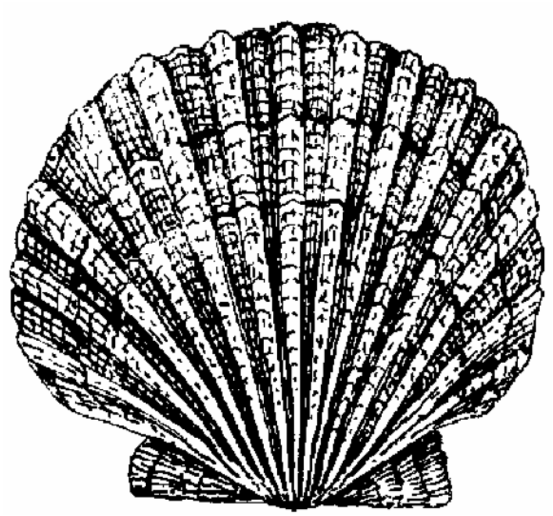
STOCK ASSESSMENT AND FISHERY EVALUATION REPORT
FOR THE SCALLOP FISHERY OFF ALASKA

March 2023

Prepared by:

The Scallop Plan Team



With contributions by:
Tyler Jackson (ADF&G Kodiak), Scott Miller (NMFS Juneau), Sarah Rheinsmith (NPFMC, Anchorage)

North Pacific Fishery Management Council
1007 W. 3rd Avenue, Suite 400
Anchorage, Alaska 99516

Executive Summary

1. **Stock**: Weathervane scallop, *Patinopecten caurinus*, in waters off Alaska. Status of other Alaska scallop stocks are detailed in the Ecosystem Component in the most recent SAFE document (SPT 2022).

2. **New information**:

   - 2021/22 - 2022/23 fishery retained catch;
   - 2021/22 - 2022/23 fishery discards and discard mortality;
   - 2021/22 - 2022/23 fishery CPUE;
   - 2022 fishery-independent dredge survey results.

3. **Fishery performance**: The 2021/22 season statewide Guideline Harvest Level (GHL) for weathervane scallops was 345,500 lb (156.7 t) of shucked meats. Of this GHL, 298,770 lb (135.5 t) were retained with an additional 13,208 lb (6 t) of estimated discard mortality for a total take of 311,978 lb (141.5 t) of shucked meats (Table 2). Nominal meat weight catch-per-unit-effort (CPUE) ranged from 55.7 lb/dredge hr to 123.6 lb/dredge hr among districts (Table 2).

   The 2022/23 season statewide GHL increased to 375,500 lb (170.3 t) due to increases in Kodiak Northeast and Kodiak Shelikof Districts (Table 3). Retained catch totaled 329,095 lb (149.3 t) of shucked meats. GHLs were met in all districts fished except Yakutat and Dutch Harbor, while Kodiak Southeast and waters between 160°W - 161°W longitude (Area M) were left unfished. Statewide discard mortality was estimated to be 329,095 lb (149.3 t), yielding a total removal of 345,690 lb (156.8 t) of shucked meats (Table 3). Nominal meat weight CPUE ranged from 19.9 lb/dredge hr to 129 lb/dredge hr among districts (Table 3).

4. **Stock status**: Status of the weathervane scallop stock relative to "overfished" is **"unknown"**. The FMP defines the minimum stock size threshold (MSST) for weathervane scallops as 4.93 million lbs (2,236 t) of shucked scallop meats. However, scallop abundance is estimated only for portions of two of nine registration areas, thus there is no biomass estimate of the full stock. This status determination is not considered to be a conservation concern since scallops are distributed in many areas that have been closed to fishing to protect crab populations and in areas not defined as commercial scallop beds.

   Estimated total fishing removals (retained and discarded) for the 2021/22 and 2022/23 seasons were 311,978 lb (141.5 t) and 345,690 lb (156.8 t) of shucked meats, respectively (Table 1). These estimates are less than 30% of the ABC/ACL and OFL, therefore, **overfishing did not occur in 2021/22 or 2022/23**.

5. **Scallop Plan Team Harvest Recommendations**: The Scallop Plan Team recommends that OFL in the 2023/24 season be set equal to maximum OY (1.284 million lb; 582 t) as defined in the Scallop FMP (2014). The Team also recommends that ABC for scallops in 2023/24 be set consistent with the maximum ABC control rule (90% of OFL) and which is equal to 1.156 million lb (524 t).

6. **Fishery Independent Survey**: The Alaska Department of Fish and Game (ADF&G) conducted a dredge survey in 2022 of weathervane scallop beds within the Northeast and Shelikof Districts of the Kodiak Registration Area, and the Kamishak District of the Cook Inlet Registration Area. Abundance and round weight biomass of exploitable-sized scallops ($\geq$ 100 mm shell height) increased from previous surveys in all districts. Trends in meat weight biomass followed abundance and round weight biomass in all beds, except within Kamishak District, which was likely due to sampling error (Table 4). Abundance and round weight biomass of scallops smaller than 100 mm shell height also increased among all districts (Table 5). Further details of the 2022 ADF&G scallop dredge survey can be found in Jackson et al. (*in review*).

Tables

Table 1: Total Alaska weathervane scallop removals (landings + discards) and OY/MSY/OFL, 1993/94 – 2022/23 seasons.

Season	Total Removals (lb meats)	OFL (lb meats)	ABC (lb meats)	% OFL	% ABC
1993/94	984,583	1,800,000	1,620,000	54.7	60.8
1994/95	1,240,775	1,800,000	1,620,000	68.9	76.6
1995/96	410,743	1,800,000	1,620,000	22.8	25.4
1996/97	732,424	1,800,000	1,620,000	40.7	45.2
1997/98	818,913	1,800,000	1,620,000	45.5	50.6
1998/99	822,096	1,240,000	1,116,000	66.3	73.7
1999/00	837,971	1,240,000	1,116,000	67.6	75.1
2000/01	750,617	1,240,000	1,116,000	60.5	67.3
2001/02	572,838	1,240,000	1,116,000	46.2	51.3
2002/03	509,455	1,240,000	1,116,000	41.1	45.7
2003/04	492,000	1,240,000	1,116,000	39.7	44.1
2004/05	425,477	1,240,000	1,116,000	34.3	38.1
2005/06	525,357	1,240,000	1,116,000	42.4	47.1
2006/07	487,473	1,240,000	1,116,000	39.3	43.7
2007/08	458,313	1,240,000	1,116,000	37.0	41.1
2008/09	342,434	1,240,000	1,116,000	27.6	30.7
2009/10	512,958	1,240,000	1,116,000	41.4	46.0
2010/11	481,509	1,240,000	1,116,000	38.8	43.1
2011/12	461,946	1,284,000	1,156,000	36.0	40.0
2012/13	424,491	1,284,000	1,156,000	33.1	36.7
2013/14	408,101	1,284,000	1,156,000	31.8	35.3
2014/15	314,364	1,284,000	1,156,000	24.5	27.2
2015/16	261,930	1,284,000	1,156,000	20.4	22.7
2016/17	236,559	1,284,000	1,156,000	18.4	20.5
2017/18	250,591	1,284,000	1,156,000	19.5	21.7
2018/19	250,372	1,284,000	1,156,000	19.5	21.7
2019/20	246,900	1,284,000	1,156,000	19.2	21.4
2020/21	234,662	1,284,000	1,156,000	18.3	20.3
2021/22	311,978	1,284,000	1,156,000	24.3	27.0
2022/23	345,690	1,284,000	1,156,000	26.9	29.9

Table 2: Guidline harvest Levels (GHL) and summary statistics (lb meat weight) from the 2021/22 Alaska weathervane scallop fishery.

Registration Area	District/ Subsection Subsection	GHL (lb)	Retained (lb)	CPUE (lb / dredge hr)	Discard Mortality (lb)
Yakutat	Yakutat	145,000	145,010	59.10	6,765
Prince William Sound	East Kayak Island	Closed			
	West Kayak Island	8,000	8,170	123.60	96
Kodiak	Northeast	30,000	30,295	102.90	2,123
	Shelikof	80,000	80,215	106.40	3,630
	Southwest	35,000	35,080	55.70	593
	Southeast	15,000	No Effort		No Effort
AK Peninsula	Central	7,500	No Effort		No Effort
	Unimak Bight	7,500	No Effort		No Effort
Dutch Harbor	Dutch Harbor	10,000	No Effort		No Effort
Bering Sea	Bering Sea	7,500	No Effort		No Effort
Statewide Total		345,500	298,770	71.1	13,208

Table 3: Guidline harvest Levels (GHL) and summary statistics (lb meat weight) from the 2022/23 Alaska weathervane scallop fishery.

Registration Area	District / Subsection Subsection	GHL (lb)	Retained (lb)	CPUE (lb / dredge hr)	Discard Mortality (lb)
Yakutat	Yakutat	145,000	128,210	67.40	8,797
Prince William Sound	East Kayak Island	Closed			
	West Kayak Island	8,000	8,130	94.20	157
Kodiak	Northeast	40,000	40,040	129.00	1,735
	Shelikof	100,000	99,970	108.30	3,995
	Southwest	35,000	35,030	67.80	931
	Southeast	15,000	No Effort		No Effort
AK Peninsula	Central	7,500	No Effort		No Effort
	Unimak Bight	7,500	7,560	35.30	684
Dutch Harbor	Dutch Harbor	10,000	2,620	19.90	97
Bering Sea	Bering Sea	7,500	7,535	22.80	197
Statewide Total		375,500	329,095	74.5	16,595

Table 4: Estimated abundance (N), round biomass (lb), meat biomass (lb) and associated CVs of scallops $\geq$ 100 mm shell height by bed, from the 2022 ADF&G Dredge Survey.

		Abundance		Round Biomass		Meat Biomass	
District	Bed	N	CV	lb	CV	lb	CV
Kamishak	KAMN	2,542,861	0.27	1,556,694	0.21	100,369	0.23
Kodiak Northeast	KNE1	1,144,185	0.29	424,979	0.32	32,124	0.32
	KNE2	981,389	0.36	387,971	0.43	32,142	0.44
	KNE3	5,683,597	0.58	2,065,712	0.56	165,731	0.54
	KNE5	1,329,510	0.67	462,919	0.66	39,682	0.67
	KNE6	6,032,955	0.37	2,516,863	0.37	217,795	0.37
Kodiak Shelikof	KSH1	22,042,155	0.20	9,973,836	0.20	733,361	0.21

Table 5: Estimated abundance (N), round biomass (lb), and associated CVs of scallops < 100 mm by bed, from the 2022 ADF&G Dredge Survey.

		Abundance		Round Biomass	
District	Bed	N	CV	lb	CV
Kamishak	KAMN	9,982,984	0.29	421,906	0.28
Kodiak Northeast	KNE1	1,614,665	0.36	101,714	0.41
	KNE2	5,903,186	0.21	249,277	0.21
	KNE3	196,276	0.41	19,493	0.55
	KNE5	1,404,267	0.29	40,712	0.22
	KNE6	3,942,918	0.26	142,668	0.28
Kodiak Shelikof	KSH1	43,017,962	0.17	1,595,755	0.20

Scallop SAFE 2023 Appendix A: Socioeconomic Update

Prepared by Scott A. Miller, Industry Economist, NOAA Fisheries, Juneau.

LLP Ownership Transfers

There have been several LLP transfers in 2022 and 2023. LLP 004, originally issued to Max Hulse, was transferred from Scott Hulse to Ty W. Babb, of Maine with no known vessel associated to fish this permit. LLP 004 was again transferred in 2022 from Ty W. Babb to Provider Fisheries LLC, an Alaska Scallop Association cooperative member. Additionally, LLPs 003 was transferred from Atlantic Capes Fisheries Inc., an east coast firm, to Arctic Hunter LLC, which is a cooperative member. This latter transfer means that the vessel Kilkenny (homeported in Kodiak), is owned by Atlantic Capes Fisheries Inc. but no longer has a scallop LLP associated with it. Historically Kilkenny delivered fresh scallop meats for marketing in Kodiak and Homer, whereas cooperative members shuck and freeze scallops at sea producing a first wholesale product. LLP 006 continues to be owned by EWT LLC, which is also an east coast company; however, EWT LLC has not fished their LLP since acquiring it and no known vessel is associated with the permit. As of 2023, LLP 006 is the only permit that is not associated with the Alaska Scallop Association cooperative. Although state waters remain open to new entrants via registration with the Alaska Department of Fish and Game, no State of Alaska waters registrants have fished for scallops since the State waters management plan was adopted.

LLP Ownership Information: Cooperative Affiliated

As documented in the 2022 Scallop SAFE socioeconomic appendix, the member entities of the Alaska Scallop Association cooperative are co-owned by multiple individuals and or companies (LLC's) organized in Washington State and Alaska. There has been no known change in cooperative membership or cooperative affiliated LLP ownership shares within the various companies other than the two LLPs transferred to Provider Fisheries LLC and Arctic Hunter LLC, as discussed above. Cooperative members collectively own three vessels qualified to fish their LLPs: the Polar Sea (LLP 005, LLP 003), the Provider (LLP 008, LLP 004), and the Ocean Hunter (LLP 007, LLP 009). LLP 002 is held by American Seafoods but is sideboarded and has not fished scallops since the LLPs were issued. American Seafoods is a cooperative member. LLP 010 is held by Alaska Scallop Fisheries LLC, which is also a cooperative members with no known vessel associated with the LLP. The vessel Provider is exclusively used to fish scallops, while Polar Sea and Ocean Hunter may also participate in the Crab Rationalization Program fisheries

Landed Value Update: 2021-22 to 2022-23

In 2022-23, landings increased from 298,755 lbs. to 329,095, a 10.16% increase. Due to widespread inflationary pressures, first wholesale price, as reported by the Alaska Scallop Association, increased from \$11.06/lb. to \$13.56/ lb., a 22.6% increase. These combined increased led to a total gross first wholesale value of increase from \$3.304 million to \$4.462 million, a 35.05% increase. Two cooperative affiliated vessels fished in 2021-22 and with an assumed maximum of 12 crew and 42% crew share allocation of total gross revenue this resulted in a potential crew share increase from $57,824 to $78,094 in 2022-23. These assumptions are based on maximum allowable crew numbers in State of Alaska Statute, and data provided by industry on crew share allocations from two vessels that fished scallops in the past. Though dated, these crew share allocations represent the best available information and have not been questioned by industry.

Port Landings 2019-2023

The Alaska Department of Fish and Game, Scallop Program has provided port landings data from 2019- the present season. In the most recent years, Dutch Harbor, Kodiak, and Yakutat have been the primary landing ports for participating cooperative member vessels. On landing was made in Seattle in the 2022/21 season due to quarantine requirements. Kodiak remains the primary port of landing, as the two presently participated vessels are homeported there.

	Season			
Port	**2019/20**	**2020/21**	**2021/22**	**2021/22**
Dutch Harbor	1			1
Homer	1			
Kodiak	5	5	8	10
Yakutat	3	2	2	3
Seattle		1		
Unknown				1
Total	**10**	**8**	**10**	15

Source: ADFG Kodiak Scallop Program Office 2023

Revisions to be done in next full SAFE (2024)

The ADF&G Kodiak Scallop Program office has compiled port of landings data (# of landings by port) has back to 1990. This information will be analyzed to present port landings history and a comparative analysis of this data will be developed to show changes in community participation over time. This analysis will also develop an updated ownership chart and ownership shares will be verified shares to extent possible. The history of port landings will also be compared with the history of LLP issuance and all ownership changes of each LLP over time to document how the Council's action to limit licenses and better manage a race for fish has evolved into a more consolidated fishery with voluntary cooperative management. Finally, dramatic changes in import markets have occurred in recent years. An updated import market assessment will be provided to document changes in scallop markets worldwide from pre-pandemic, pandemic, and post pandemic eras. This analysis will also provide a comparison of the relative performance, volume, and value of the Atlantic sea scallop fishery, as is normally done in the full version of the scallop SAFE report.

Response to SSC Comments:

1. The SSC is encouraged to see that its multi-year comments on socioeconomic considerations in the scallop SAFE are in the process of being addressed and looks forward to continued work in this area as described in Appendix 1. This fishery is important from a socioeconomic analytic perspective in that the National Standard 8 goal of providing for the sustained participation of fishing communities does not appear to have been met over time. It has the potential to serve as a case study including lessons learned that would be of benefit to future management program design and application in other fisheries. The SSC requests that the analyst carefully examine the text regarding fishery taxes and crew shares to ensure accuracy and remove speculative content.

Response:

The point of identifying the types of taxes industry pays is to clarify that they do keep track of harvests in State waters versus the waters of the EEZ and pay the differing taxes that apply to each area. The text will be clarified with this regard. Crew share information is taken from a previous version of the scallop SAFE that documents crew share payments actually made by two past vessel operators. This data is quite dated but industry has not identified it as inaccurate, and one of those two vessels is operating in the fishery presently, albeit with partially different ownership. The number of crew positions is based on the maximum allowed under State of Alaska Statute and is accurate for the cooperative affiliated vessels presently participating.

In enacting the License Limitation Program, the Council sought to bring an open access “race for fish” fishery characterized by overcapacity and boom and bust harvest cycles into more formal management. This action followed a completely unregulated harvest event in the waters of the EEZ that resulted in complete fishery closure. The analysis supporting the Council action documented a break even analysis, which is also provided and updated to present conditions in the 2022 Scallop SAFE socioeconomic appendix. At the time, the Council determined that ten permits provided the best balance of license limitation with potential for profitability for fishery participants. The Council also chose to allow permit stacking of up to two permits per owning entity, and sideboarded a permit due to the owner’s American Fisheries Act status. Thus, the council clearly understood that there was the potential for consolidation to five owners based on original permit issuance.

Subsequent to Council action, one LLP, issued on an interim basis, was determined to not meet the issuance requirements and was rescinded. This left the 9 LLP that exist to date with one sideboarded to an extent that it has never been fished and participates as a cooperative member. Thus, there are effectively 8 LLPs that can be stacked to four owning entities and with recent permit transfers to cooperative affiliated entities seven of these LLPs are co-owned by four cooperative affiliated entities, which are themselves owned by multiple individuals and/or companies (LLCs) organized in Washington State and Alaska. One LLP remains independent of the cooperative and has no known vessel association.

