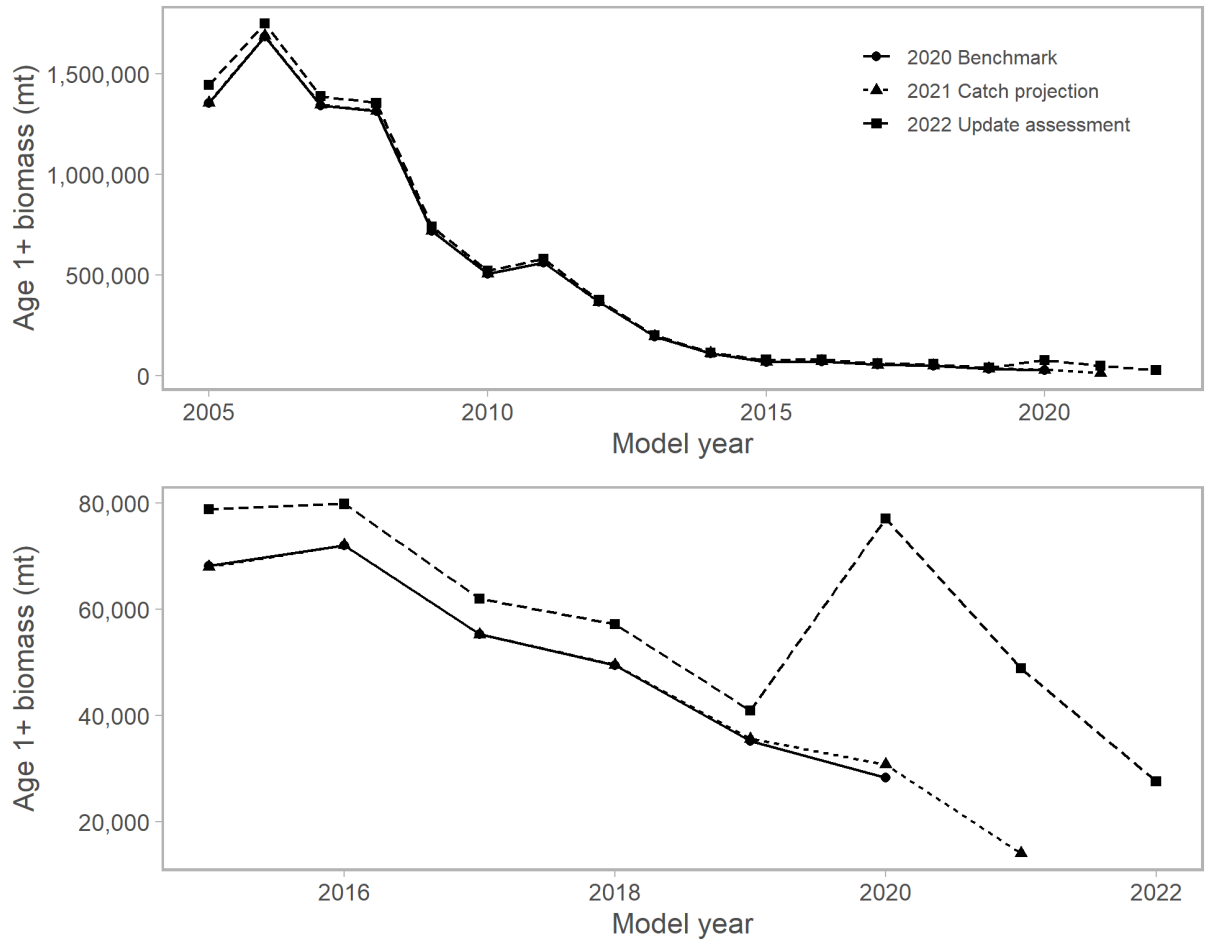

Figure 5: Time series of summary biomass (age 1+; mt) for the 2020 benchmark assessment (circles), 2021 catch-only projection (triangles), and 2022 update assessment (squares). The last point of each line is the forecast summary biomass.

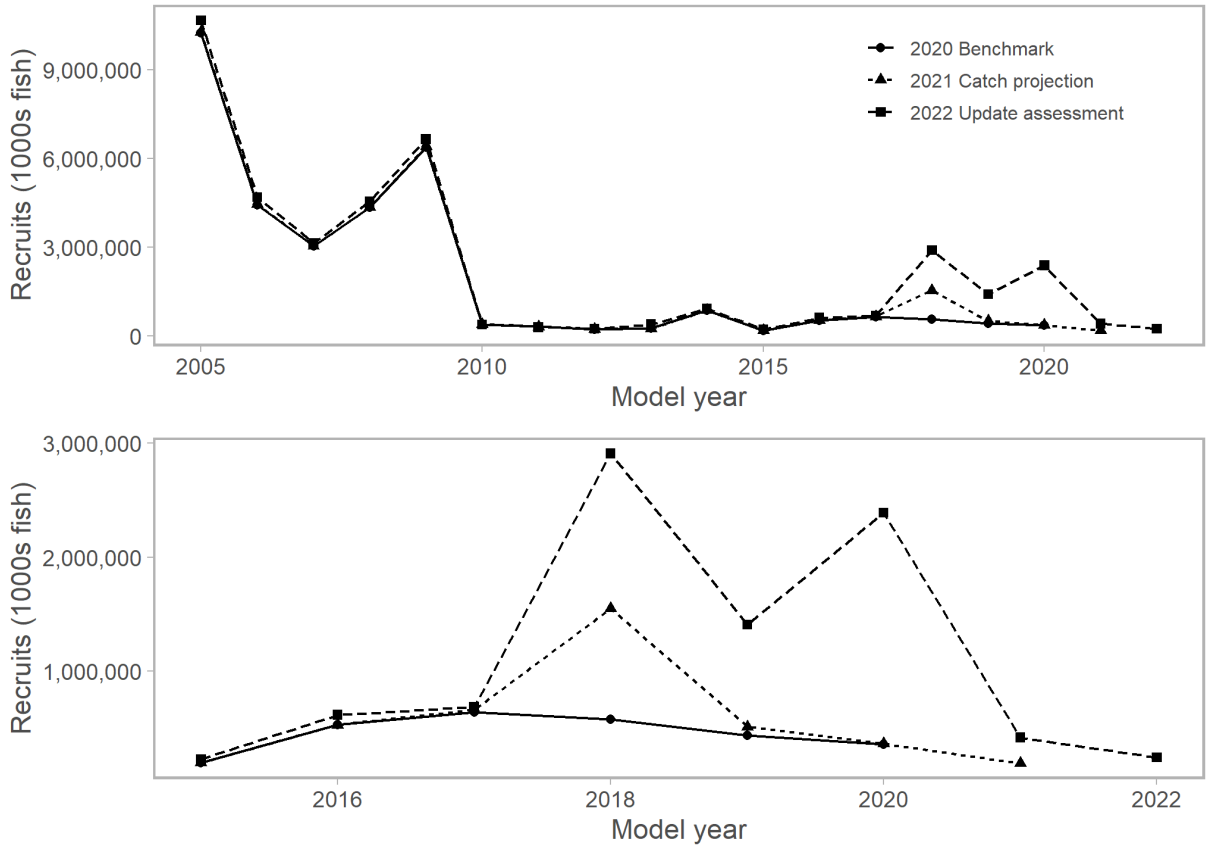

Figure 6: Time series of recruits entering the population (thousands of age-0 fish) for the 2020 benchmark assessment (circles), 2021 catch-only projection (triangles), and the 2022 update assessment (squares). The top panel shows values from 2005-2022, the bottom shows 2015-2022.

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 less than 1% in 2021 (Fig. 7). Mexico had an annual exploitation rate of 27%, and the total exploitation rate for Mexico, USA, and Canada was 28% of the total biomass. These exploitation rates are lower than those reported in the 2021 catch-only projection due to the higher recruitments estimated for recent years (Fig. 6).

