Appendix B: Stock Synthesis Evaluation of Kodiak Shelikof

Tyler Jackson
Alaska Department of Fish and Game, tyler.jackson@alaska.gov

March 2023

Purpose

This document furthers efforts by Zheng (2018) and Jackson (2022) to evaluate population dynamics of weathervane scallops *Patinopecten caurinus* using the Stock Synthesis (Methot and Wetzel 2013). This analysis focuses solely on the Kodiak Shelikof District in which there is an annual commercial fishery and biannual fishery independent survey since 2016 (Burt et al., 2021).

Data

Timeseries Data

- Annual landings estimated in units of round (i.e. whole animal) biomass (t) from 1993 - 2022. Log standard error of retained catch was assumed to be 0.01 (Table 1).
- Nominal catch-per-unit-effort (CPUE; lb / dredge hr) from the commercial fishery from 1993 - 2008 (Table 1).
- Standardized CPUE estimates (Appendix C) from the commercial fishery from 2009 - 2022 (Table 1).
- Estimated round biomass from the ADF&G Dredge Survey from 2016 - 2022 (Table 2).
- Shell height composition from the commercial fishery 2009 - 2022 and the ADF&G Dredge Survey from 2016 - 2022.
- Size conditional age composition from the commercial fishery 2009 - 2021 and the ADF&G Dredge Survey from 2016 - 2022.

Population Dynamics Parameters

- Base natural mortality M was assumed to be 0.19 yr^{-1} (Jackson and Zheng 2022; Zheng 2018).
- Round weight at shell height parameters were estimated from ADF&G Dredge Survey data (2016-2022) using the equation $W = \alpha SH^{\beta}$ to be $\alpha = 1.21 \times 10^{-4}$ and $\beta = 2.86$.
- Size at maturity was estimated from ADF&G Dredge Survey data using logistic regression (Jackson et al. 2021). Size at 50% maturity (SM$_{50}$ = 7.3 cm) and slope of the regression equation (β_1 = -1.5) were used in this analysis.
- Dredge survey catchability is assumed full (i.e., $Q = 1$) as a gear efficiency coefficient ($q = 0.83$) was applied outside of the model.

Model

Stock Synthesis (Methot 1989, 1990; Methot and Wetzel 2013) is a generalized age and size structured population dynamics model implemented in ADMB (Fournier et al. 2012). It contains a population sub-model to model growth, maturity, fecundity, recruitment, movement, and mortality, an observation sub-model to estimate expected values, a statistical sub-model to evaluate goodness of fit, and a forecast sub-model to project management quantities (Methot et al. 2020). Technical details of the modelling framework can be found in Methot (2000) and Methot and Wetzel (2013).

Model Structure

- Size structure consisted of 33 shell height bins ranging from 2.1 cm to 18.1+ cm.
- Age structure consisted of 18 age bins (ages 1 - 18+).
- The modeled timeseries spans from 1992 - 2022.
- Each modeled year includes a single 12 month season (April - March) with model processes occurring at the following time steps:
  - The ADF&G Dredge Survey occurs in May (month 2).
  - Spawning occurs in June (month 3).
  - The month that the fishery occurs varies from July (month 4) to January (month 10).

Assumptions

Assumptions specific to models presented here include:

1. Males and females are combined in all model processes, and the sex ratio was assumed to be 50:50.
2. Natural mortality (0.19 yr^{-1}) is kept constant across all sizes and modeled years.
3. Shell height at age is estimated using the Schnute (1981) parametrization of von Bertalanffy growth model. The minimum age for von Bertalanffy growth is age-0 and the age at maximum shell height is age-18.
4. Round weight at shell height is allometric and estimated outside of the model (see above).
5. Maturity is a logistic function of shell height and estimated outside of the model using survey gonad condition data. Individuals can first become mature at age-3.
6. Egg production (i.e. fecundity) is assumed to be equal to spawning biomass.
7. Annual recruitment is estimated using with unconstrained annual recruitment deviations distributed $\mathcal{N}(0, 2)$.
8. Catchability (Q) was estimated as a proportional scalar for both fishery CPUE indices separately, and is constant across years.
9. Fishery and survey selectivities (i.e., size and age) are estimated as a logistic function of shell height, and are constant across years. All models assumed selectivity was based on shell height and not age.

Scenarios Evaluated

The following model scenarios are presented in this report:

- **22.1a**: Model KSH22.1 (Jackson 2022) with updated 2022 ADF&G Dredge Survey biomass and size and age composition data, as well as 2022/23 fishery catch, CPUE (based on retained catch), and size composition data.

- **23.0**: Model 22.1a including fishery discarded catch from 1996/97-2022/23 and size composition from 2009/10-2022/23.
- **23.0a**: Model 23.0 with extra standard error on standardized fishery CPUE from 2009/10-2022/23.
- **23.0a1**: Model 23.0a without dredge survey size and age composition data from 2016 - 2018.
- **23.0a3**: Model 23.0a with down-weighted dredge survey size composition data from 2016 - 2018 ($0.5 \cdot N_{eff}$).
- **23.3**: Model 23.0a with full dredge survey selectivity (i.e. selectivity = 1) across all size classes.

Results and Discussion

All model scenarios reached convergence and estimated parameters within bounds, with the exception of a dredge survey selectivity parameter in models 22.1a and 23.0a1 approaching the lower bound. Models 22.1a, 23.0 and 23.0a fit pre-2008 nominal fishery CPUE better than other models (Figure 1; Table 4), while models 22.1a, 23.0, 23.0a, and 23.0a3 resulted in the best fits to 2009 - 2022 standardized fishery CPUE (Figure 2; Table 4). Fit to dredge survey biomass was best in models 23.0a and 23.0a3, and was poor in model 22.1a (Figure 3; Table 4).

All models generally captured the shell height composition of discarded and retained scallops in most years (Figure 4 - 6), with models 23.0a1 and 23.0a3 having slightly better fits overall (Table 4). All models tend to over estimate the proportion of scallops in size classes greater than 150 mm and especially the plus group ($\geq$ 180 mm), suggesting some mispecification of mortality associated with those size classes. Fits to dredge survey shell height composition were poor for all models from 2016-2018, but were adequate for 2020 and 2022 (Figure 7). From 2016 - 2018 the dredge survey was still under development while gear rigging and on-deck sampling methods were not fully standardized until 2020. Shell height selectivity in the fishery was similar among models that partitioned discarded and retained shell height compositions (all 23.x models), but was slightly lower for model 22.1a (Figure 8; Table 5). Models that estimated dredge survey selectivity had difficulties doing so. Models 22.1a and 23.0a1 had parameter β_2 approaching its lower bound of zero, which brings selectivity to approximately 1 across all sizes. Models 23.0, 23.0a, and 23.0a3 estimated unusually low selectivities (Figure 8; Table 5), which led to a much larger resulting spawning stock biomass for those models (Figure 32 - 33). The precise cause of these discrepancies is unclear, but there seems to be support for full selectivity based on the large proportion of small scallops (i.e., < 100 mm) in the observed shell height composition and the gear design (i.e., the dredge employs a 38 mm mesh liner, Burt et al. 2021). Fits to age composition data were similar among all models for both the fishery and dredge survey. Generally, all models underestimated mean age of the largest size classes (Figure 10 - 23).

Recruitment trends were similar among all models, though the scale of recruitment pulses varied by model (Figure 24 - 25; Table 5). Models 23.0, 23.0a, and 23.0a3 tended to estimate the largest recruitment through much of the timeseries. All models estimated a large recruitment pulse in 2021, which will likely be refined in future modelling efforts, since recruitment estimates are solely based on the high proportion of scallops < 50 mm caught in the 2022 dredge survey. It is noteworthy that models 22.1a, 23.0a1, and 23.3 estimated substantially lower recruitment in 2021 than other models, which relates to the estimated shell height selectivity in the dredge survey.

Spawning stock biomass (SSB) increased in the early years of the timeseries and peaked in the mid-1990s, before decreasing until 2001. Following 2001, SSB increased steadily until peaking again in 2005-2007 and decreasing to the lowest levels of the timeseries in 2017, which coincides with the lowest retained catch in the timesries (Table 1). Trends in SSB begin to diverge by model scenario after ~ 2018 with 23.0a1 and 23.3 undergoing a modest increase to levels lower than the 2005-2007 peak, 22.1a and 23.0a3 undergoing more drastic increases that were the highest values in the timerseries, and 23.0 and 23.0a undergoing near exponential increases which are still climbing (Figure 32 - 33). Models 23.0a1 and 23.3 appear to yield the most realistic timeseries trend in SSB based on what is known about the management history of the stock.

Model 23.3 had considerably less retrospective bias in both SSB (Mohn's ρ = -0.058) and recruitment (Mohn's

ρ = -0.074) than did other models (Figures 34 - 45). Retrospective patterns for models 22.1a - 23.0a3 were likely related to poor fits to dredge shell height composition data from 2016 - 2018 and associated issues with estimating selectivity.

Author's Recomendation

Despite model 23.3 having the most probable trend in SSB and least retrospective bias, it did not fit fishery CPUE and dredge survey biomass as well as other models (Table 4). The author recommends continuing to explore model 23.3 as well as 23.0a, which resulted in the best overall fit among other models (Table 4). Specifically, further work should focus on

- Recovering 1992 - 2008 fishery CPUE data to compute a standardized index and more informed standard error.
- Recovering fishery shell height composition data pre-2009, and adding age composition data from 2020 - present.
- Improving model 23.3 fits to relative abundance indices.
- Exploring dredge survey catchability (currently applied outside of the model), including timevarying catchability to account for standardization of survey methods from 2016 - 2018 and after 2023 (new survey dredge).
- Continuing to troubleshoot estimation of dredge survey selectivity.

Literature Cited

Burt, R., M. Byerly, A. Hopkins, T. Jackson, and K. McNeel. 2021. Weathervane scallop dredge survey operational plan, 2021–2023. Alaska Department of Fish and Game, Division, Division of Commercial Fisheries, Regional Operational Plan No. ROP.CF.4K.2021.09, Kodiak.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods Software 27: 233-249.

Jackson, T., R. Burt, and A. Hopkins. 2021. 2019–2020 Weathervane scallop dredge survey report. Alaska Department of Fish and Game, Fishery Data Series No. 21-16, Anchorage.

Jackson, T., J. Zheng. 2022. Size and age structured modelling of weathervane scallops using Stock Synthesis. *In* NPFMC (North Pacific Fishery Management Council). 2022. Stock Assessment and Fishery Evaluation (SAFE) Report for the Weathervane Scallop Fishery off Alaska. North Pacific Fishery Management Council, 605 West 4th Ave, Suite 306. Anchorage, AK.

Jackson, T., A. Hopkins, and R. Burt. *in press*. Weathervane scallop dredge survey, 2022. Regional Information Report.

Methot, R.D., 1989. Synthetic estimates of historical and current biomass of northern anchovy, Engraulis mordax. American Fisheries Society Symposium 6: 66–82.

Methot, R.D., 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. International North Pacific Fisheries Commission Bulletin 50: 259–277.

Methot, R.D., 2000. Technical description of the Stock Synthesis assessment program. NOAA Tech Memo. NMFS-NWFSC-43.

Methot, R.D., and C.R. Wetzel. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142: 86-99. Methot R.D., C.R. Wetzel, I.G. Taylor, and K. Doering. 2020. Stock Synthesis user manual version 3.30.16. NOAA Fisheries, Seattle WA.

Zheng, J. 2018. Evaluation of a Stock Synthesis Approach to Assess Weathervane Scallops in Kamishak Bay, Alaska. Presentation to the NPFMC Scallop Plan Team, February, 2018.

Tables

Table 1: Retained round weight of catch and discard mortality, catch per unit effort indices (1993-2008; 2009-2022) and associated standard errors for the Kodiak Shelikof District.

Year	Retained Catch (t)	Discard Mortality (t)	CPUE Index	Index ln σ
1993	530.55		0.246	0.40
1994	1,566.18		0.256	0.40
1995	Closed			
1996	851.51	17.87	0.246	0.40
1997	1,405.22	8.45	0.256	0.40
1998	965.26	19.61	0.237	0.40
1999	862.71	26.27	0.201	0.40
2000	802.12	11.66	0.276	0.40
2001	830.19	21.70	0.244	0.40
2002	842.53	45.00	0.222	0.40
2003	782.22	36.51	0.240	0.40
2004	744.62	39.50	0.215	0.40
2005	659.37	21.20	0.289	0.40
2006	636.9	21.30	0.292	0.40
2007	769.09	34.18	0.262	0.40
2008	931.64	2.93	0.283	0.40
2009	775.71	28.84	0.883	0.03
2010	836.21	31.40	0.951	0.02
2011	650.28	10.49	1.014	0.02
2012	451.05	10.41	0.877	0.03
2013	409.83	6.55	0.728	0.04
2014	277.66	3.33	0.674	0.04
2015	195.14	4.59	0.655	0.05
2016	120.14	3.96	0.561	0.06
2017	95.83	3.36	0.737	0.06
2018	108.73	13.49	0.922	0.05
2019	112.91	10.41	1.277	0.04
2020	185.59	4.53	2.021	0.02
2021	391.81	16.47	2.097	0.02
2022	442.64	18.12	1.977	0.02

Table 2: Dredge survey round biomass and associated standard errors for the Kodiak Shelikof District.

Year	Biomass (t)	ln σ
2016	949	0.16
2017	959	0.17
2018	1,886	0.17
2020	4,049	0.18
2022	5,248	0.20

Table 3: Number of estimable parameters by model scenario.

Process	22.1a	23.0	23.0a	23.0a1	23.0a3	23.3
Growth	5	5	5	5	5	5
Initial Numbers-at-Age	17	17	17	17	17	17
Virgin Recruitment	1	1	1	1	1	1
Recruitment Deviations	32	32	32	32	32	32
Catchability	2	2	3	3	3	3
Selectivity	4	4	4	4	4	2
Retention	0	2	2	2	2	2
Total	61	63	64	64	64	62

Table 4: Likelihood components by model scenario.

Process	22.1a	23.0	23.0a	23.0a1	23.0a3	23.3
Total	1,850.670	2,283.240	2,064.390	1,643.200	1,713.760	2,023.270
Catch	1.140e-10	2.389e-11	4.182e-11	5.916e-10	1.159e-10	4.599e-10
Discards		290.677	303.024	277.889	289.804	289.401
Recruitment Deviations	3.143	8.971	9.872	7.340	9.153	7.563
CPUE 1992-2008	-12.666	-12.709	-12.641	-10.495	-11.946	-10.255
CPUE 2009-2022	101.576	135.019	-16.877	-3.445	-16.843	-1.714
Survey Biomass	118.316	0.403	-3.089	3.423	-4.083	9.228
Fishery Length Comp.	194.700	435.175	417.418	384.878	386.402	427.855
Survey Length Comp.	207.743	198.960	185.012	29.950	110.848	126.899
Fishery Age Comp.	560.563	555.656	548.610	529.043	543.914	531.135
Survey Age Comp.	452.618	399.826	371.312	134.687	134.854	372.953
Fishery Size at Age	104.093	146.245	130.950	149.250	137.658	137.340
Survey Size at Age	118.869	123.195	129.693	139.441	132.763	131.810
Parameter Priors	1.704	1.821	1.108	1.232	1.239	1.049

Table 5: Select parameter estimates for each model scenario. Parameters estimates approaching bounds are denoted by red text and (*) denotes fixed parameters.

Parameter	Bounds	22.1a	23.0	23.0a	23.0a1	23.0a3	23.3
Natural Mortality*		0.190	0.190	0.190	0.190	0.190	0.190
LvB L_1	(-1, 8)	2.388	2.273	2.438	2.171	2.169	2.409
LvB L_2	(5, 20)	16.725	16.638	16.652	16.616	16.588	16.667
LvB κ	(0.05, 0.35)	0.226	0.230	0.217	0.242	0.231	0.231
CV growth < min SH	(0.05, 1.5)	0.173	0.162	0.170	0.135	0.151	0.151
CV growth > max SH	(0.01, 1.25)	0.072	0.076	0.076	0.082	0.082	0.077
Weight-at-SH α*		1.480e-04	1.480e-04	1.480e-04	1.480e-04	1.480e-04	1.480e-04
Weight-at-SH β*		2.786	2.786	2.786	2.786	2.786	2.786
Size at 50% maturity*		7.300	7.300	7.300	7.300	7.300	7.300
Maturity Slope*		-1.500	-1.500	-1.500	-1.500	-1.500	-1.500
Log Virgin Rec	(1, 25)	9.302	9.723	9.670	8.610	9.246	8.597
SD Log Rec*		2.000	2.000	2.000	2.000	2.000	2.000
CPUE 2009-2022 ln Q	(-12, 5)	-8.184	-9.165	-8.898	-7.274	-8.242	-7.418
CPUE 2009-2022 extra σ	(0, 1)			0.151	0.443	0.152	0.505
CPUE 1993-2008 ln Q	(-12, 5)	-9.961	-10.550	-10.245	-9.868	-9.919	-10.044
Fishery Selectivity β_1	(2, 20)	11.002	11.728	12.238	12.117	12.290	11.953
Fishery Selectivity β_2	(0.01, 80)	3.408	2.811	2.953	3.036	2.938	3.078
Dredge Selectivity β_1	(0.01, 65)	1.106	43.125	29.473	1.182	21.064	
Dredge Selectivity β_2	(0.01, 80)	0.344	40.719	24.647	0.460	21.443	

Table 6: Unfished recruitment and unfished and forecasted spawning biomass for each model scenarios.