This consolidation as resulted in the cooperative affiliated vessels being all homeported in Kodiak and primarily delivering to Kodiak, with occasional deliveries to Yakutat and Dutch Harbor. These delivery ports are all relatively close to the currently open scallop fishing grounds and all have readily available barge transport infrastructure. Kodiak also has ample harbor space and vessel servicing facilities.

While consolidation has resulted in landings in fewer communities than occurred prior to LLP issuance, the Council put in place a permit program that was expected to have consolidation via permit stacking to potentially five owning entities and that is exactly what has occurred. However, the ADF&G Kodiak Scallop Program Office has recently provided port of landings data back to 1990. For the 2024 full scallop SAFE report, that landings data will be provided along with a comparative analysis of permit ownership of each LLP over time. This analysis will also provide a discussion of the factors (e.g closed beds, vessel and gear efficiency, vessel/owner location etc.) that may have led to permit transfers. The analysis will also discuss the economic conditions that led to the formation of the cooperative and the resulting consolidation.

2. The SSC recommends that the SPT consider whether there would be value in conducting an analysis to assess whether this fishery is underutilized and, if so, identify barriers to increased participation in this fishery.

The response to comment 1, above identifies the current status of permit ownership and consolidation within the cooperative, and the one remaining independent permit. That response also identifies that the Council created the LLP program in the scallop fishery to address the inefficiencies of excess capitalization and the “race for fish” that existed in the open access fishery. The Council allowed permit stacking of up to two permits per owning entity, thus likely resulting in five owning entities, which is exactly what has happened over the years since the program was implemented.

This comment suggests that the Scallop Plan Team evaluate the LLP program, that the Council put in place, with regard to whether the Council’s action resulted in an underutilized fishery or created barriers to participation. It should be noted that the LLP program, by its very nature, limits participation to address fishery inefficiencies and overcapitalization. Such an analysis is not within the prevue of the Scallop Plan Team without such tasking by the Council, as it is essentially an evaluation of the Council’s action in creating the program. The Council could, at staff tasking, assign this task to Council staff, with participation from SPT members as needed, as a program review.

Appendix B: Stock Synthesis Evaluation of Kodiak Shelikof

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

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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.

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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

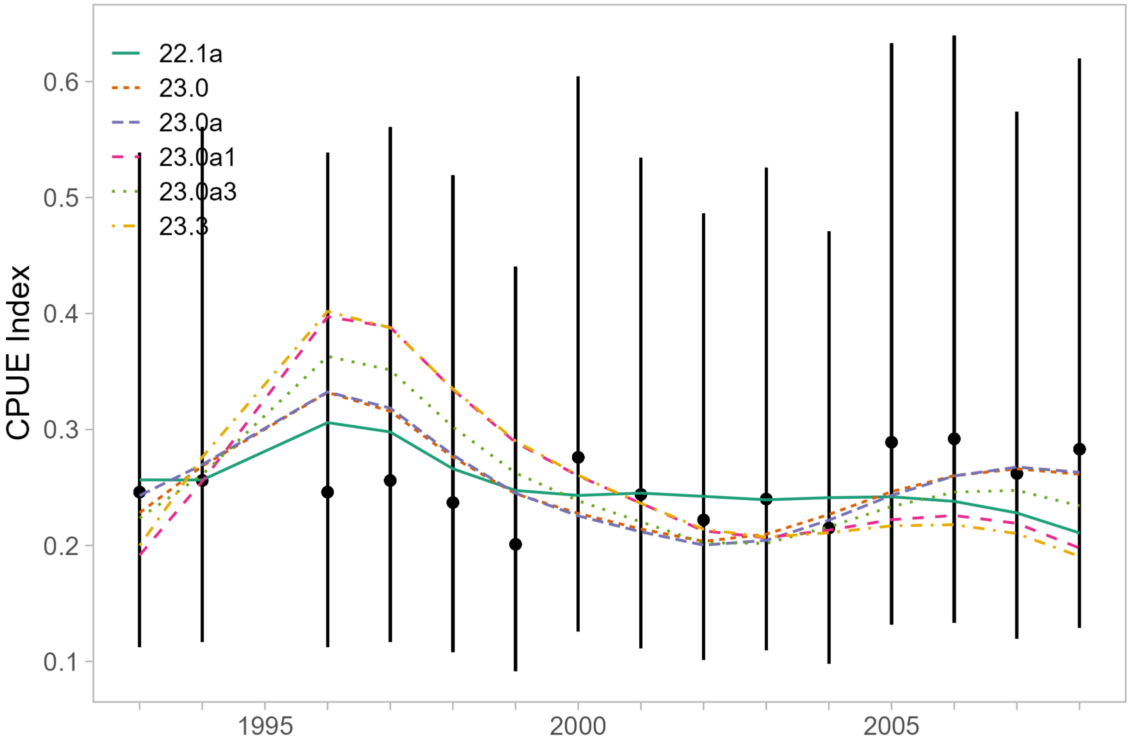

Figure 1: Fit to nominal fishery CPUE index from 1992-2008 by model scenario. Error bars indicate 95% confidence intervals.

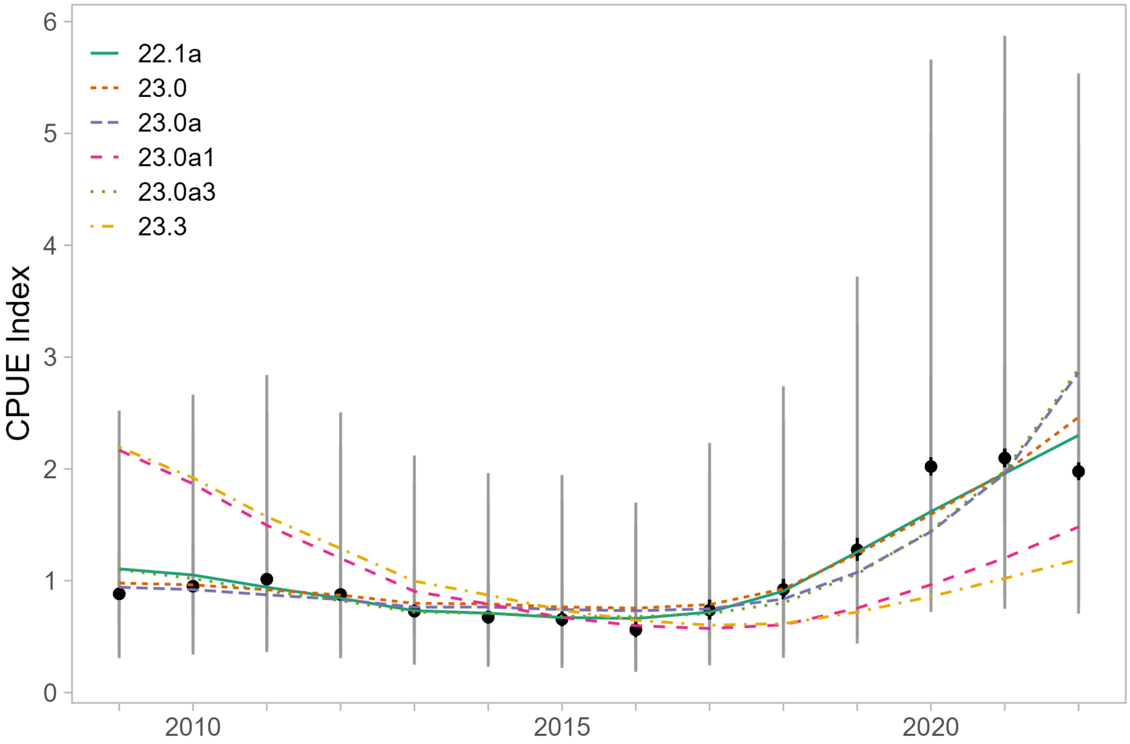

Figure 2: Fit to standardized fishery CPUE index from 2009-2022 by model scenario. Black error bars indicate 95% confidence intervals and grey error bars indicate addition estimated error.

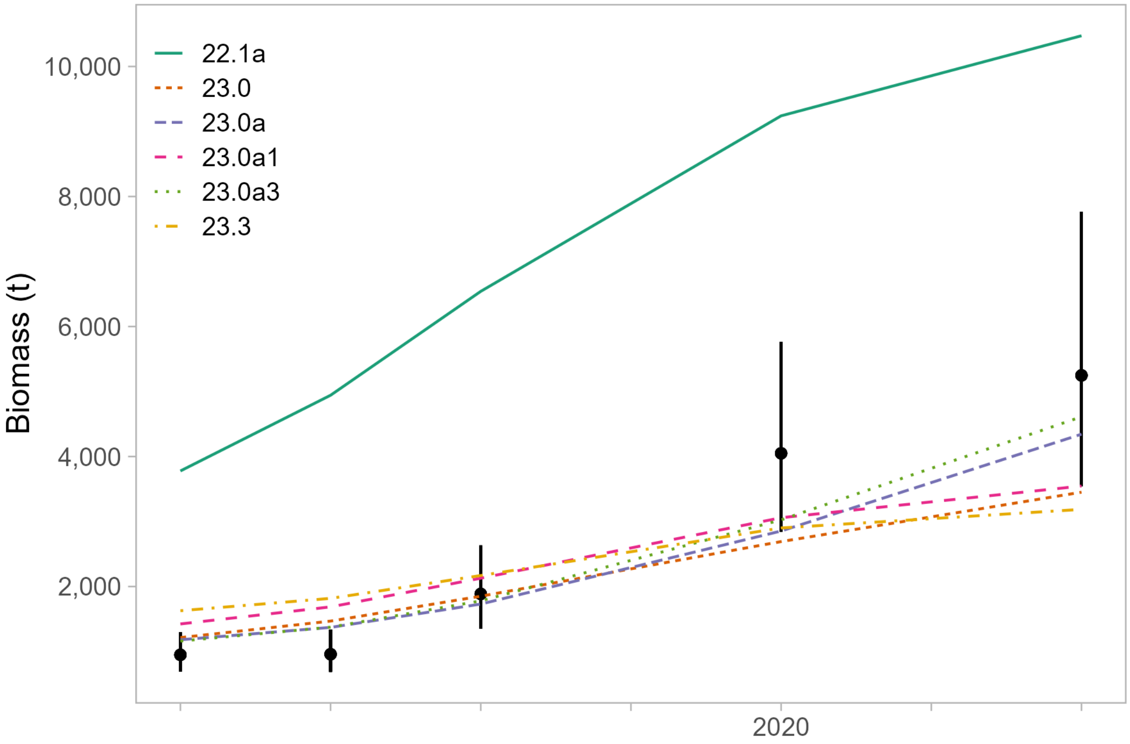

Figure 3: Fit to ADF&G dredge survey biomass by model scenario. Black error bars indicate 95% confidence intervals and grey error bars indicate addition estimated error.

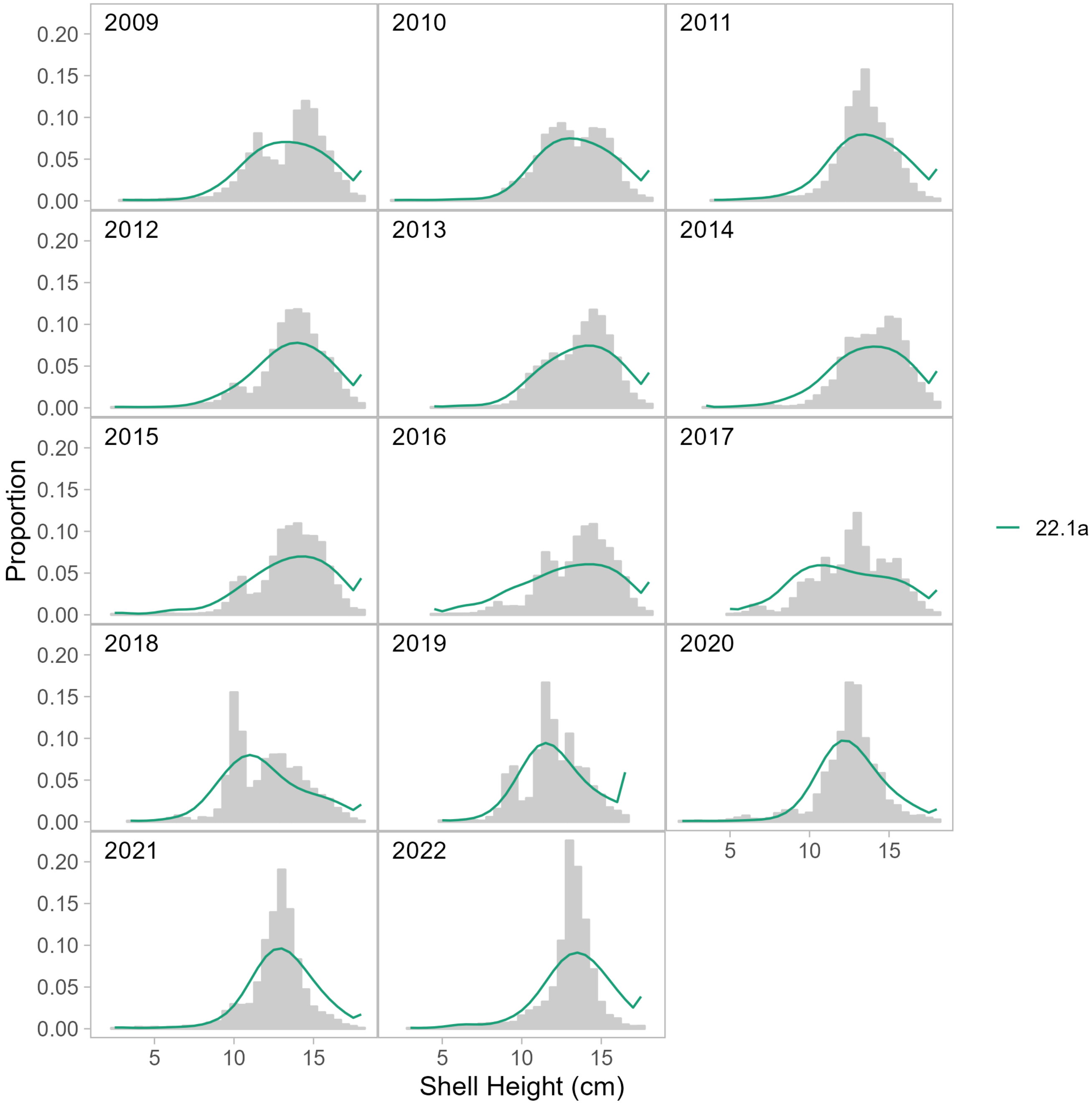

Figure 4: Fit to fishery shell height composition (i.e., retained and discarded scallops) for model 22.1a.

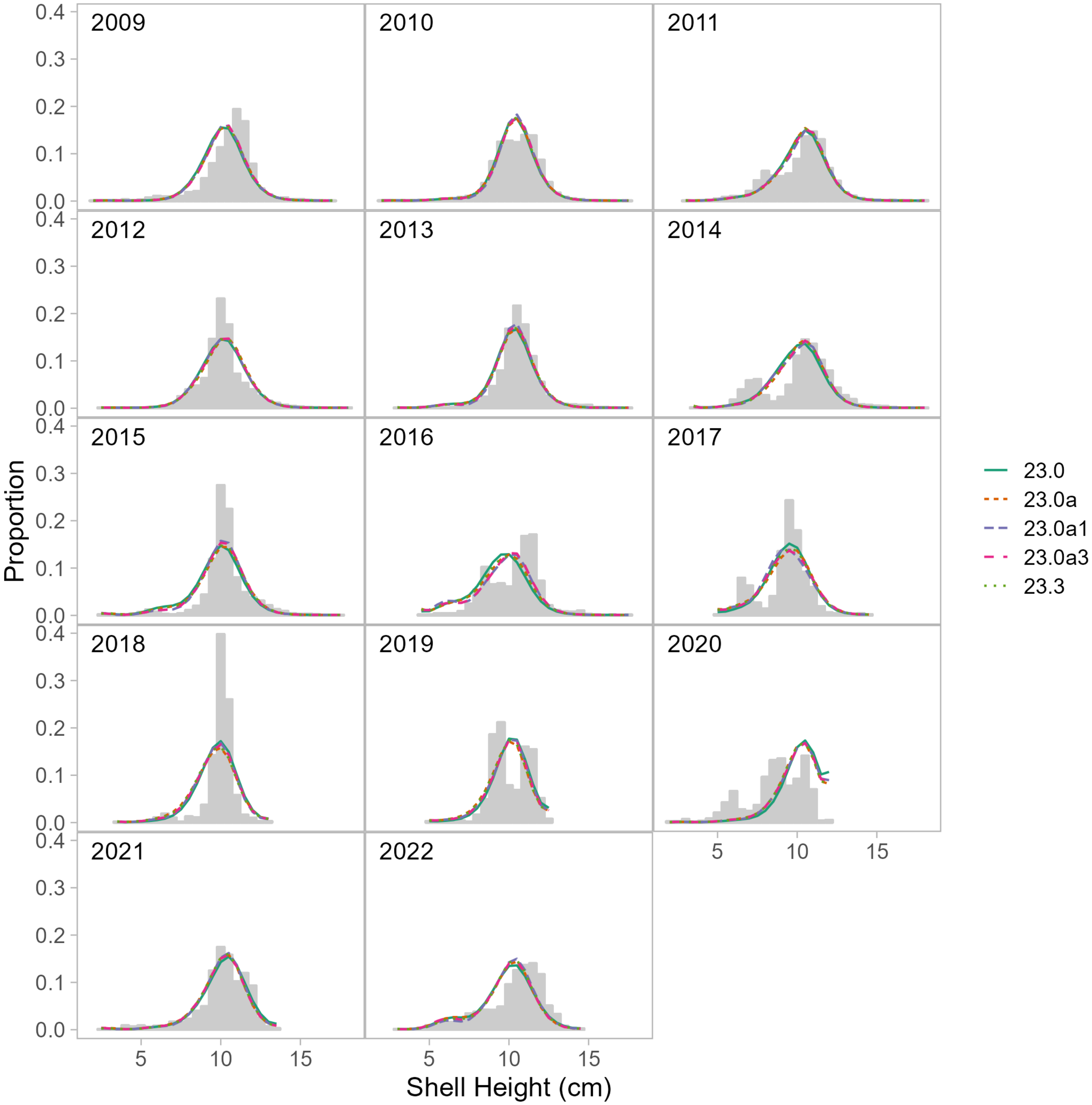

Figure 5: Fit to fishery discarded scallop shell height composition by model scenario.