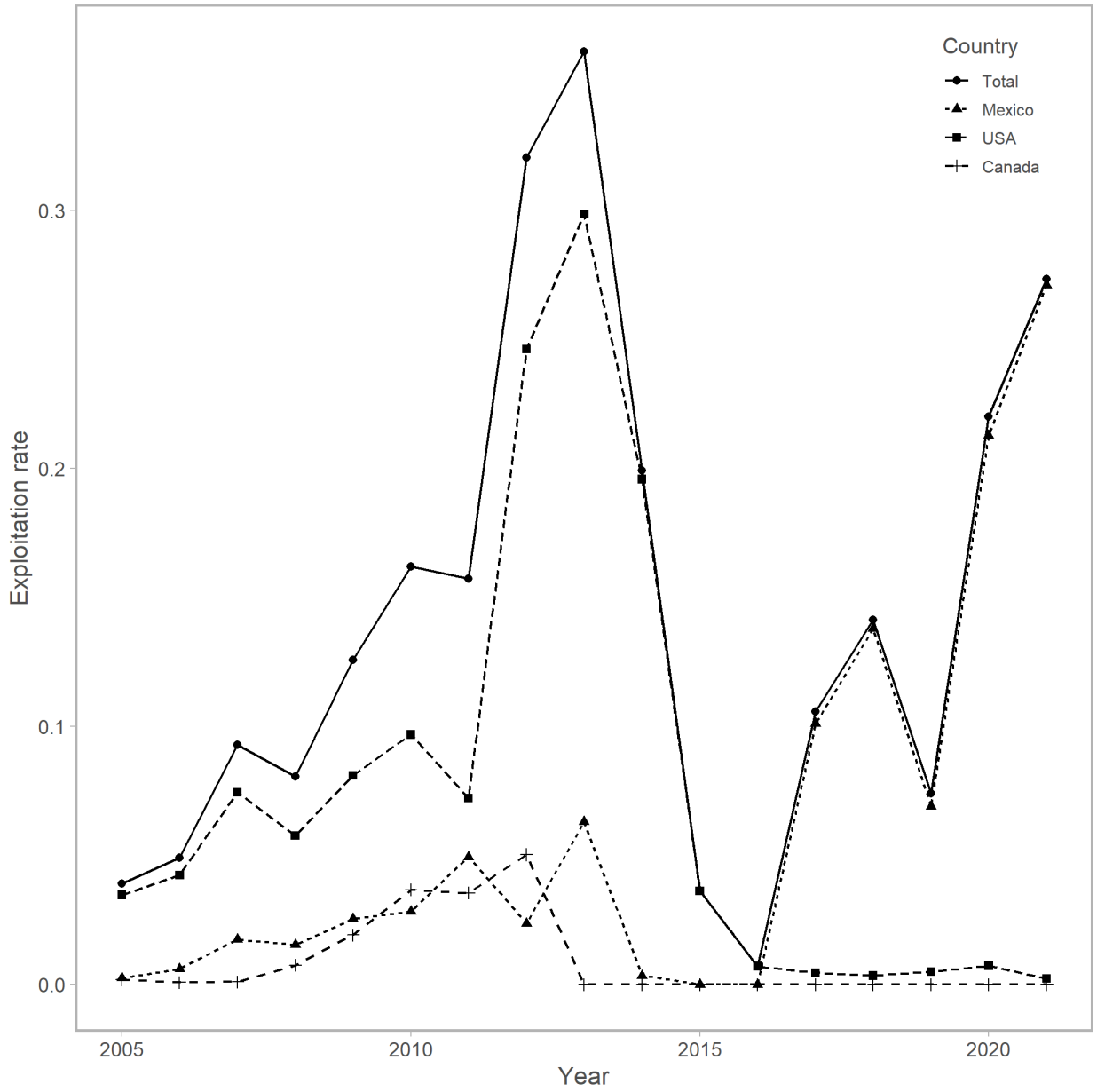

Figure 7: Plots of total exploitation rate (circles) and exploitation rates from Mexico (triangles), USA (squares), and Canada (pluses).

Harvest Control Rules

The harvest guidelines are shown in the Table 4, based on the forecast age 1+ biomass of 27,369 mt. The stock is below the 150,000 mt management threshold and the harvest guideline is 0 mt for 2022. Acceptable biological catches for a range of P-star values are also shown in the Table 4 (Tier 1 σ=0.5; Tier 2 σ=1.0; Tier 3 σ=2.0).

Table 4: Harvest control rules for the 2022-2023 management year.

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 Formula Parameters									
BIOMASS (ages 1+, mt)	**27,369**								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{(Tier\ 1;\ Sigma\ 0.5)}$	0.93910	0.88102	0.82476	0.76936	0.71373	0.65651	0.59558	0.52688	0.43936
ABC $Buffer_{(Tier\ 2;\ Sigma\ 1.0)}$	0.88191	0.77620	0.68023	0.59191	0.50942	0.43101	0.35472	0.27761	0.19304
ABC $Buffer_{(Tier\ 3;\ Sigma\ 2.0)}$	0.77777	0.60248	0.46272	0.35036	0.25950	0.18577	0.12582	0.07707	0.03726
CalCOFI $SST_{(2019\text{-}2021)}$	16.0393								
E_{MSY}	0.231257								
FRACTION	0.200000								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**5,506**								
ABC(Sigma 0.607) =	5,171	4,851	4,542	4,236	3,930	3,615	3,280	2,901	2,419
ABCTier 2 =	4,856	4,274	3,746	3,259	2,805	2,373	1,953	1,529	1,063
ABCTier 3 =	4,283	3,318	2,548	1,929	1,429	1,023	693	424	205
HG =	**0**								

Recent management performance

US landings in the past years have remained below the annual catch limits (or annual catch targets, when applicable; Table 5). The 2021-2022 annual catch target for Pacific sardine was 3000 mt for Pacific sardine (Table 5). Landings-to-date of the northern subpopulation in the U.S. were 105 mt for 2021-22, 3.5% of the annual catch target (Table 6).

Table 5: USA northern subpopulation (NSP) landings, overfishing limit (OFL), allowable biological catch (ABC), annual catch limit (ACL), and annual catch target (ACT) values for recent fishing years. All units are in mt.

Fishing-year	USA NSP Landings	OFL	ABC	ACL	ACT
2017-2018	372	16,957	15,497	8,000	
2018-2019	651	11,324	9,436	7,000	
2019-2020	705	5,816	4,514	4,514	4,000
2020-2021	852	5,525	4,288	4,288	4,000
2021-2022	105	5,525	3,329	3,000	3,000

Table 6: Annual catch limit (ACL), annual catch target (ACT) values, and NSP catches from USA, Mexico, and Canada for recent fishing years. All units are in mt. Note, Mexican landings for the 2021-2022 fishing year (*) have not been reported yet.

Fishing-year	USA ACL	USA ACT	USA Landings	Mexico Landings	Canada Landings
2017-2018	8,000		372	9,736	0
2018-2019	7,000		651	11,634	0
2019-2020	4,514	4,000	705	29,555	0
2020-2021	4,288	4,000	852	48,005	0
2021-2022	3,000	3,000	105	*	0

Sensitivities

Four sensitivity runs were conducted during the March 2022 CPS Subcommittee review: three looked at different calculations of the ratios for survey catchability and one that assumed a maximum recent catch of 10,000 mt.

Scenario 1 involved calculation of Q ratios based on the value of the core AT estimate divided by the AT core + AT nearshore estimates. Scenario 2 involved Q calculations based on the value of the AT core estimate divided by the AT core + aerial estimates. Scenario 3 calculated Q based on the ratio of the core AT estimate divided by the AT core + average of aerial and AT nearshore estimates. Results from these scenarios had generally the same trends, and scenarios with higher Q values had higher age 1+ biomass estimates (Fig. 8). The Q values used for each of these scenarios are shown in Table 7.

Table 7: Log catchability (Q) values input to the three sensitivity scenarios. These were the time periods for which AT nearshore collected from fishing vessels and aerial estimates were available.

Model Yr-Sem	Scen1: Nearshore only	Scen2: Aerial only	Scen3: Average
2019-1	-0.315	-0.015	-0.176
2019-2	-	-	-
2020-1	-	-	-
2020-2	-2.644	-2.929	-2.797
2021-1	-0.314	-0.011	-0.174

Scenario 4 evaluated uncertainty in the catch estimates reported from Mexico, which were landings greater than 33,000 mt in 2019-2 and 48,000 mt in 2020-2. In this scenario, catch amounts were capped at a maximum of 10,000 tons. The result was that age 1+ biomass had a relatively flatter trajectory in 2020, which resulted in a lower forecasted recruitment and age1+ biomass for 2022 (Fig. 8).