	22.1a	23.0	23.0a	23.0a1	23.0a3	23.3
Unfished SSB (t)	7,897	11,913	11,016	3,999	7,327	3,913
Unfished R (thousands)	10,957	16,691	15,841	5,485	10,364	5,415
Forecast (2023) SSB (t)	9,636	31,502	35,431	3,164	19,025	2,750

Figures

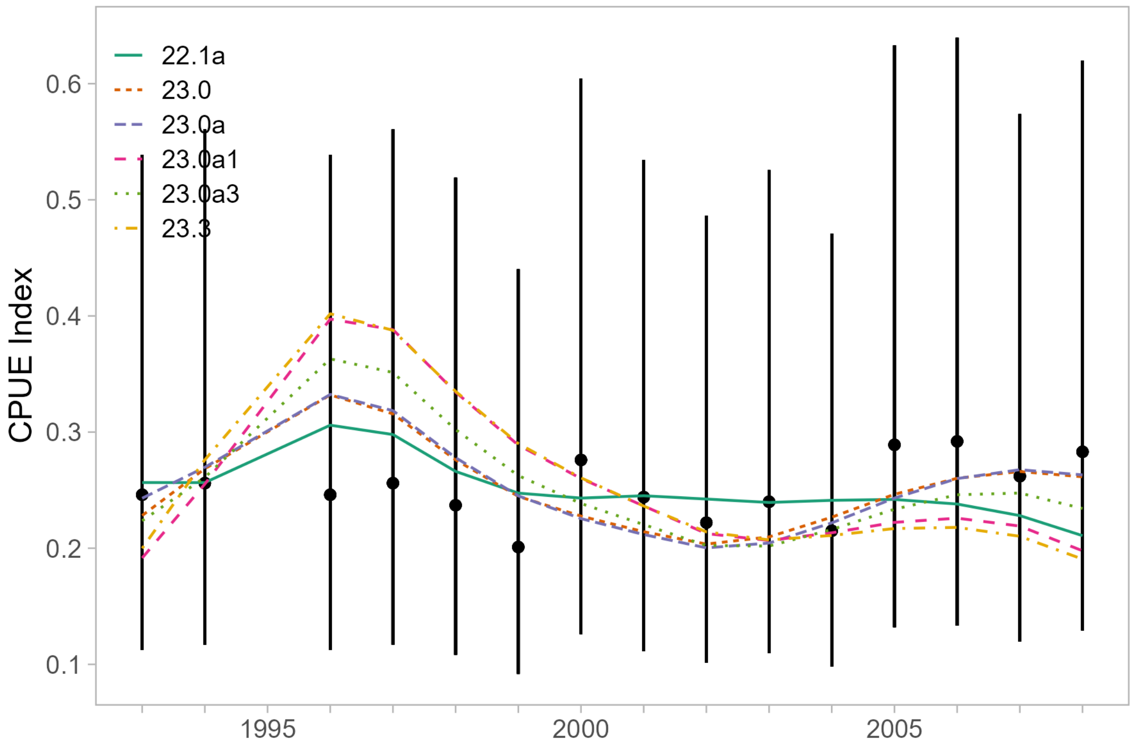

Figure 1: Fit to nominal fishery CPUE index from 1992-2008 by model scenario. Error bars indicate 95% confidence intervals.

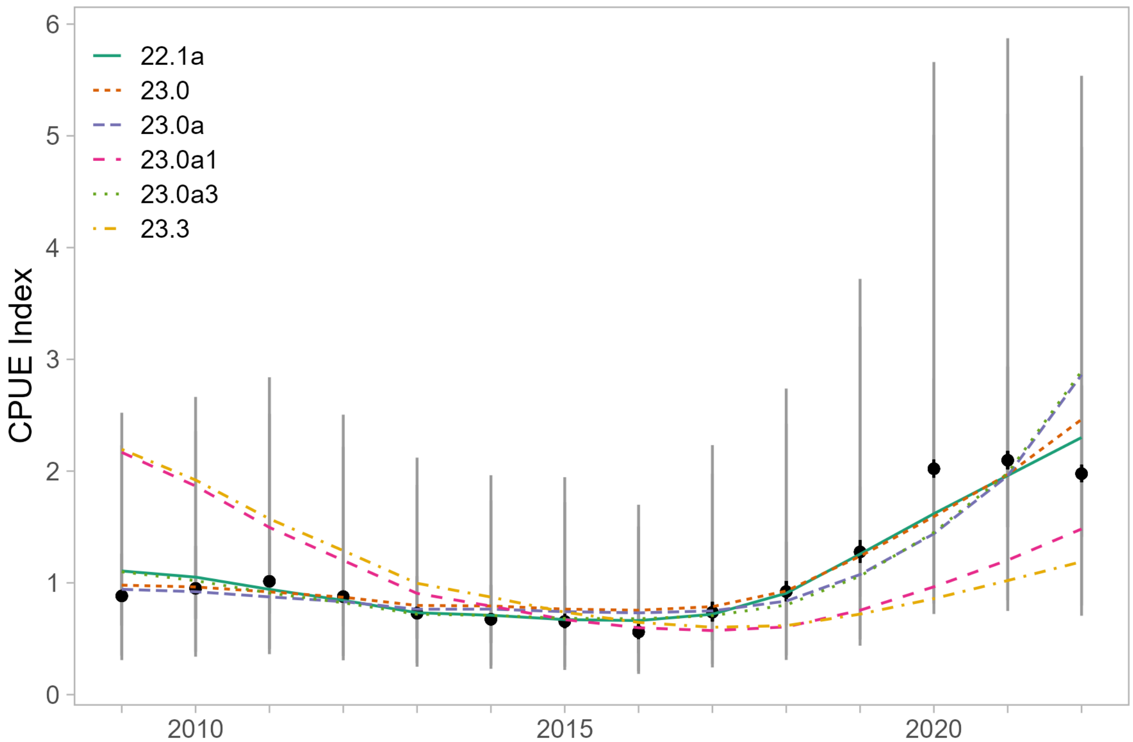

Figure 2: Fit to standardized fishery CPUE index from 2009-2022 by model scenario. Black error bars indicate 95% confidence intervals and grey error bars indicate addition estimated error.

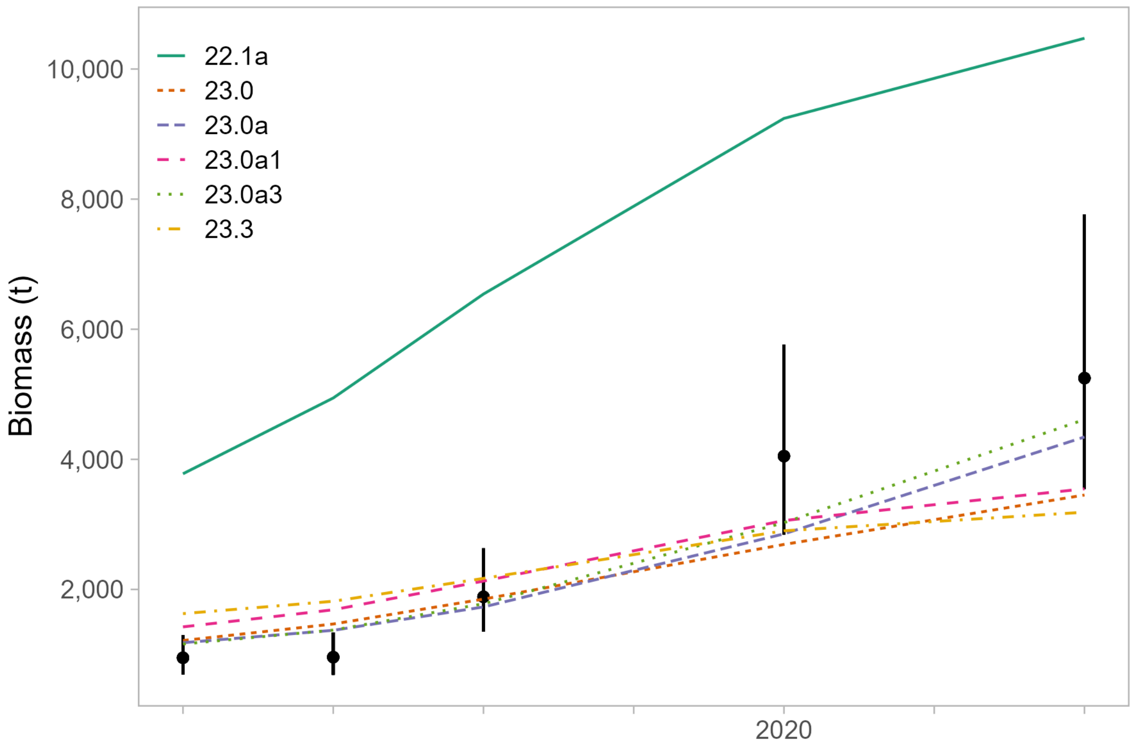

Figure 3: Fit to ADF&G dredge survey biomass by model scenario. Black error bars indicate 95% confidence intervals and grey error bars indicate addition estimated error.

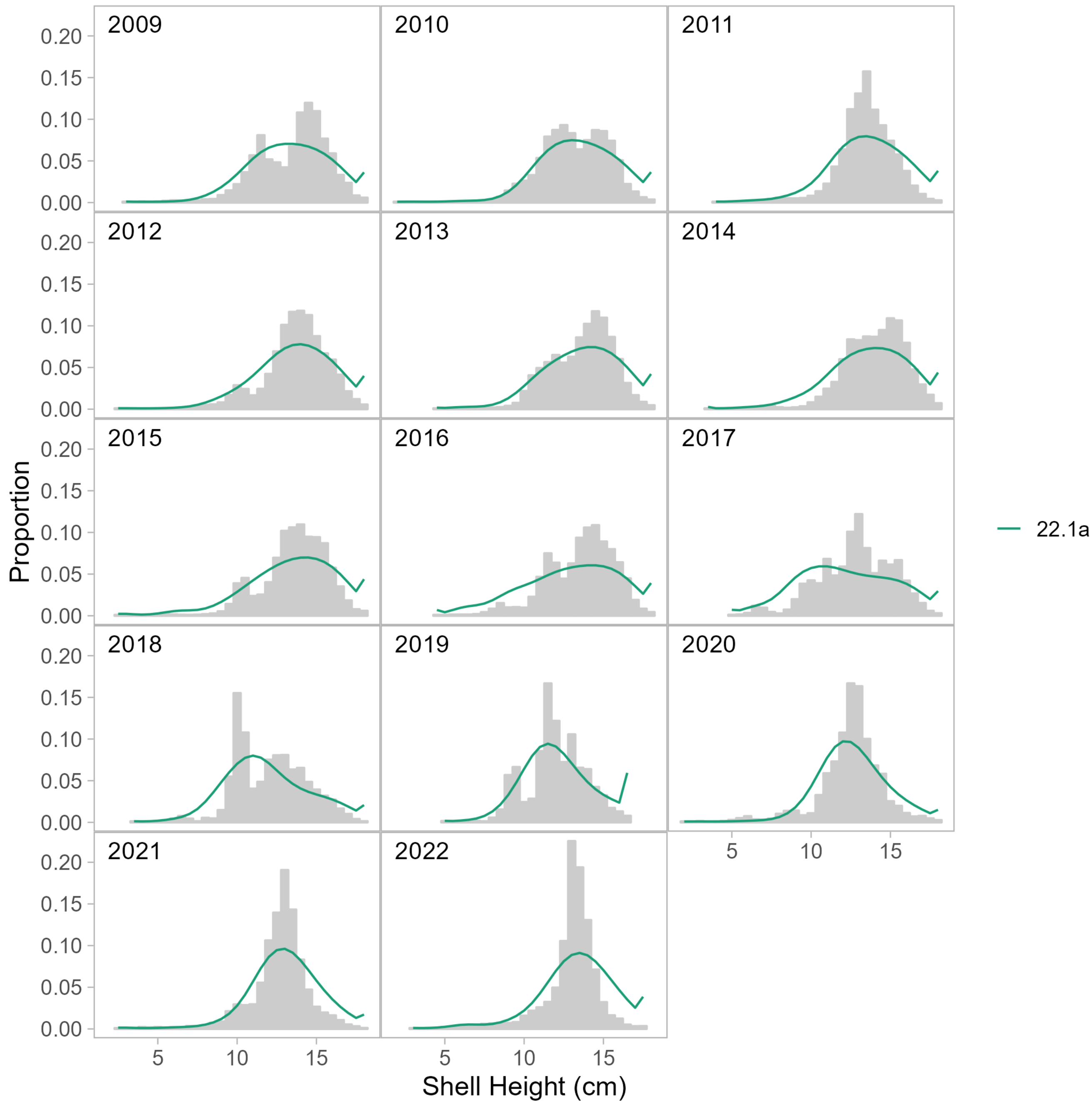

Figure 4: Fit to fishery shell height composition (i.e., retained and discarded scallops) for model 22.1a.

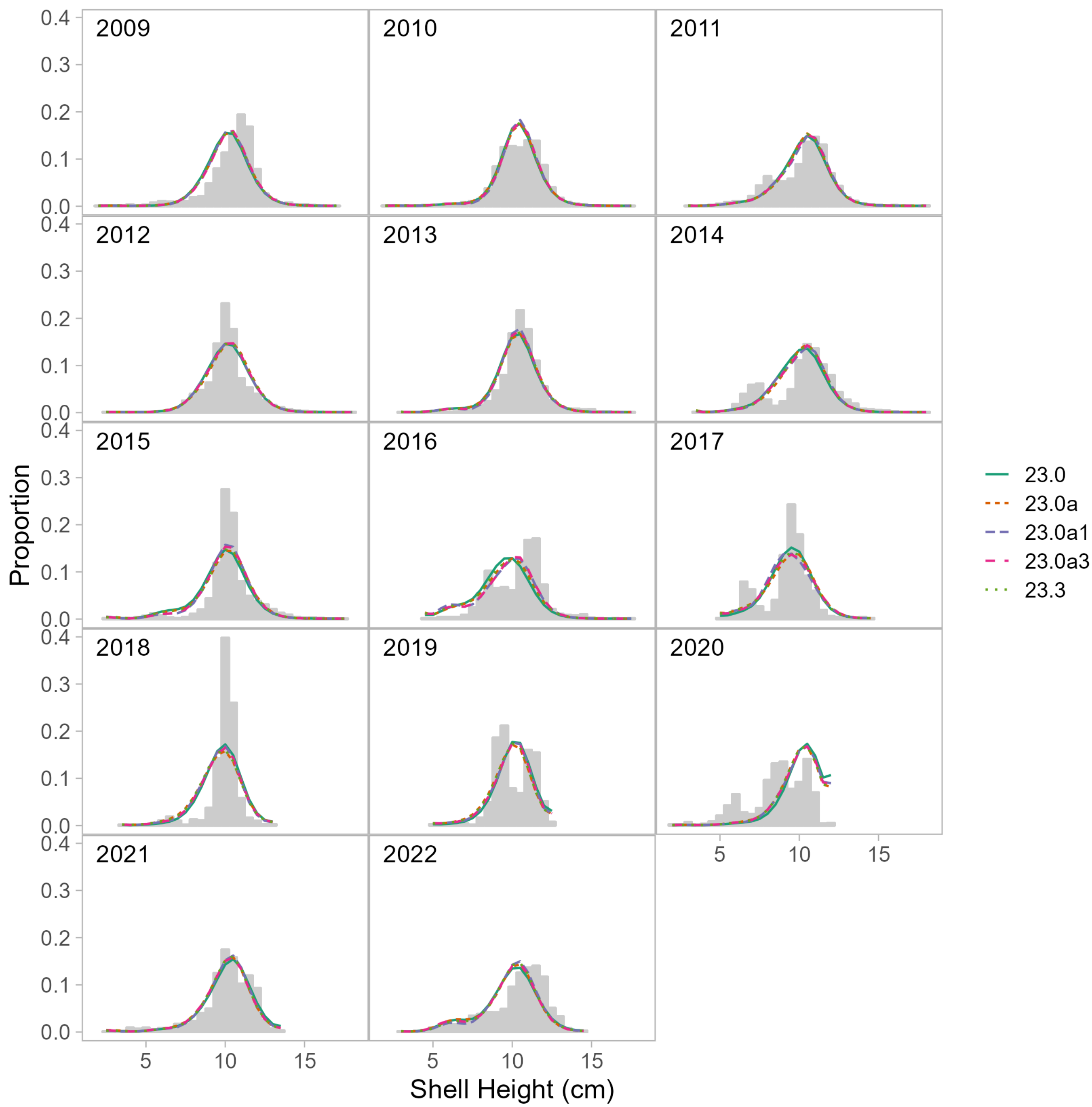

Figure 5: Fit to fishery discarded scallop shell height composition by model scenario.

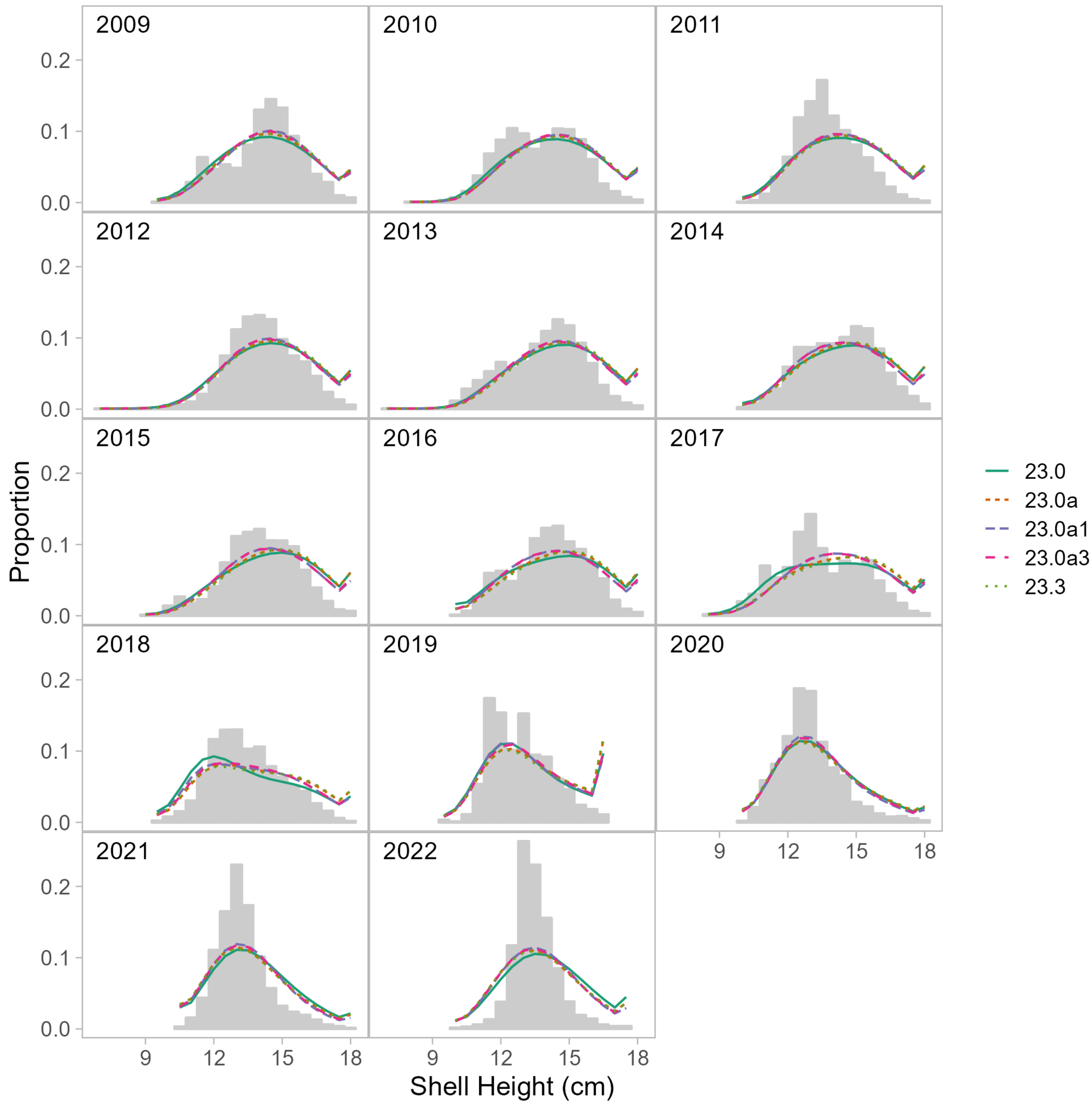

Figure 6: Fit to fishery retained scallop shell height composition by model scenario.