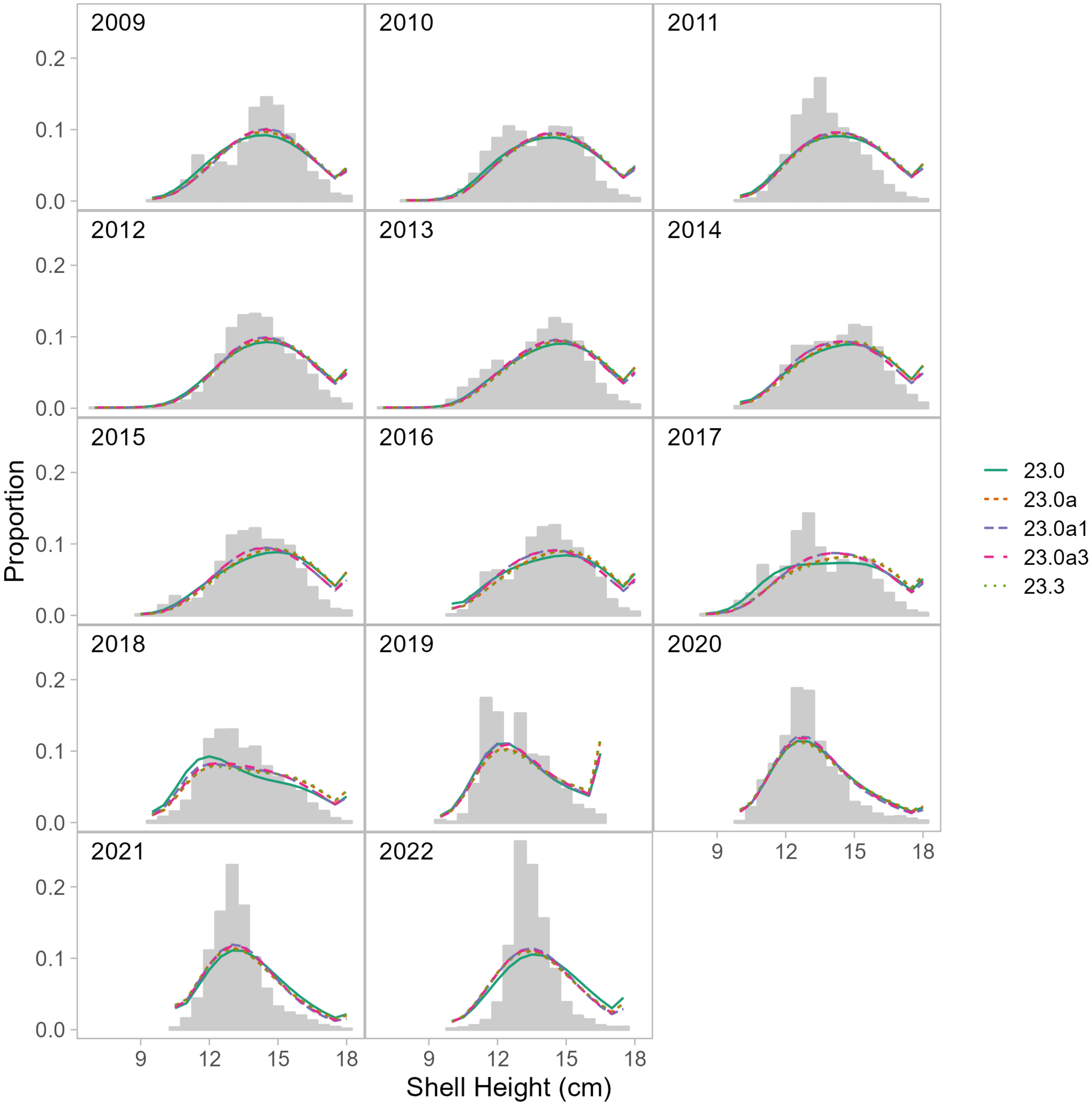

Figure 6: Fit to fishery retained scallop shell height composition by model scenario.

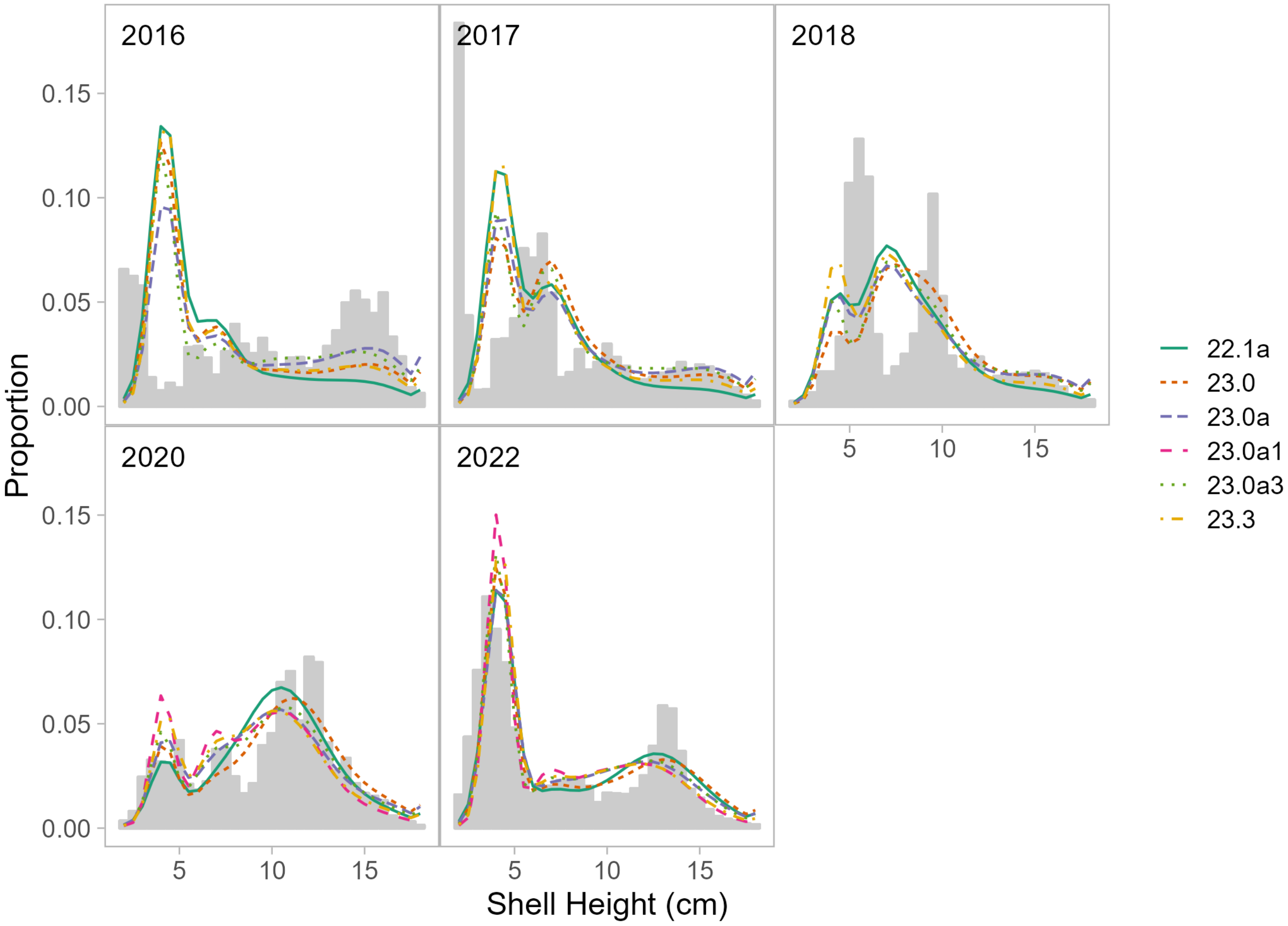

Figure 7: Fit to ADF&G dredge survey shell height composition by model scenario.

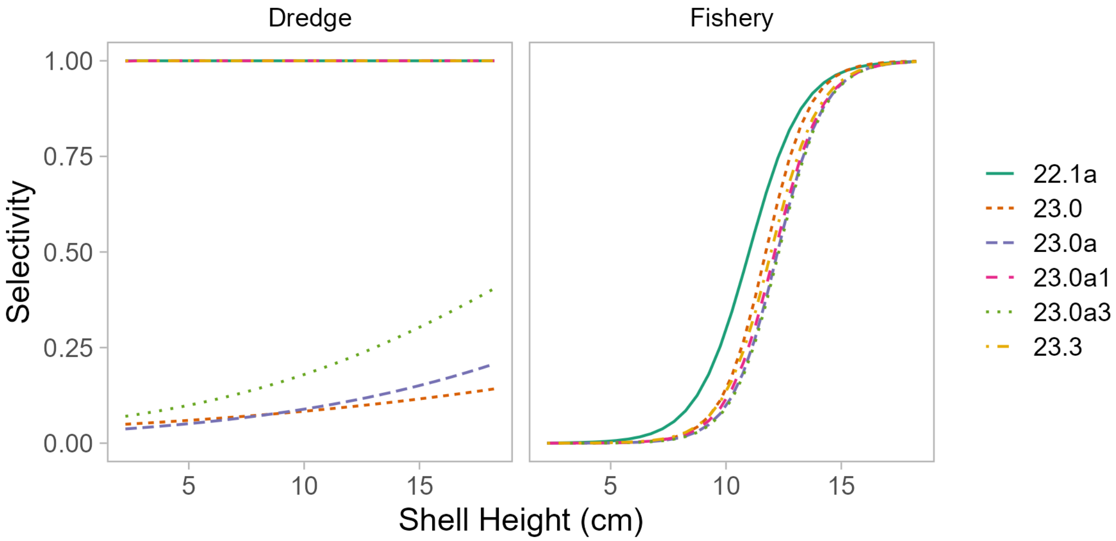

Figure 8: Fishery and ADF&G dredge survey shell height selectivity by model scenario.

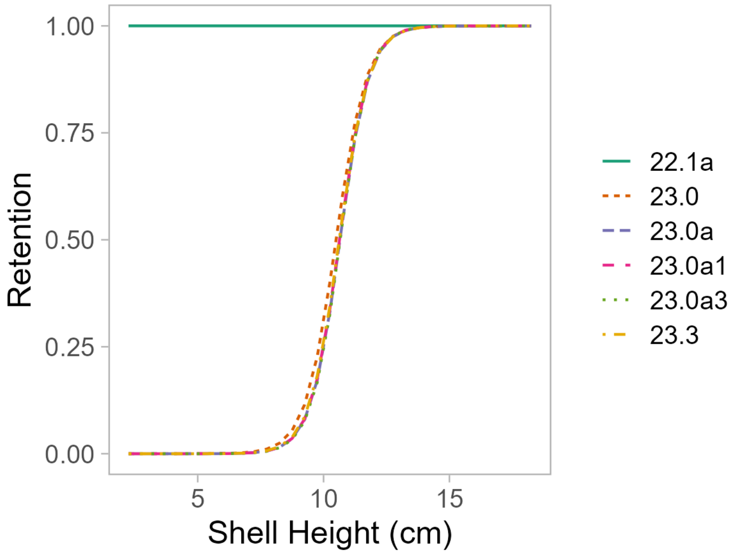

Figure 9: Fishery retention on the basis of shell height by model scenario.

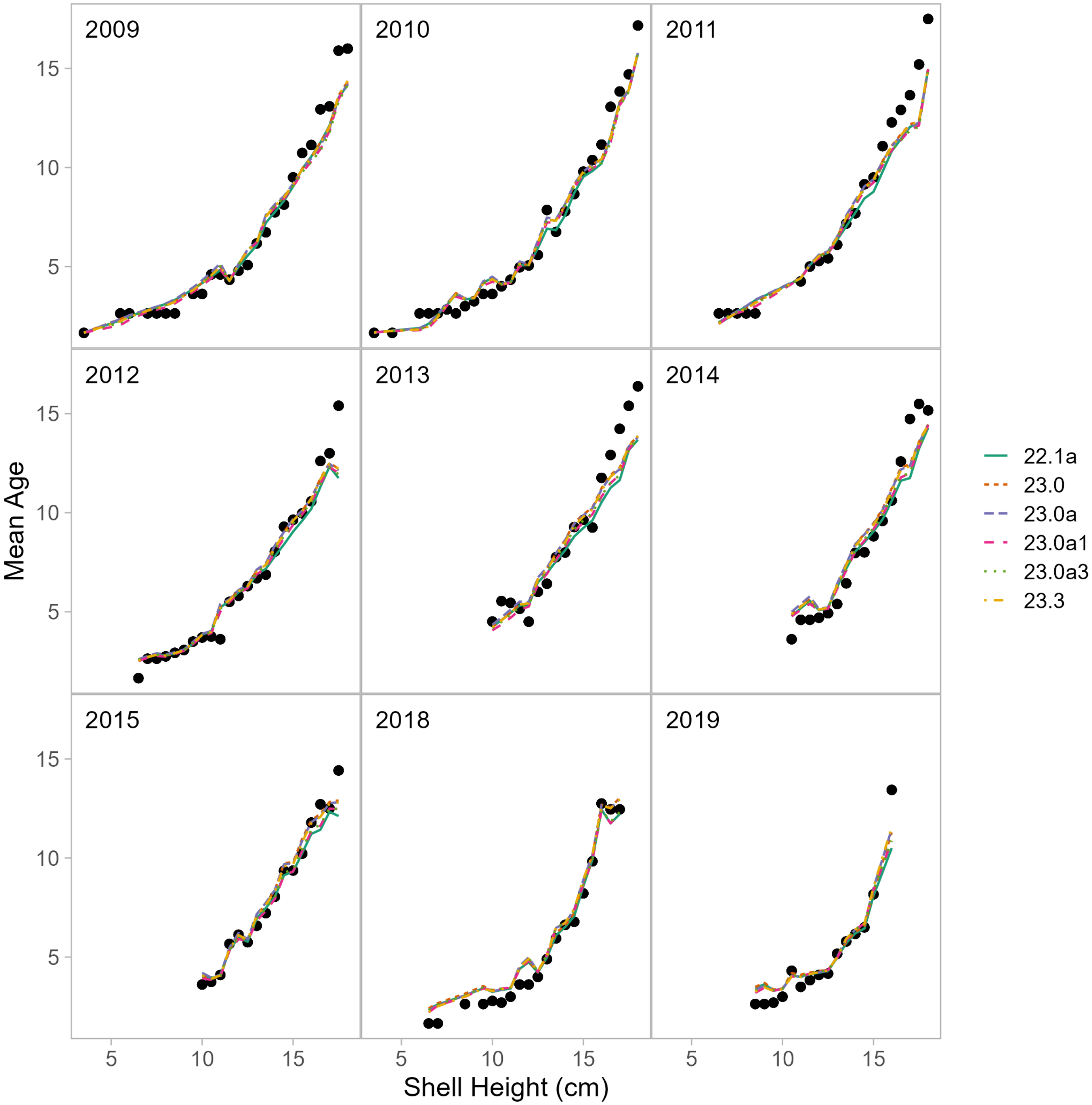

Figure 10: Fit to fishery age composition by model scenario.

