

# 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 remain high. Additionally, observations from the acoustic-trawl survey indicate 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 ( $\text{yr}^{-1}$ ; 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.

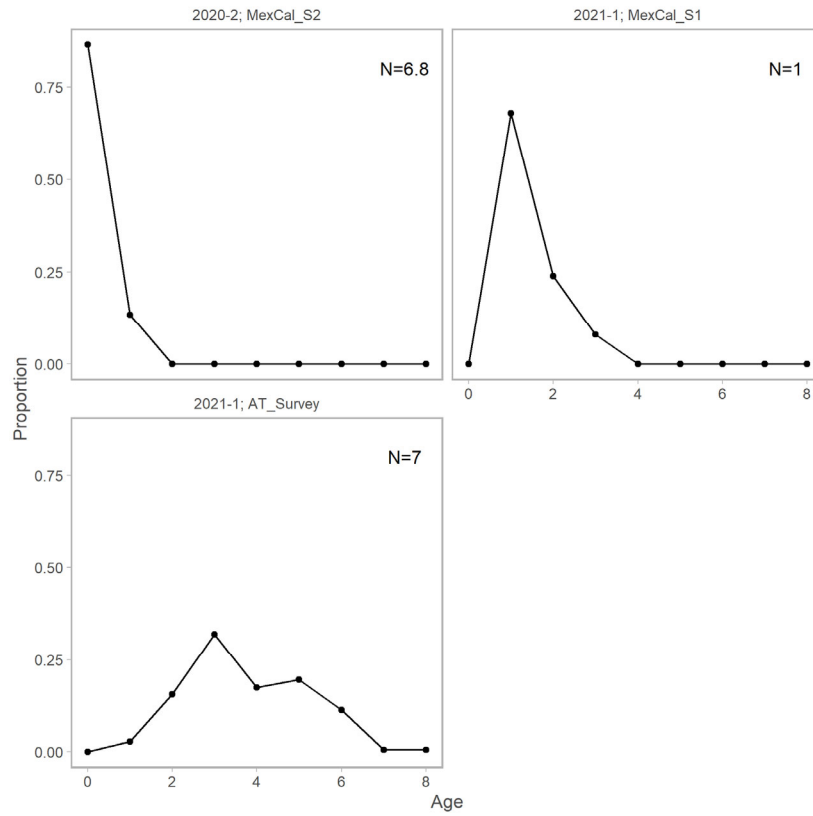
**Table 1a:** Pacific sardine landings (mt) for major fishing regions off northern Ensenada, Mexico, the United States, and British Columbia, Canada. Ensenada (ENS) and Southern California (SCA) landings are presented as totals and northern subpopulation values. Time periods shown are calendar year-semester 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	<b>MexCal S1</b>	MexCal S2	<b>MexCal S2</b>	PNW	<b>PNW</b>
2019-2	2019-1	223.61	<b>223.61</b>	0	<b>0</b>	8.20	<b>8.198</b>
2020-1	2019-2	0	<b>0</b>	33,070.23	<b>33,070.23</b>	0.06	<b>0.06</b>
2020-2	2020-1	764.00	<b>542.27</b>	0	<b>0</b>	0.42	<b>0.42</b>
2021-1	2020-2	--	<b>0</b>	--	<b>48,312.25</b>	--	<b>2.93</b>
2021-2	2021-1	--	<b>92.84</b>	--	<b>0</b>	--	<b>11.22</b>
2022-1	2021-2	--	<b>0</b>	--	<b>48,312.25</b>	--	<b>2.93</b>

New age compositions from fisheries in California and the summer 2021 AT survey were included (Figure 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. Sample sizes for the AT survey correspond to the number of positive clusters in the survey grid.



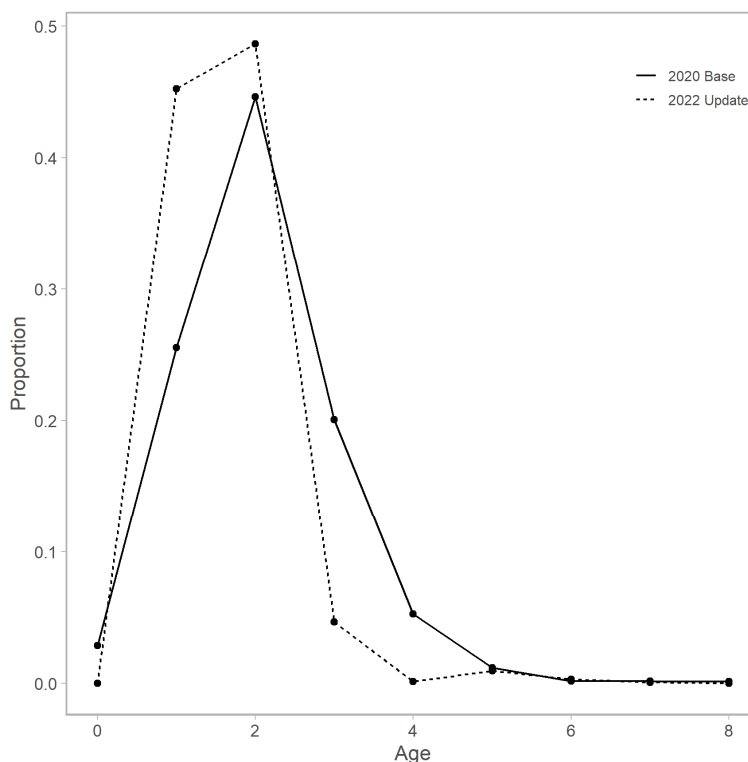
**Figure 1:** Age compositions for two fishing fleets and the AT survey and the model year-semester. Input sample sizes are shown in the top right. For the fisheries, one sample corresponds to 25 individual fish, and data from the survey are weighted by the number of positive clusters in that particular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

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						Aerial	Q ratio	LnQ ratio
	Core	CV	Nearshore	CV	Nearshore Type	Total			
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

Age compositions from the 2016 summer survey (model year-semester 2016-1) were re-aged as well (Figure 2).



**Figure 2:** Updated age compositions for the summer 2016 AT survey (dashed line). The previous age compositions are also shown (solid line).

The 2020 benchmark assessment used  $F$  values ( $\text{yr}^{-1}$ ; 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.