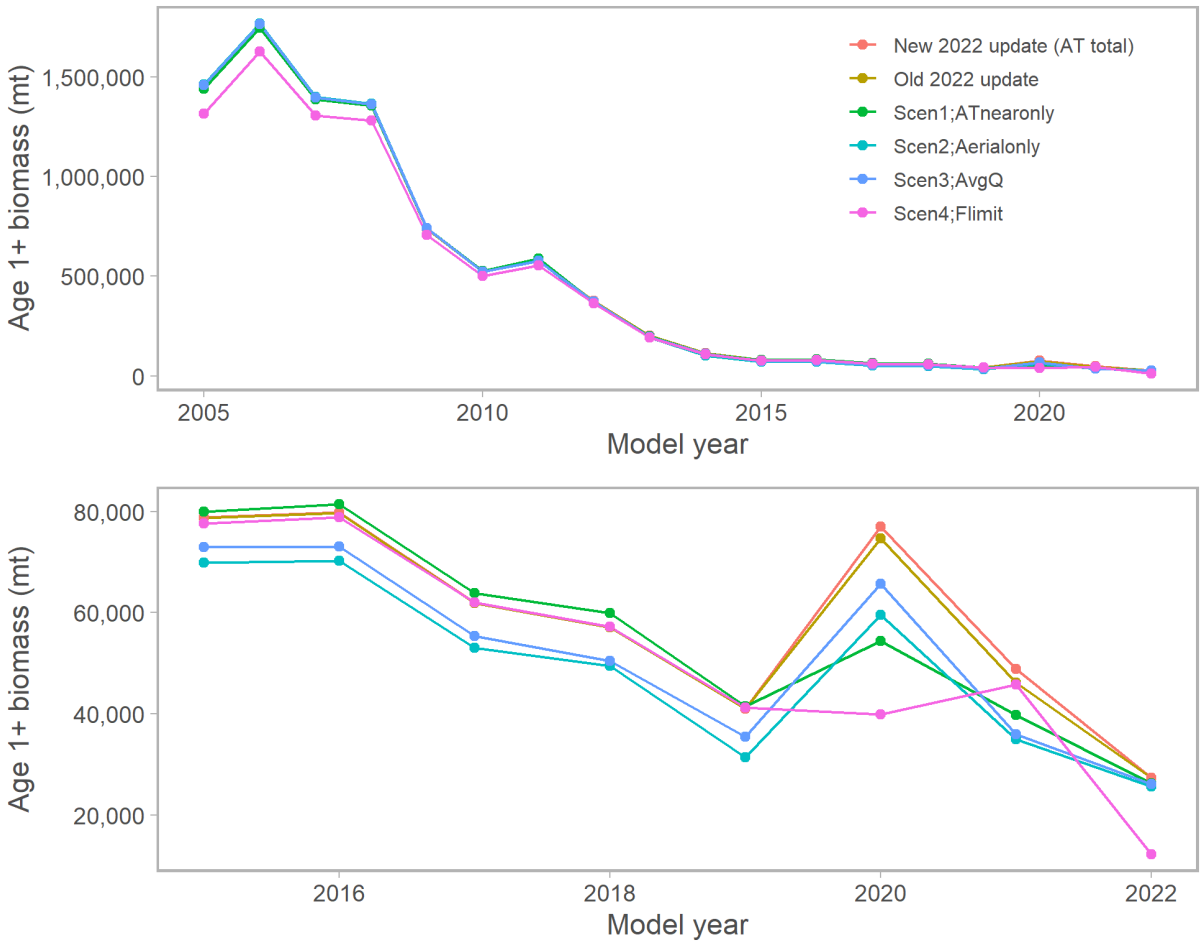

Figure 8: Age 1+ biomass time series from the four sensitivities. Scenarios 1-3 involved different calculations of Q ratio, and scenario 4 had a maximum catch of 10,000 mt in recent years. Panels show time series values from 2005-2022 (top) and 2015-2022 (bottom).

Uncertainties

The uncertainties discussed in the 2020 benchmark and 2021 catch-only projection reports remain in this assessment. The amount of nearshore biomass and proportion of northern subpopulation in Mexican waters remains an uncertainty. Specifically, the MexCal_S2 F value of 4, used in projecting the population forward for management, is a major uncertainty.

This assessment estimated an increase in recruits compared to the previous assessments, likely in order to match the population dynamics to the input catch values removed by the fisheries. This increase is shown in Table 8, comparing the total (age 0+) biomass values across recent assessments. The increases in summary (age 1+) biomass values are shown in Table 9.

Table 8: Total biomass (age 0+; mt) estimated from the 2020 benchmark assessment (2020bench), 2021 catch-only projection (2021proj), and 2022 update (2022update).

Model Y-S	2020bench	2021proj	2022update
2018-1	62,012	62,516	70,639
2018-2	44,264	44,793	49,445
2019-1	60,689	103,697	168,607
2019-2	38,008	64,179	103,628
2020-1	47,548	53,428	139,028
2020-2	29,698	32,017	82,003
2021-1	NA	30,196	176,006
2021-2	NA	18,626	82,428
2022-1	NA	NA	49,926
2022-2	NA	NA	22,130

Table 9: Summary biomass (age 1+; mt) estimated from the 2020 benchmark assessment (2020bench), 2021 catch-only projection (2021proj), and 2022 update (2022update).

Model Y-S	2020bench	2021proj	2022update
2018-1	49,449	49,528	57,214
2018-2	27,003	26,954	31,063
2019-1	35,186	35,591	40,954
2019-2	22,444	22,628	25,996
2020-1	28,276	30,758	77,066
2020-2	17,936	18,186	44,449
2021-1	NA	14,011	48,856
2021-2	NA	8,752	19,222
2022-1	NA	NA	27,369
2022-2	NA	NA	10,917

Research and Data Needs

While uncertainty regarding nearshore biomass remains, the 2021 spring and summer AT surveys increased nearshore coverage using acoustics in collaboration with the fishing industry. The spring 2021 survey found a majority of the observed biomass nearshore and outside of the core survey grid (Table 2). There were updates to the CCPSS aerial survey, and these data were incorporated through adjustments to Q. The recommendations for the aerial survey included the need to coordinate visual estimates with randomly sampled purse-seine point sets, temporal rather than spatial replication, and sufficient biological sampling on mixed anchovy and sardine schools. The 2021 spring and summer acoustic-trawl surveys will make strides toward increasing nearshore coverage using acoustics in collaboration with the fishing industry.

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Kuriyama, P.T., Hill, K.T., Zwolinski, J.P. 2021. Assessment of the Pacific sardine resource in 2021 for U.S. management in 2021-2022, U.S. Department of Commerce

Appendix A: CalCOFI Sea Surface Temperature calculations

Although CalCOFI surveys occurred in all four seasons for 2021, the spring survey sampled fewer stations than typical and had less spatial coverage than cruises in other seasons (Fig. A1). There is no council-approved protocol to account for missing CalCOFI data.

Previously a linear regression with the NOAA Extended Reconstructed Sea Surface Temperature (ERSST) database* has been used to predict quarterly values when entire cruises were missing in 2014, 2019, 2020. That is, the CalCOFI seasonal mean was predicted from the seasonal mean of ten 2x2° ERSST blocks that overlap the core CalCOFI sampling area (years 1984 through the most recent year available at the time; Fig. A1). The yearly mean was then calculated as the mean of the predicted value and the three measured seasonal values as usual.

A similar exploratory analysis was conducted for 2021, except that linear regressions were fit for individual ERSST blocks 2, 3, and 5, and then the spring value was estimated as the mean of the measured means in the other seven blocks and the three predicted values. The yearly mean was then calculated as the mean of the corrected spring value and the other three seasonal cruise means.

The annual mean SST calculated using the corrected spring value was 15.71°C. This was very similar to the uncorrected annual SST value of 15.73°C, as calculated using the standard procedure. Thus, the missing data were unlikely to have a large effect on the temperature calculation used in the harvest control rule.

*https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html

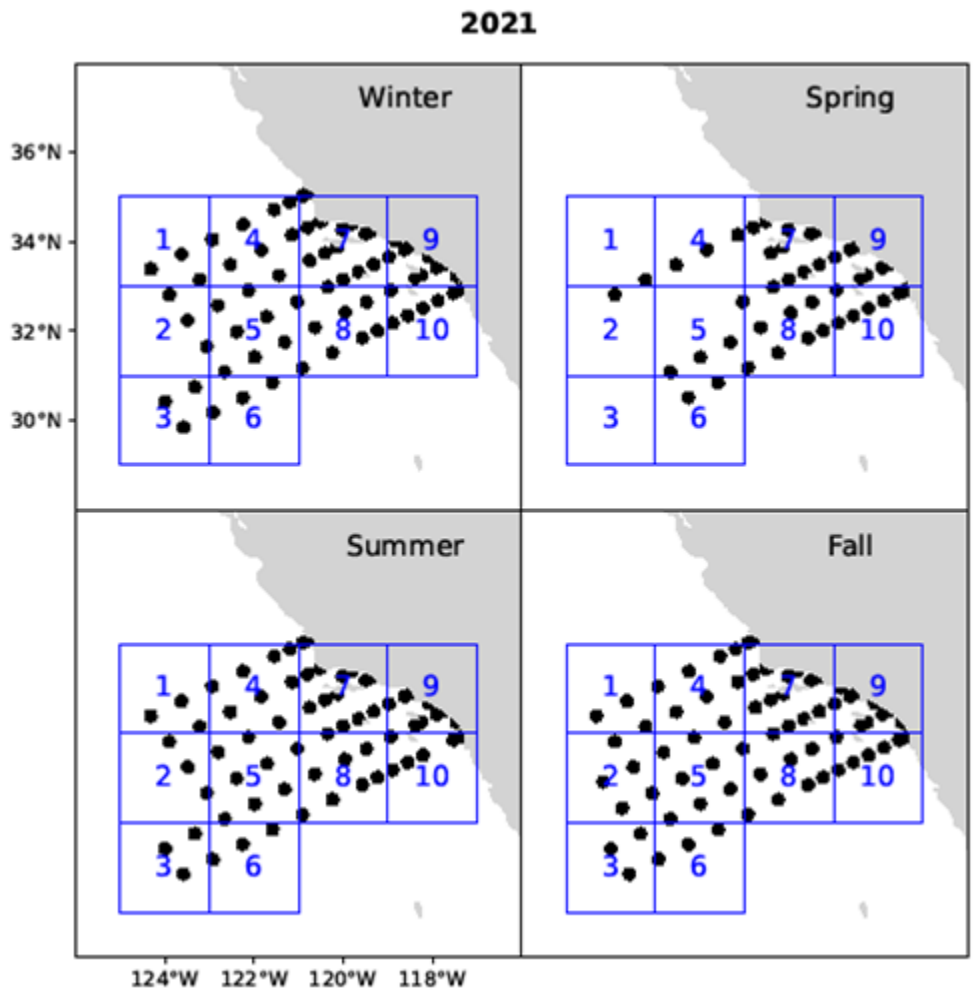

Fig A1: CalCOFI survey coverage in 2021.