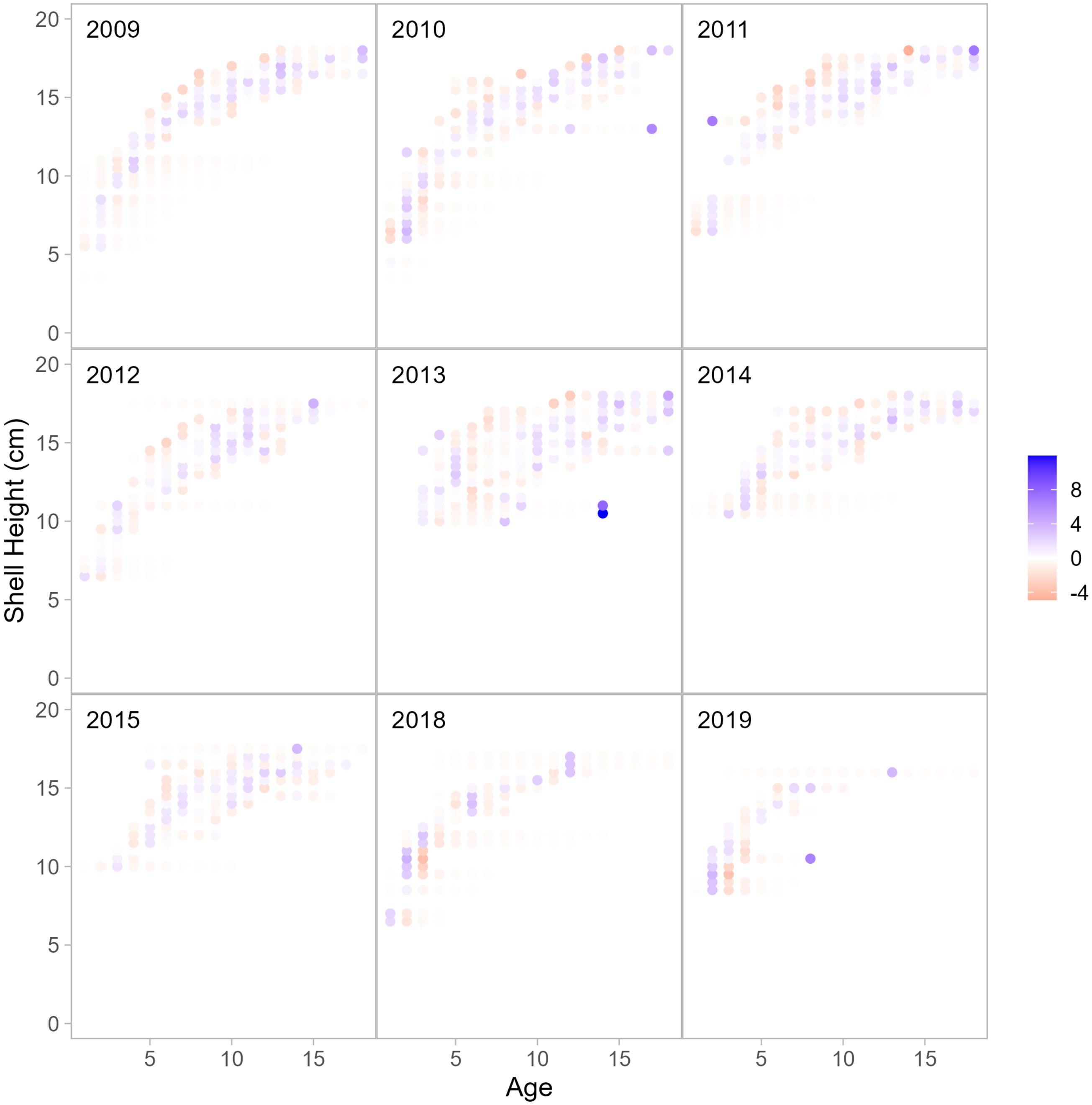

Figure 11: Fishery age composition pearson residuals for model 22.1a

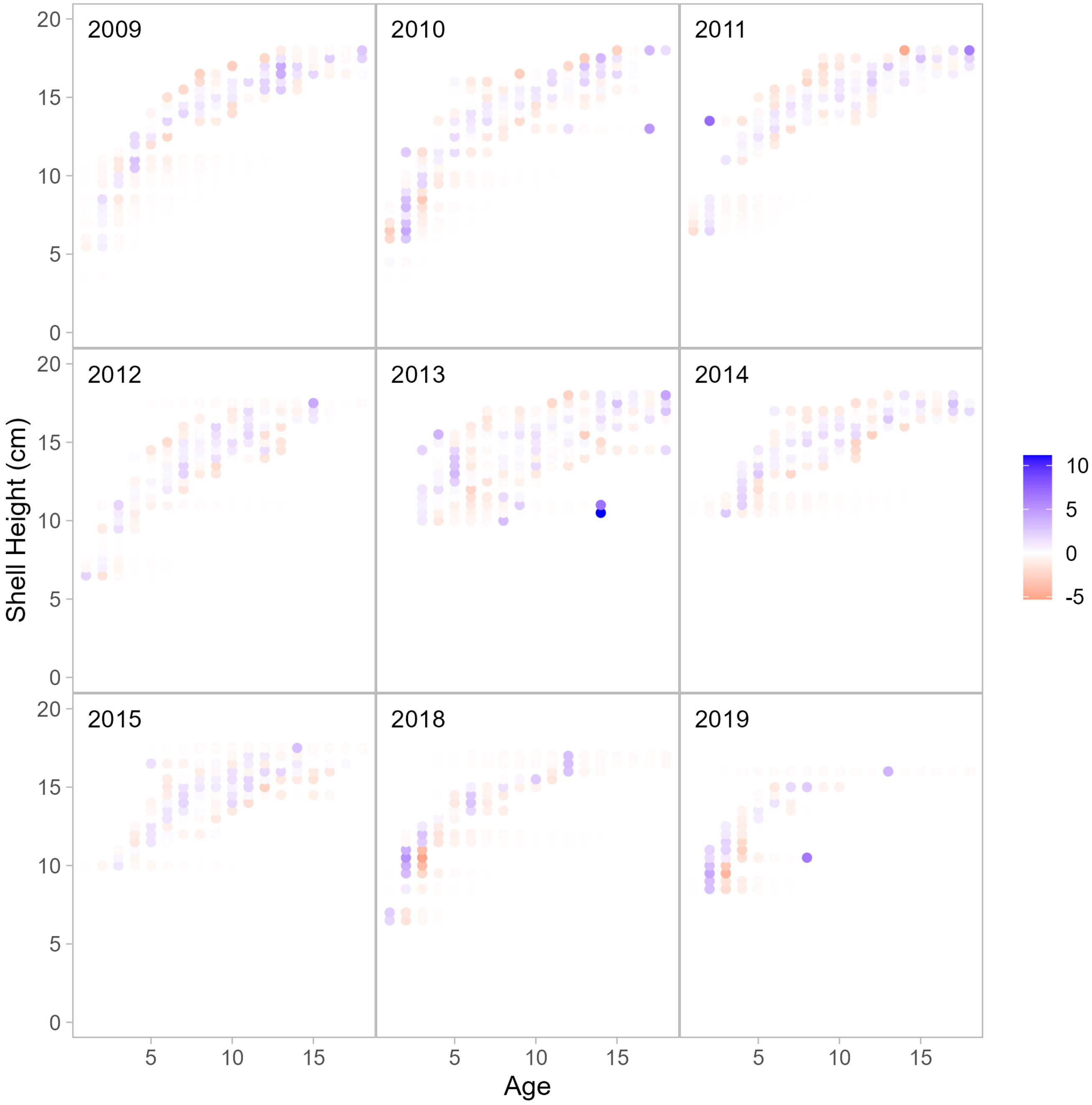

Figure 12: Fishery age composition pearson residuals for model 23.0.

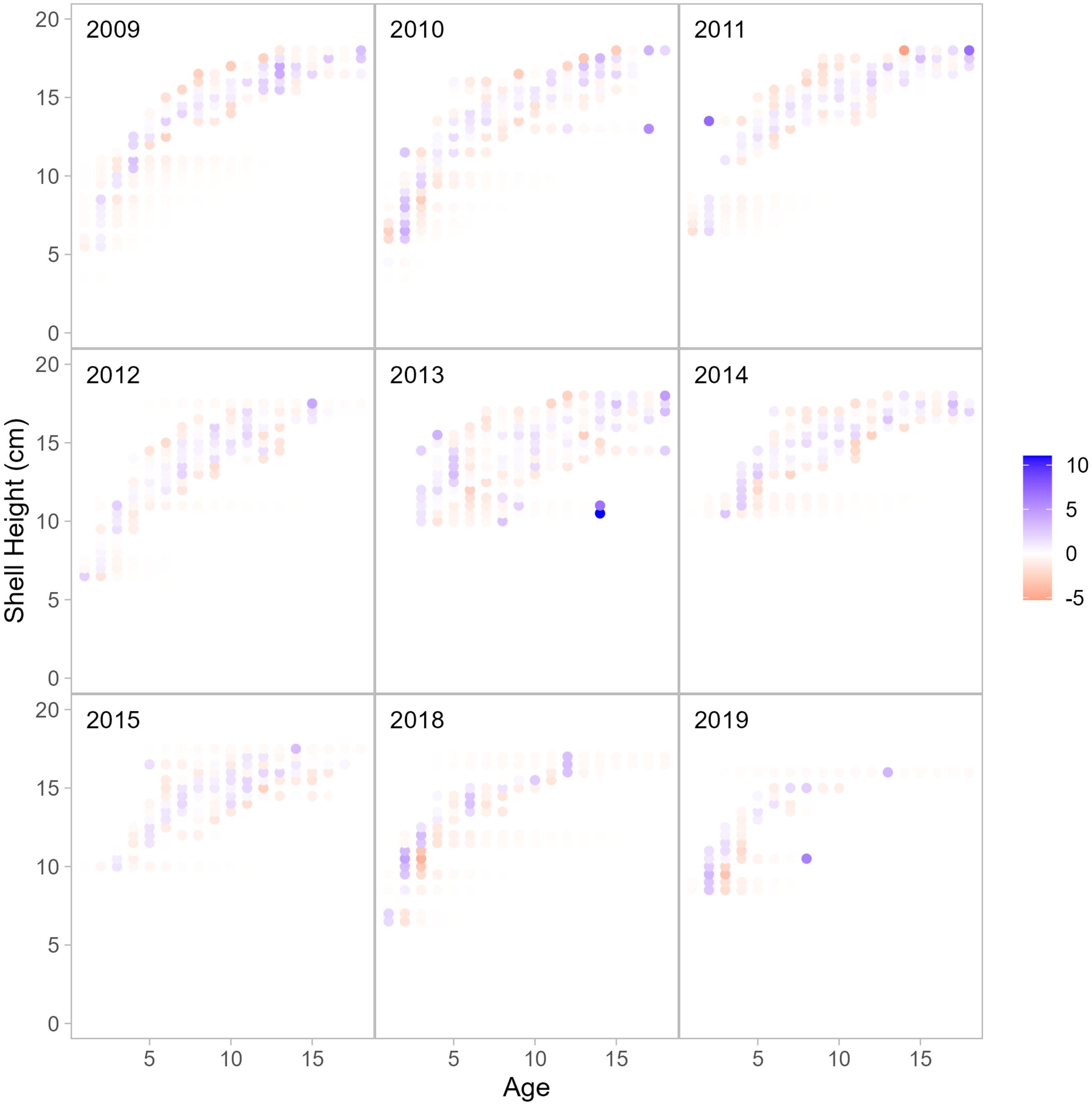

Figure 13: Fishery age composition pearson residuals for model 23.0a.

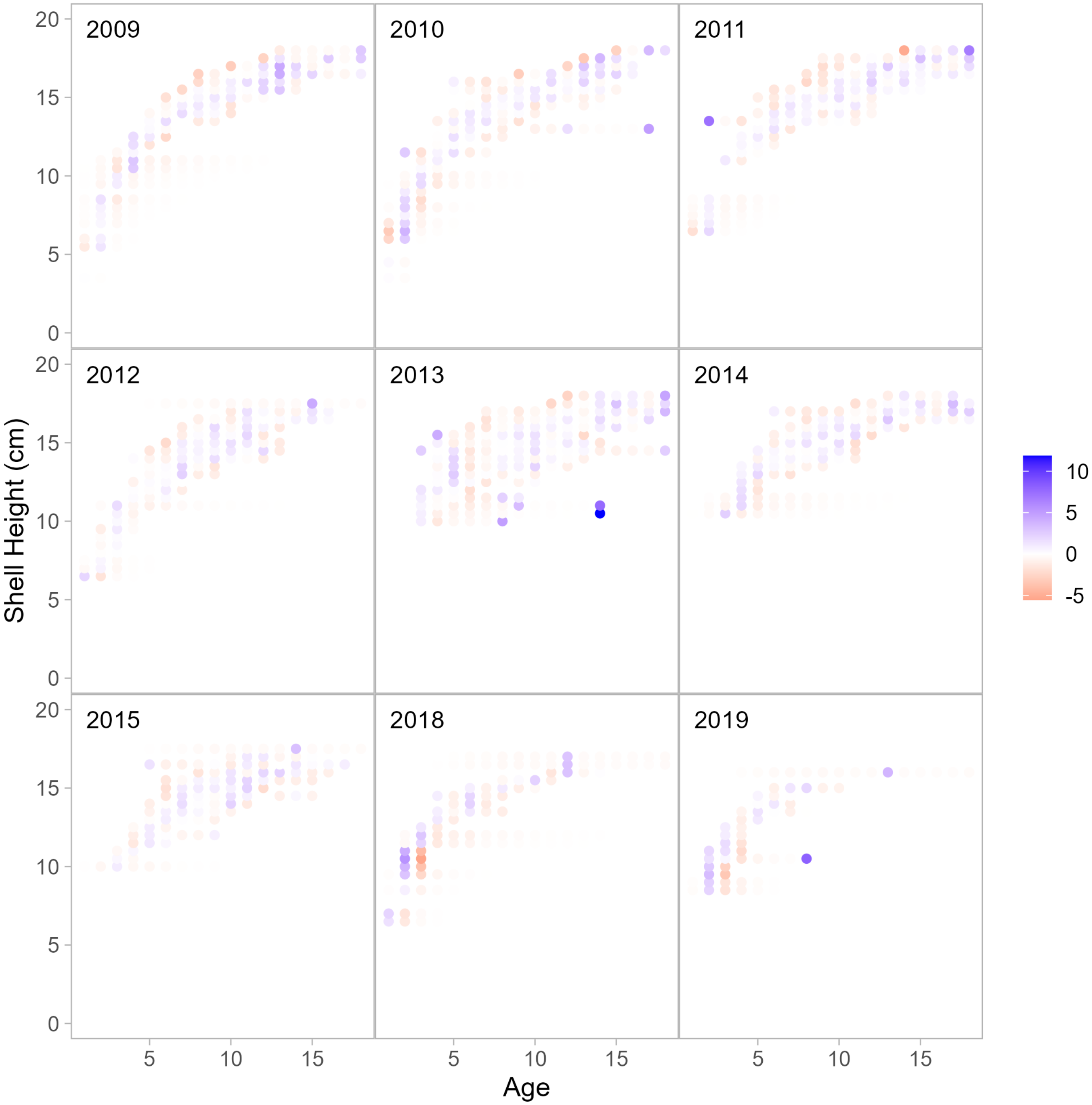

Figure 14: Fishery age composition pearson residuals for model 23.0a1.

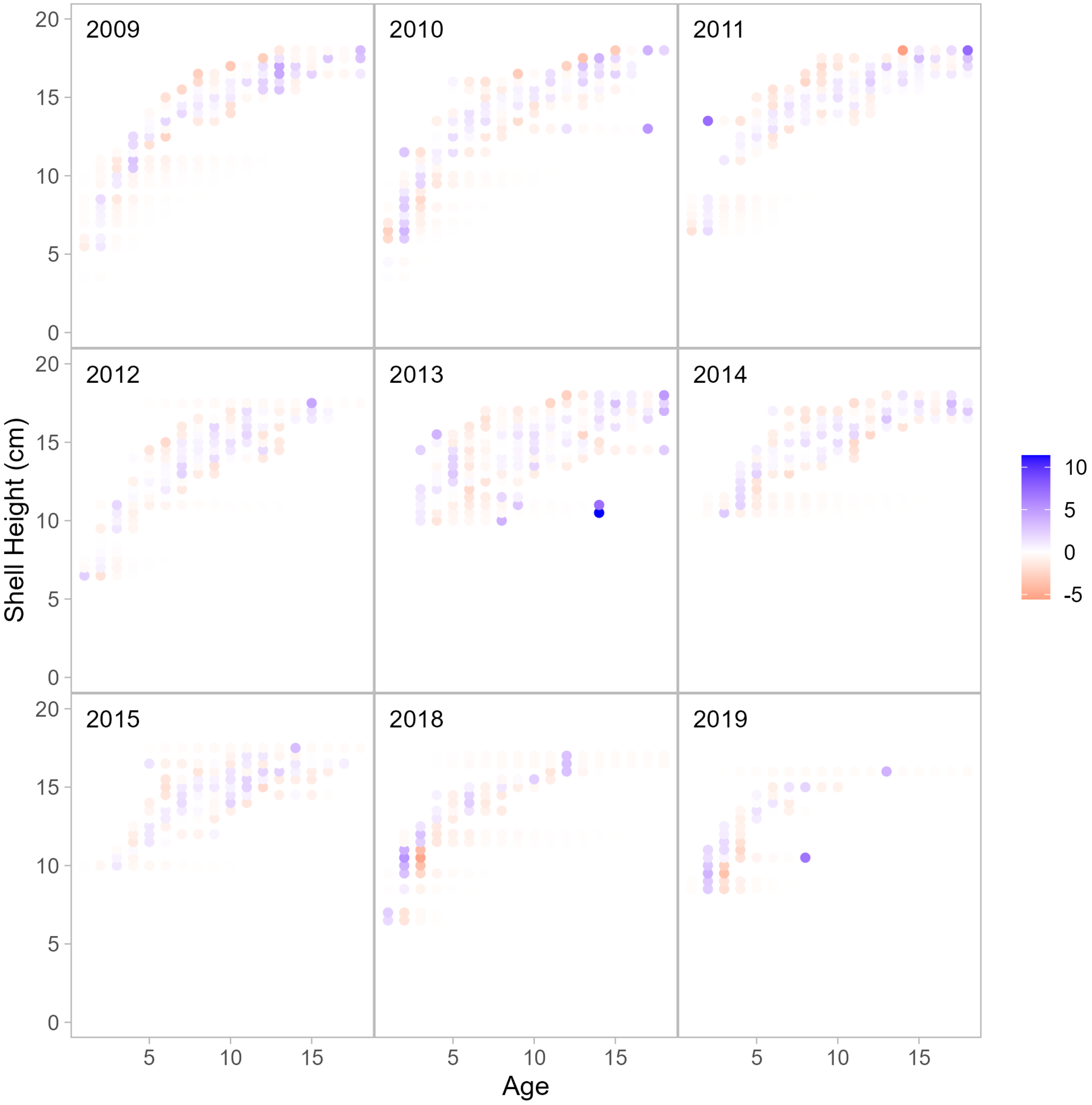

Figure 15: Fishery age composition pearson residuals for model 23.0a3.