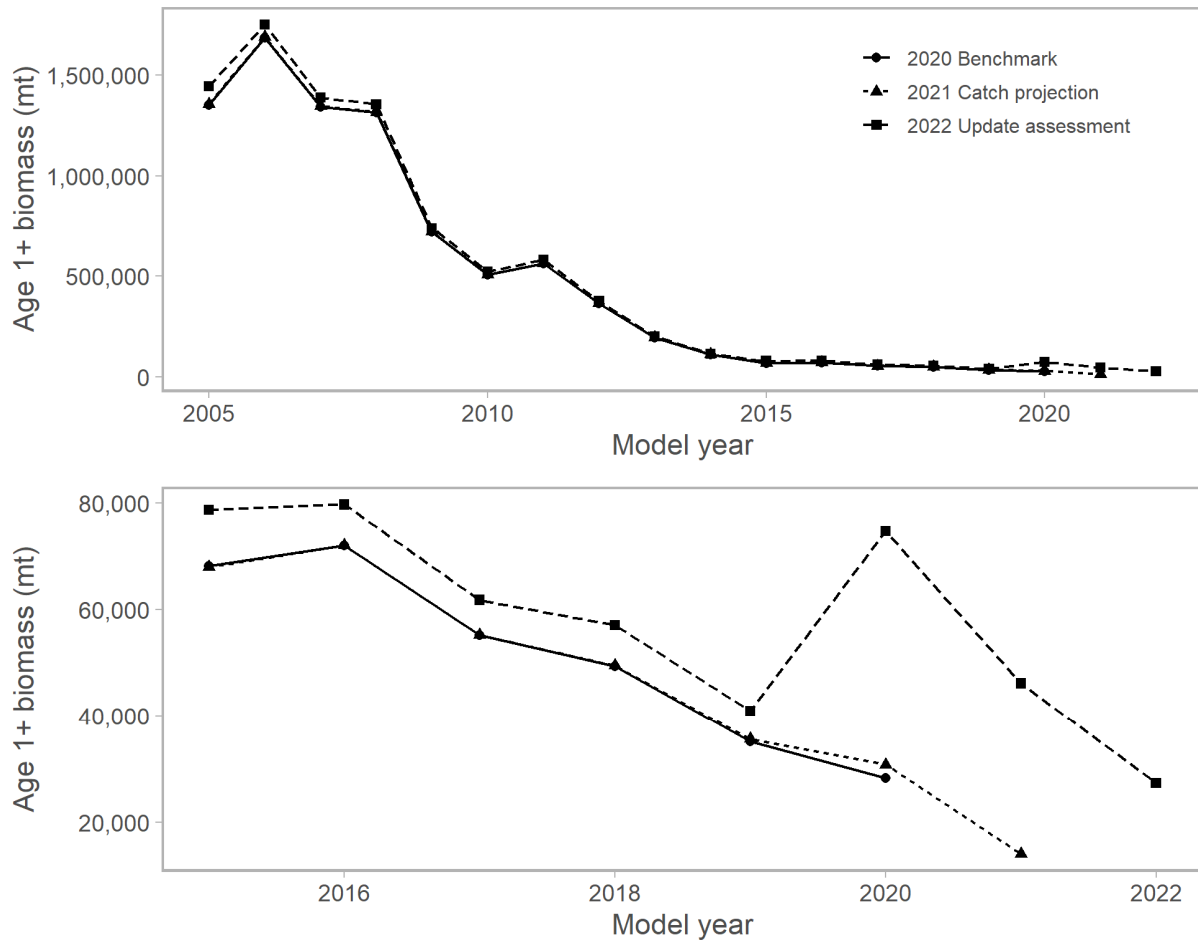
**Table 3:** Catch values and associated  $F$  values estimated in model year 2021 in the update assessment. The  $F$  values were input as values for model year 2022 in the forecast file.

Calendar Y-S	Model Y-S	MexCal_S1		MexCal_S2		PNW	
		Catch	$F$ ( $\text{yr}^{-1}$ )	Catch	$F$ ( $\text{yr}^{-1}$ )	Catch	$F$ ( $\text{yr}^{-1}$ )
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

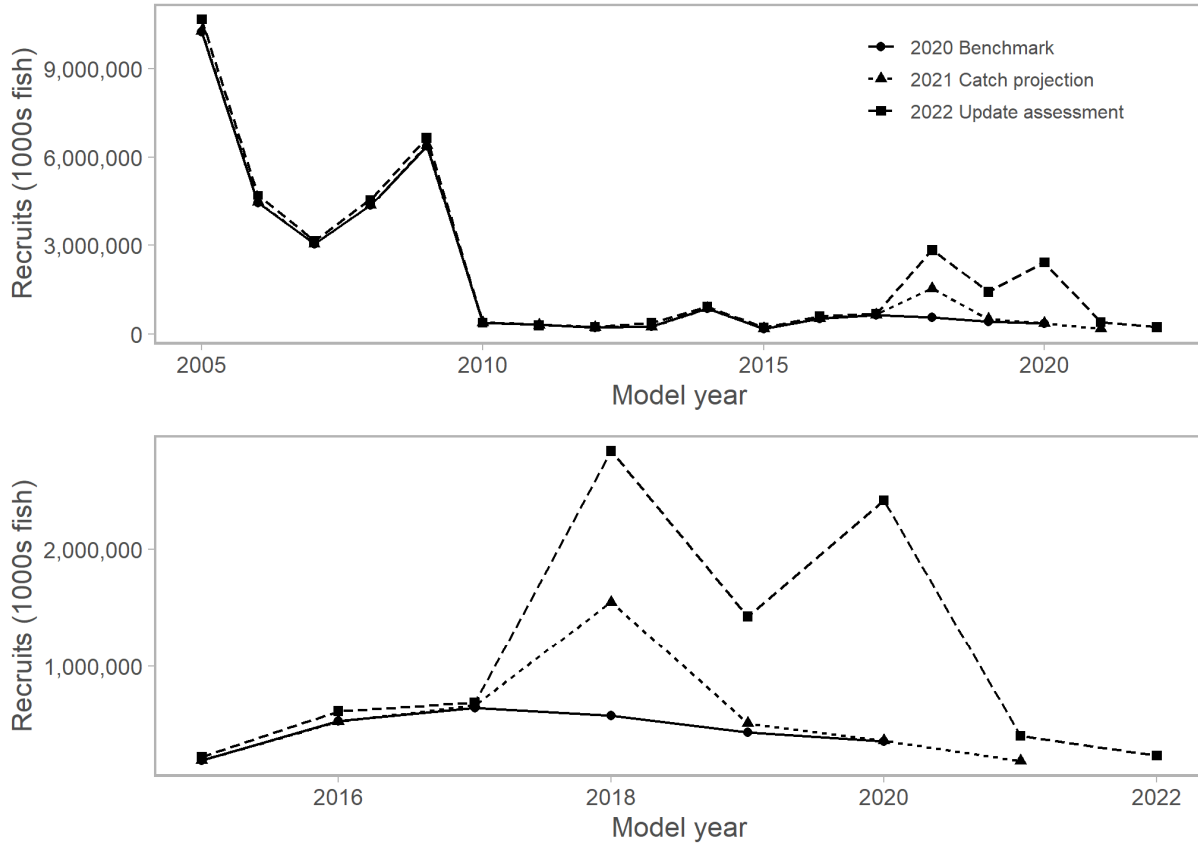
## Results

Summary biomass (age 1+) for the 2022 fishing year is forecast to be 27,311 mt (Figure 3), and recruitment is forecast to be 241 million age-0 fish (Figure 4). The update assessment estimated higher recruitment events in 2018, 2019, and 2020 (Figure 4), 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).



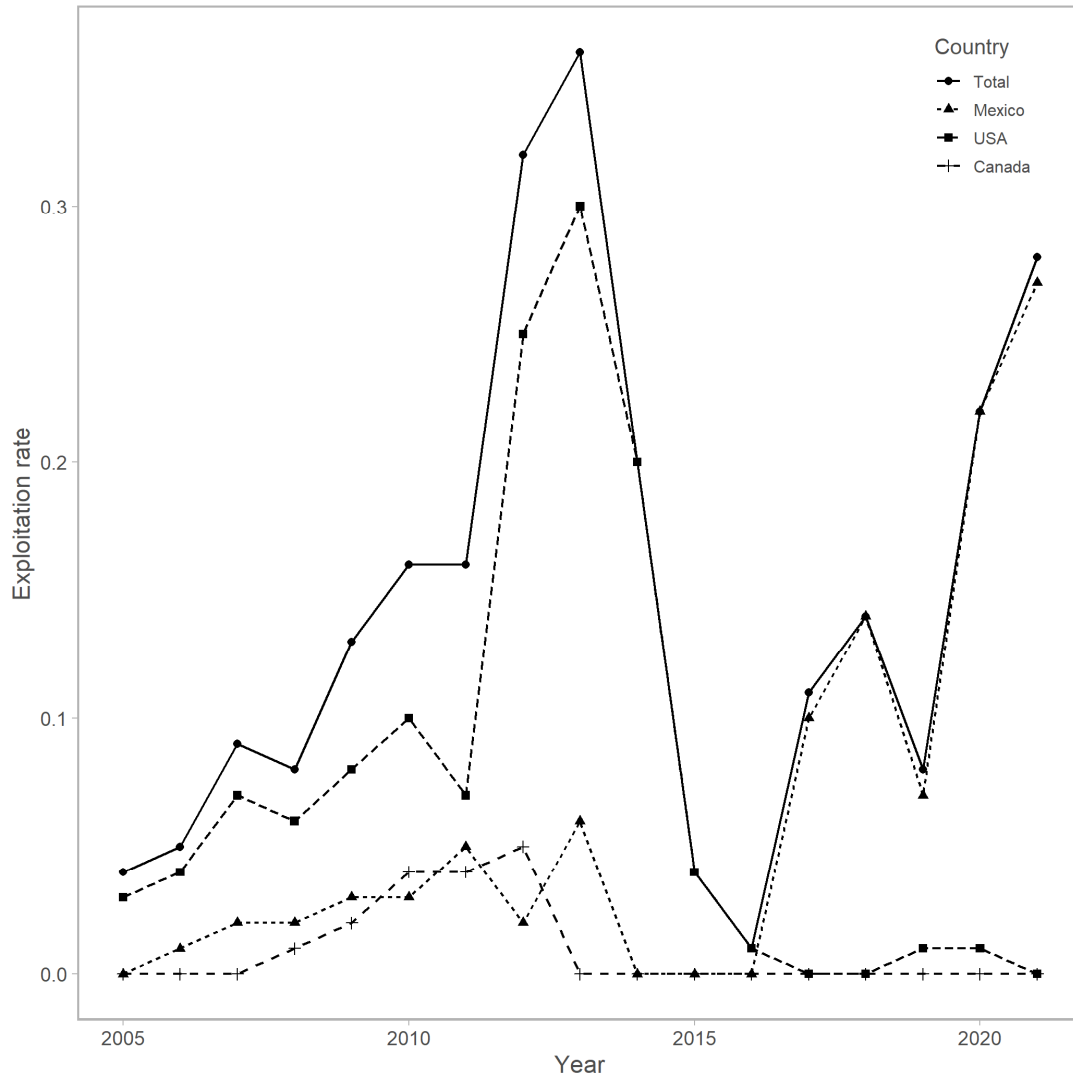
**Figure 3:** Time series of summary biomass (age 1+; mt) for the 2020 benchmark assessment (circles), 2021 catch-only projection (triangles), and 2022 update assessment (squares). The last point of each line is the forecast summary biomass.