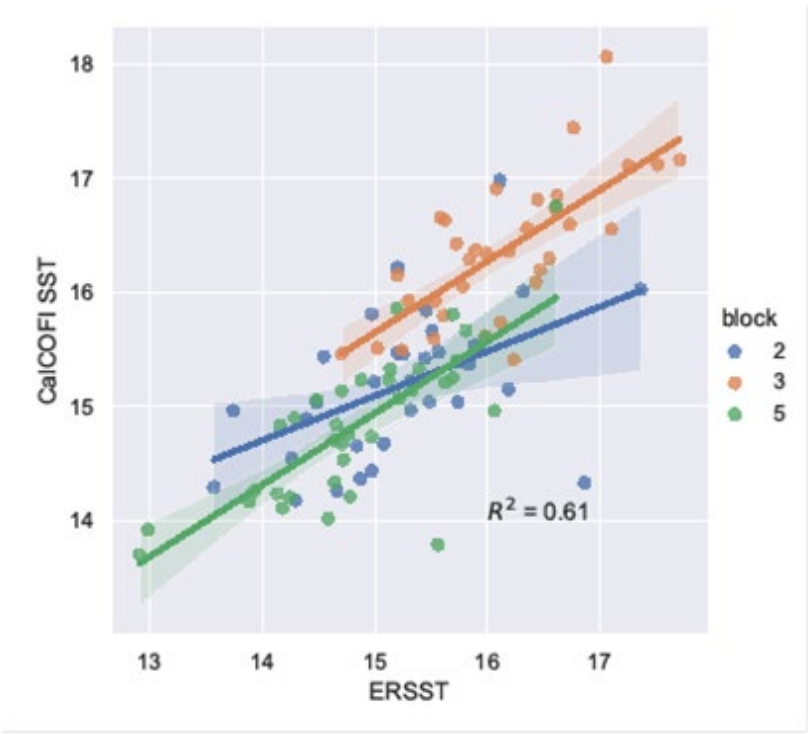

Fig A2: ERSST regression against CalCOFI SST values.

Appendix B: r4ss Diagnostic Figures

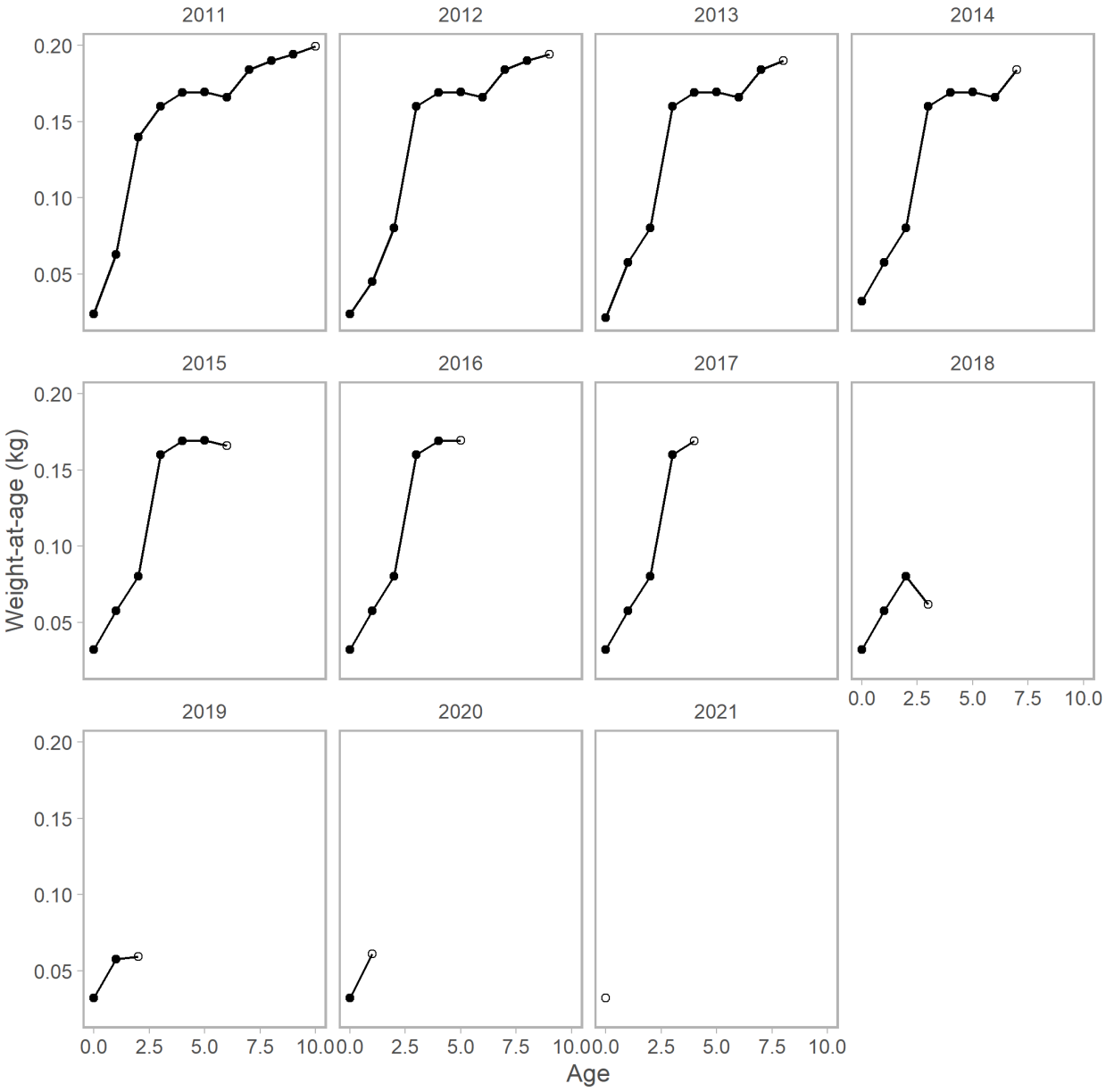

Figure B1: Weight-at-age values (kg) arranged by cohort for the MexCal S1 fleet. New values are indicated with open circles and previous values in solid points.