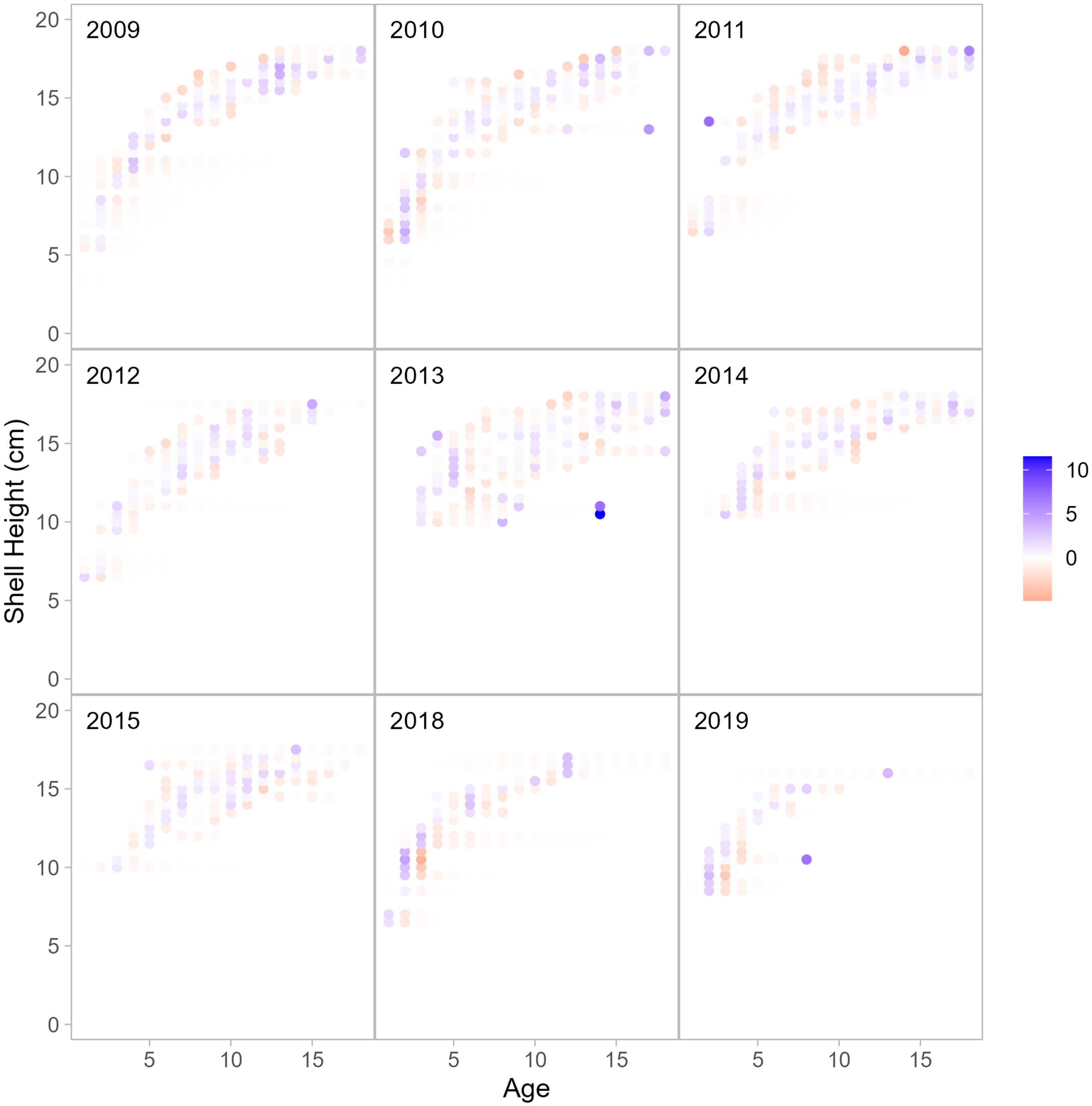

Figure 16: Fishery age composition pearson residuals for model 23.3.

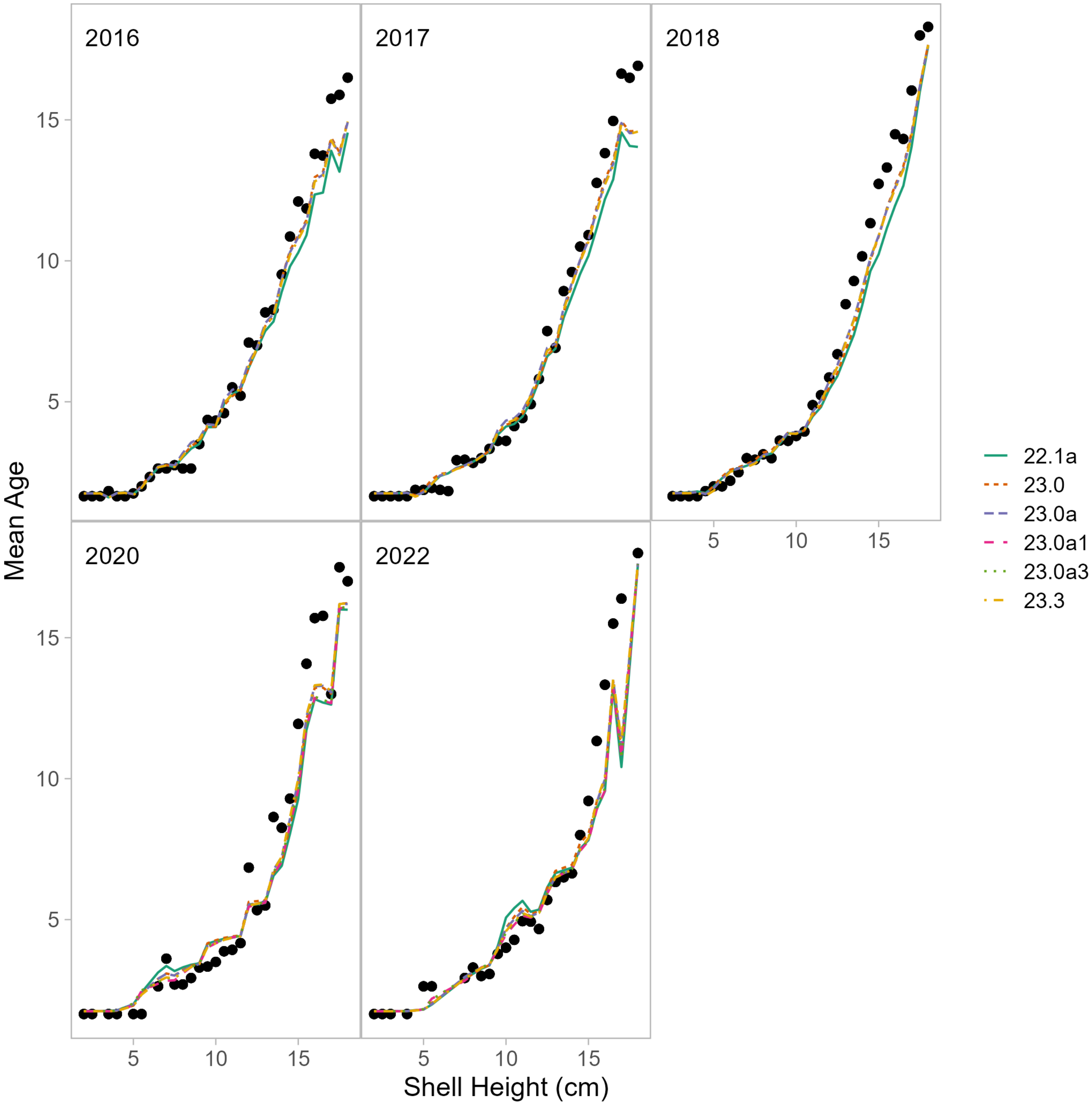

Figure 17: Fit to ADF&G dredge survey age composition by model scenario.

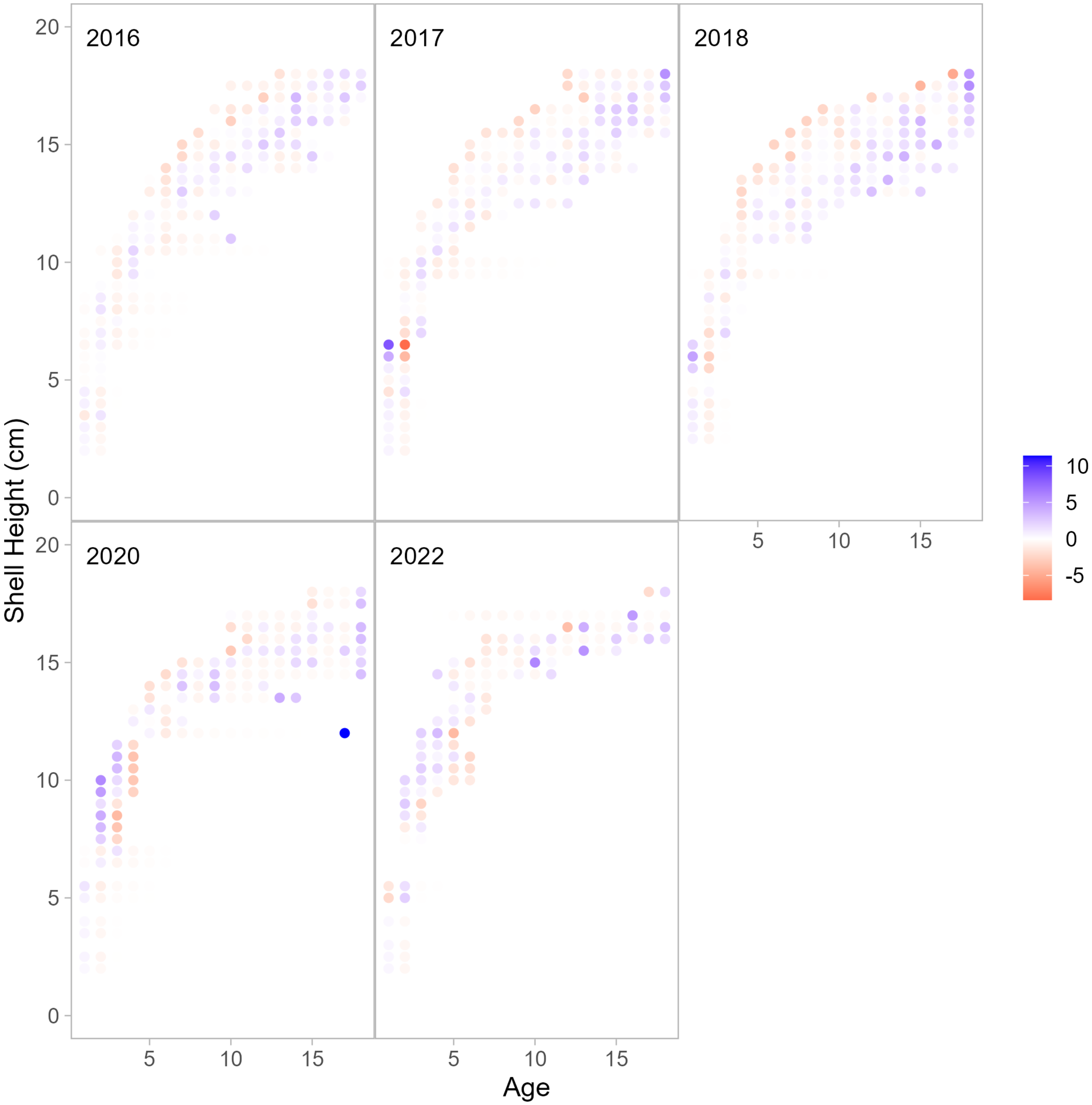

Figure 18: ADF&G dredge survey age composition pearson residuals for model 22.1a

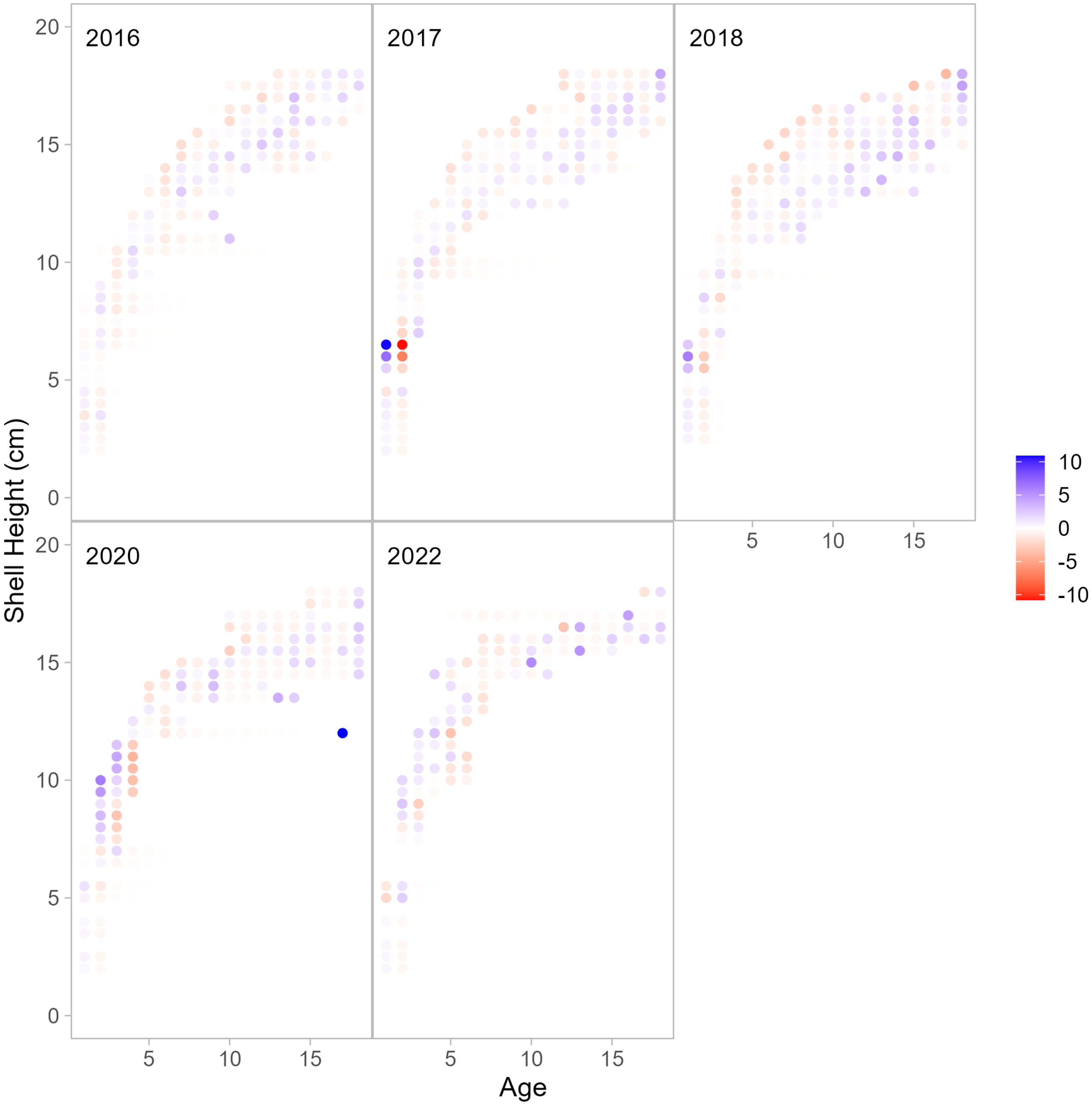

Figure 19: ADF&G dredge survey age composition pearson residuals for model 23.0.

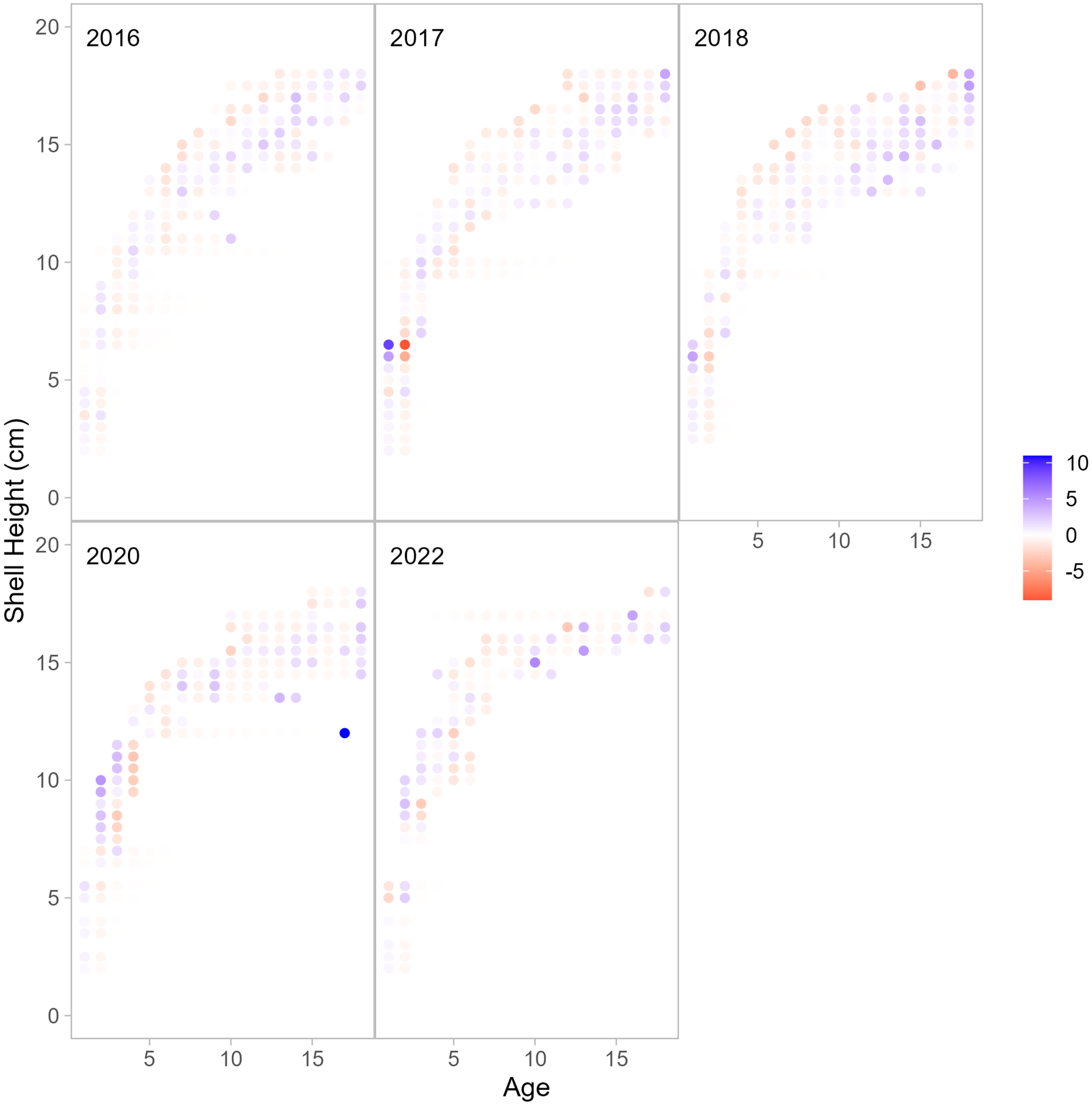

Figure 20: ADF&G dredge survey age composition pearson residuals for model 23.0a.