**Figure 4:** 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 (Figure 5). 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 (Figure 4).



**Figure 5:** 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 27,331 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  $\sigma=0.5$ ; Tier 2  $\sigma=1.0$ ). Note that Table 4 is preliminary (indicated by italicized and gray values) as the CalCOFI SST has not yet been updated for 2021 but should be available at the review. Moreover, the most appropriate Sigmas for ABC Tiers will be established at the time of the review.

**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 <sub>P-star</sub> = BIOMASS * BUFFER <sub>P-star</sub> * $E_{MSY}$ * 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)	<b>27,331</b>									
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	
ABC Buffer <sub>(Sigma 0.5)</sub>	0.93910	0.88102	0.82476	0.76936	0.71373	0.65651	0.59558	0.52688	0.43936	
ABC Buffer <sub>Tier 2</sub>	0.88191	0.77620	0.68023	0.59191	0.50942	0.43101	0.35472	0.27761	0.19304	
ABC Buffer <sub>Tier 3</sub>	0.77777	0.60248	0.46272	0.35036	0.25950	0.18577	0.12582	0.07707	0.03726	
Ca/COFI SST (2018-2020)	16.0140									
EMSY	0.239680									
FRACTION	0.239680									
CUTOFF (mt)	150,000									
DISTRIBUTION (U.S.)	0.87									
Harvest Control Rule Values (MT)										
OFL =	<b>5,699</b>									
ABC(Sigma 0.607) =	5,352	5,021	4,700	4,385	4,068	3,742	3,394	3,003	2,504	
ABCTier 2 =	5,026	4,424	3,877	3,373	2,903	2,456	2,022	1,582	1,100	
ABCTier 3 =	4,433	3,434	2,637	1,997	1,479	1,059	717	439	212	
HG =	<b>0</b>									

### 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 2020, 3.5% of the annual catch target (Table 6).

**Table 5:** Summary biomass (age 1+) estimated in this assessment, 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	Summary Biomass	OFL	ABC	ACL	ACT
2017-2018	61,830	16,957	15,497	8,000	
2018-2019	57,067	11,324	9,436	7,000	
2019-2020	40,940	5,816	4,514	4,514	4,000
2020-2021	74,722	5,525	4,288	4,288	4,000
2021-2022	46,175	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.

<b>Fishing-year</b>	<b>USA ACL</b>	<b>USA ACT</b>	<b>USA Landings</b>	<b>Mexico Landings</b>	<b>Canada Landings</b>
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

### 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 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 7, comparing the total (age 0+) biomass values across recent assessments. The increases in summary (age 1+) biomass values are shown in Table 8.

**Table 7:** Total biomass (age 0+; mt) estimated from the 2020 benchmark assessment (2020bench), 2021 catch-only projection (2021proj), and 2022 update.

Model Y-S	2020bench	2021proj	2022update
2018-1	62,012	62,516	70,561
2018-2	44,264	44,793	49,451
2019-1	60,689	103,697	165,383
2019-2	38,008	64,179	101,657
2020-1	47,548	53,428	137,450
2020-2	29,698	32,017	81,220
2021-1	NA	30,196	176,006
2021-2	NA	18,626	82,994
2022-1	NA	NA	49,184
2022-2	NA	NA	21,669

**Table 8:** Summary biomass (age 1+; mt) estimated from the 2020 benchmark assessment (2020bench), 2021 catch-only projection (2021proj), and 2022 update.

Model Y-S	2020bench	2021proj	2022update
2018-1	49,449	49,528	57,068
2018-2	27,003	26,954	30,977
2019-1	35,186	35,591	40,941
2019-2	22,444	22,628	25,981
2020-1	28,276	30,758	74,722
2020-2	17,936	18,186	43,175
2021-1	NA	14,011	46,176
2021-2	NA	8,752	18,460
2022-1	NA	NA	27,331
2022-2	NA	NA	10,807

### 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.

### References

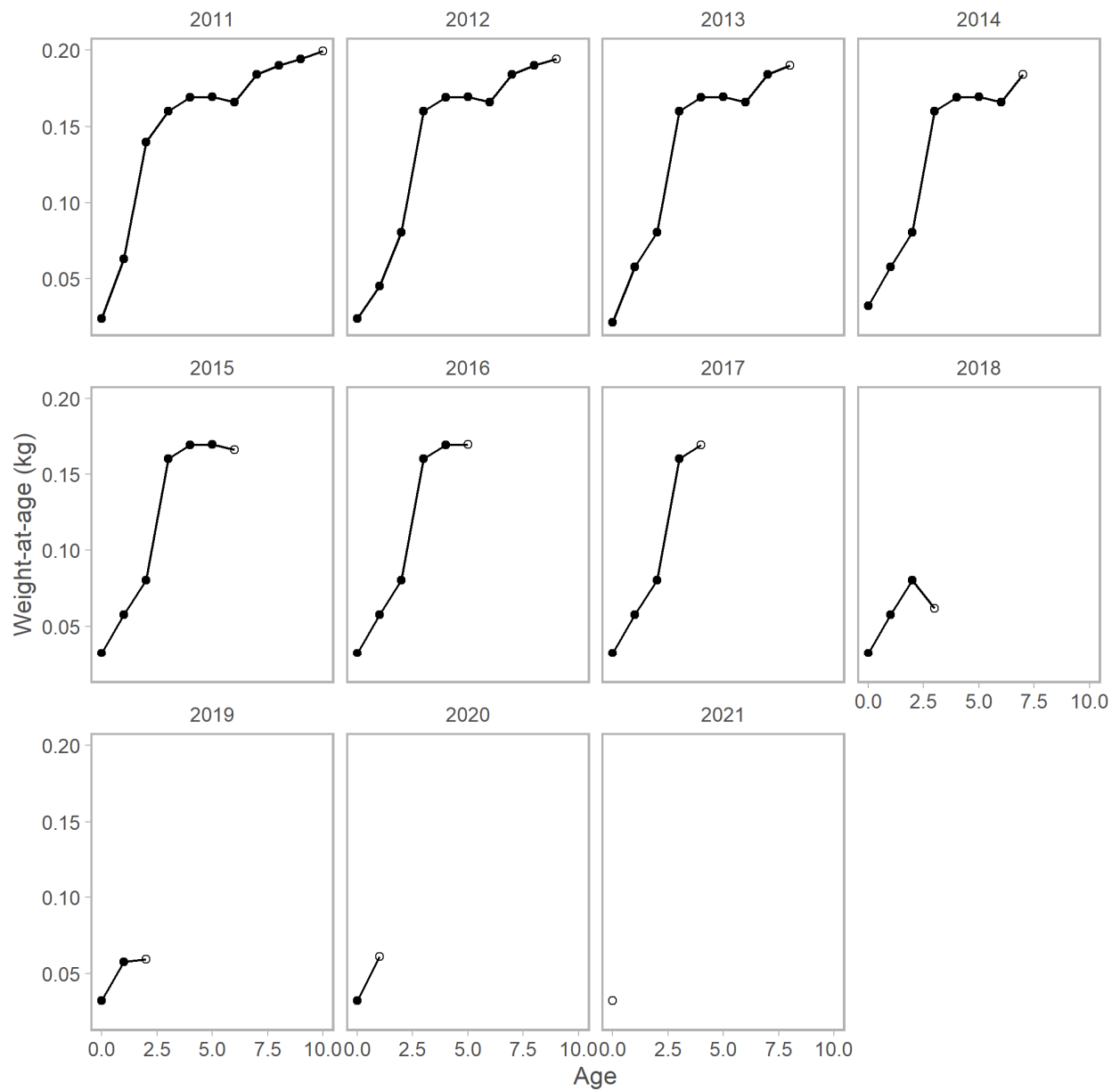
Hill, K.T., Kuriyama P. T., Crone, P.R. 2020. Pacific sardine rebuilding analysis based on the 2020 stock assessment. Pacific Fishery Management Council. Portland, OR.