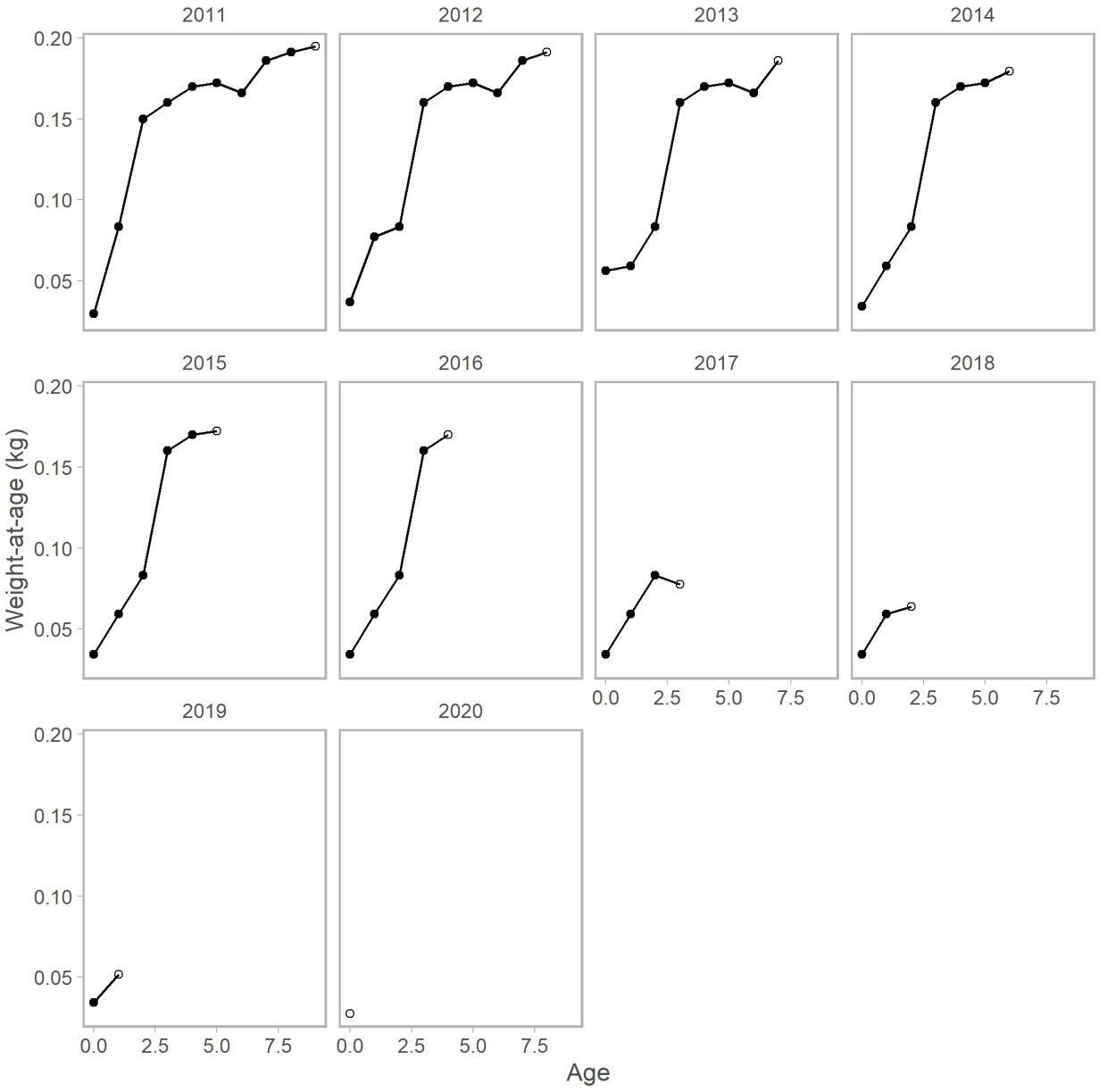

Figure B2: Weight-at-age values (kg) arranged by cohort for the MexCal S2 fleet. New values are indicated with open circles and previous values in solid points.

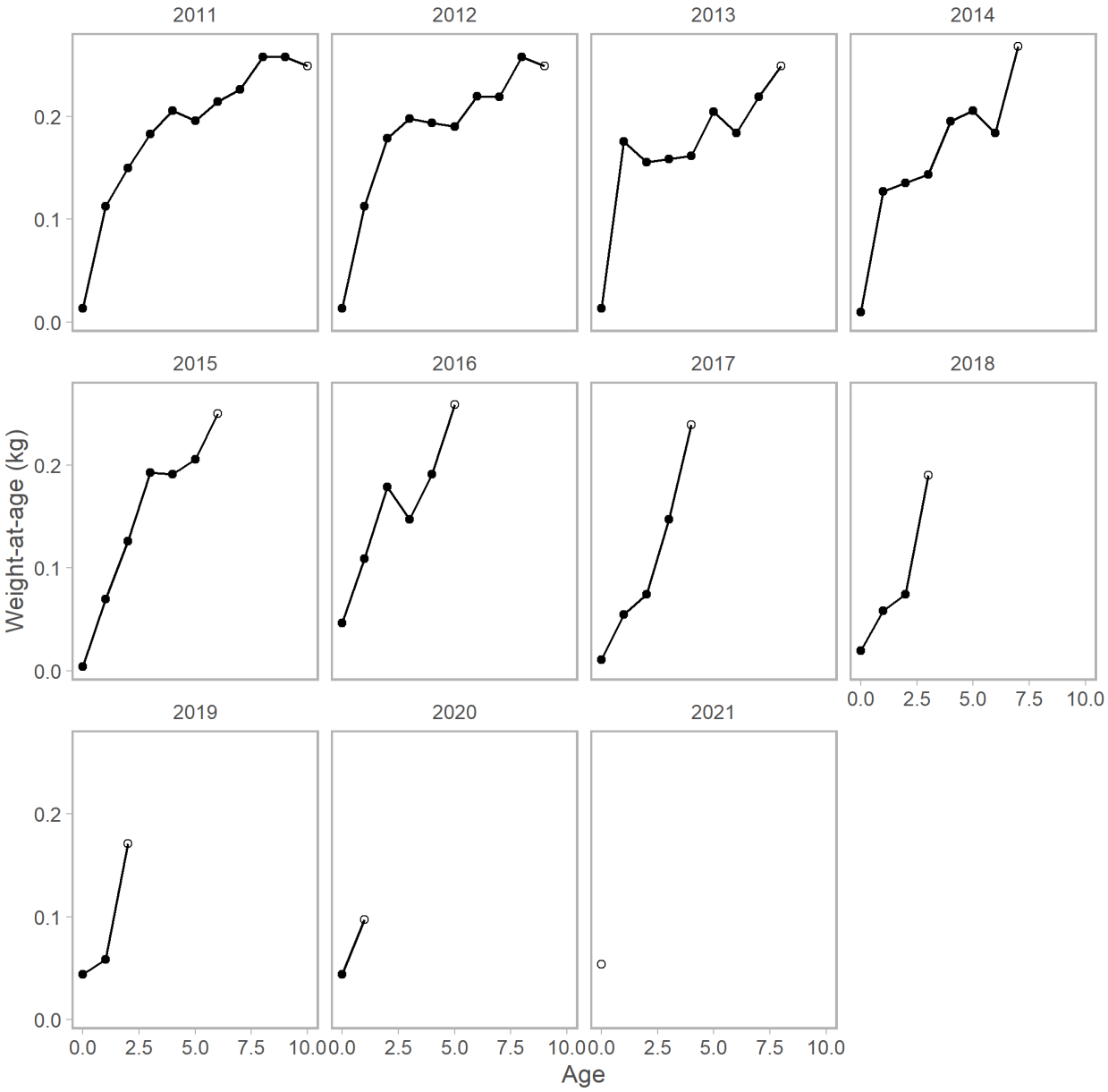

Figure B3: Weight-at-age values (kg) arranged by cohort for the AT survey. New values are indicated with open circles and previous values in solid points.

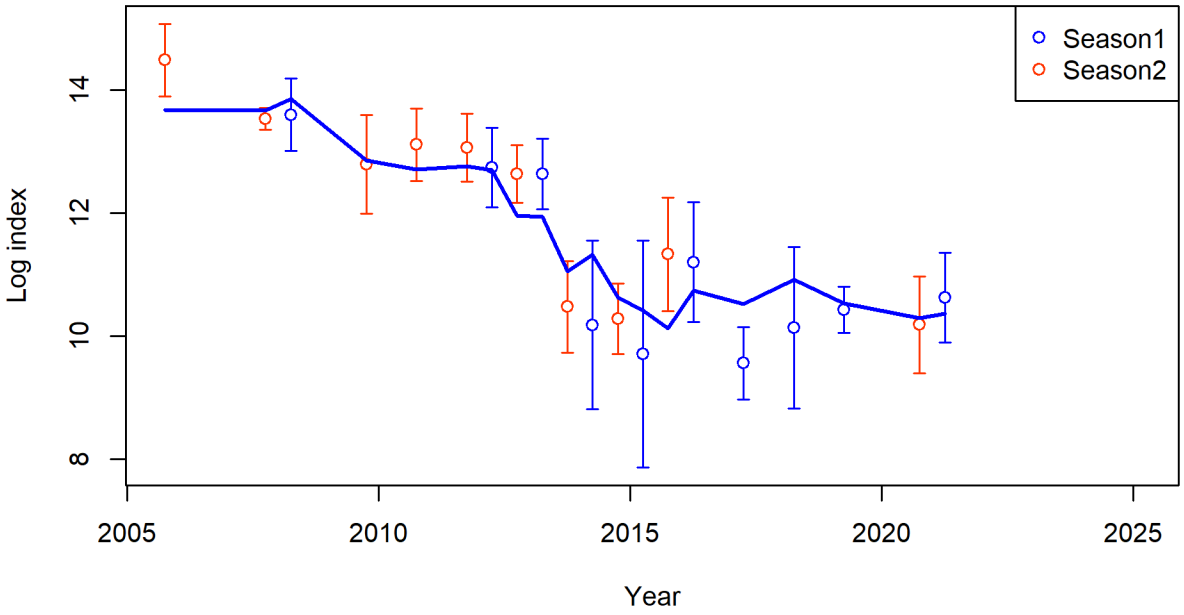

Figure B4: Fit to log-transformed index data for AT survey. Lines indicate 95% uncertainty interval around index values.