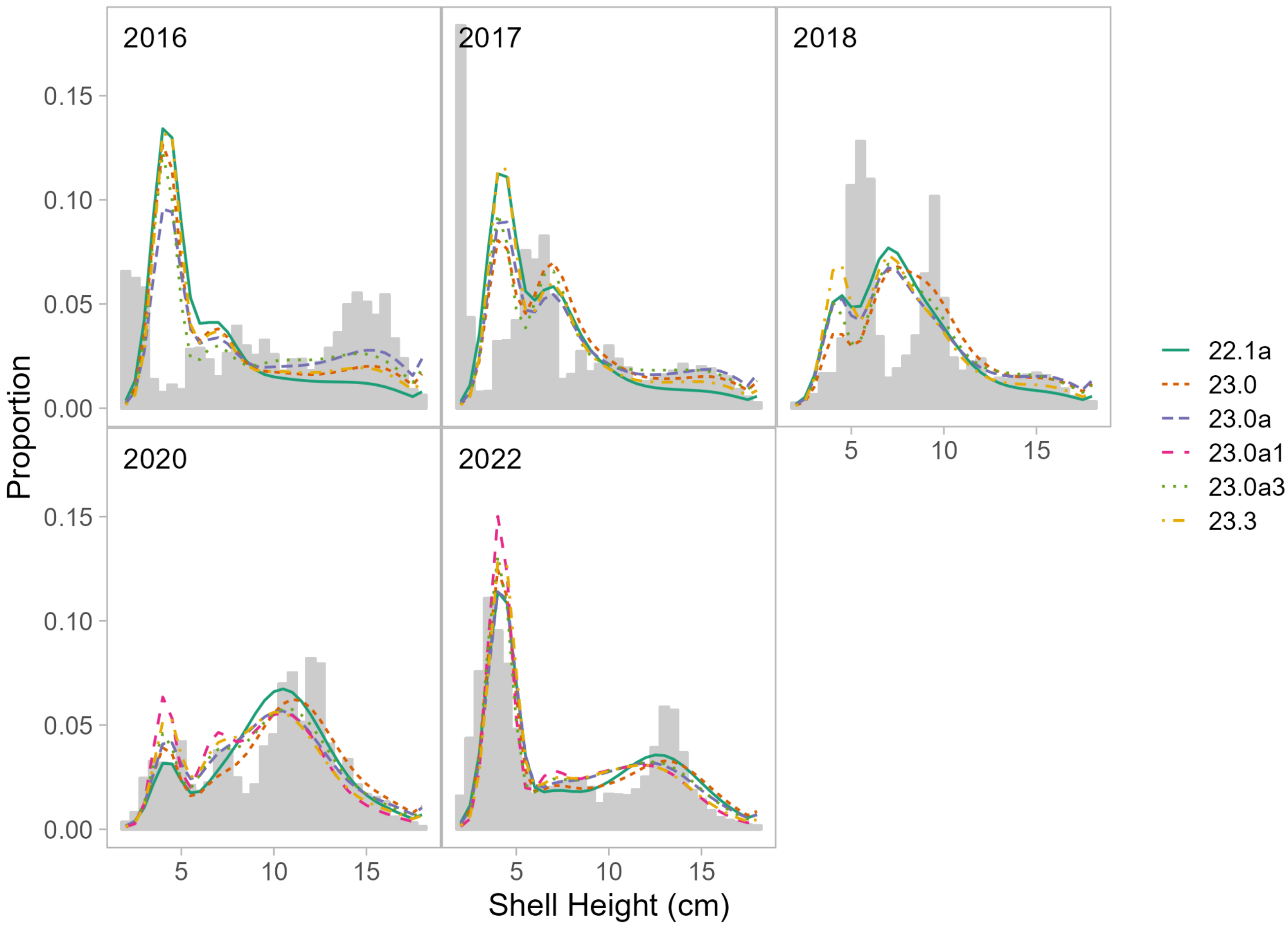

Figure 7: Fit to ADF&G dredge survey shell height composition by model scenario.

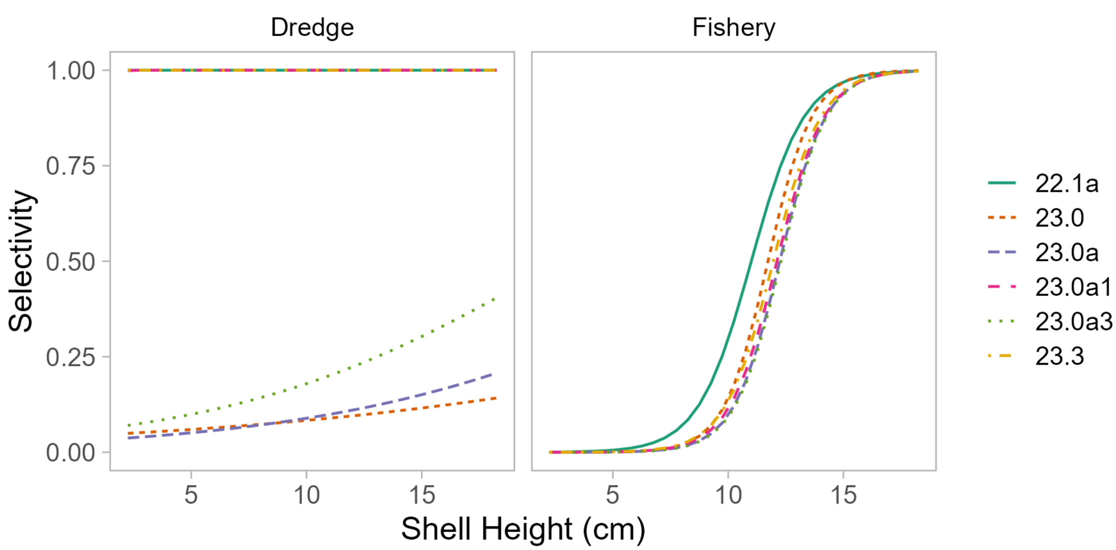

Figure 8: Fishery and ADF&G dredge survey shell height selectivity by model scenario.

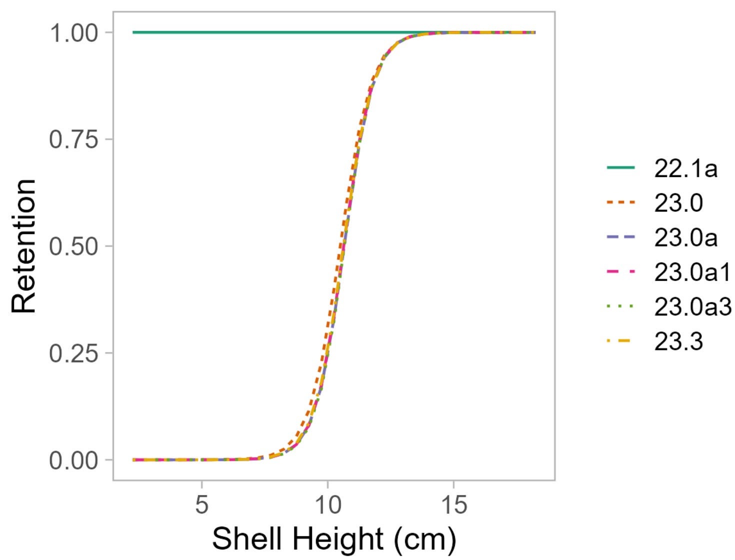

Figure 9: Fishery retention on the basis of shell height by model scenario.

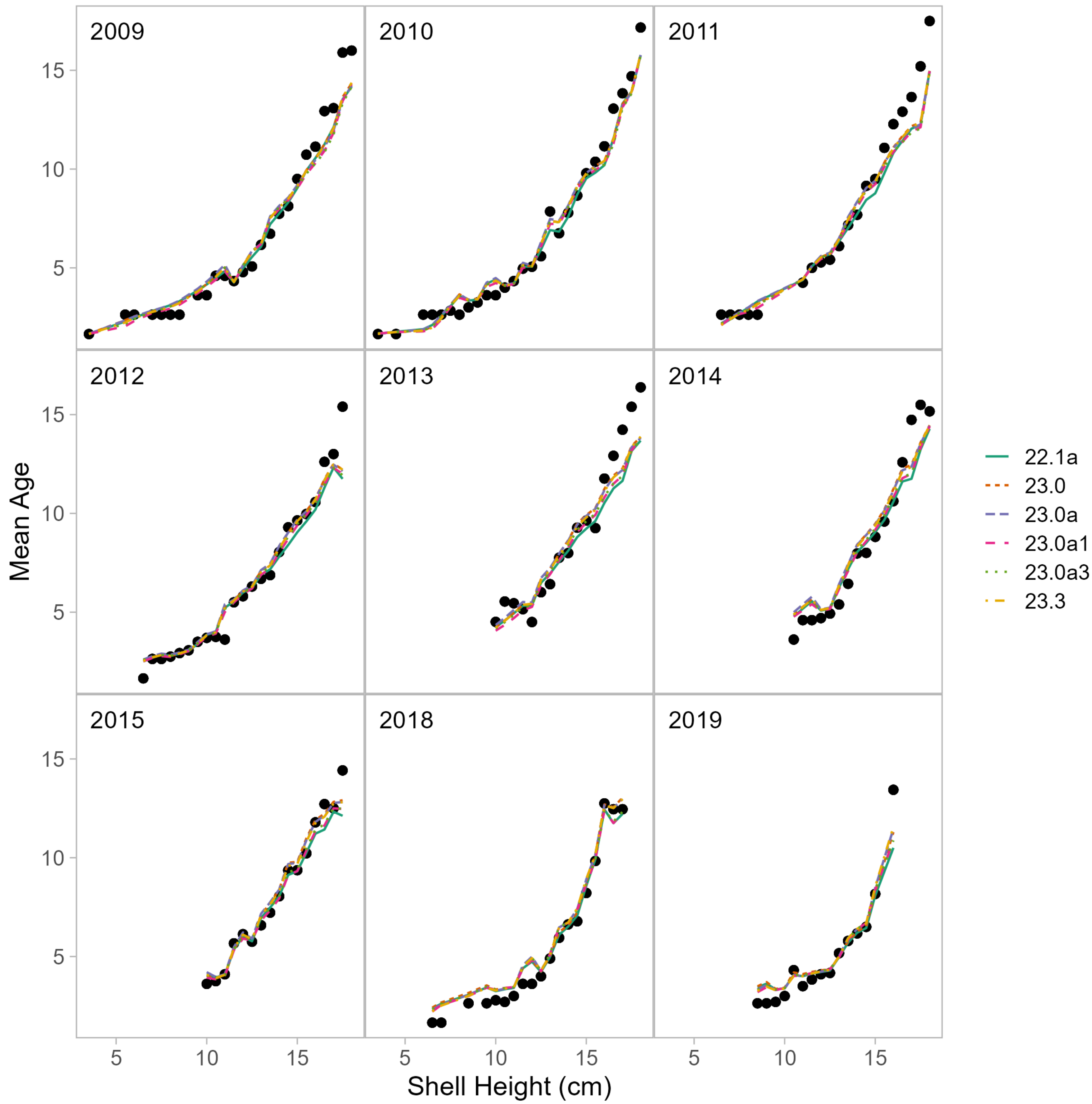

Figure 10: Fit to fishery age composition by model scenario.

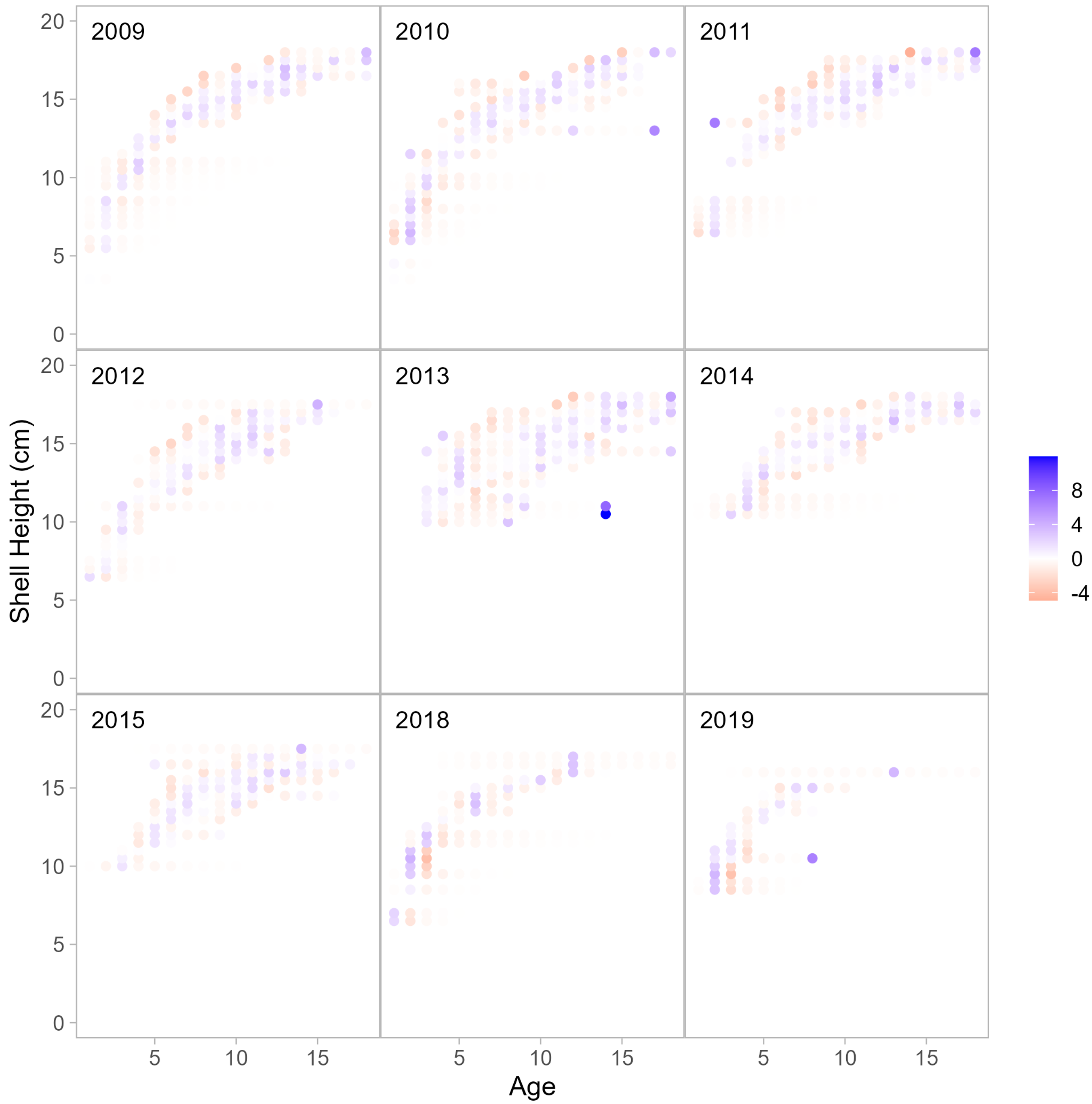

Figure 11: Fishery age composition pearson residuals for model 22.1a

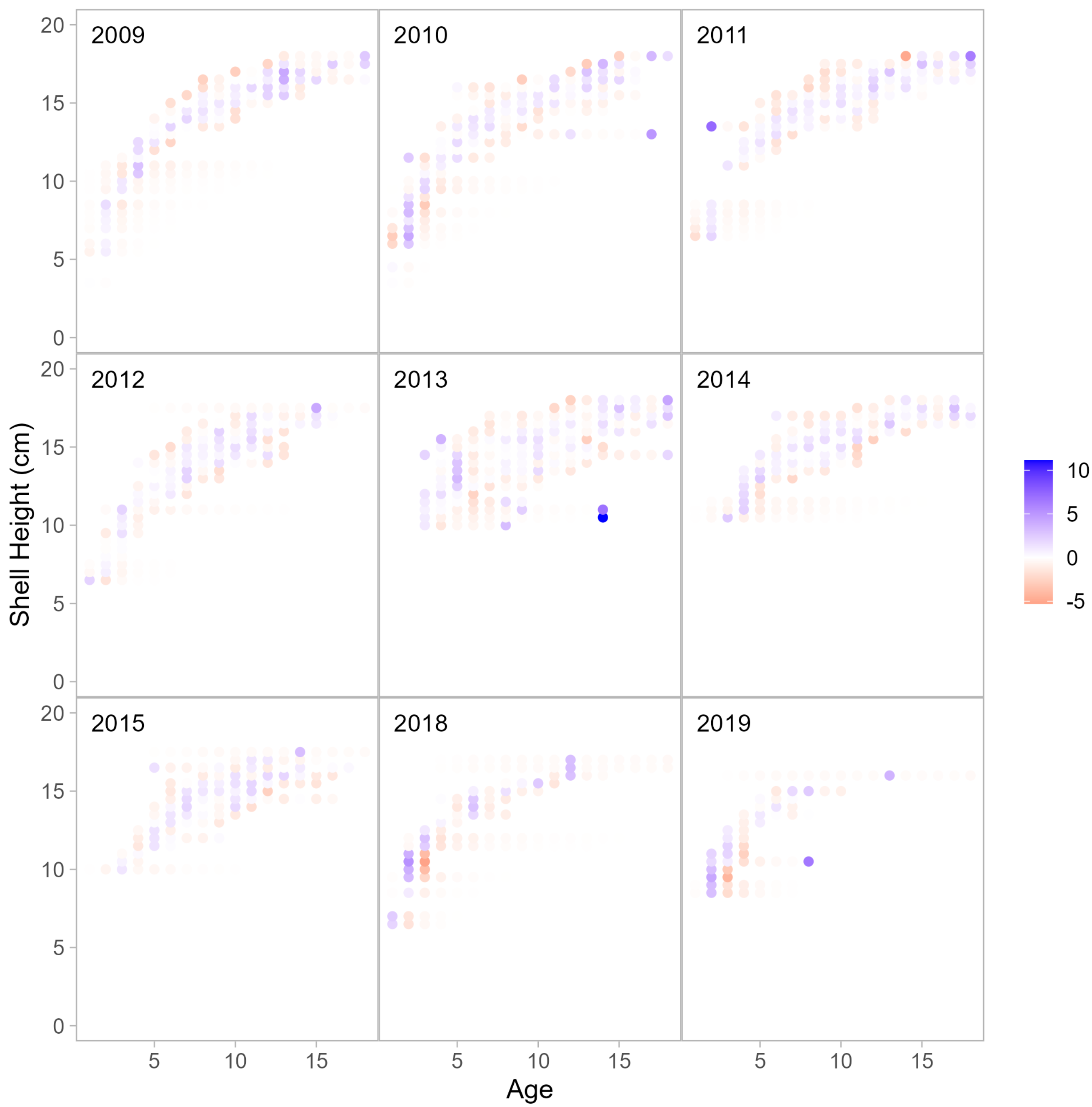

Figure 12: Fishery age composition pearson residuals for model 23.0.