Kuriyama, P.T., Zwolinski, J.P., Hill, K.T., Crone, P. R. 2020. Assessment of the Pacific sardine resource in 2020 for U.S. management in 2020-2021, U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-628.

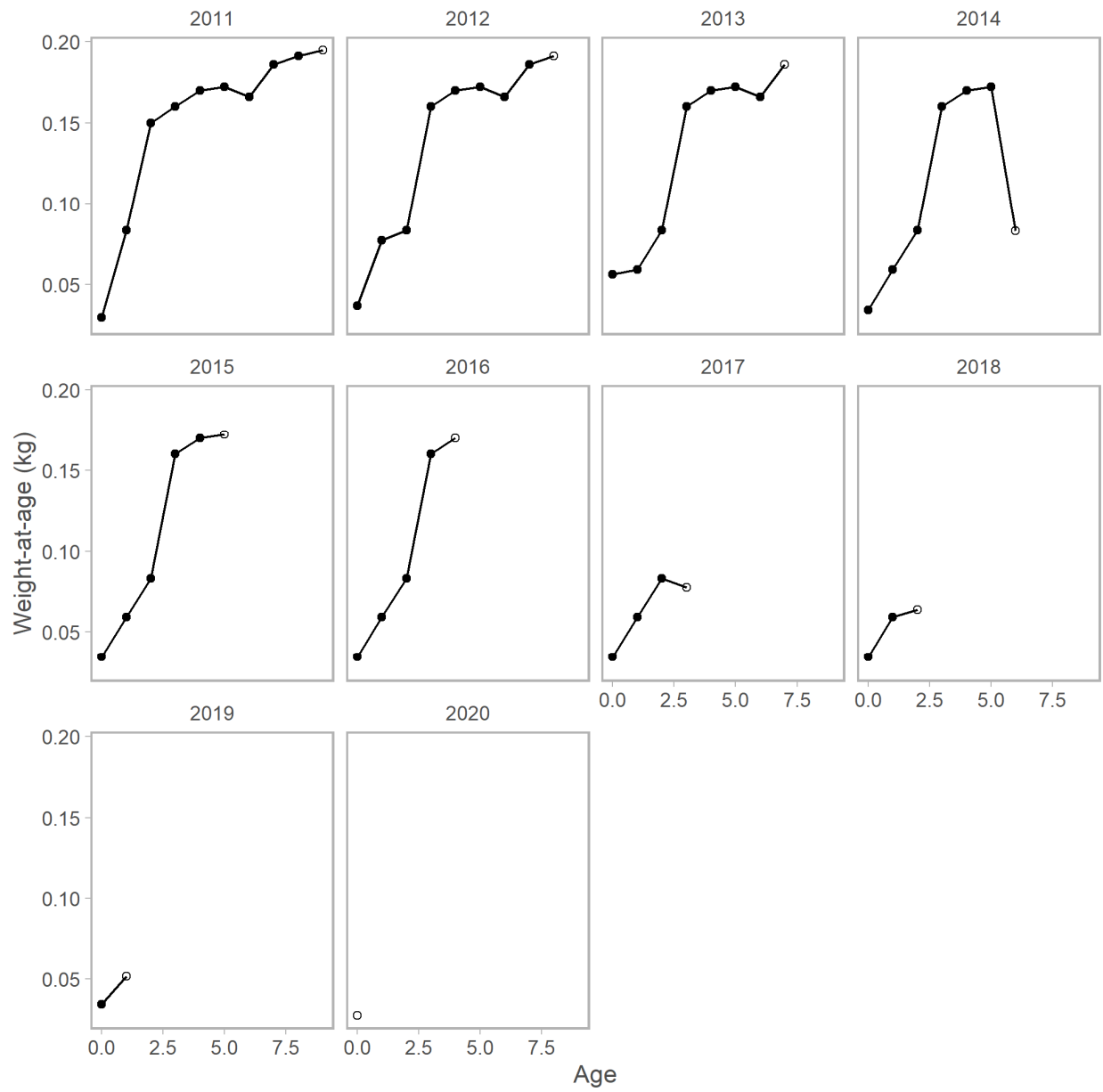
Kuriyama, P.T., Hill, K.T., Zwolinski, J.P. 2021. Assessment of the Pacific sardine resource in 2021 for U.S. management in 2021-2022, U.S. Department of Commerce