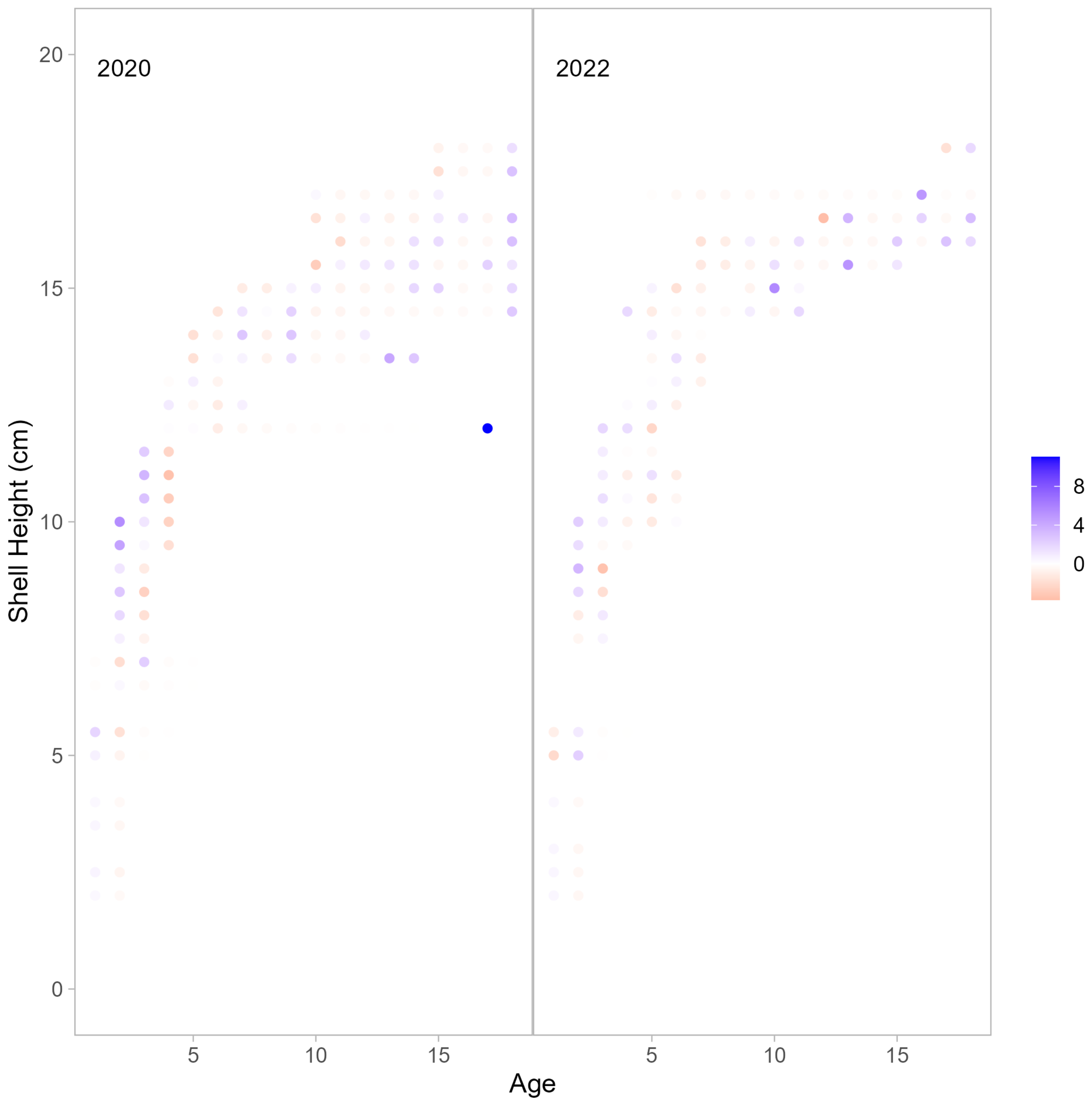

Figure 21: ADF&G dredge survey age composition pearson residuals for model 23.0a1.

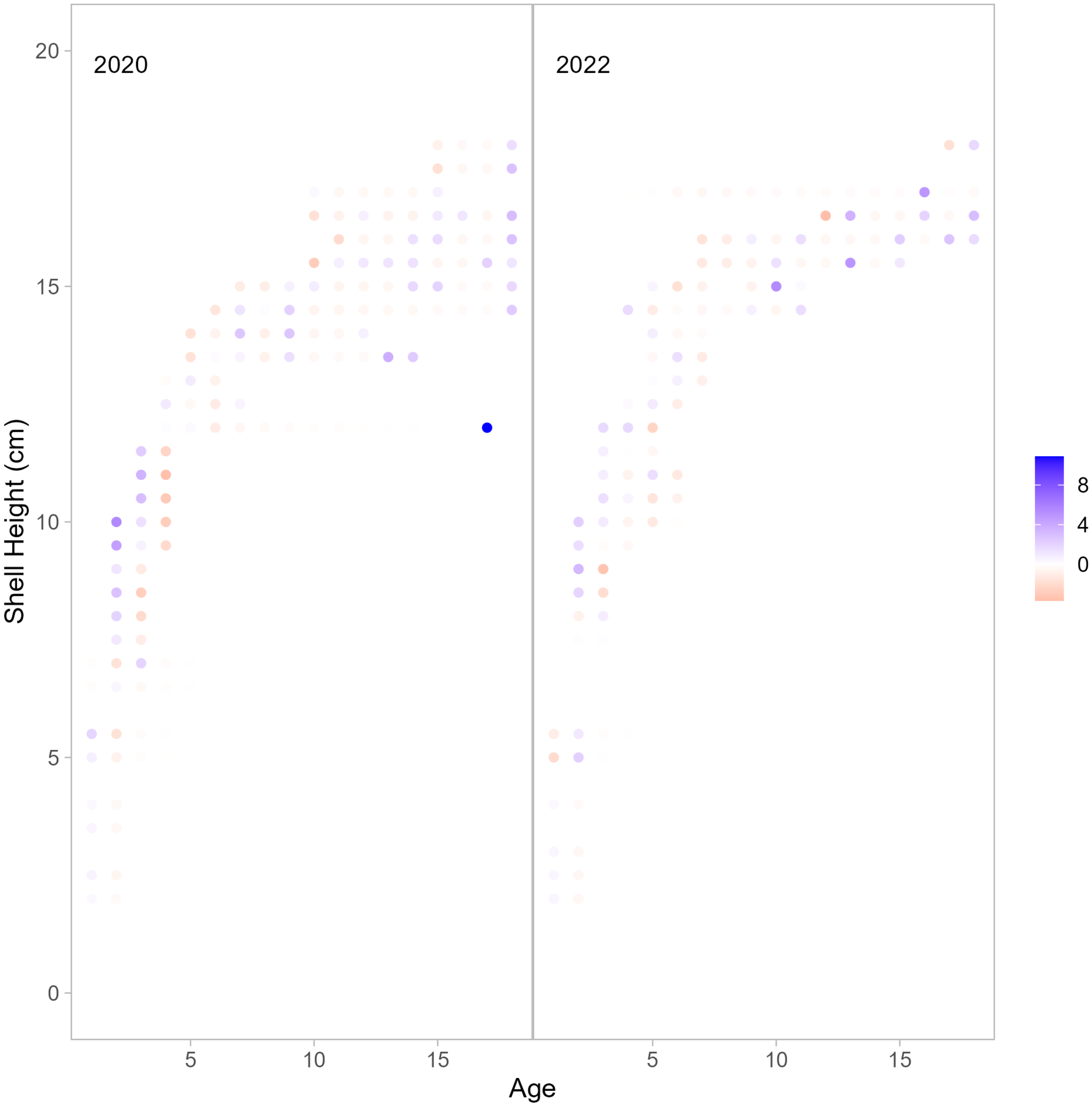

Figure 22: ADF&G dredge survey age composition pearson residuals for model 23.0a3.

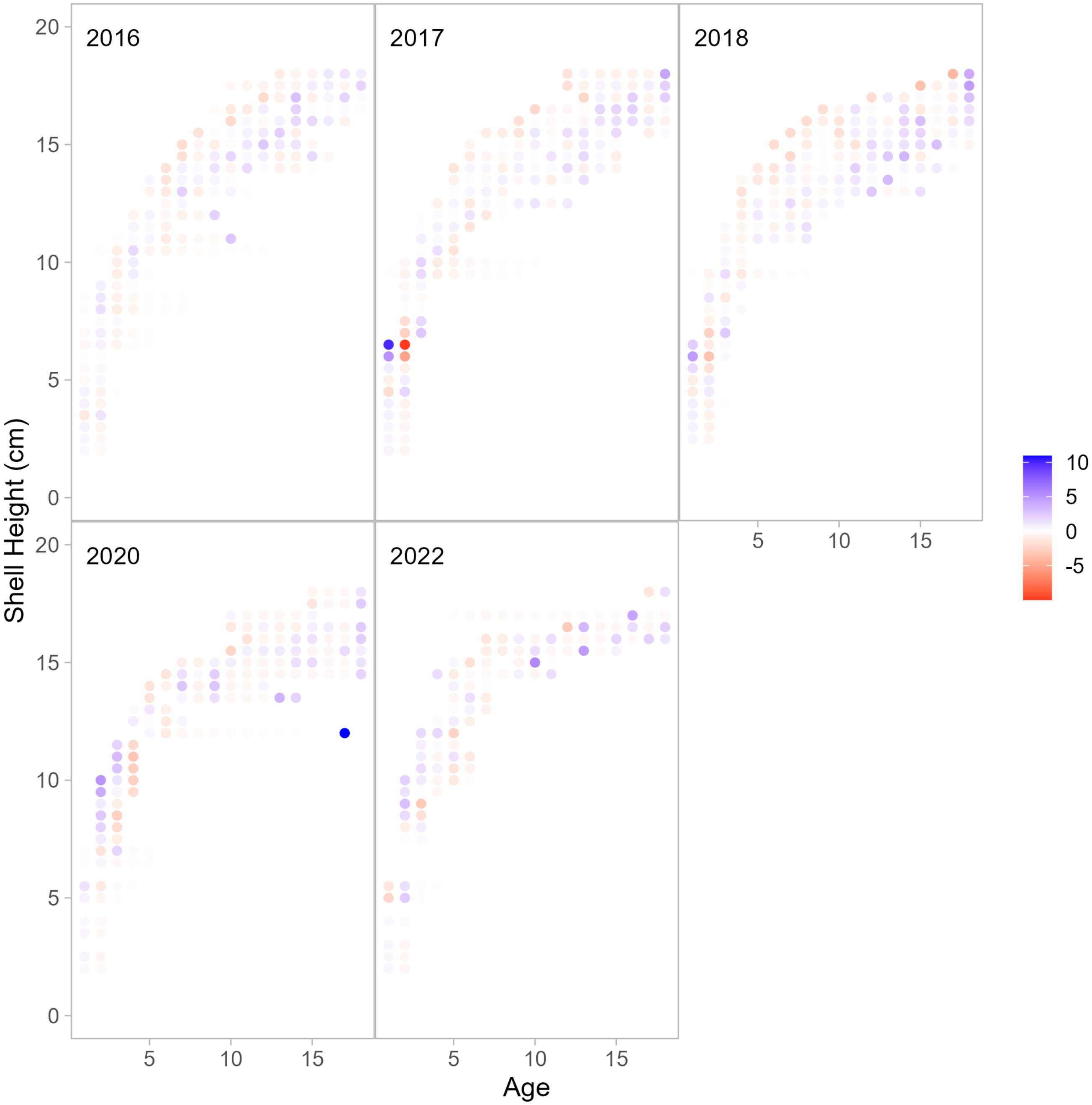

Figure 23: ADF&G dredge survey age composition pearson residuals for model 23.3.

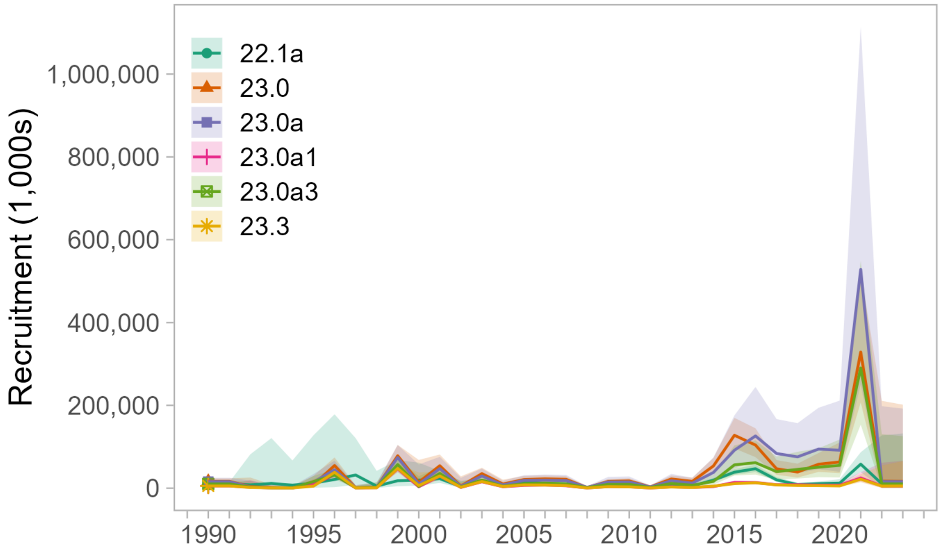

Figure 24: Predicted annual recruitment (millions) by model scenario.

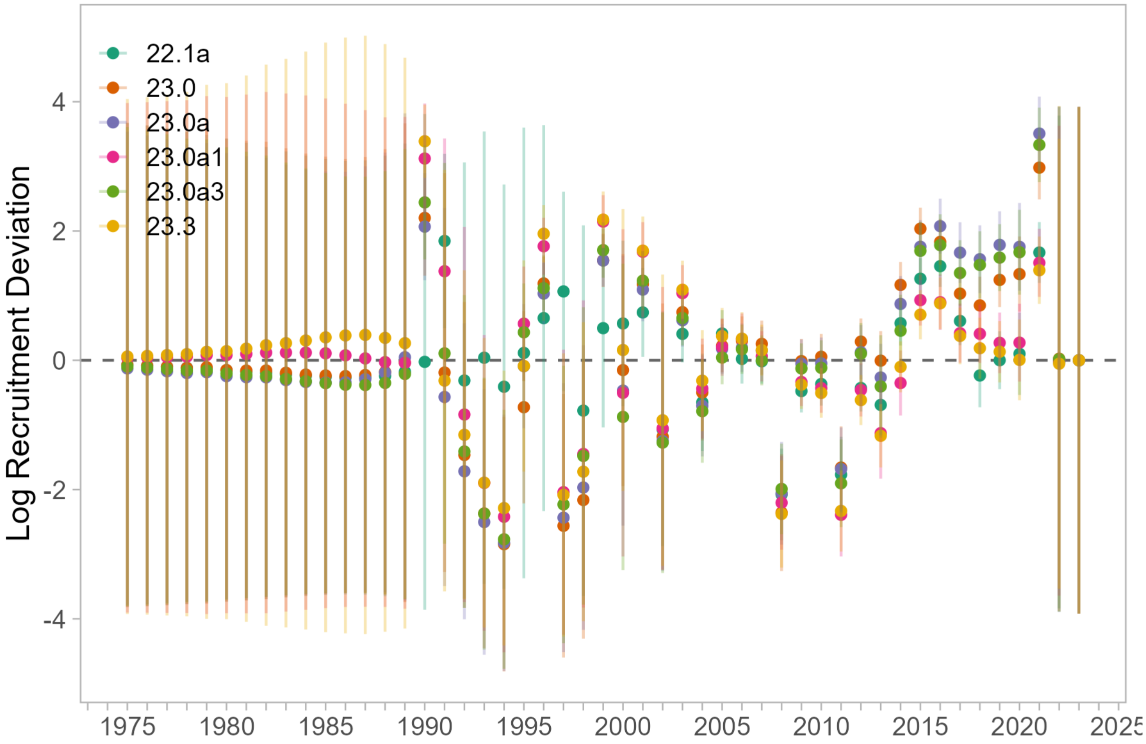

Figure 25: Recruitment deviations and associated 95% confidence intervals.

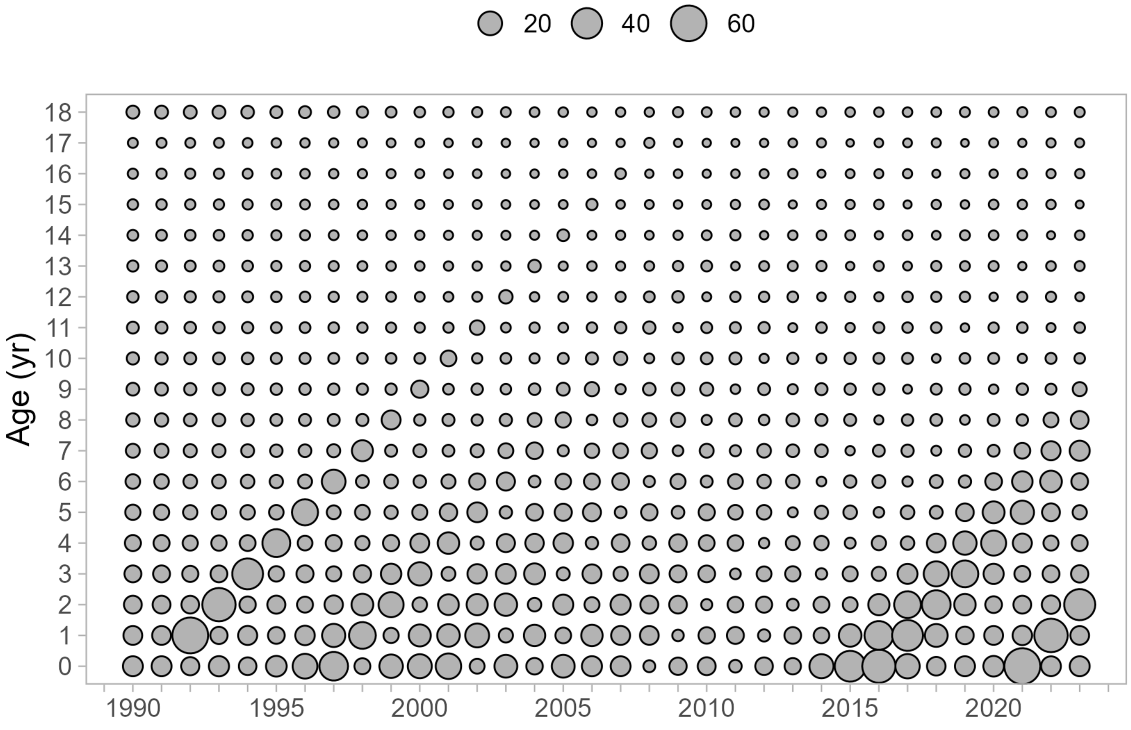

Figure 26: Beginning of year numbers at age matrix (millions) for model 22.1a.