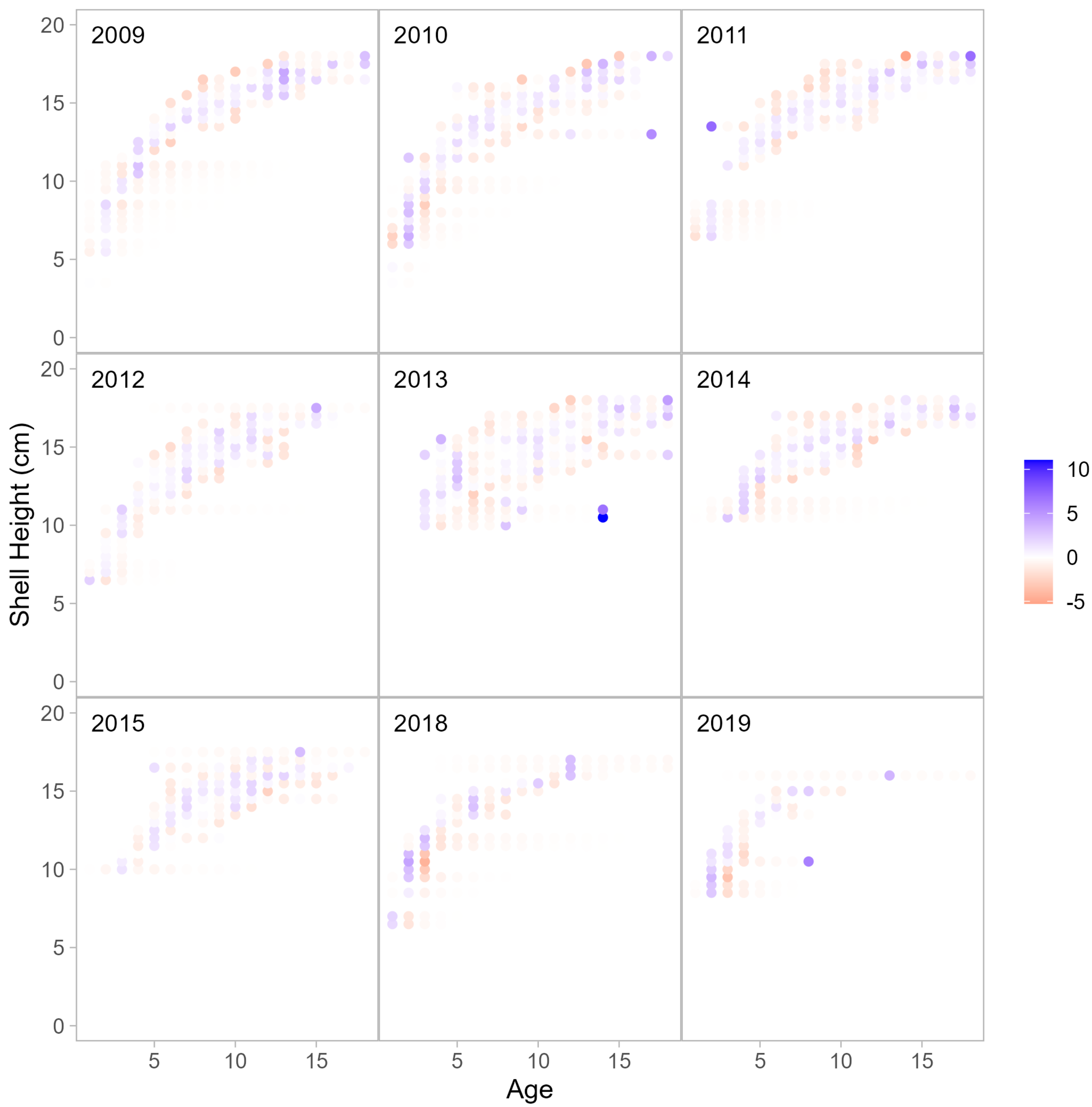

Figure 13: Fishery age composition pearson residuals for model 23.0a.

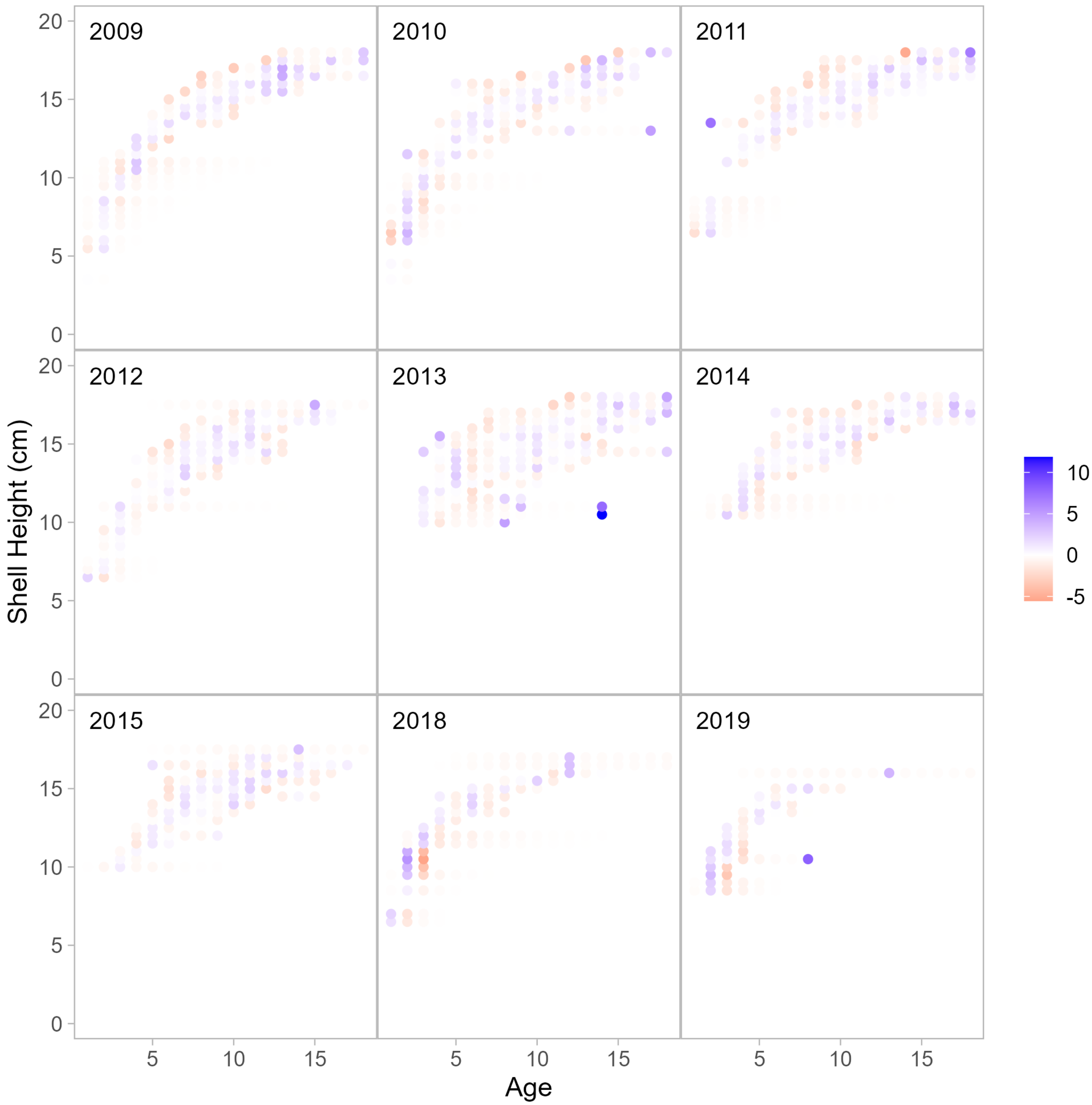

Figure 14: Fishery age composition pearson residuals for model 23.0a1.

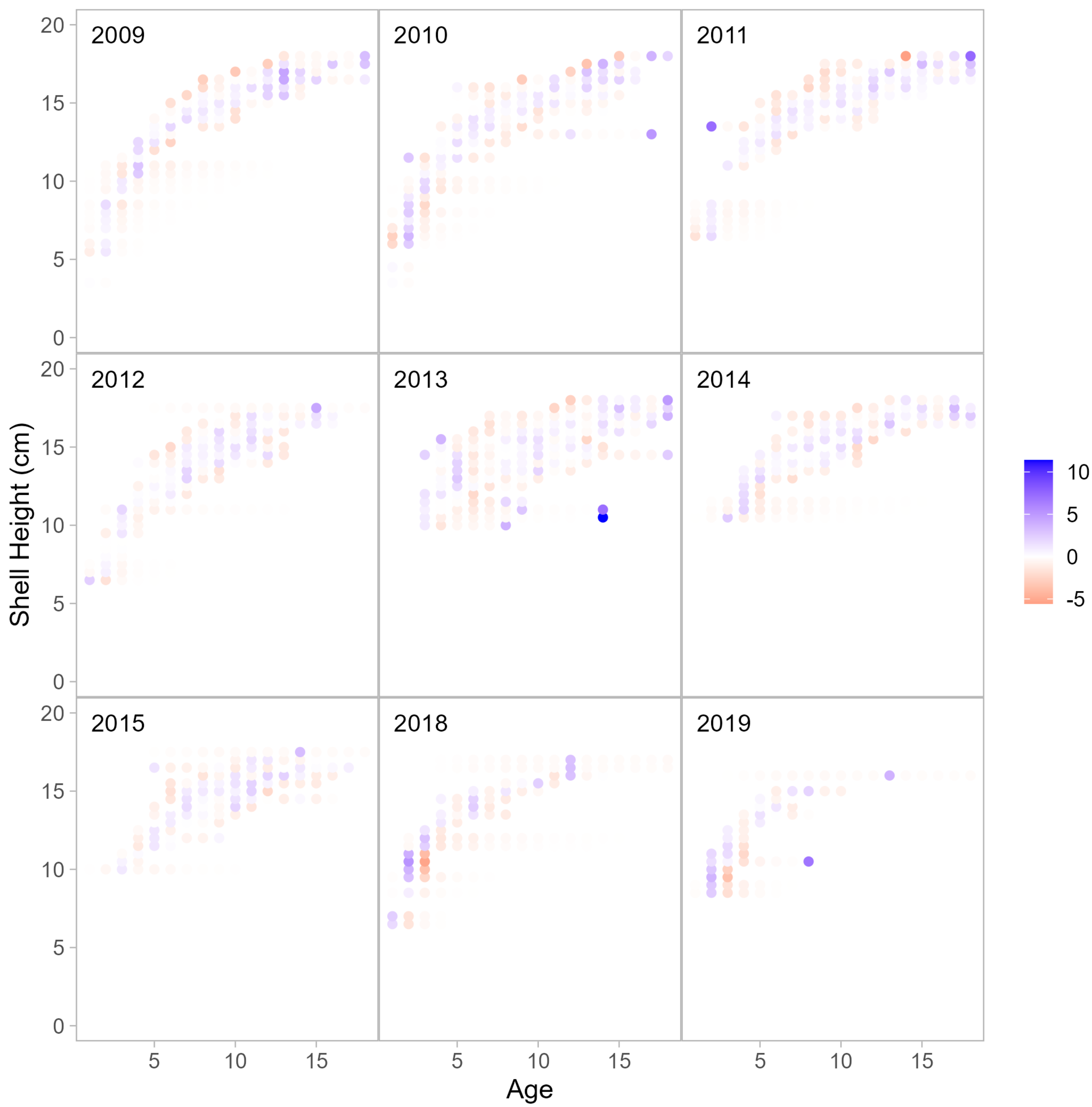

Figure 15: Fishery age composition pearson residuals for model 23.0a3.

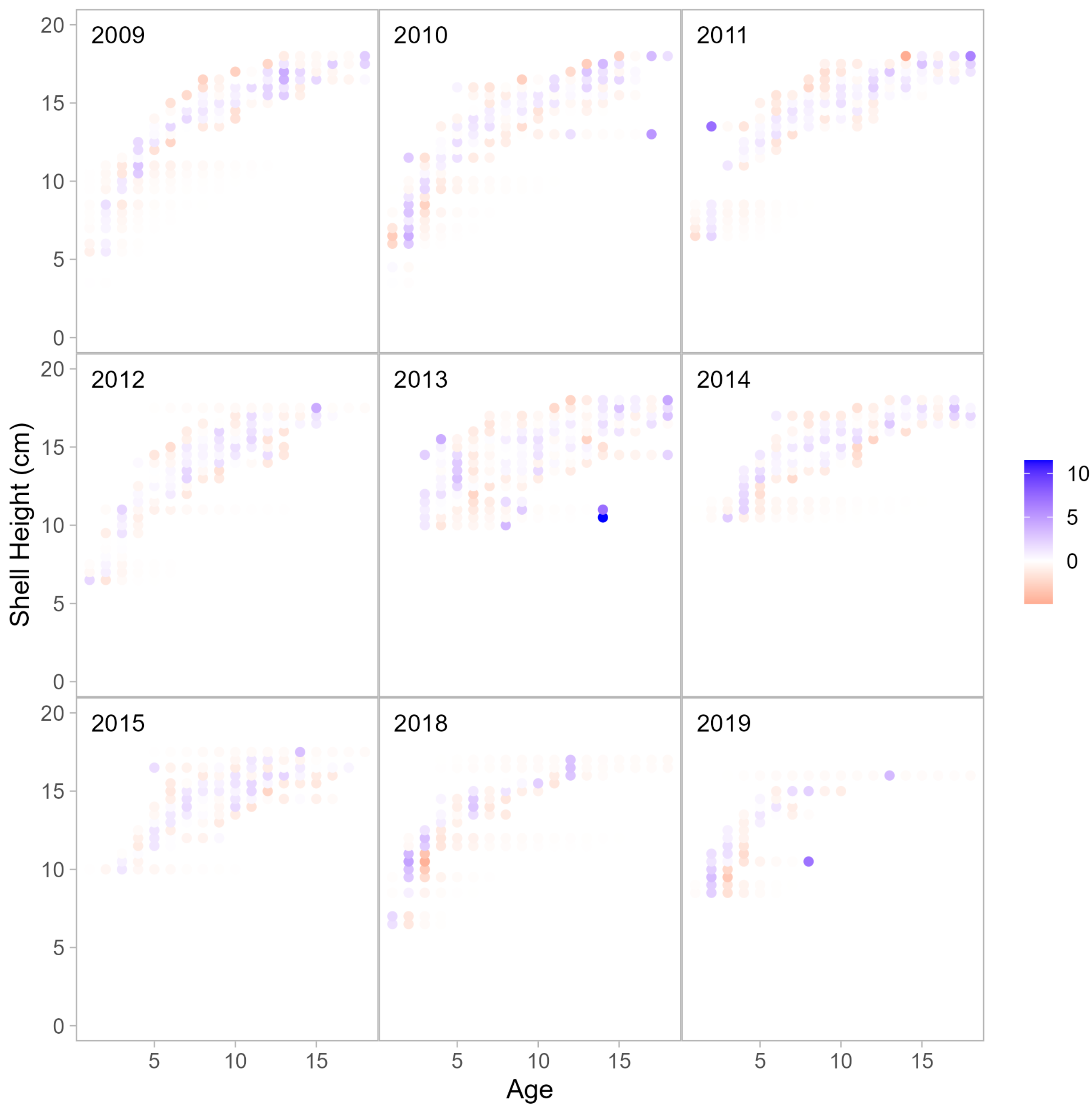

Figure 16: Fishery age composition pearson residuals for model 23.3.

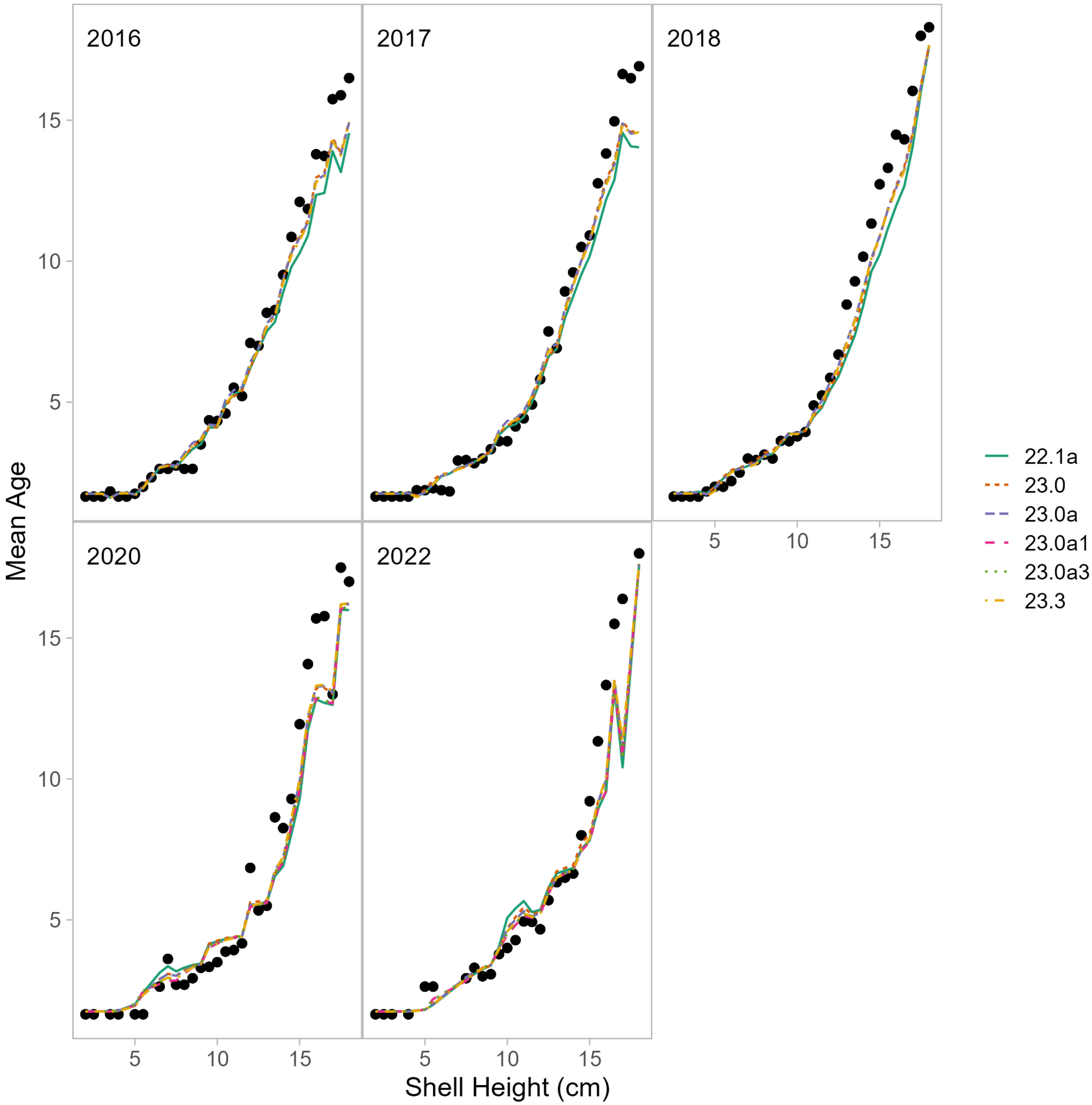

Figure 17: Fit to ADF&G dredge survey age composition by model scenario.