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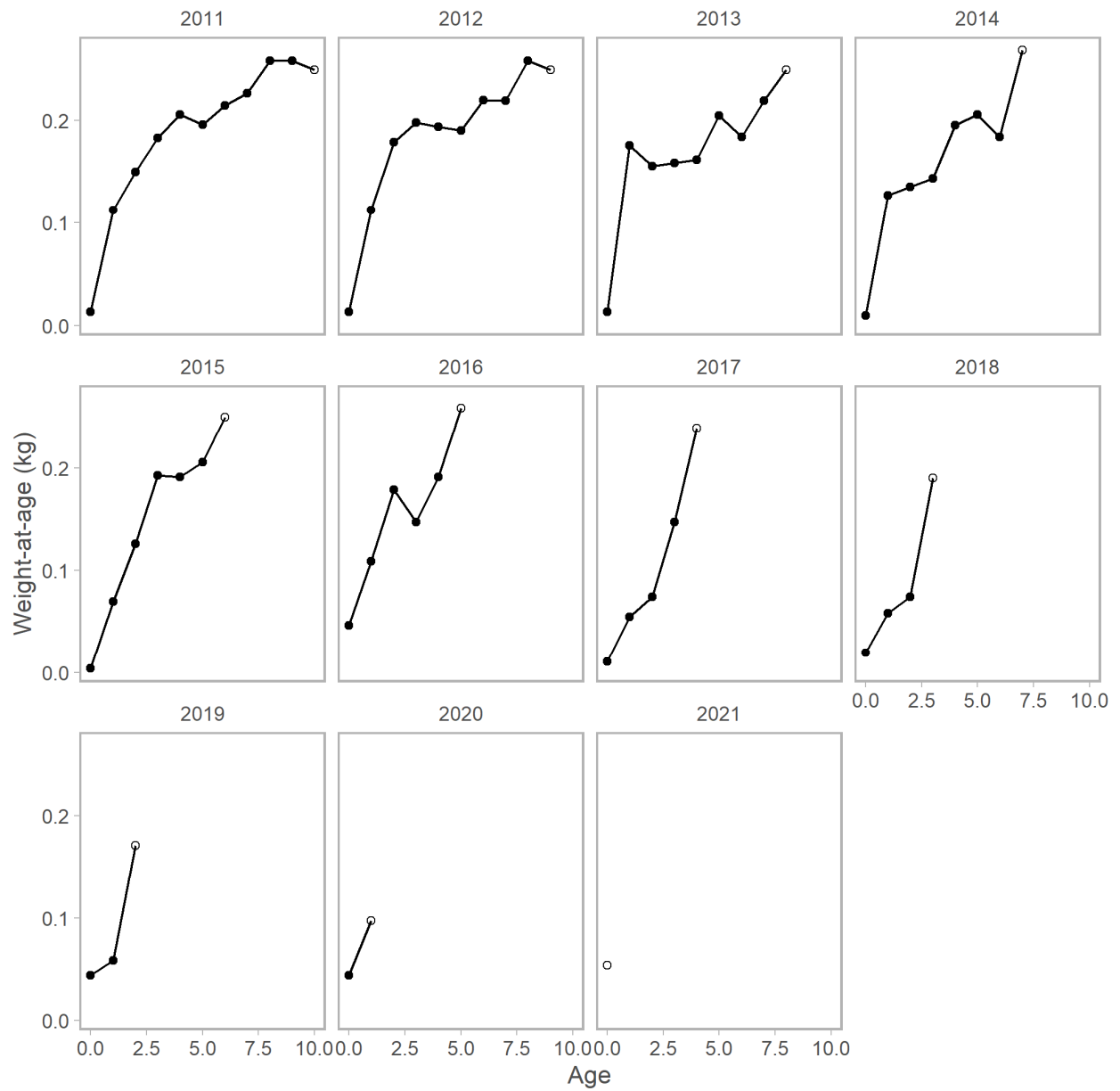
## Appendix A: r4ss Diagnostic Figures



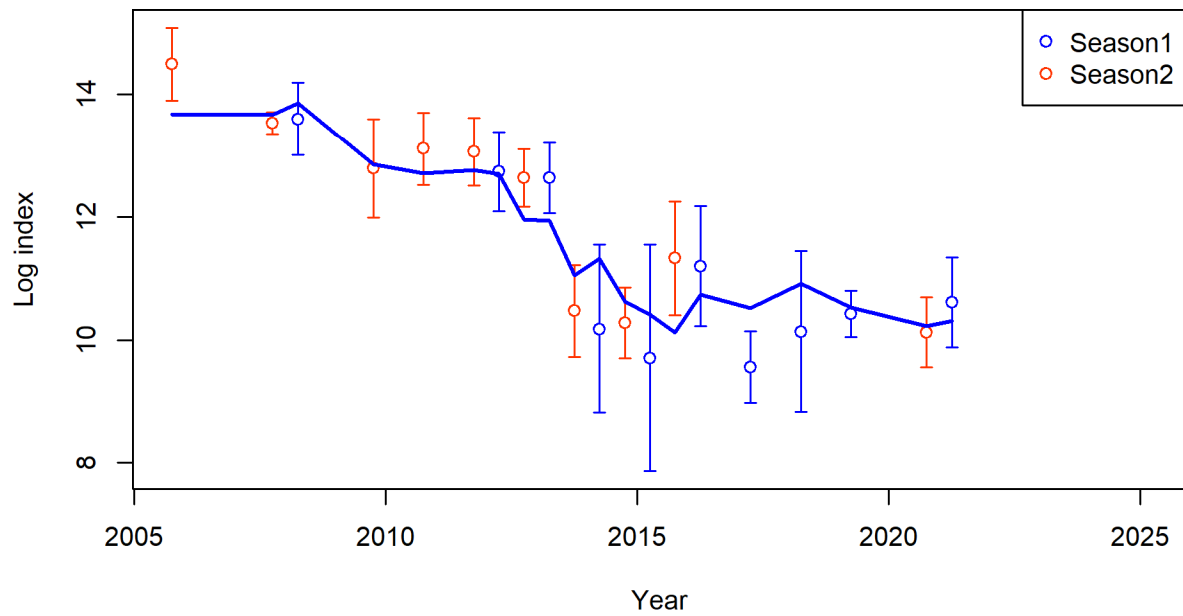
**Figure A1:** Weight-at-age values (kg) arranged by cohort for the MexCal S1 fleet. New values are indicated with open circles and previous values in solid points.



**Figure A2:** 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.

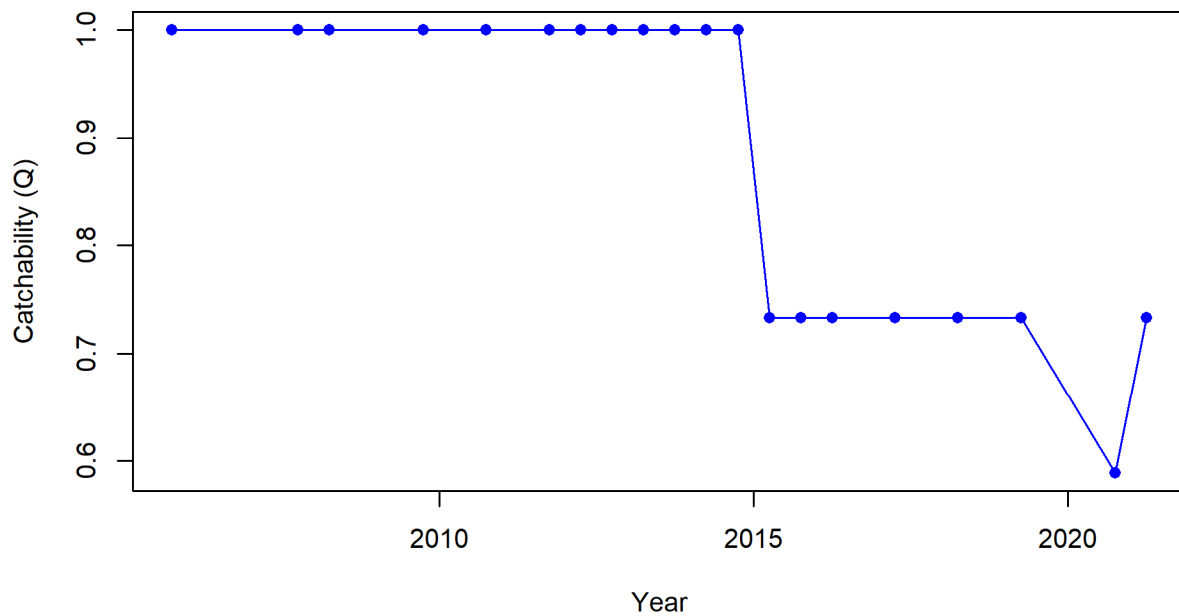


**Figure A3:** Weight-at-age values (kg) arranged by cohort for the AT survey. New values are indicated with open circles and previous values in solid points.