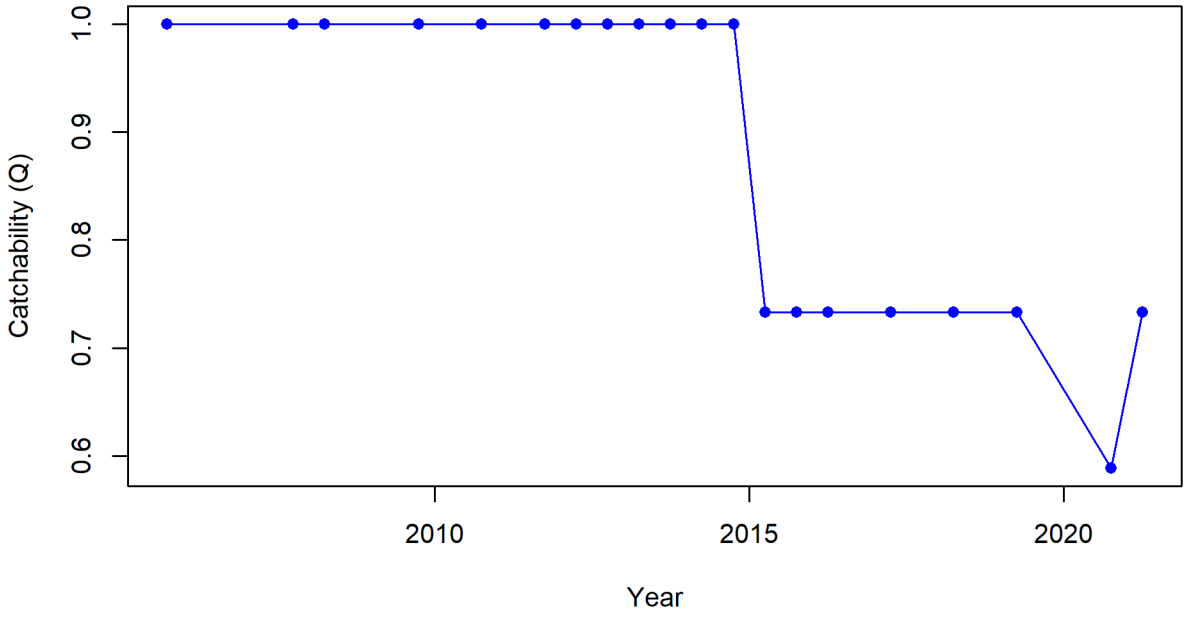

Figure B5: Catchability (Q) values input to the assessment. Starting in 2015, these values were calculated as a ratio of the AT survey observations and the aerial survey observations.

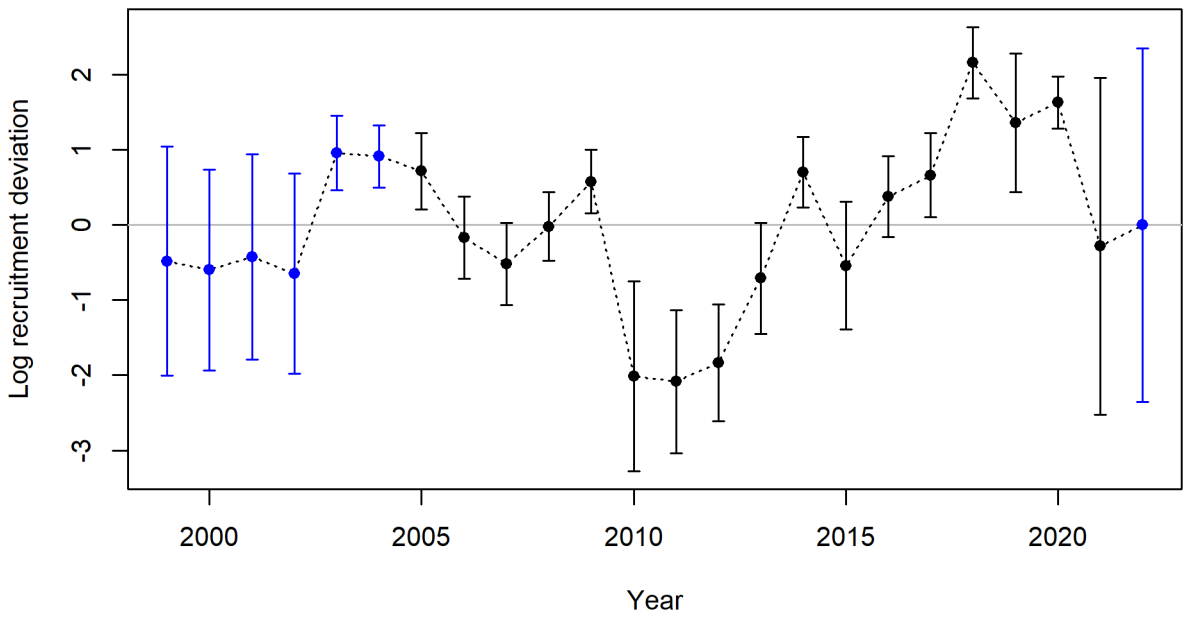

Figure B6: Recruitment deviations and standard errors.

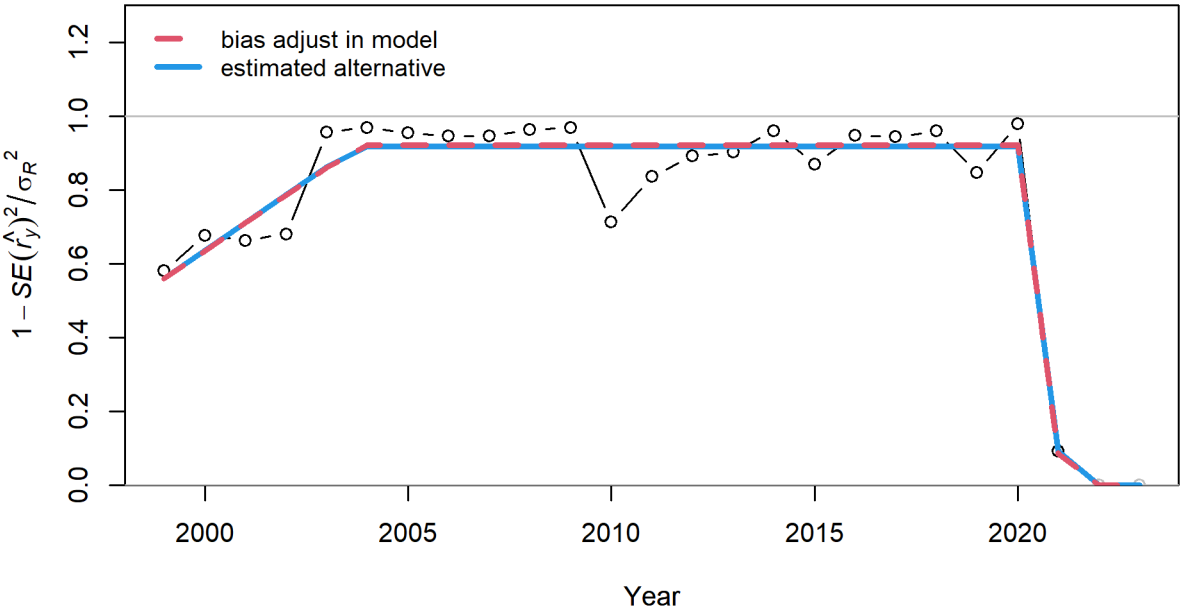

Figure B7: Recruitment bias adjustment plot for early, main, and forecast periods.

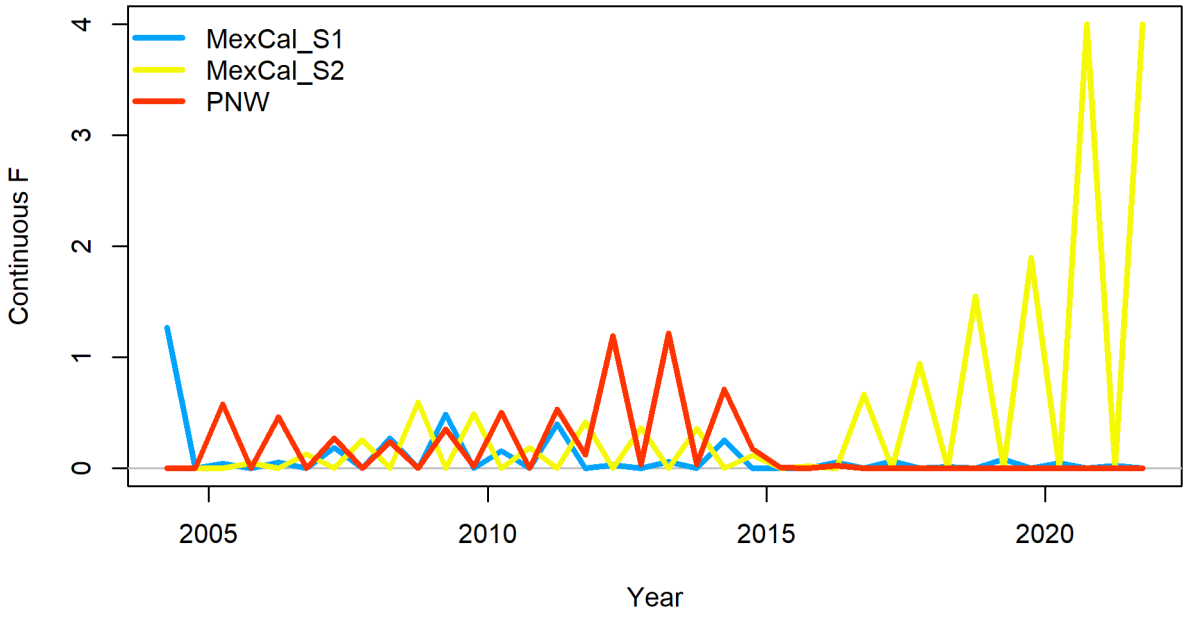

Figure B8: Instantaneous fishing mortality time series.