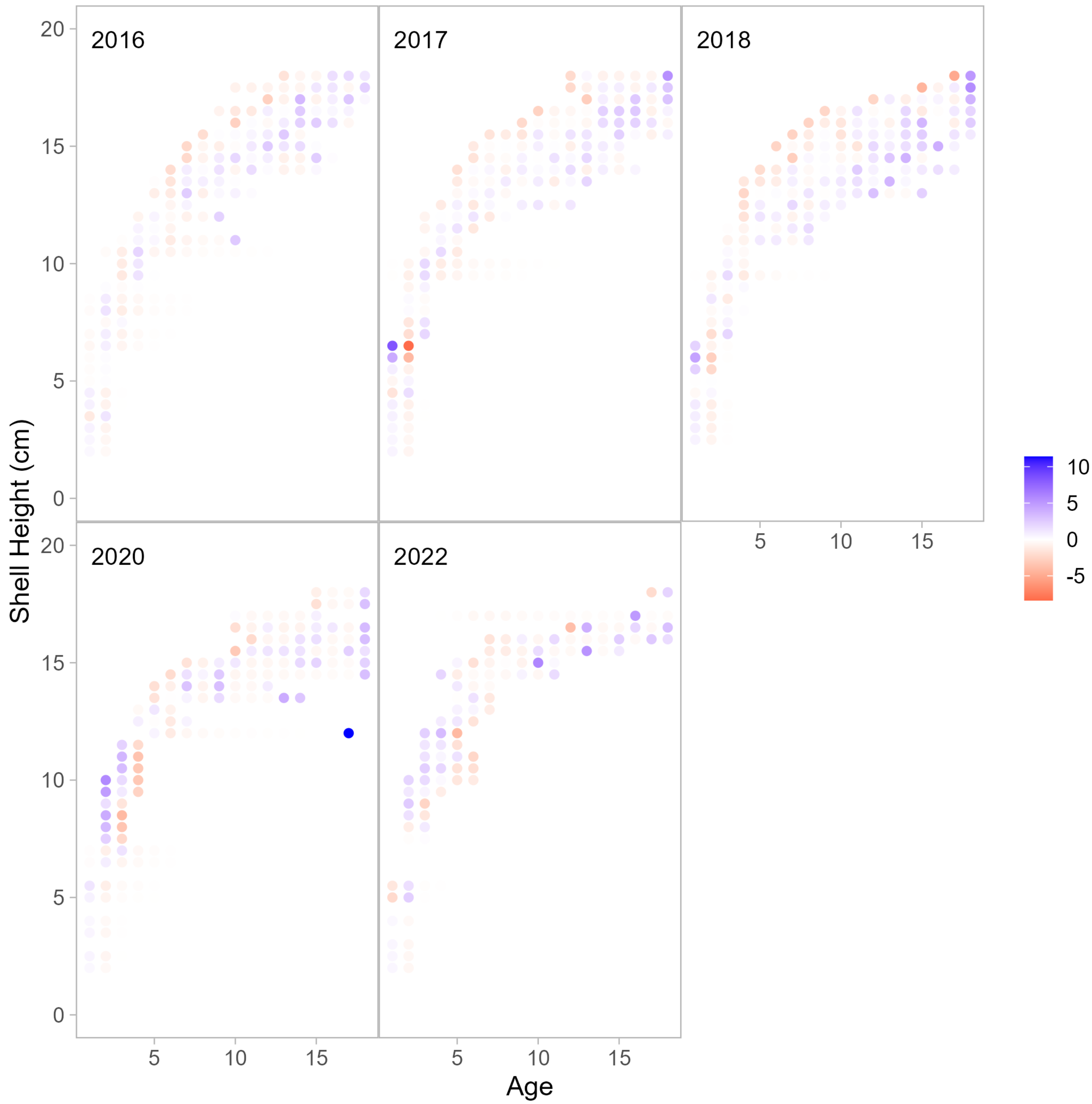

Figure 18: ADF&G dredge survey age composition pearson residuals for model 22.1a

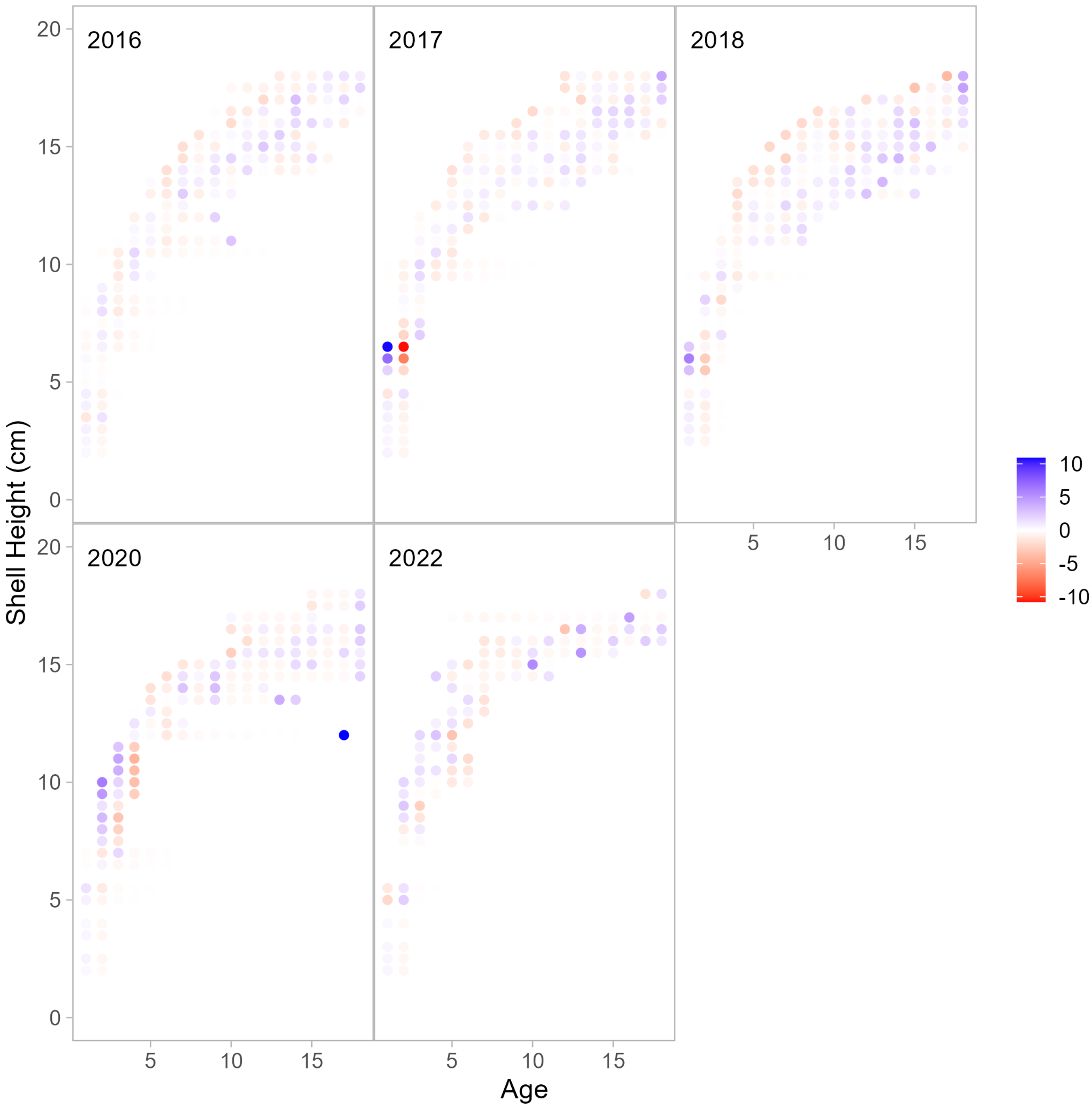

Figure 19: ADF&G dredge survey age composition pearson residuals for model 23.0.

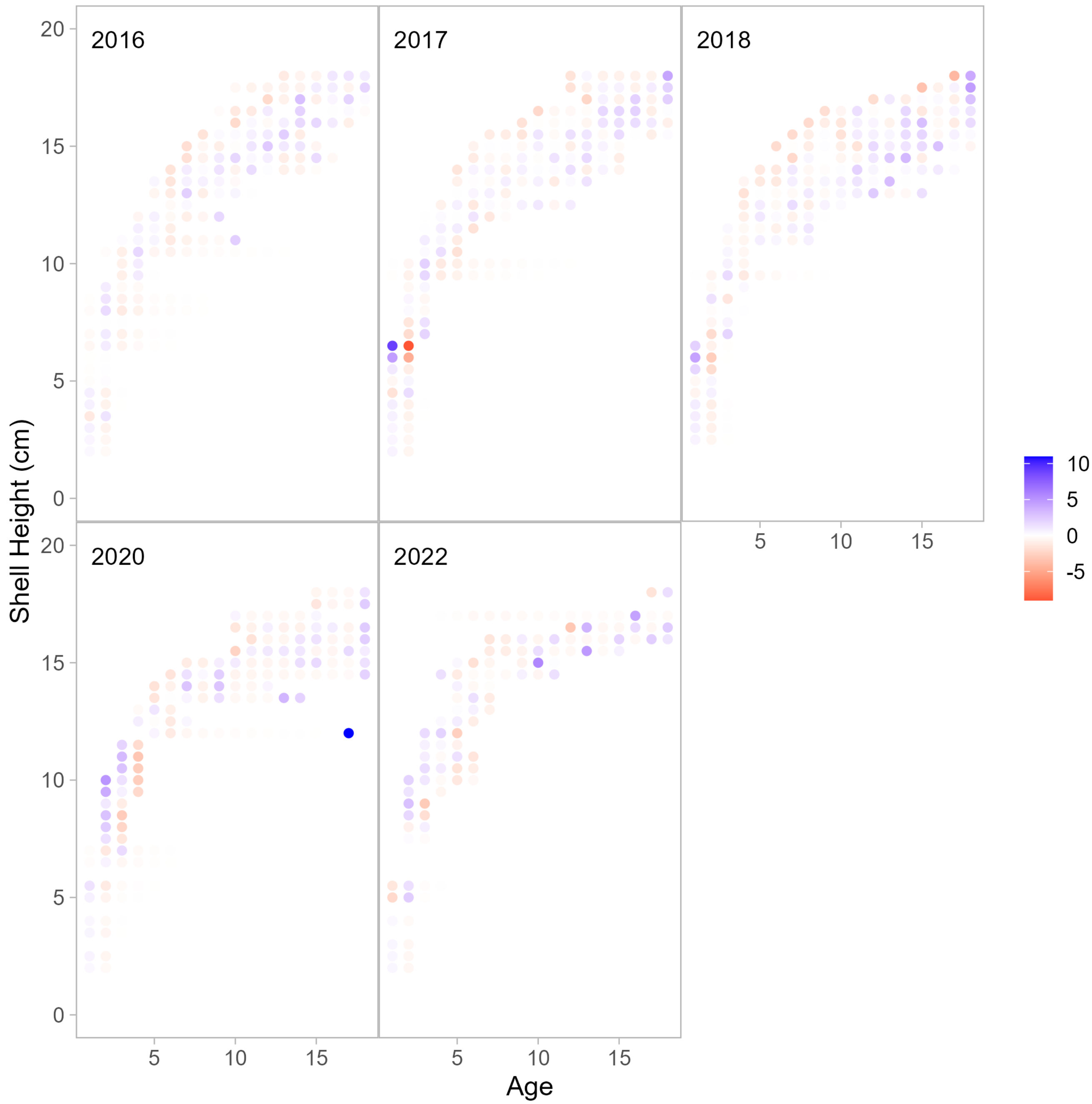

Figure 20: ADF&G dredge survey age composition pearson residuals for model 23.0a.

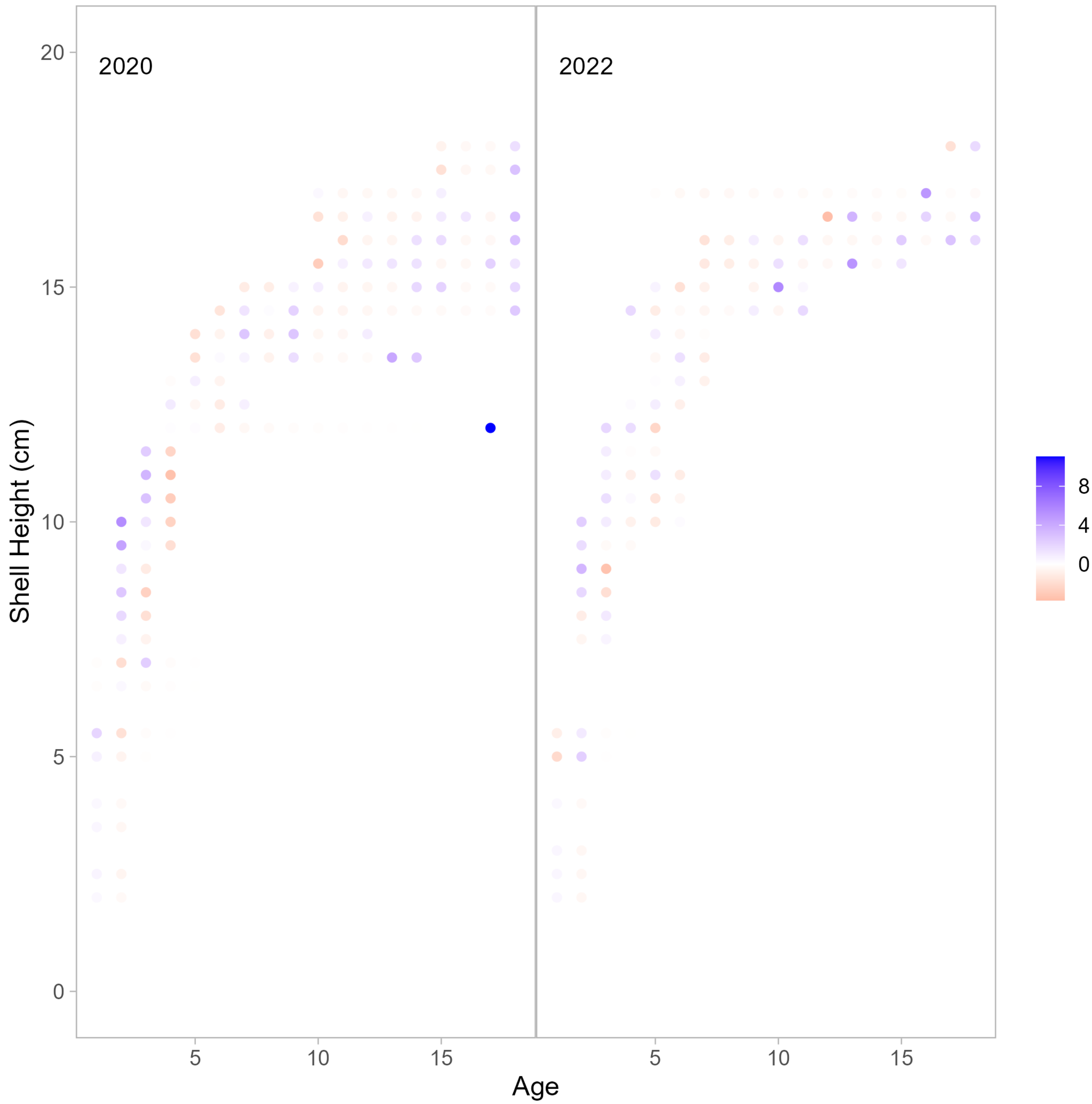

Figure 21: ADF&G dredge survey age composition pearson residuals for model 23.0a1.

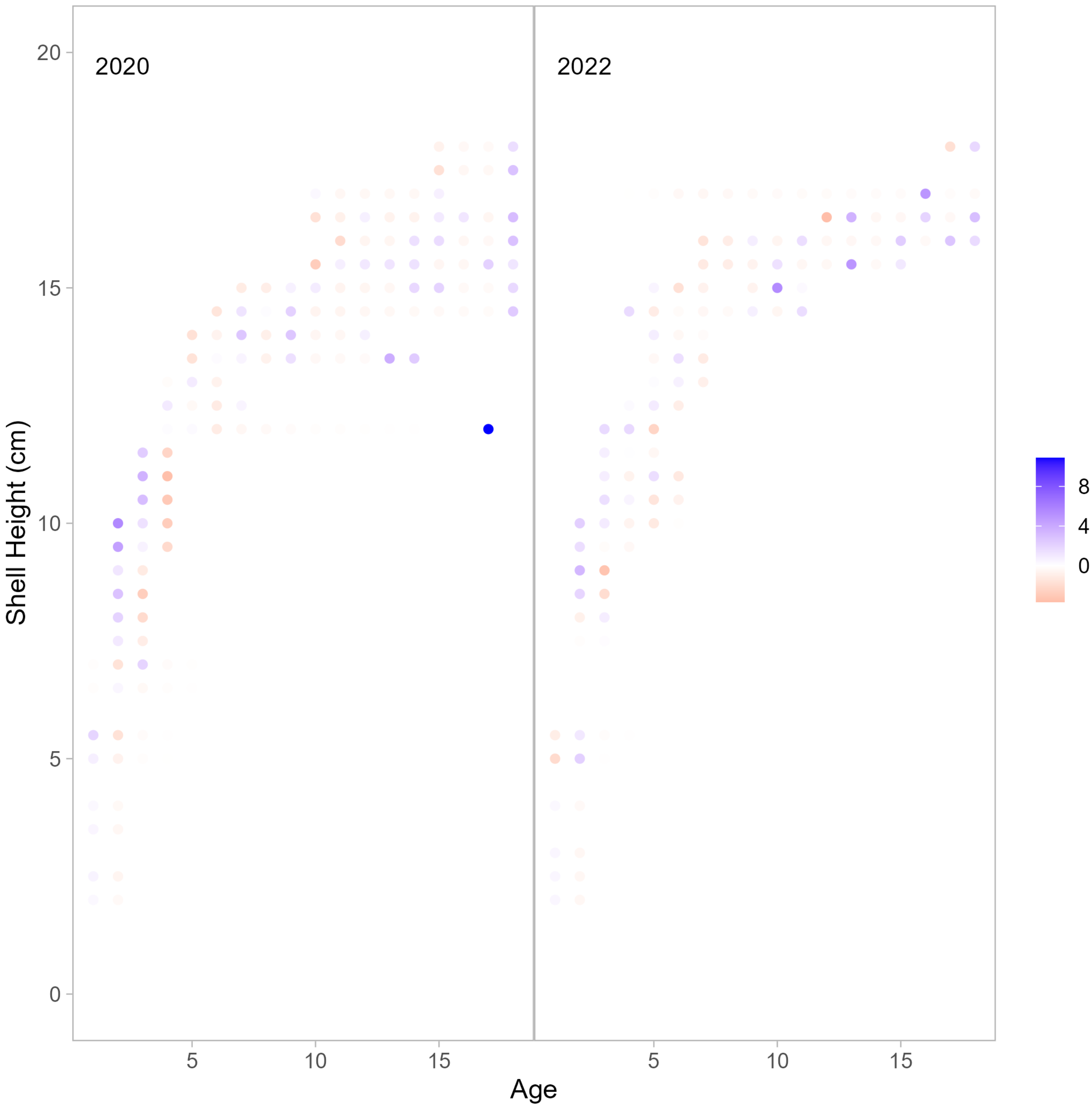

Figure 22: ADF&G dredge survey age composition pearson residuals for model 23.0a3.