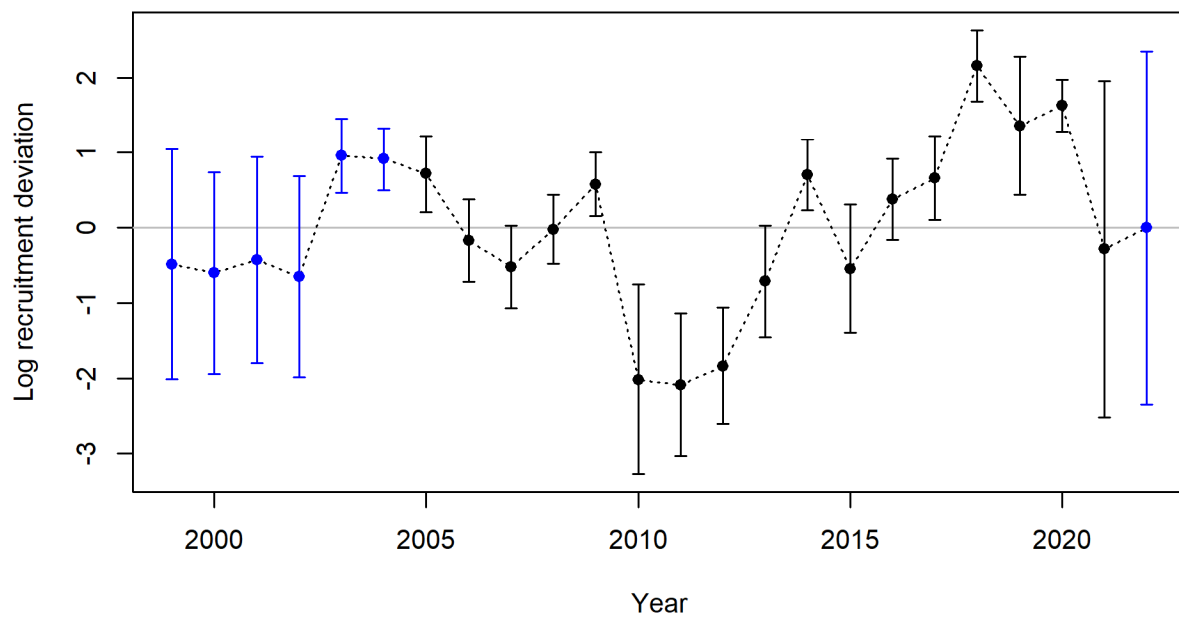


**Figure A4:** Fit to log-transformed index data for AT survey. Lines indicate 95% uncertainty interval around index values.

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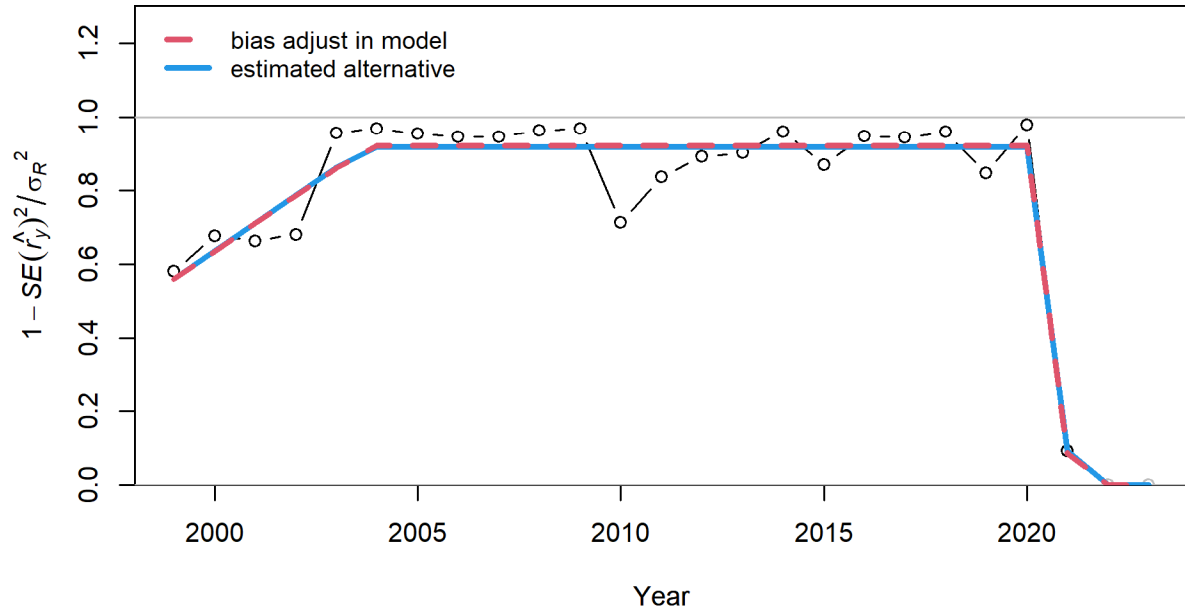


**Figure A5:** Catchability (Q) values input to the assessment. Starting in 2015, these values were calculated as a ratio of the AT survey observations and the aerial survey observations.



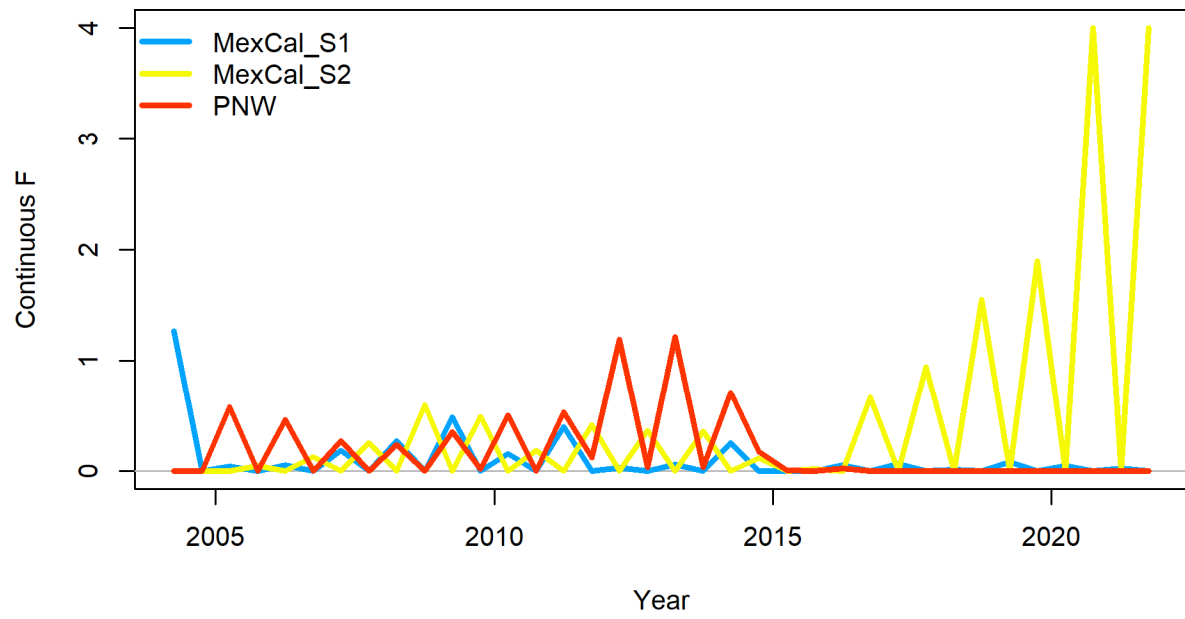
**Figure A6:** Recruitment deviations and standard errors.