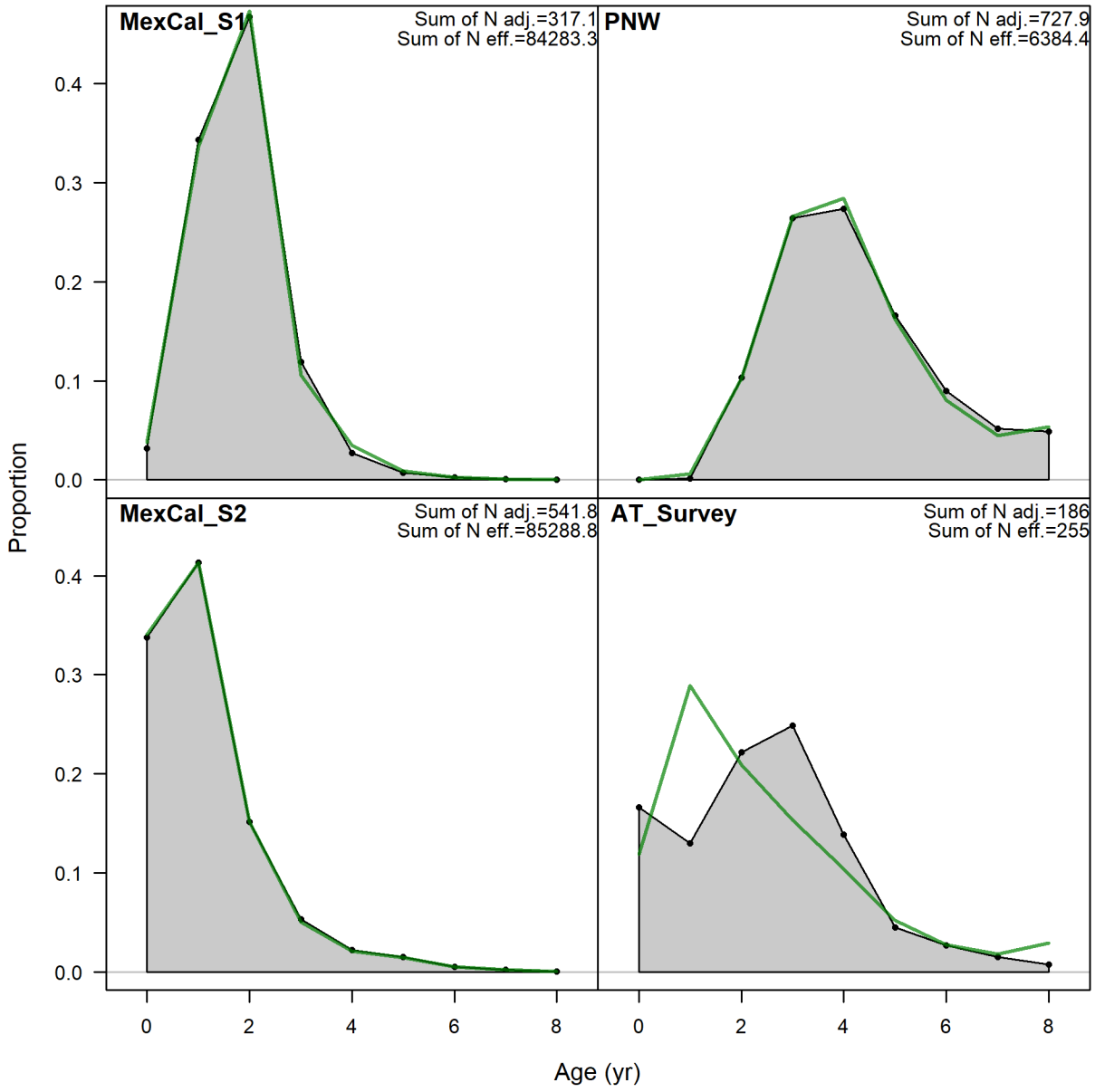

Figure B9: Fits to the aggregated age compositions, arranged by fleets.

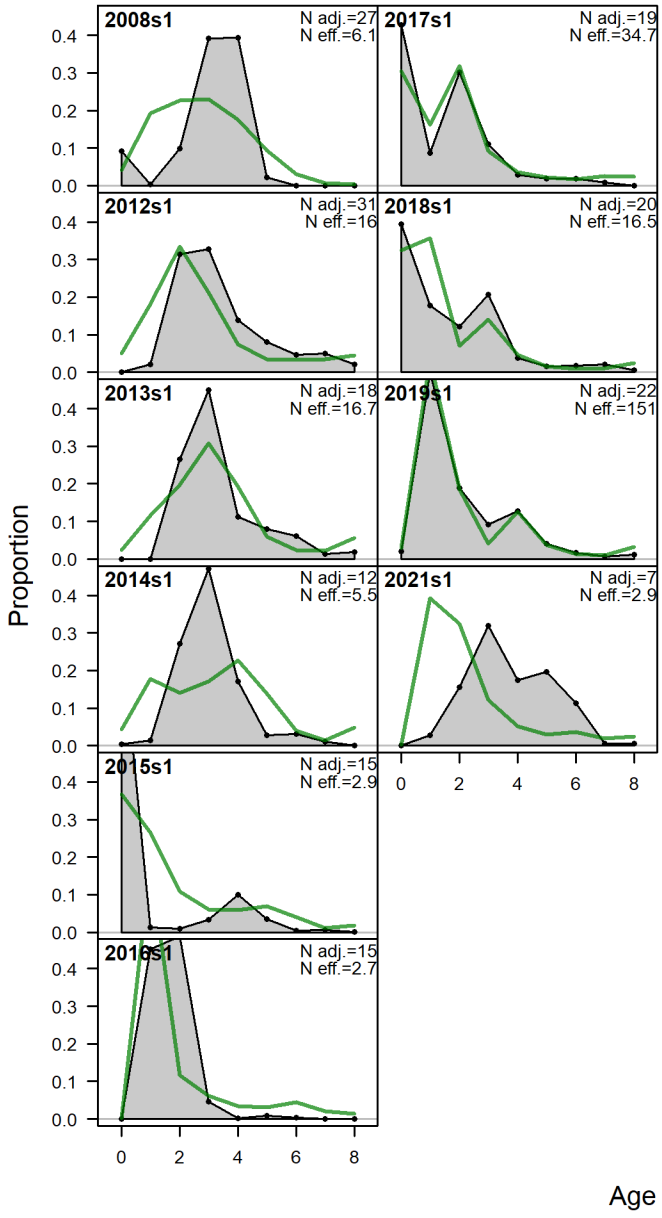

Figure B10: Fits to the AT survey age compositions by year.

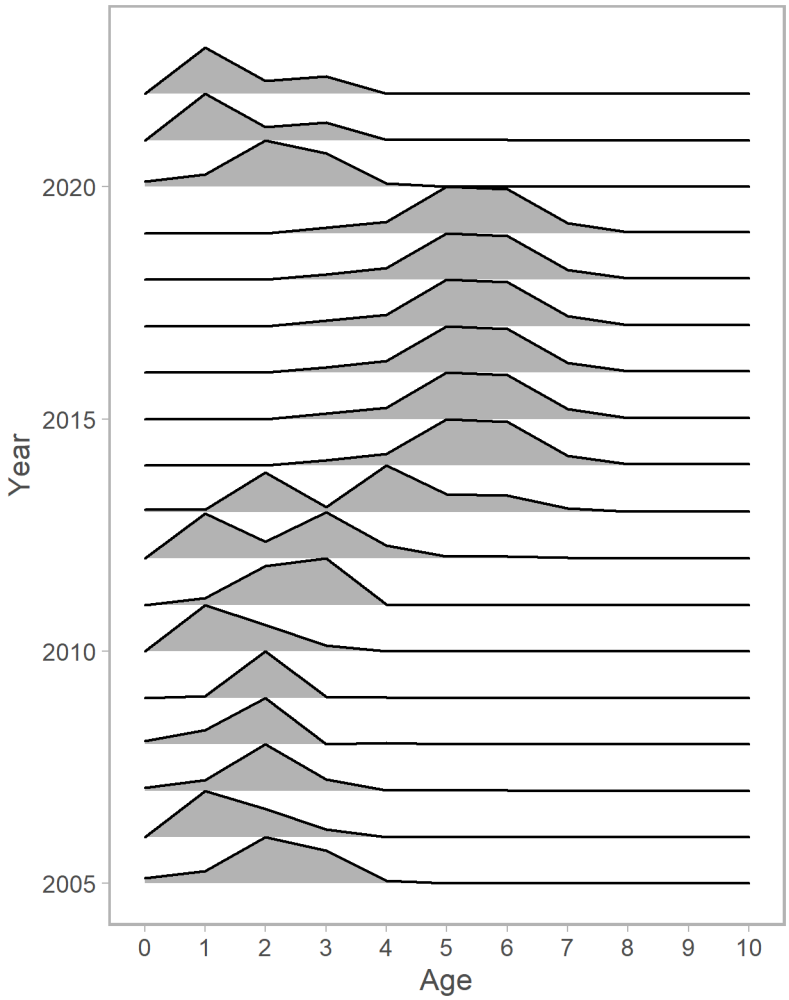

Figure B11: Time-varying age-based selectivity patterns for MexCal S1.