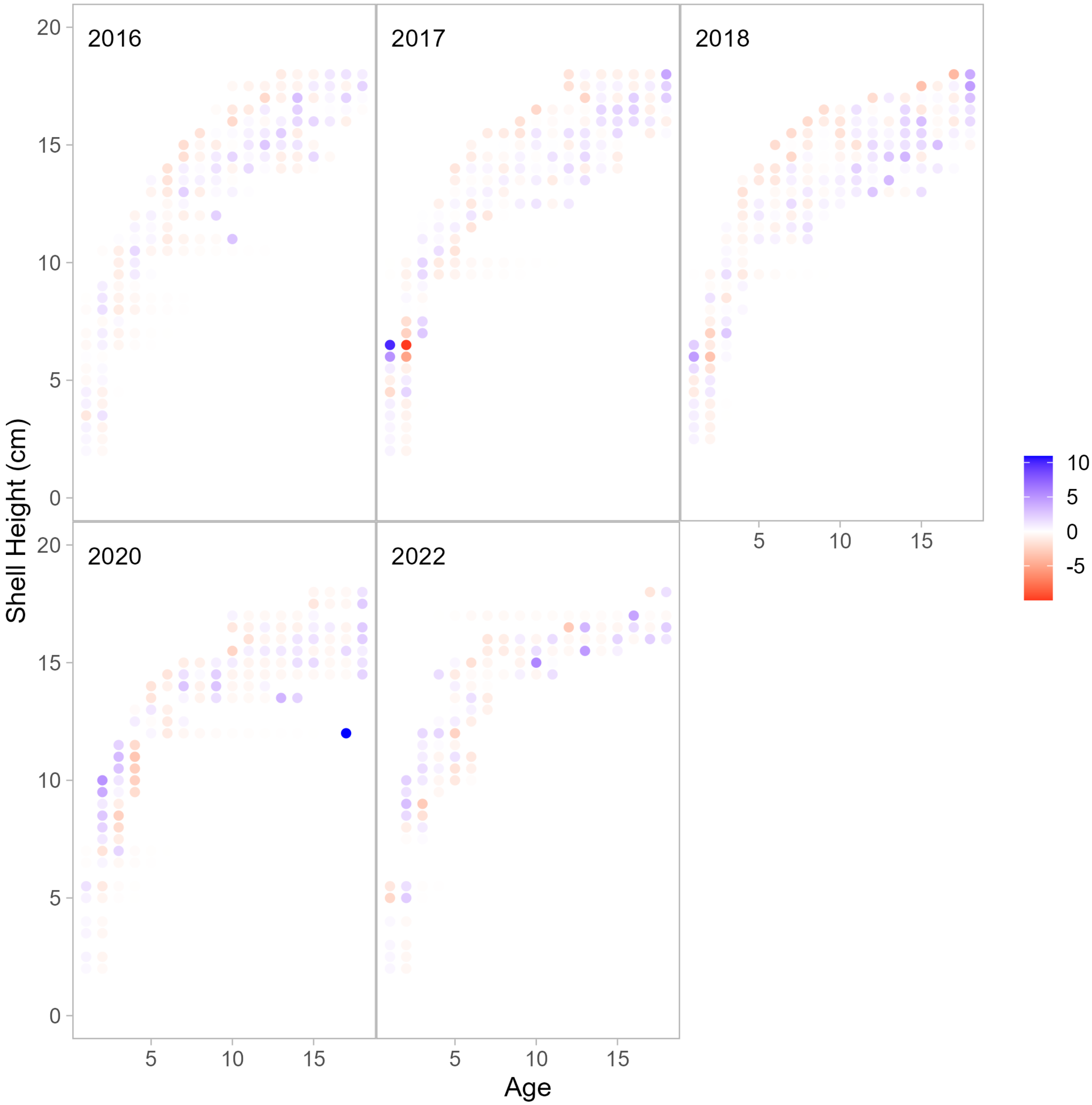

Figure 23: ADF&G dredge survey age composition pearson residuals for model 23.3.

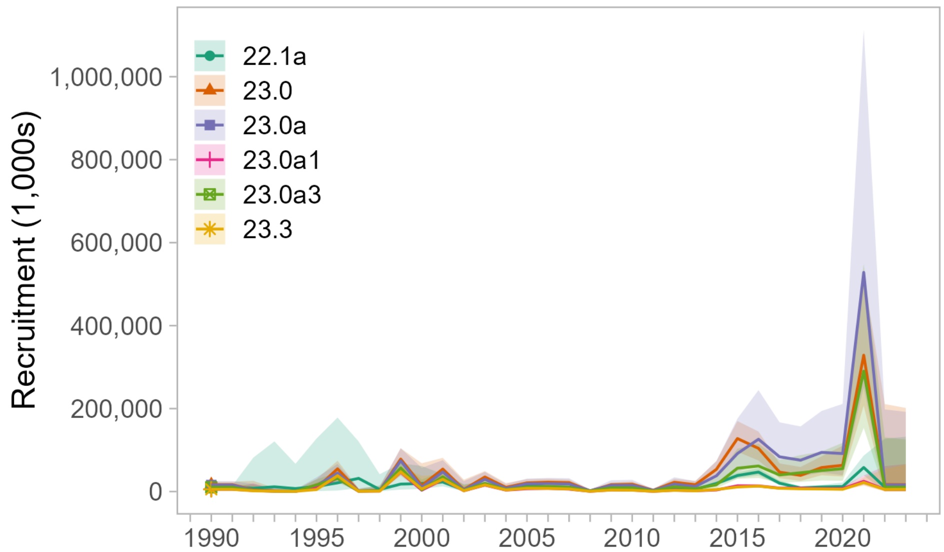

Figure 24: Predicted annual recruitment (millions) by model scenario.

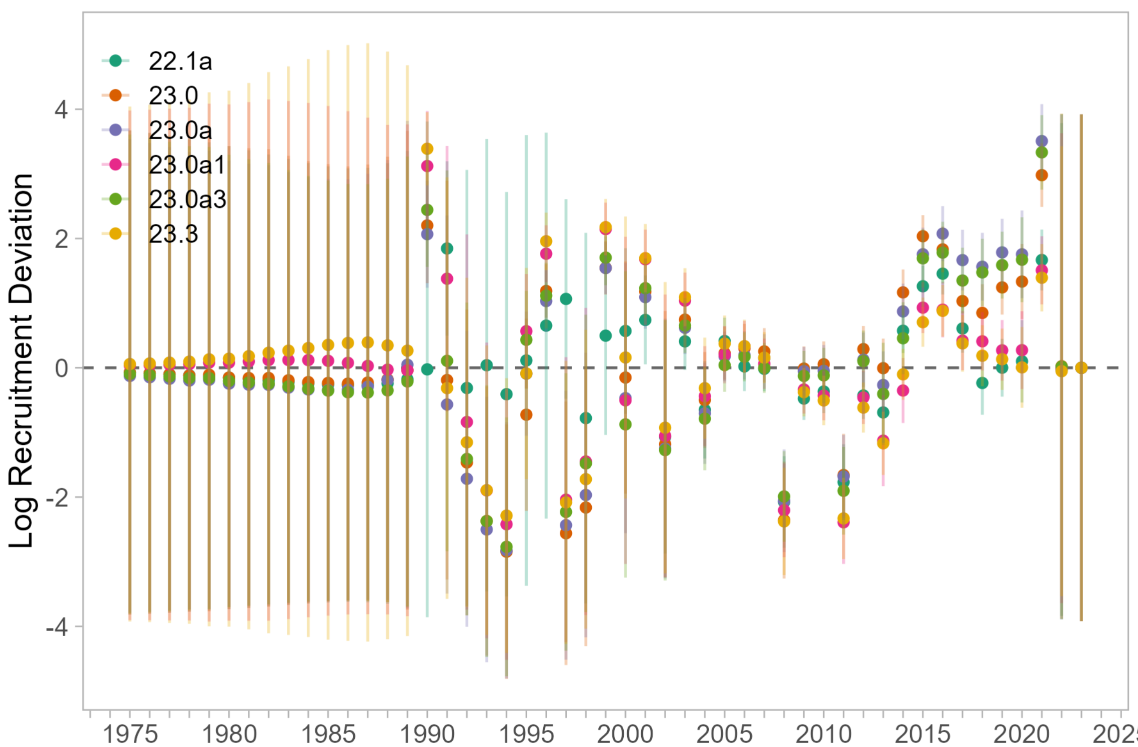

Figure 25: Recruitment deviations and associated 95% confidence intervals.

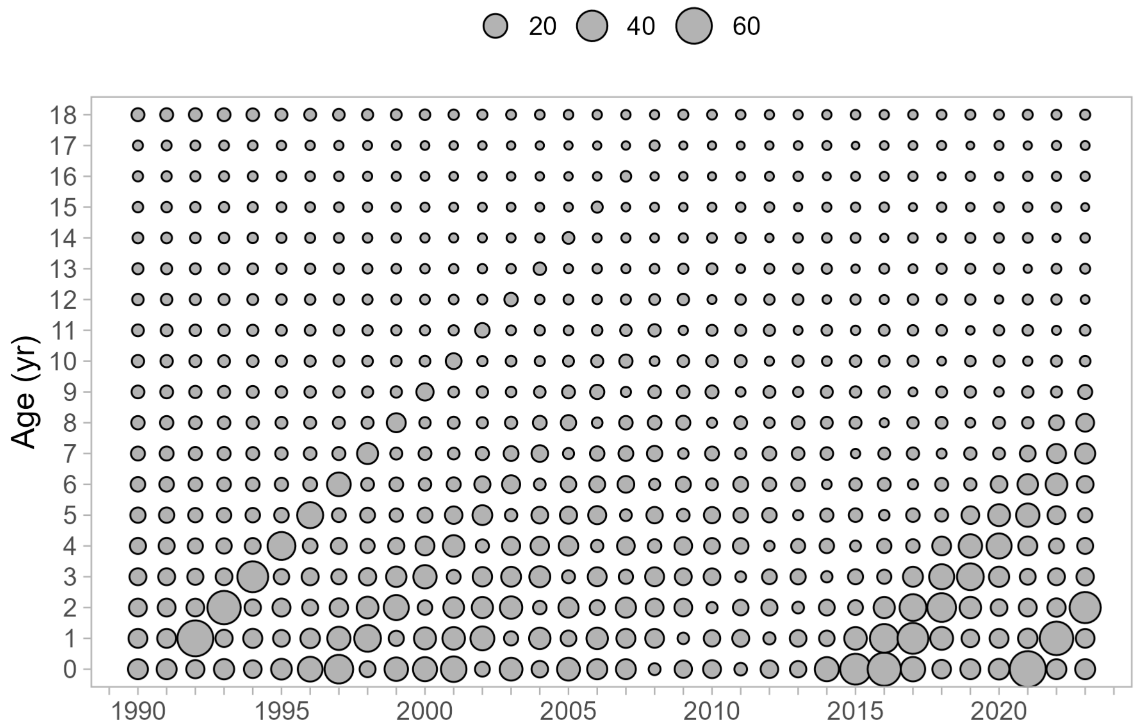

Figure 26: Beginning of year numbers at age matrix (millions) for model 22.1a.

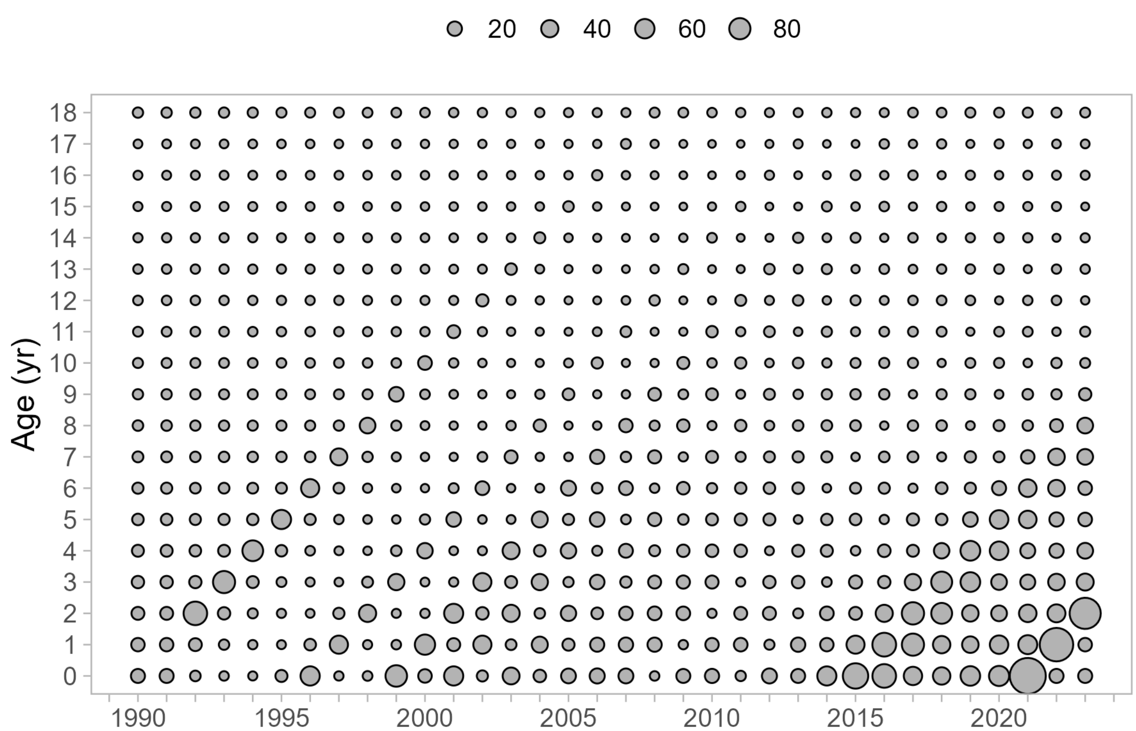

Figure 27: Beginning of year numbers at age matrix (millions) for model 23.0.

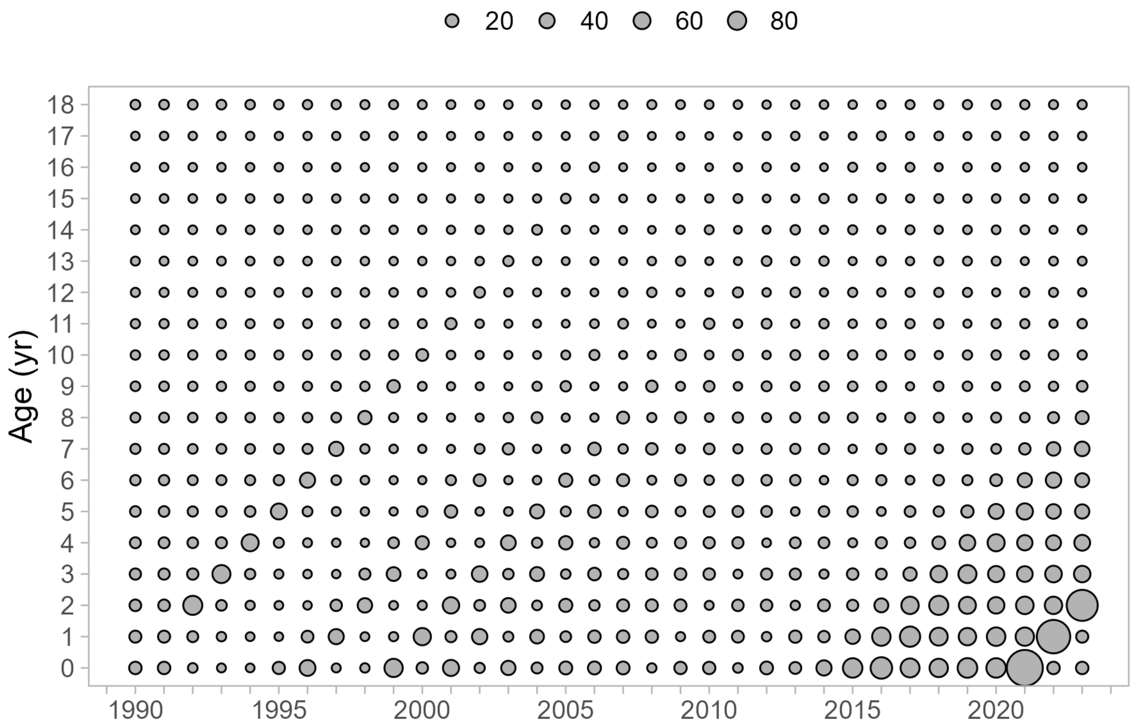

Figure 28: Beginning of year numbers at age matrix (millions) for model 23.0a.