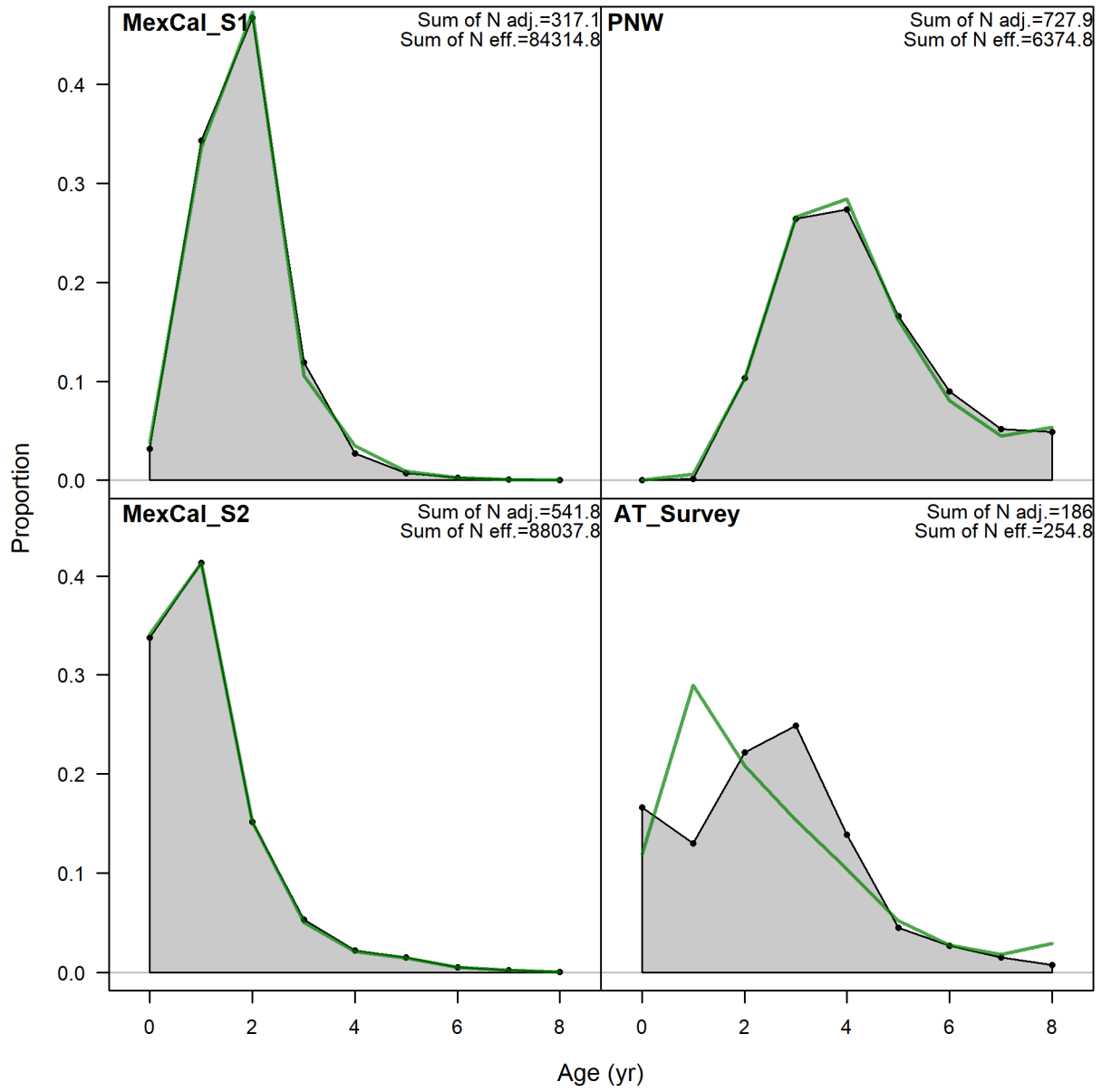
**Figure A7:** Recruitment bias adjustment plot for early, main, and forecast periods.

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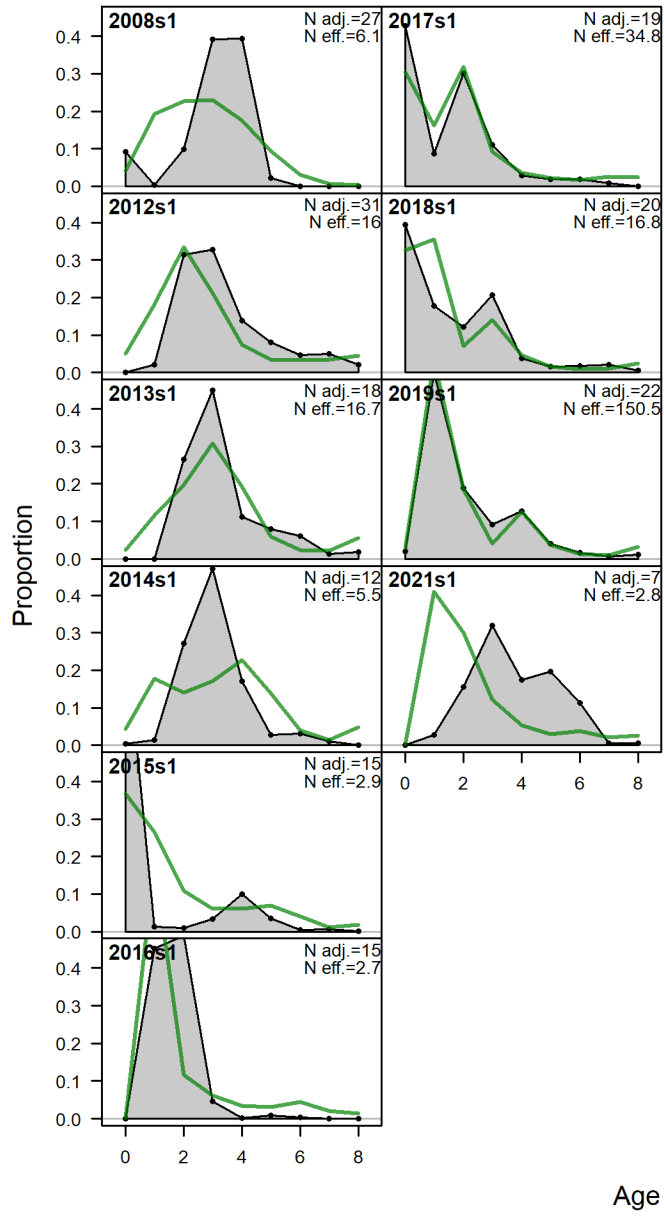