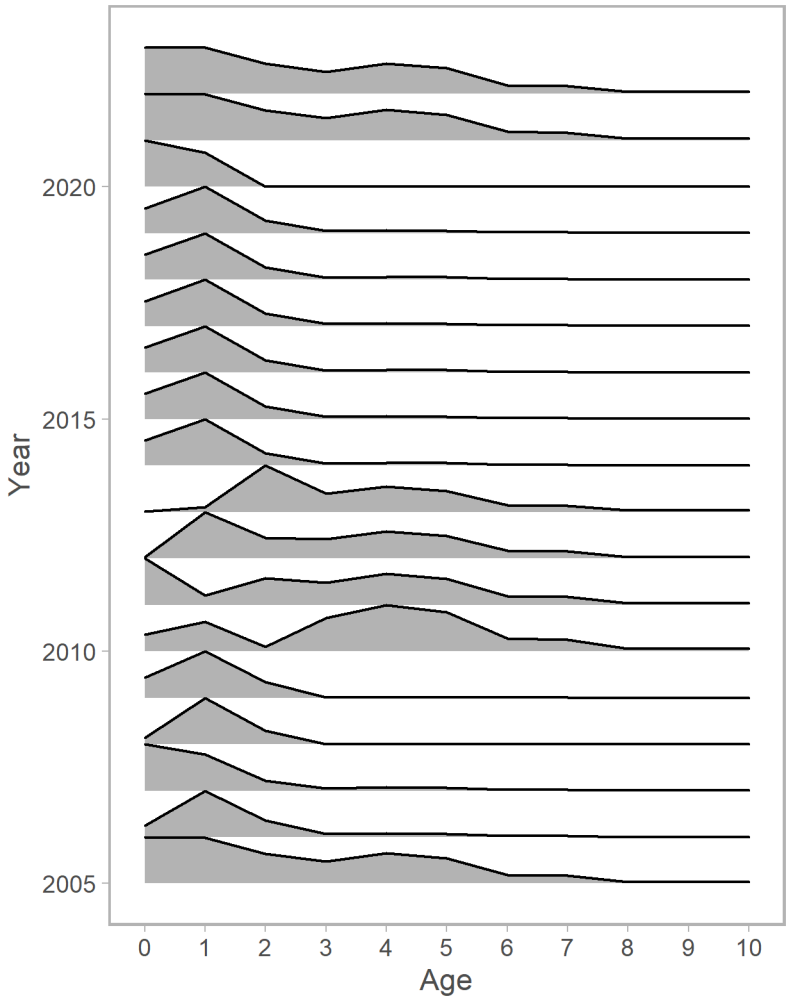

Figure B12: Time-varying age-based selectivity patterns for MexCal S2.

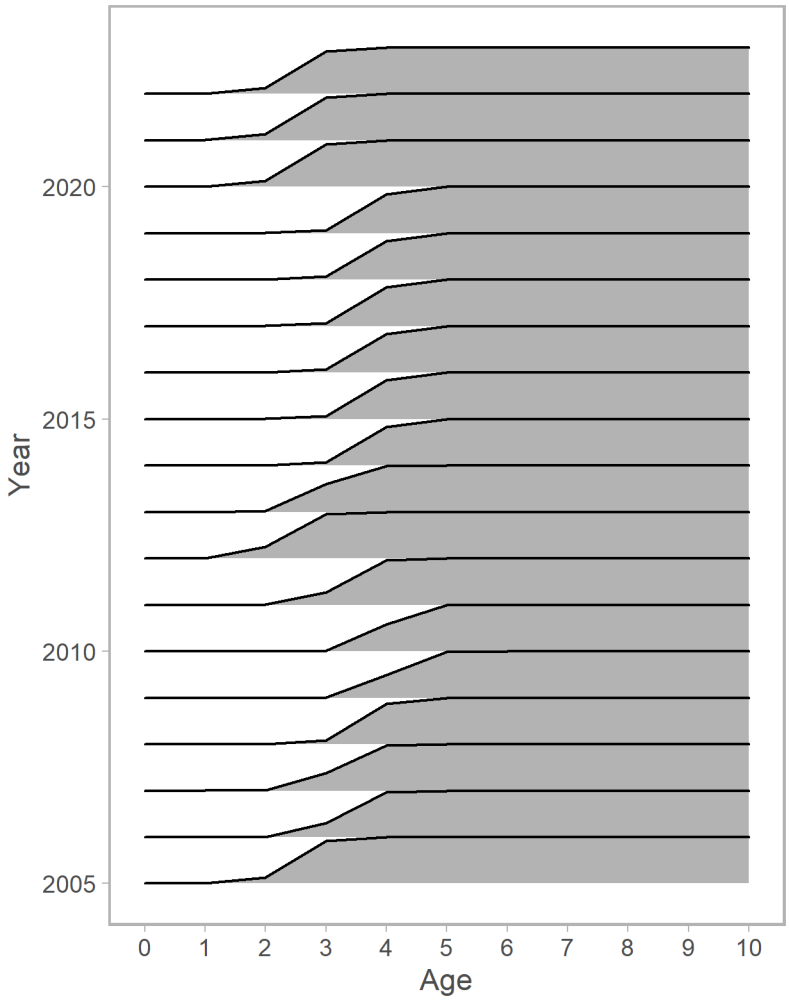

Figure B13: Time-varying age-based selectivity patterns for PNW.

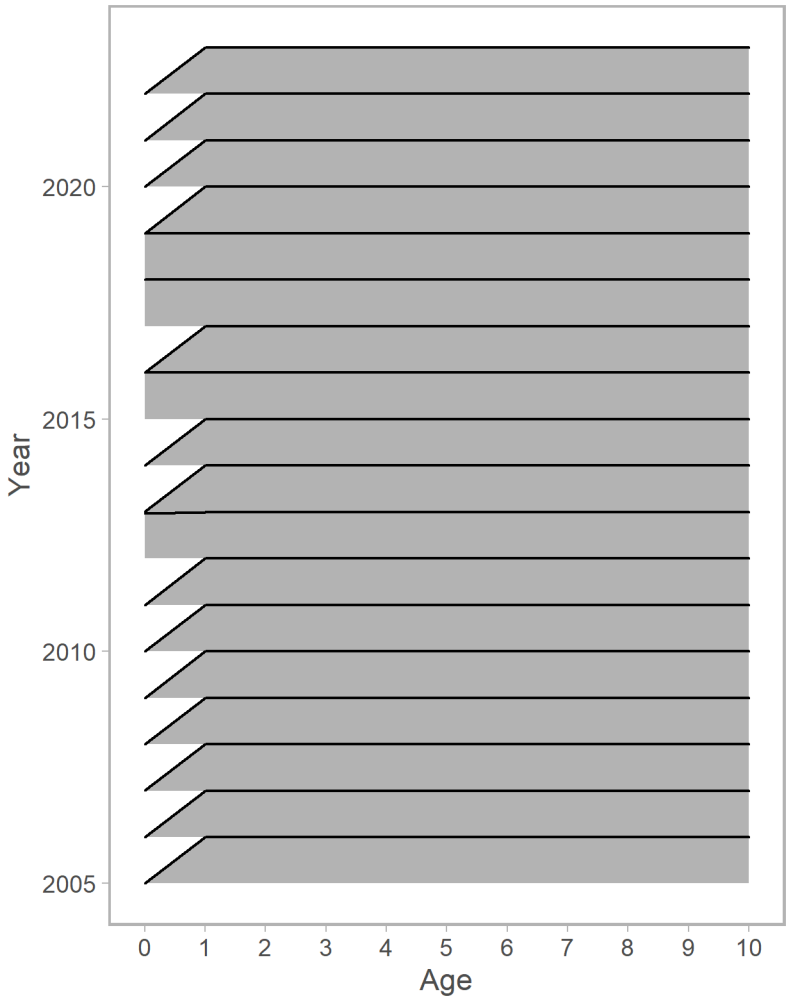

Figure B14: Time-varying age-based selectivity patterns for AT survey.