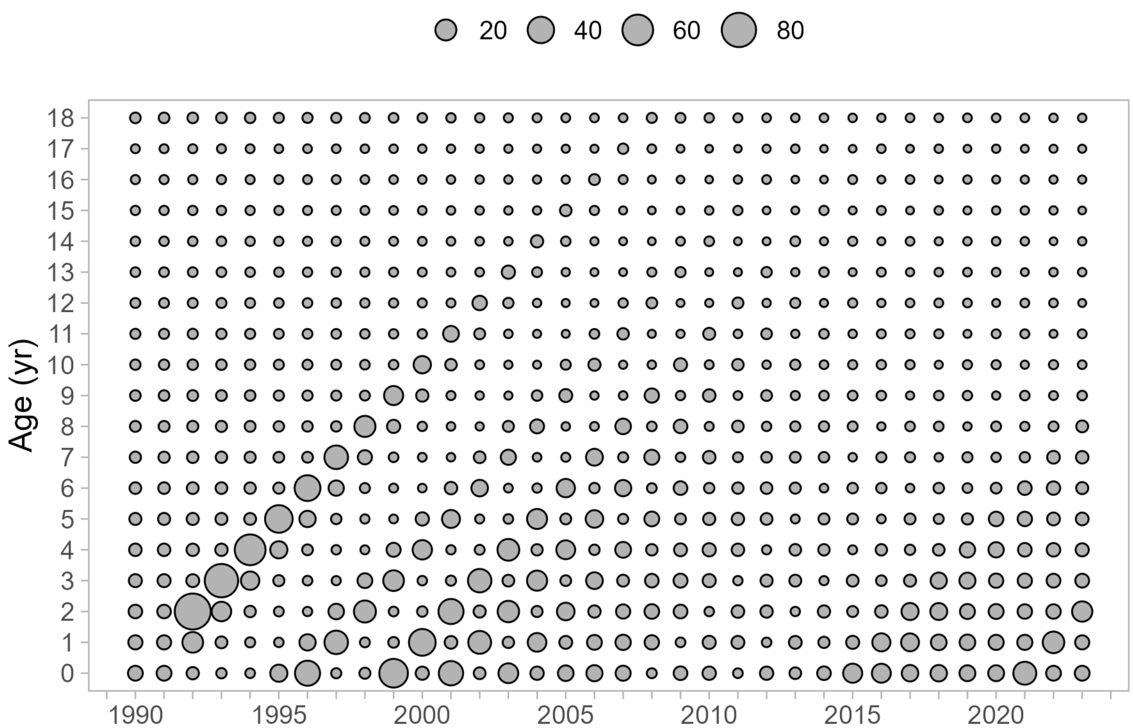

Figure 29: Beginning of year numbers at age matrix (millions) for model 23.0a1.

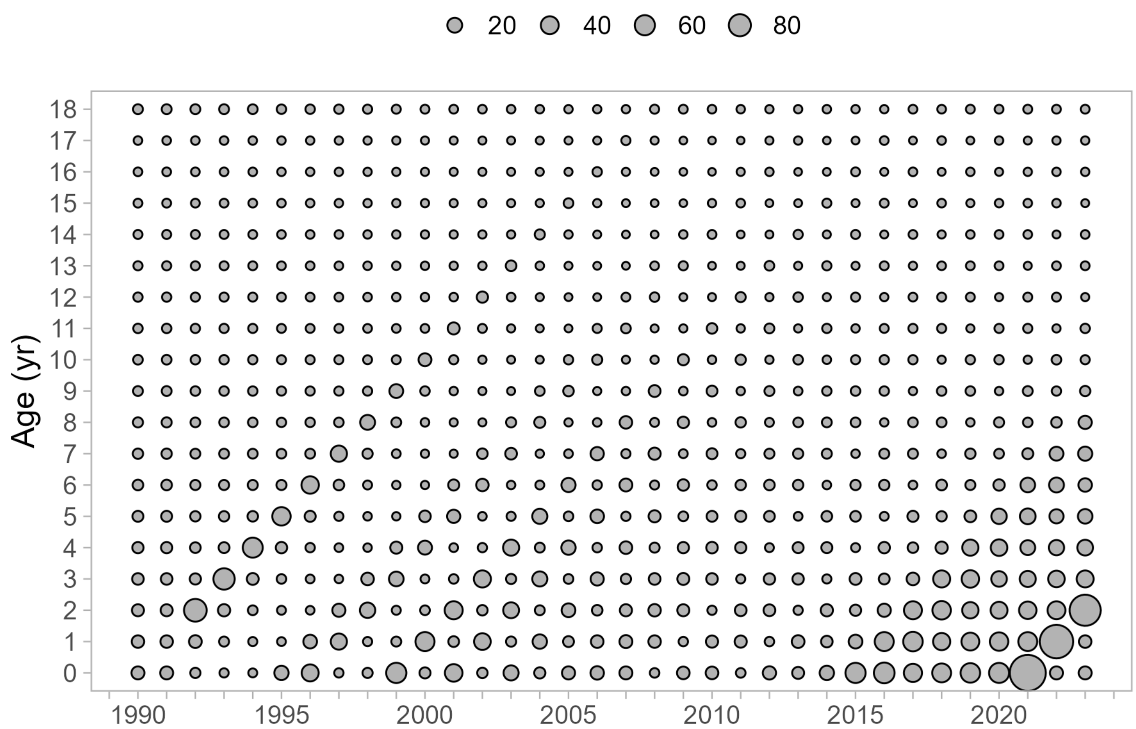

Figure 30: Beginning of year numbers at age matrix (millions) for model 23.0a3.

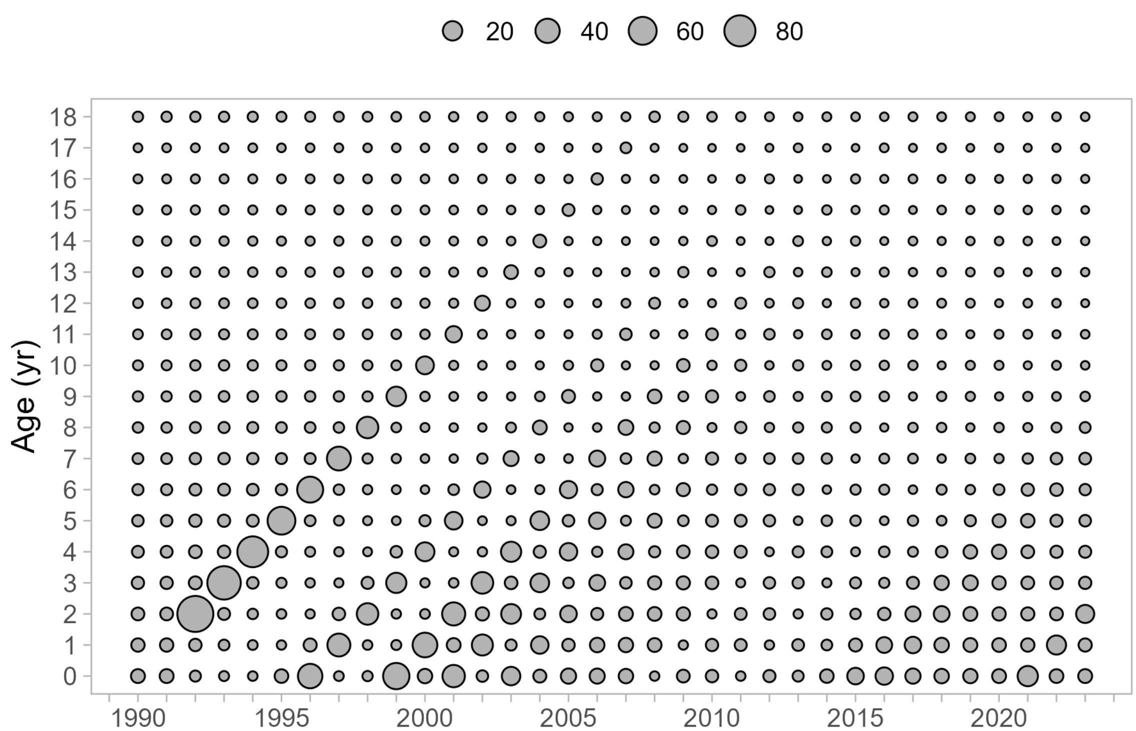

Figure 31: Beginning of year numbers at age matrix (millions) for model 23.3.

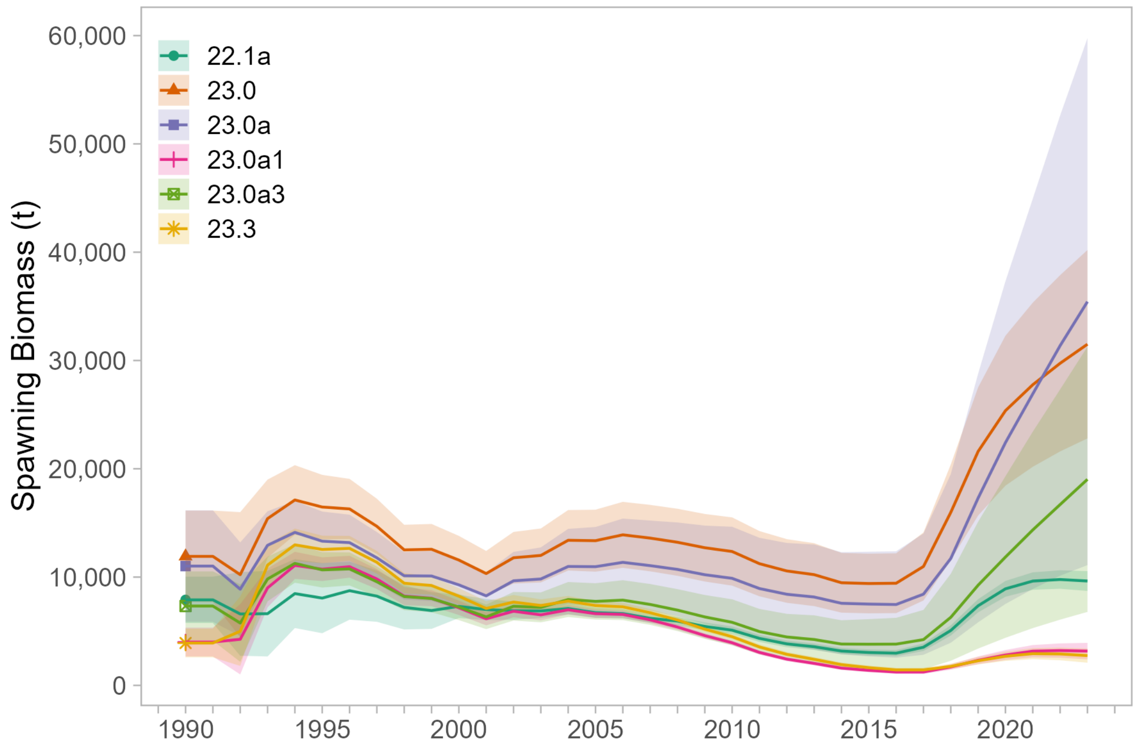

Figure 32: Estimated spawning stock biomass (t) by model scenario.

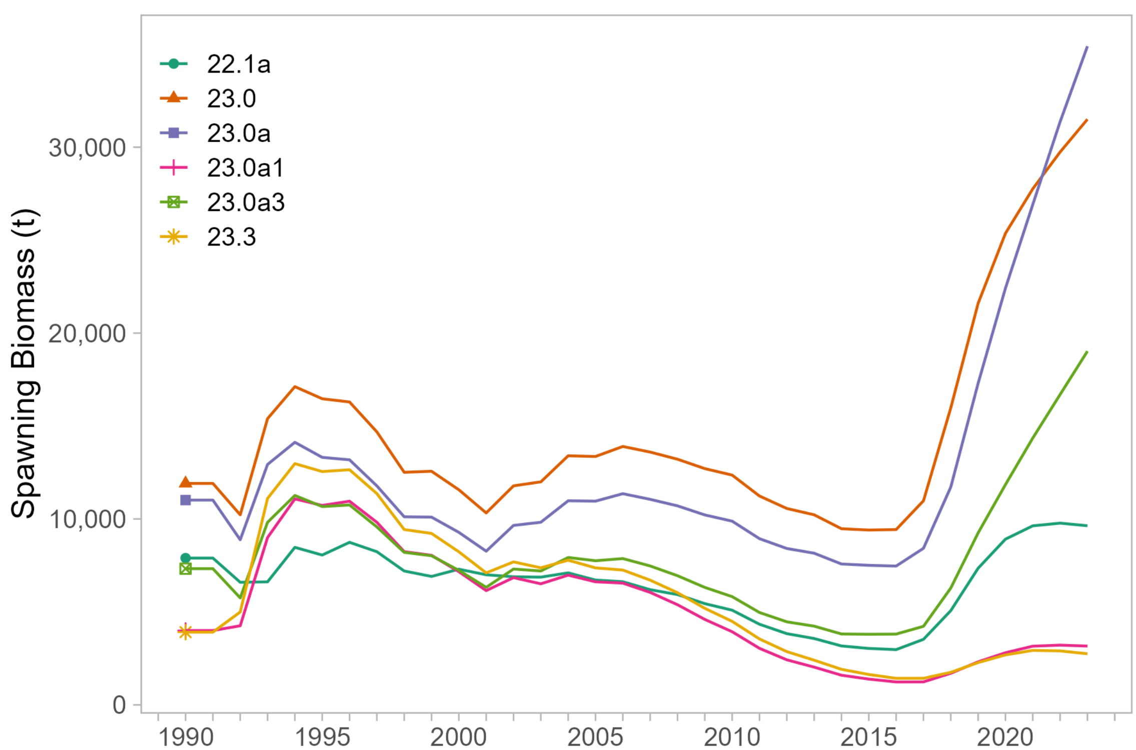

Figure 33: Estimated spawning stock biomass (t) by model scenario, without 95% confidence intervals.

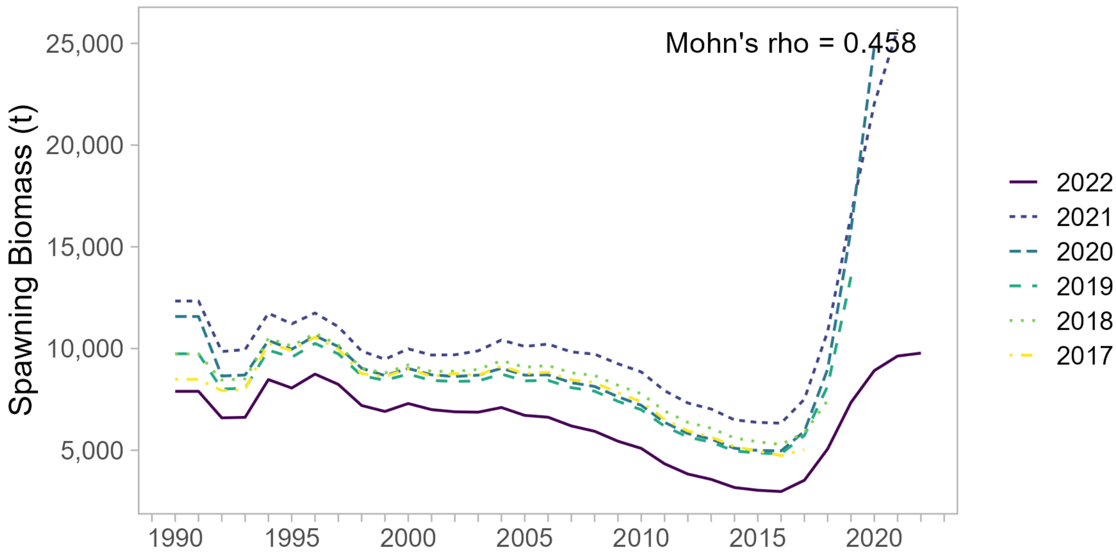

Figure 34: Spawning stock biomass from retrospective analysis of model 22.1a going back to 2017.

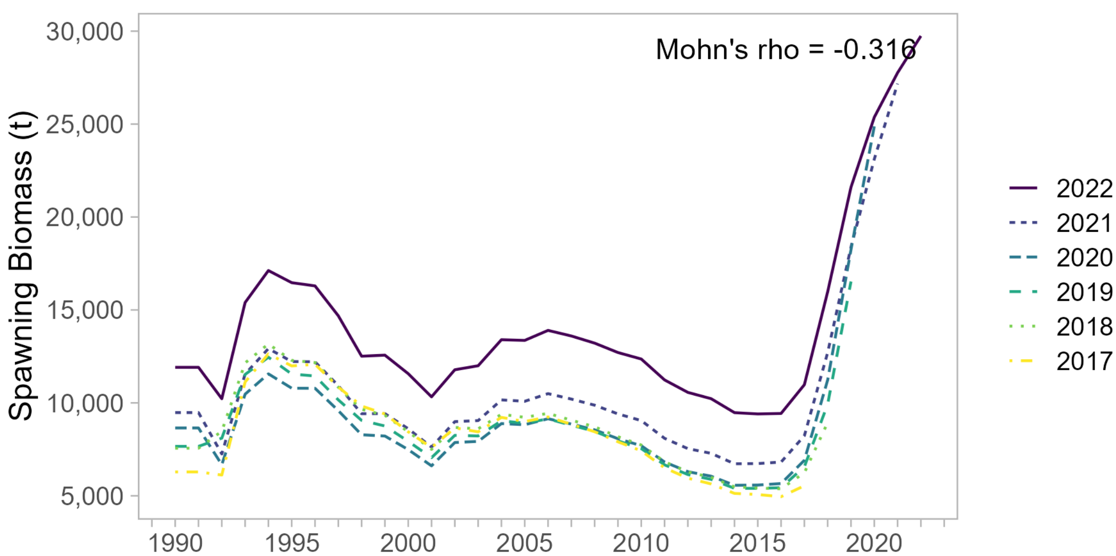

Figure 35: Spawning stock biomass from retrospective analysis of model 23.0 going back to 2017.

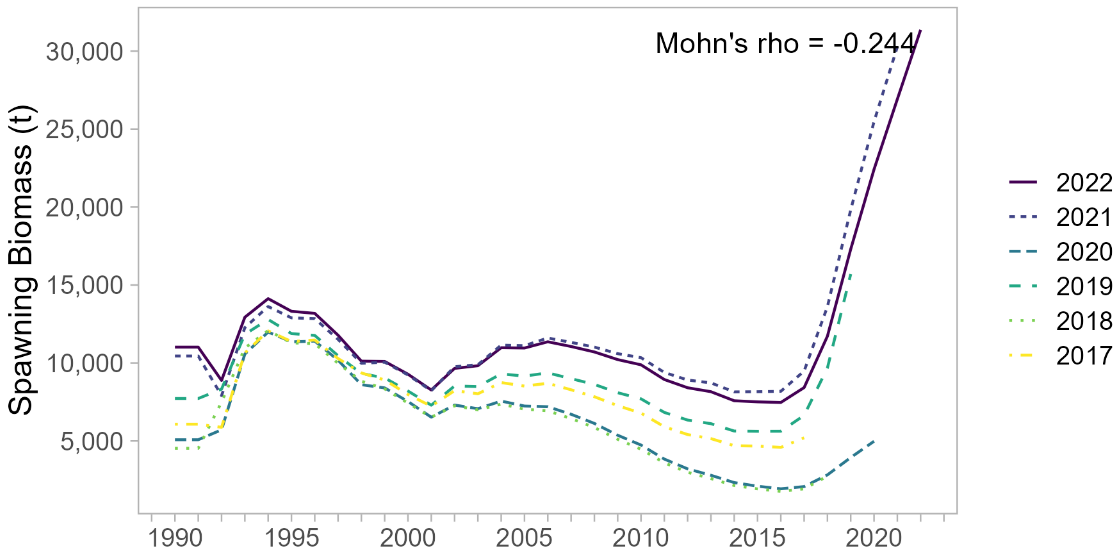

Figure 36: Spawning stock biomass from retrospective analysis of model 23.0a going back to 2017.