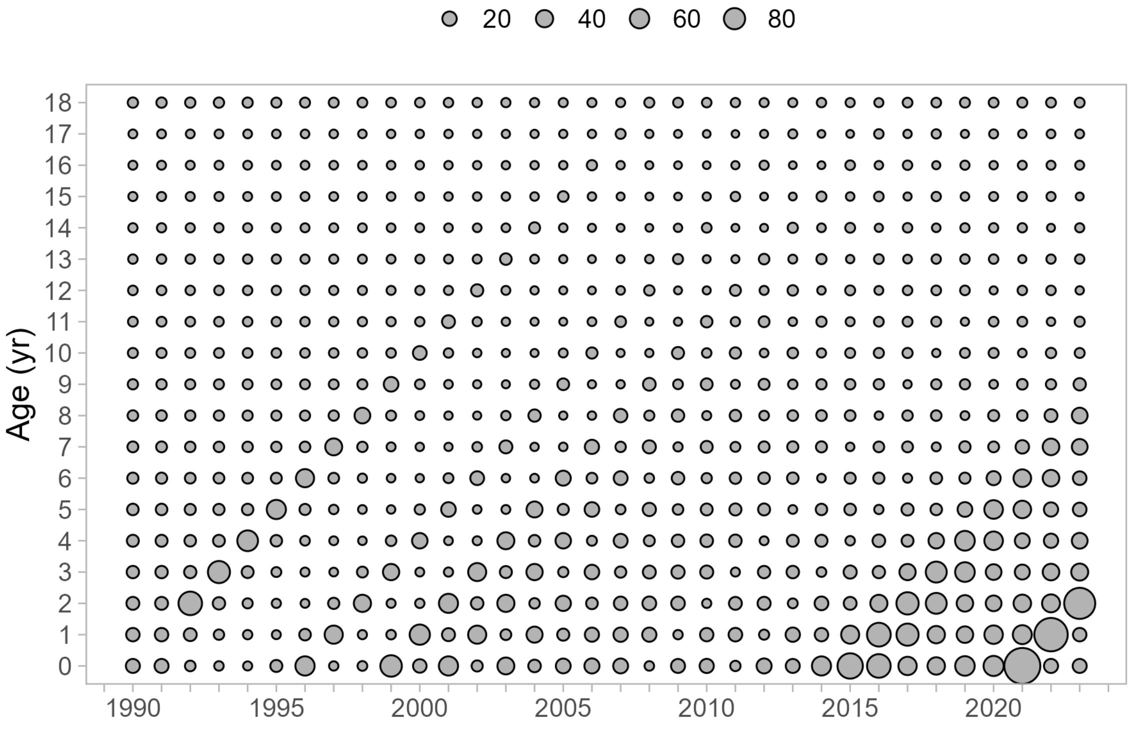

Figure 27: Beginning of year numbers at age matrix (millions) for model 23.0.

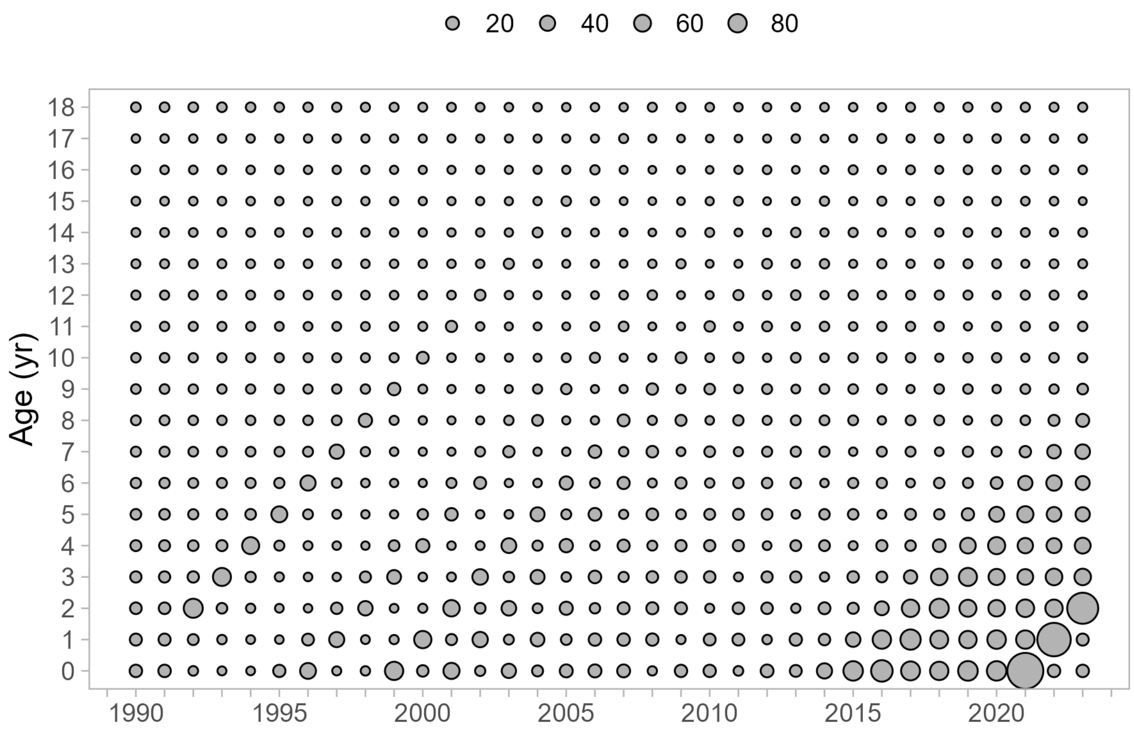

Figure 28: Beginning of year numbers at age matrix (millions) for model 23.0a.

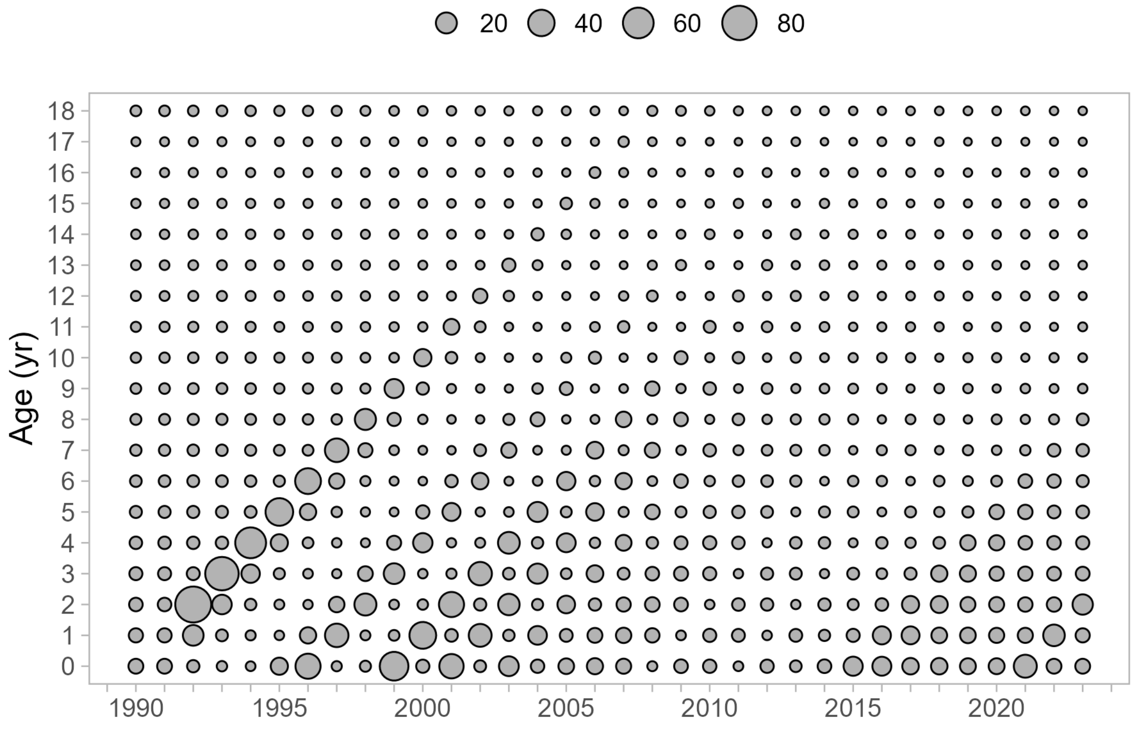

Figure 29: Beginning of year numbers at age matrix (millions) for model 23.0a1.

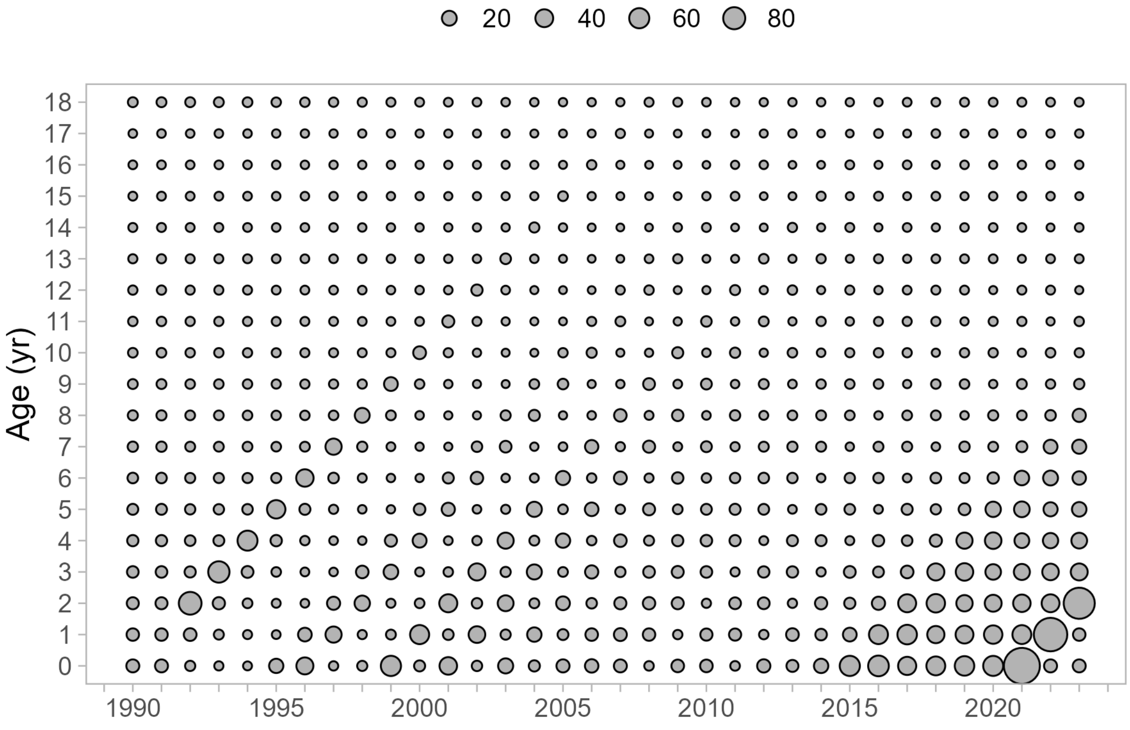

Figure 30: Beginning of year numbers at age matrix (millions) for model 23.0a3.

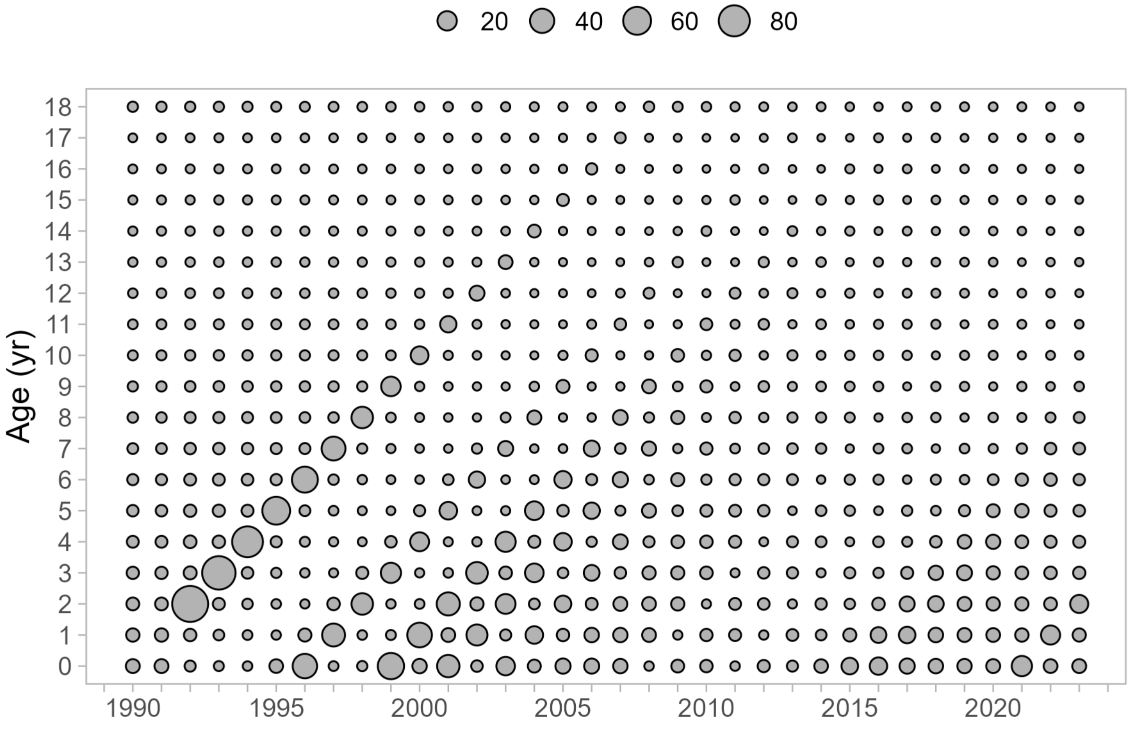

Figure 31: Beginning of year numbers at age matrix (millions) for model 23.3.

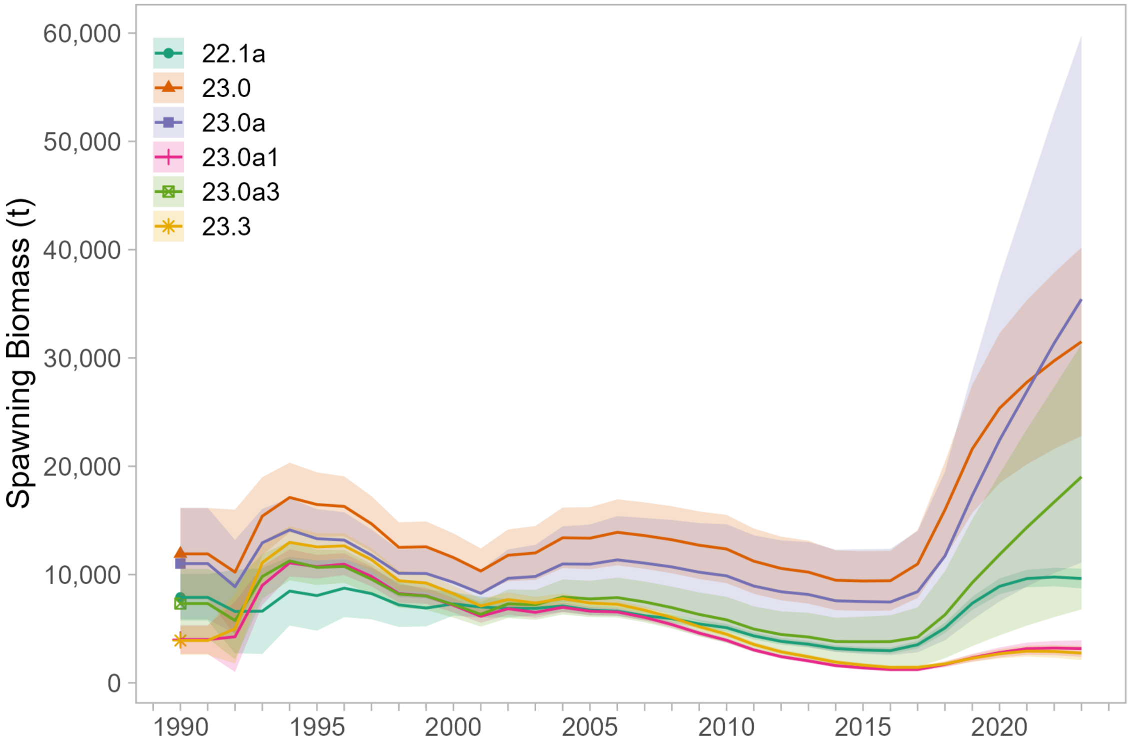

Figure 32: Estimated spawning stock biomass (t) by model scenario.