**Figure A8:** Instantaneous fishing mortality time series.

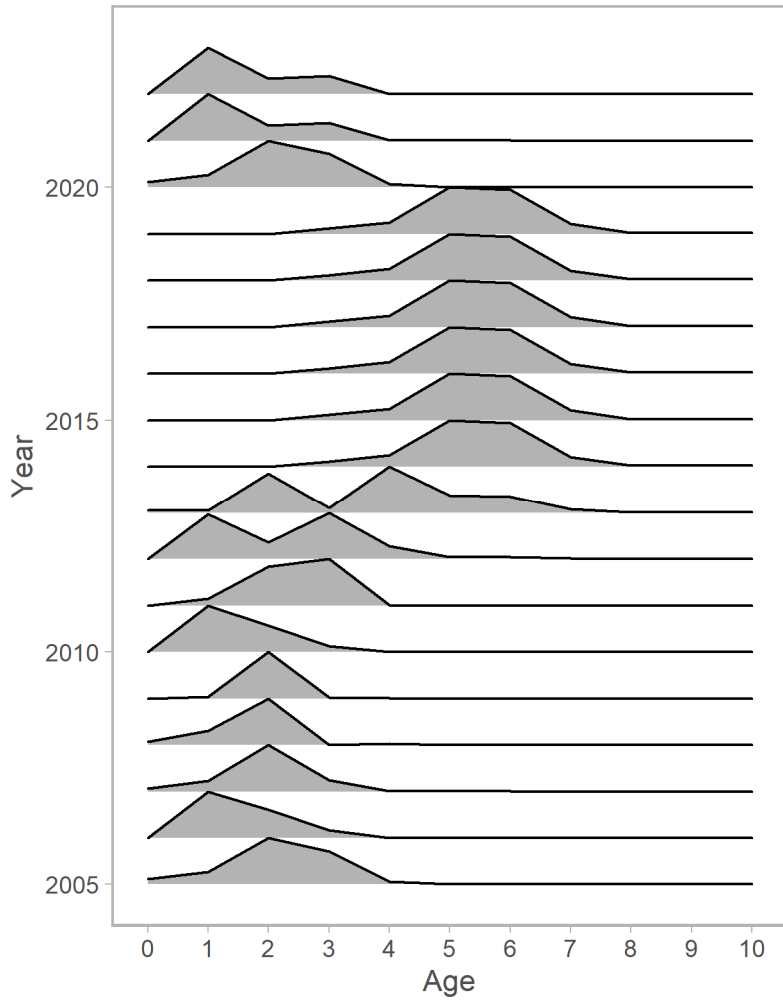
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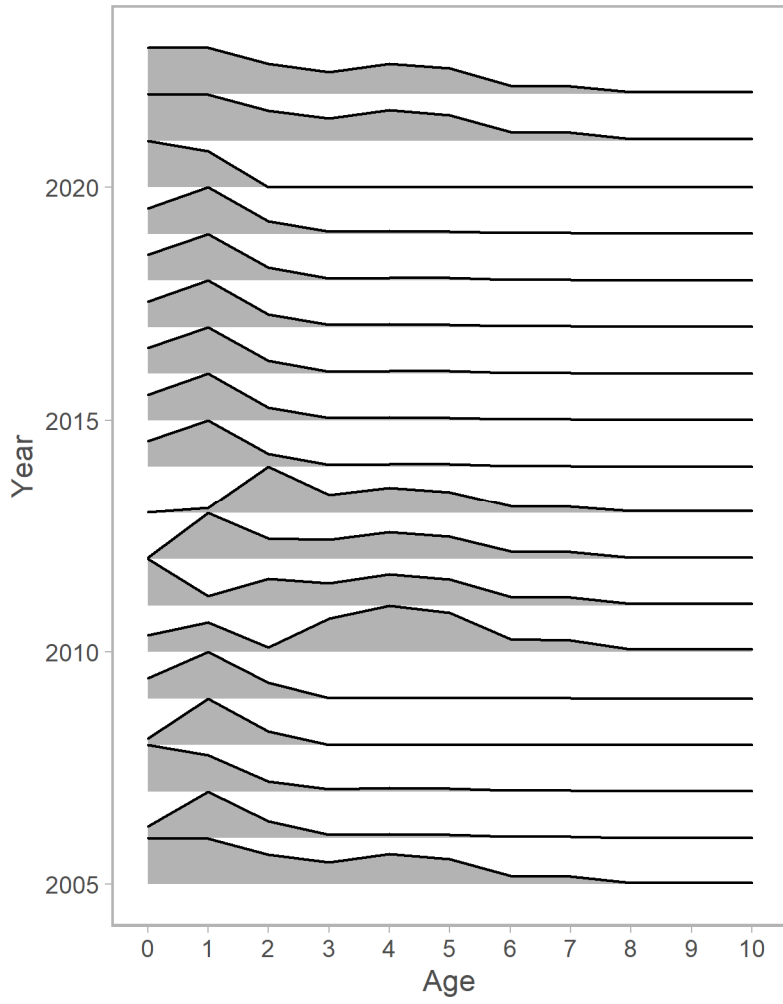
**Figure A8:** Fits to the aggregated age compositions, arranged by fleets.



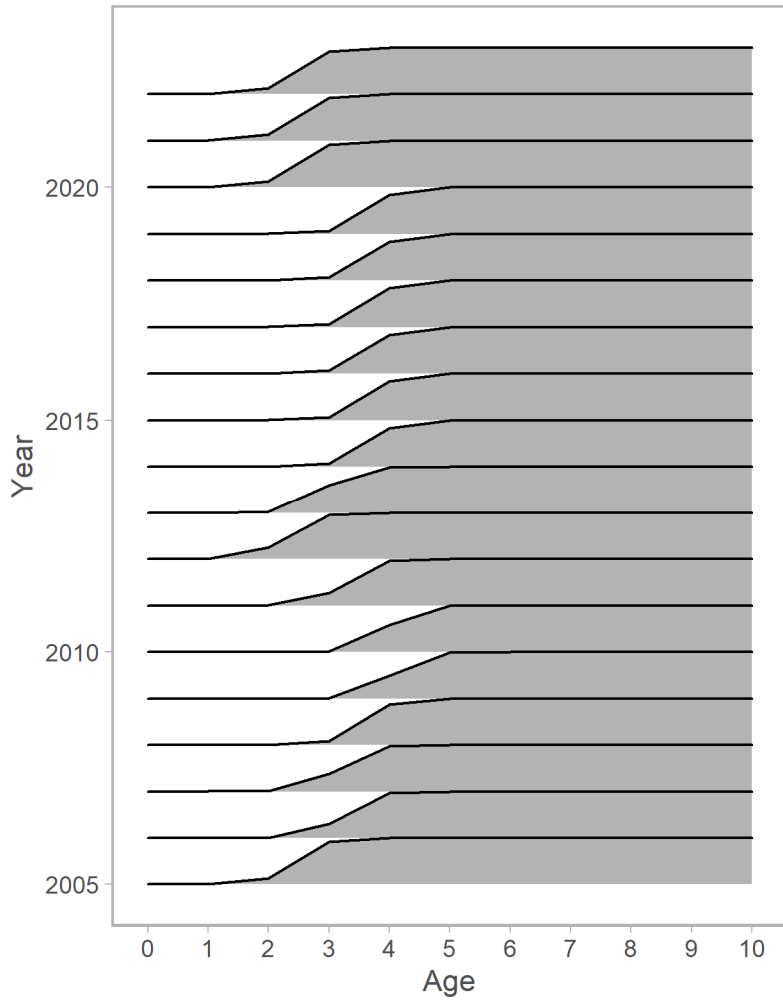
**Figure A9:** Fits to the AT survey age compositions by year.



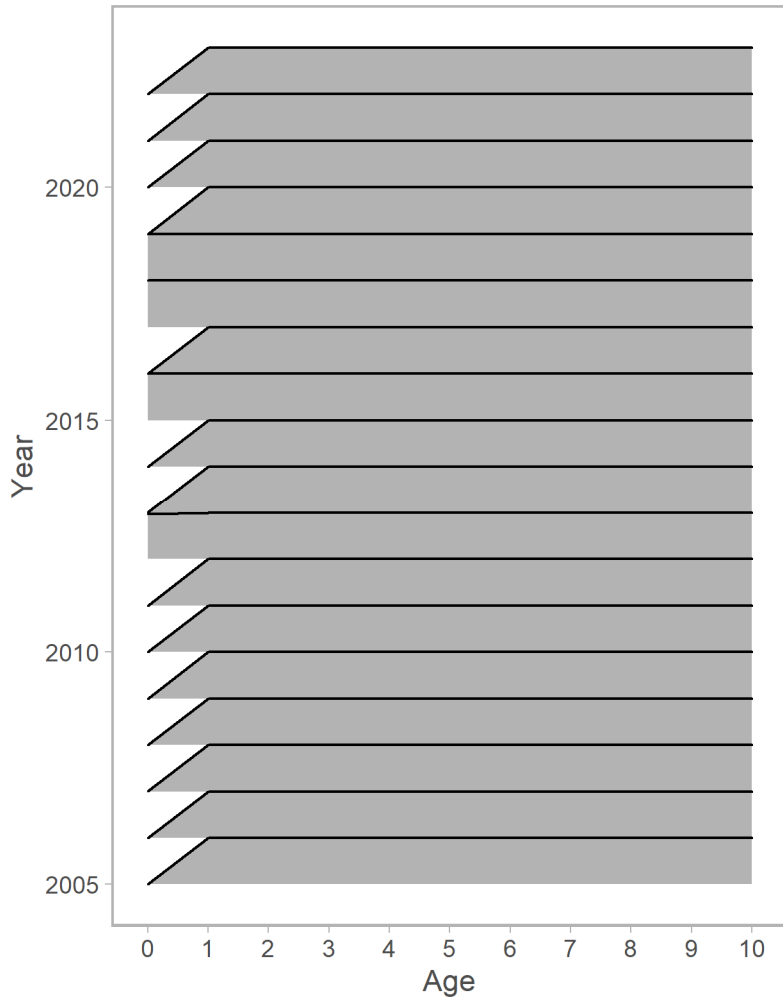
**Figure A10:** Time-varying age-based selectivity patterns for MexCal S1.



**Figure A11:** Time-varying age-based selectivity patterns for MexCal S2.



**Figure A12:** Time-varying age-based selectivity patterns for PNW.



**Figure A13:** Time-varying age-based selectivity patterns for AT survey.