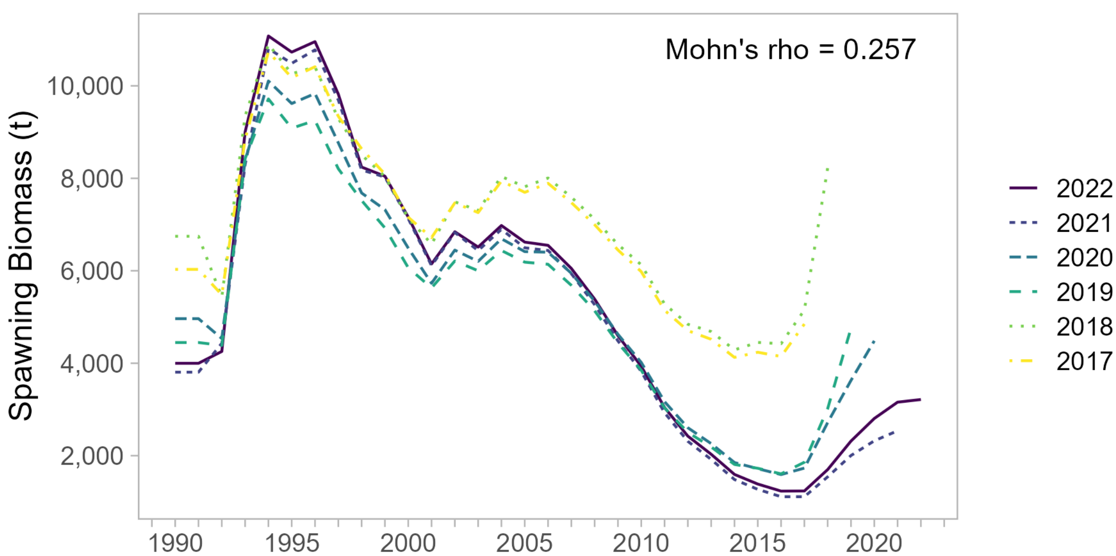

Figure 37: Spawning stock biomass from retrospective analysis of model 23.0a1 going back to 2017.

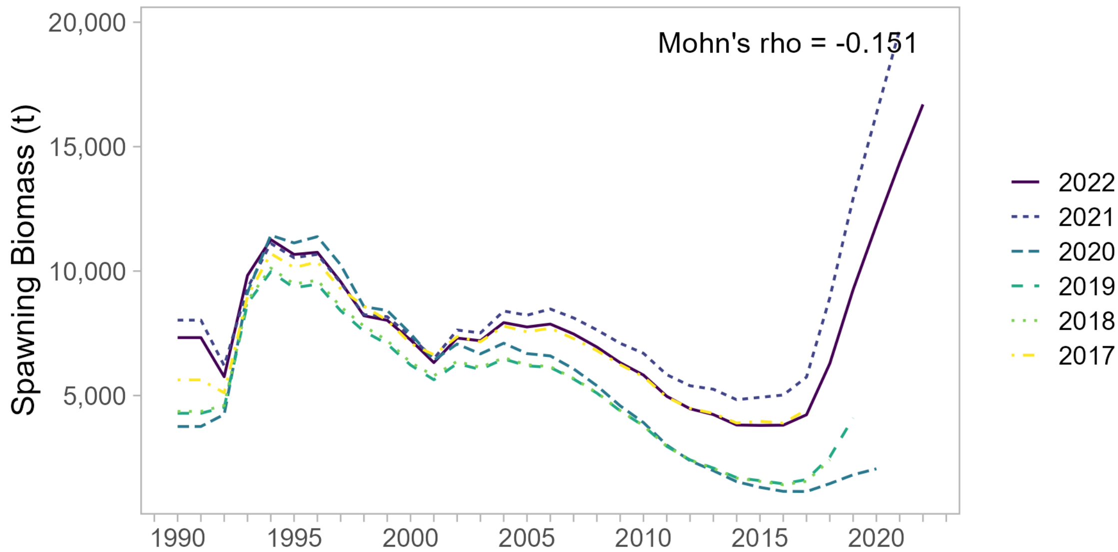

Figure 38: Spawning stock biomass from retrospective analysis of model 23.0a3 going back to 2017.

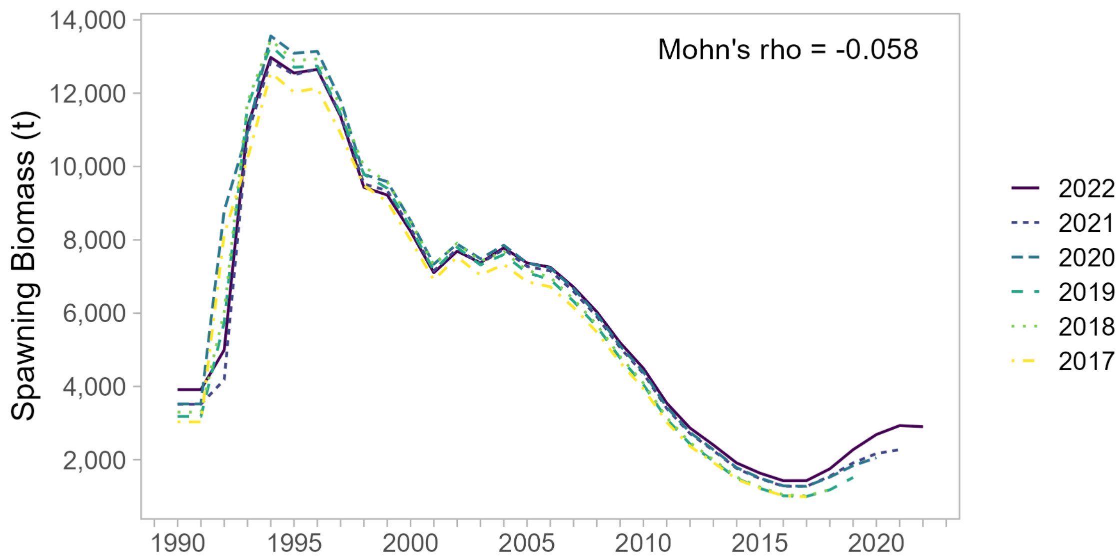

Figure 39: Spawning stock biomass from retrospective analysis of model 23.3 going back to 2017.

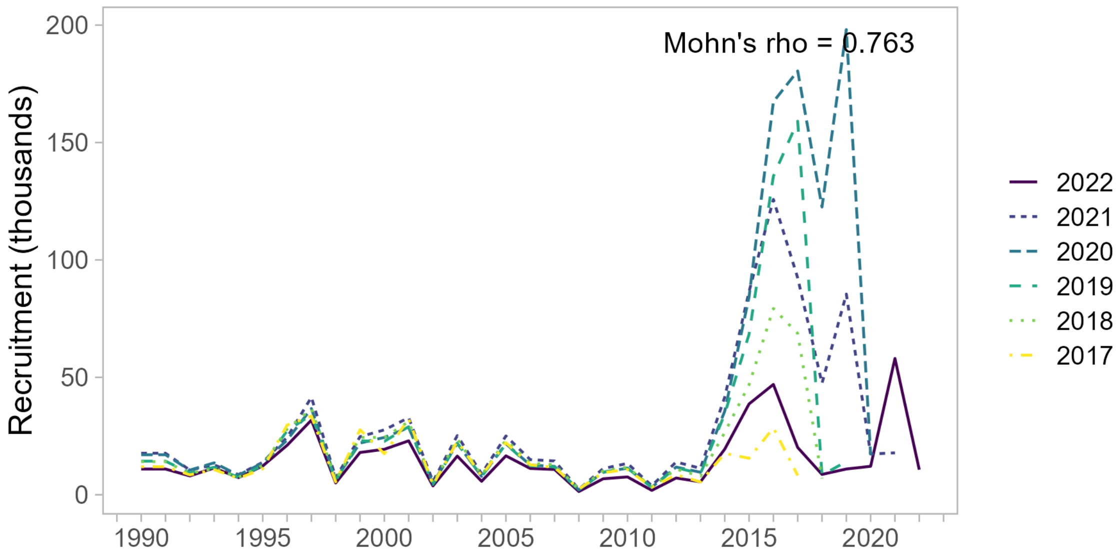

Figure 40: Recruitment estimates (millions) from retrospective analysis of model 22.1a going back to 2017.

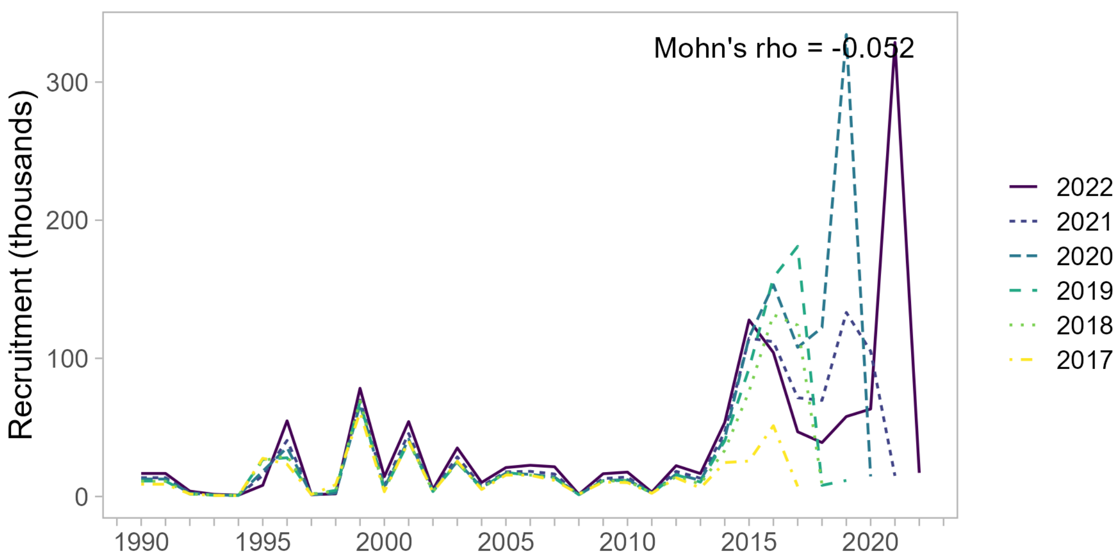

Figure 41: Recruitment estimates (millions) from retrospective analysis of model 23.0 going back to 2017.

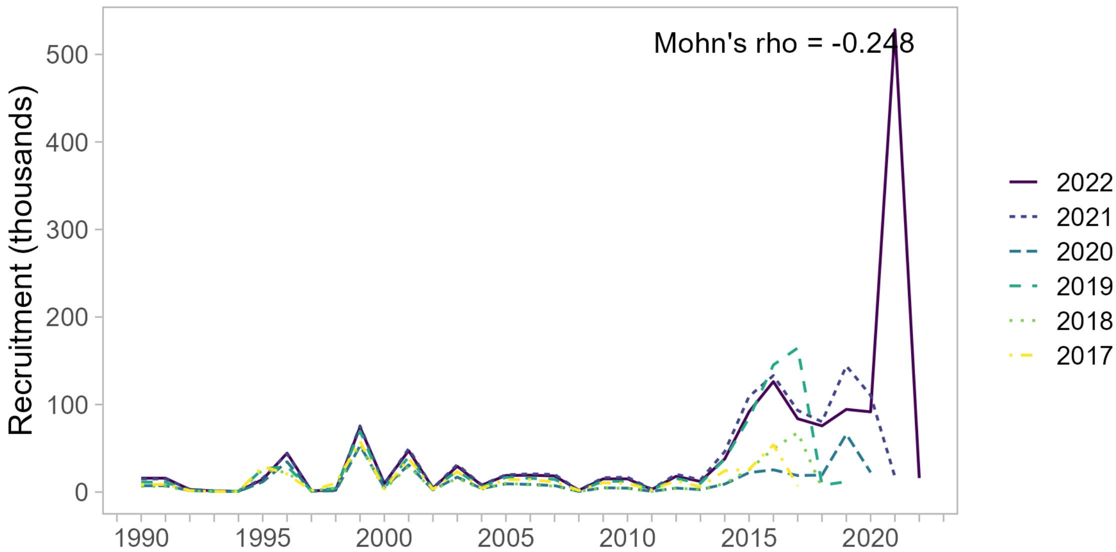

Figure 42: Recruitment estimates (millions) from retrospective analysis of model 23.0a going back to 2017.

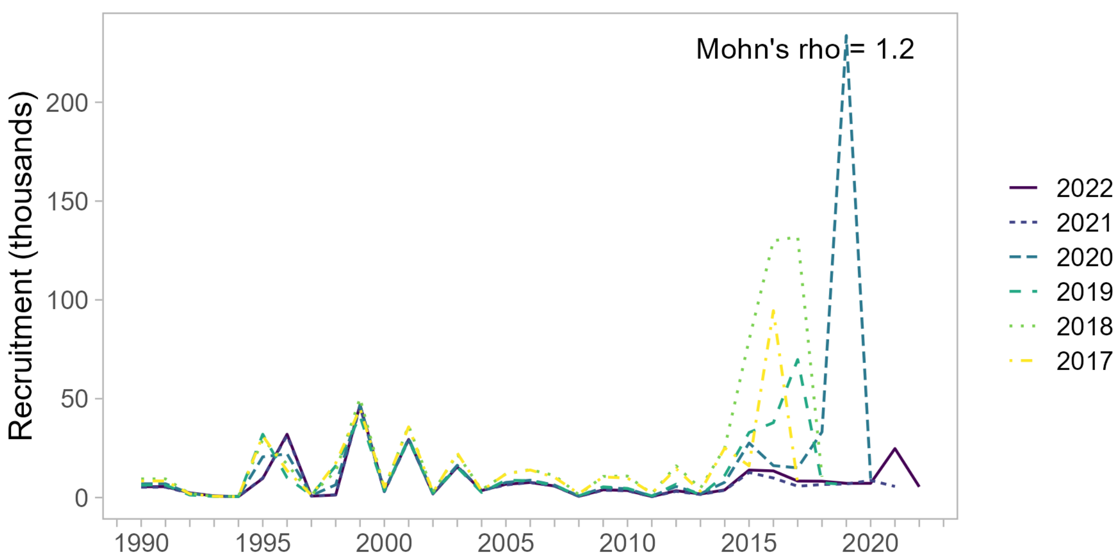

Figure 43: Recruitment estimates (millions) from retrospective analysis of model 23.0a1 going back to 2017.

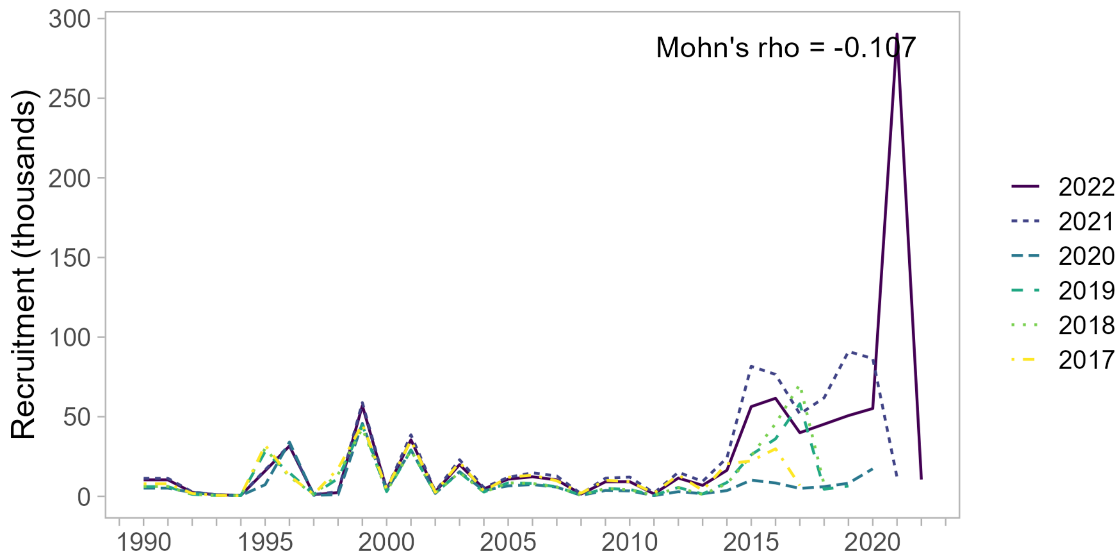

Figure 44: Recruitment estimates (millions) from retrospective analysis of model 23.0a3 going back to 2017.

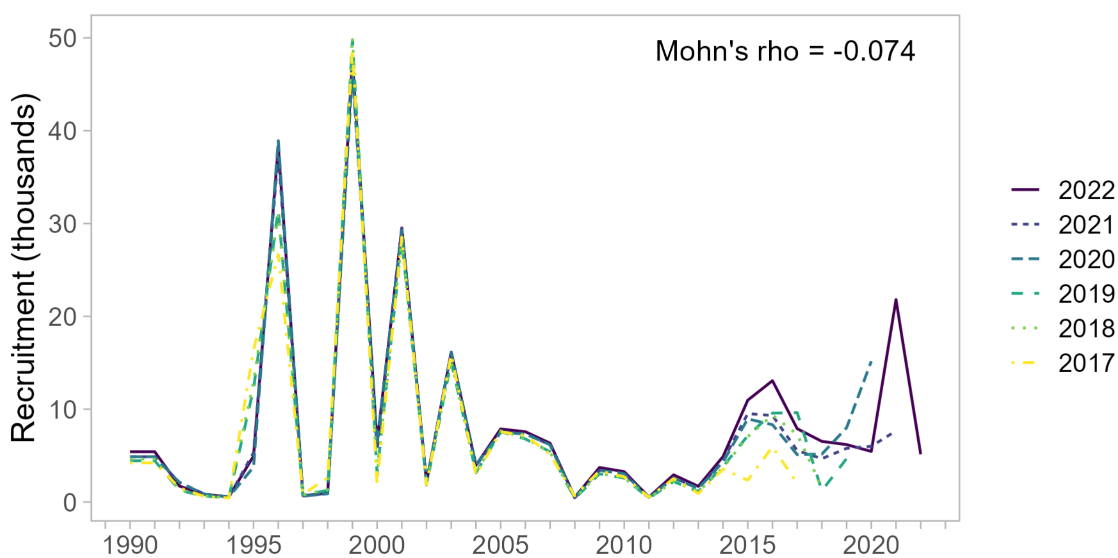

Figure 45: Recruitment estimates (millions) from retrospective analysis of model 23.3 going back to 2017.