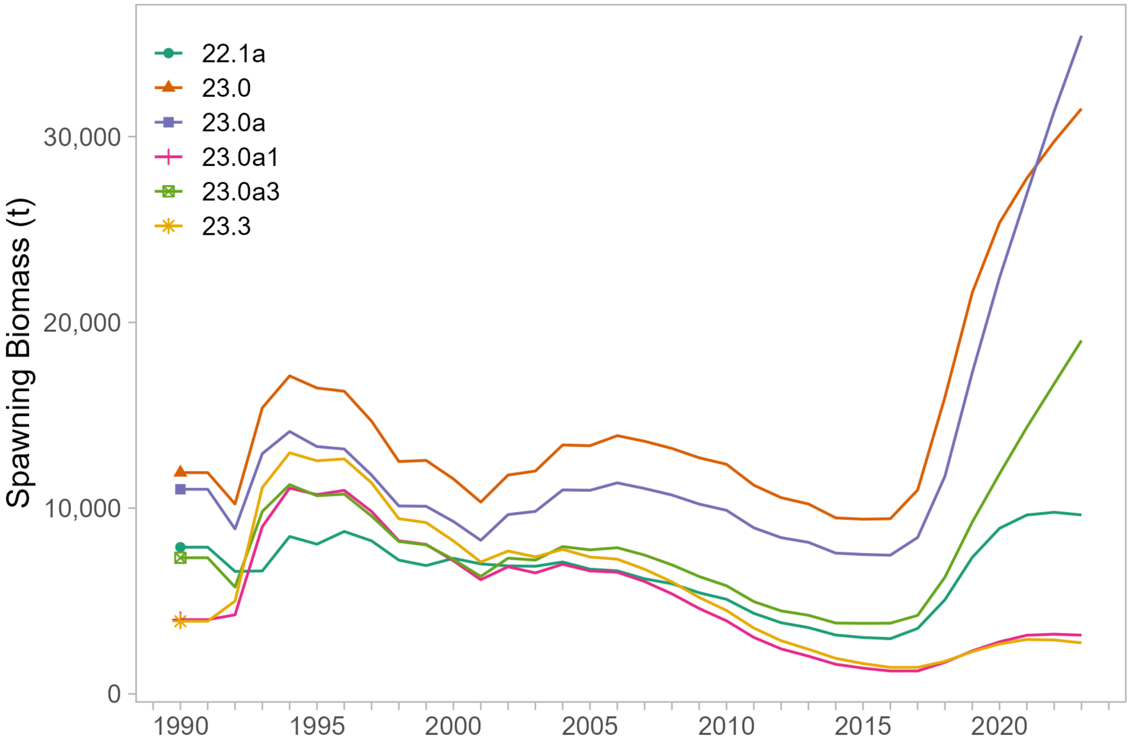

Figure 33: Estimated spawning stock biomass (t) by model scenario, without 95% confidence intervals.

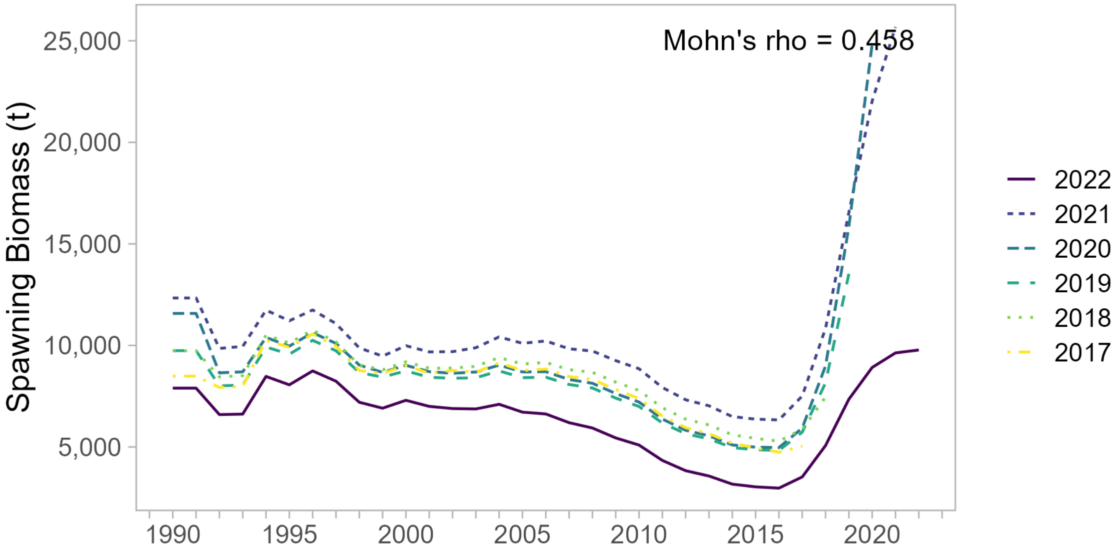

Figure 34: Spawning stock biomass from retrospective analysis of model 22.1a going back to 2017.

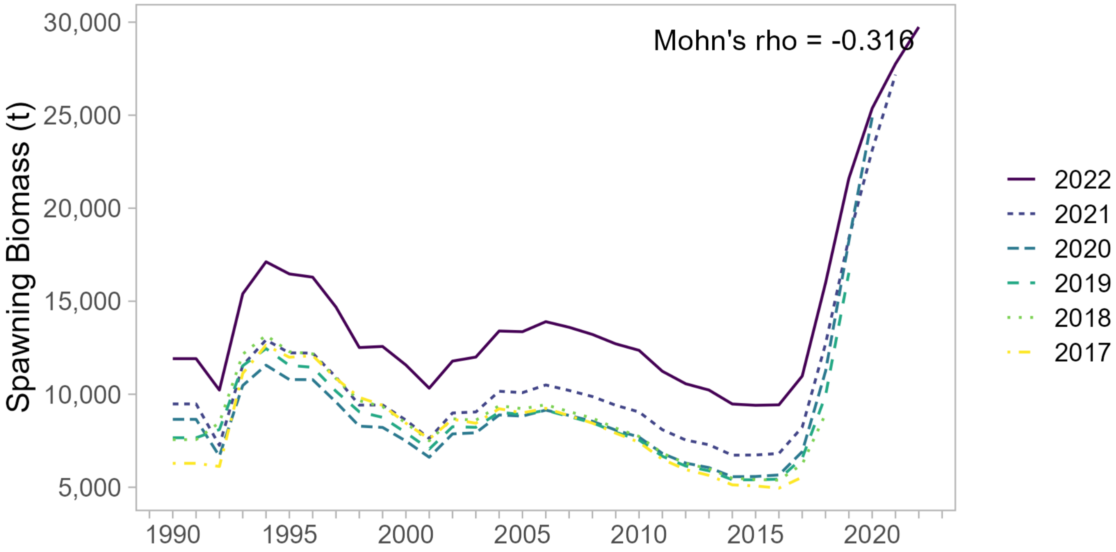

Figure 35: Spawning stock biomass from retrospective analysis of model 23.0 going back to 2017.

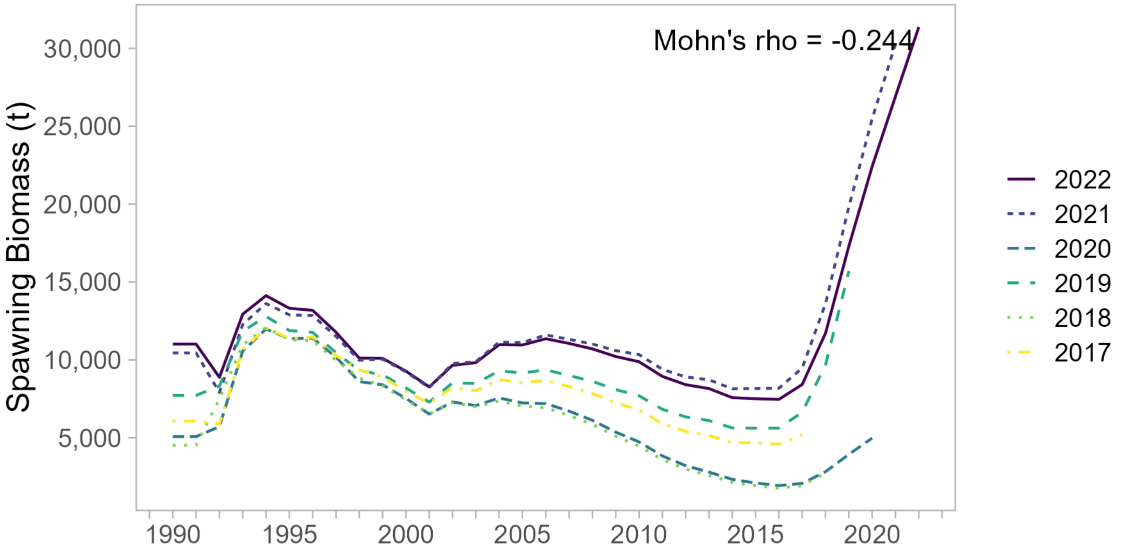

Figure 36: Spawning stock biomass from retrospective analysis of model 23.0a going back to 2017.

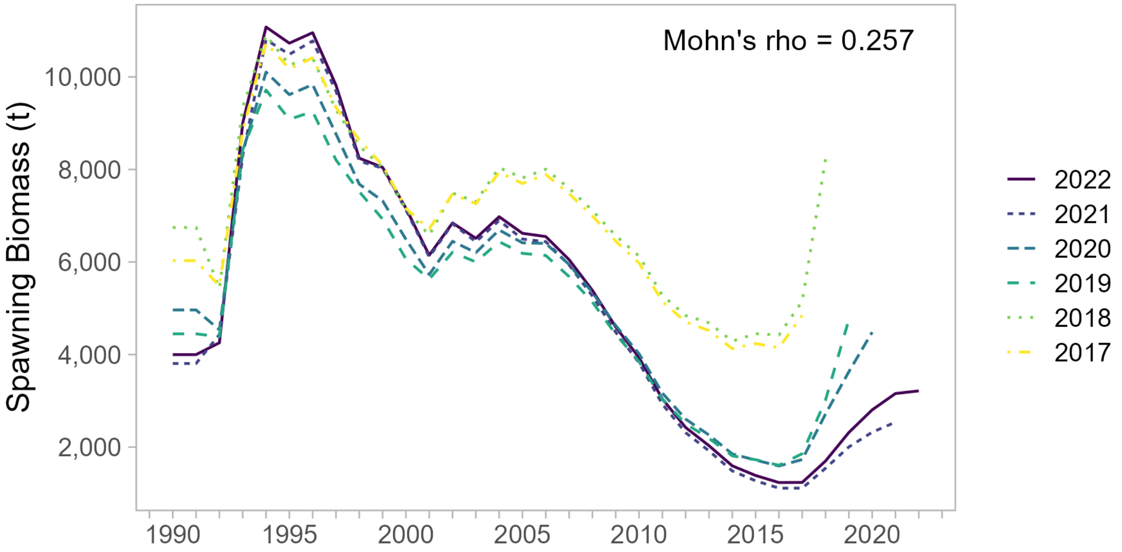

Figure 37: Spawning stock biomass from retrospective analysis of model 23.0a1 going back to 2017.

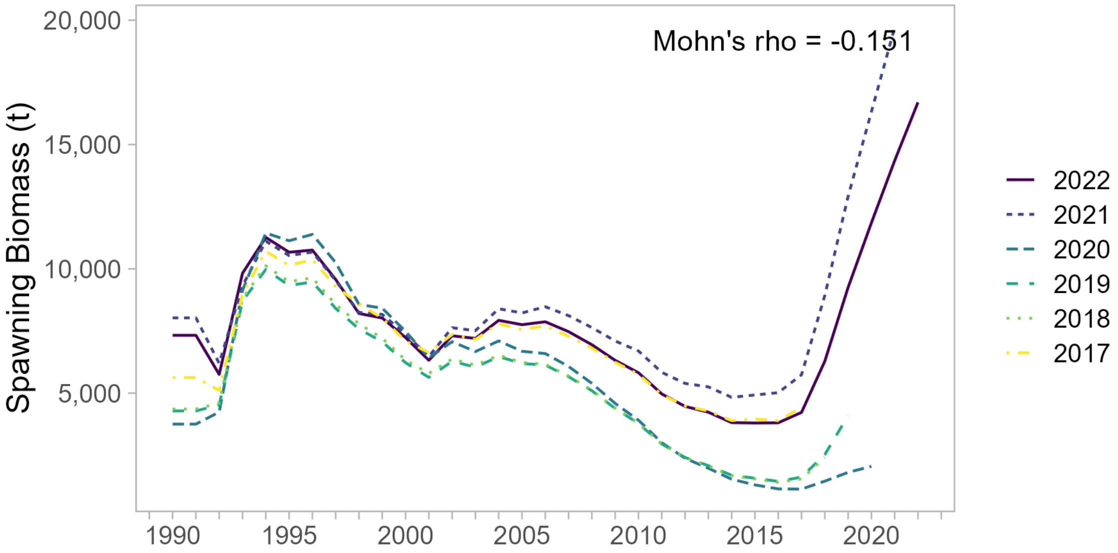

Figure 38: Spawning stock biomass from retrospective analysis of model 23.0a3 going back to 2017.

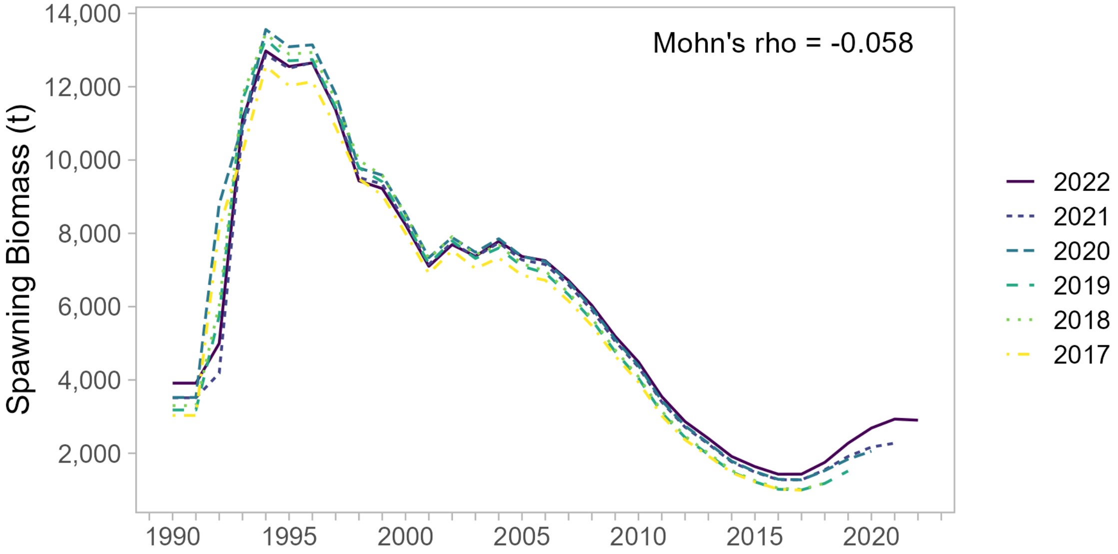

Figure 39: Spawning stock biomass from retrospective analysis of model 23.3 going back to 2017.

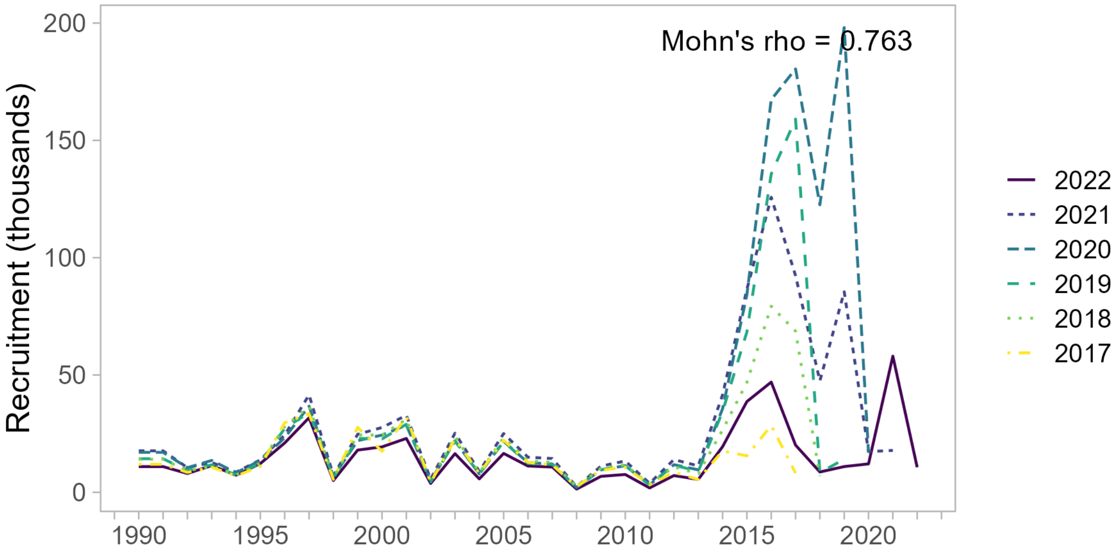

Figure 40: Recruitment estimates (millions) from retrospective analysis of model 22.1a going back to 2017.

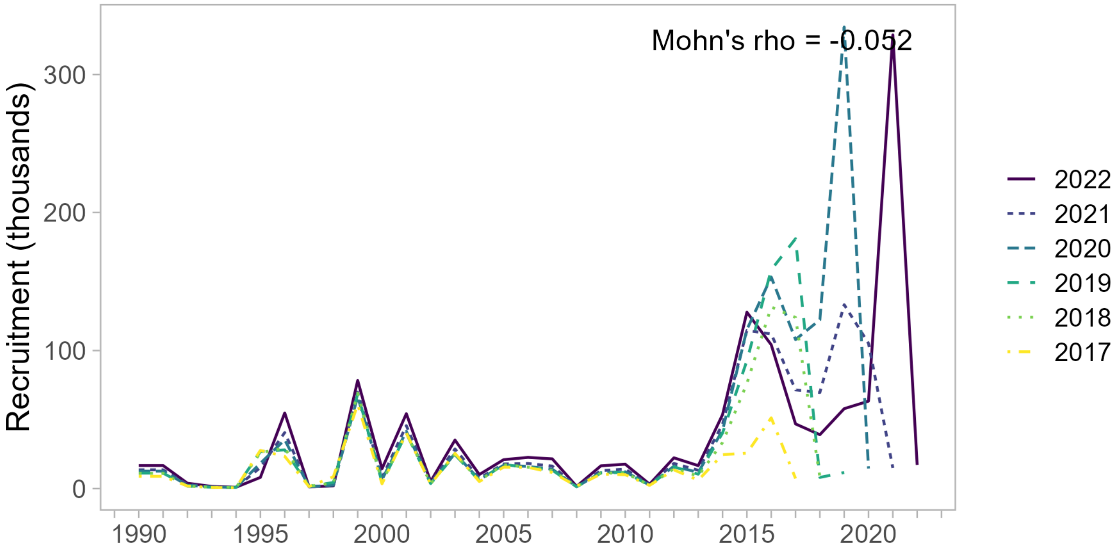

Figure 41: Recruitment estimates (millions) from retrospective analysis of model 23.0 going back to 2017.

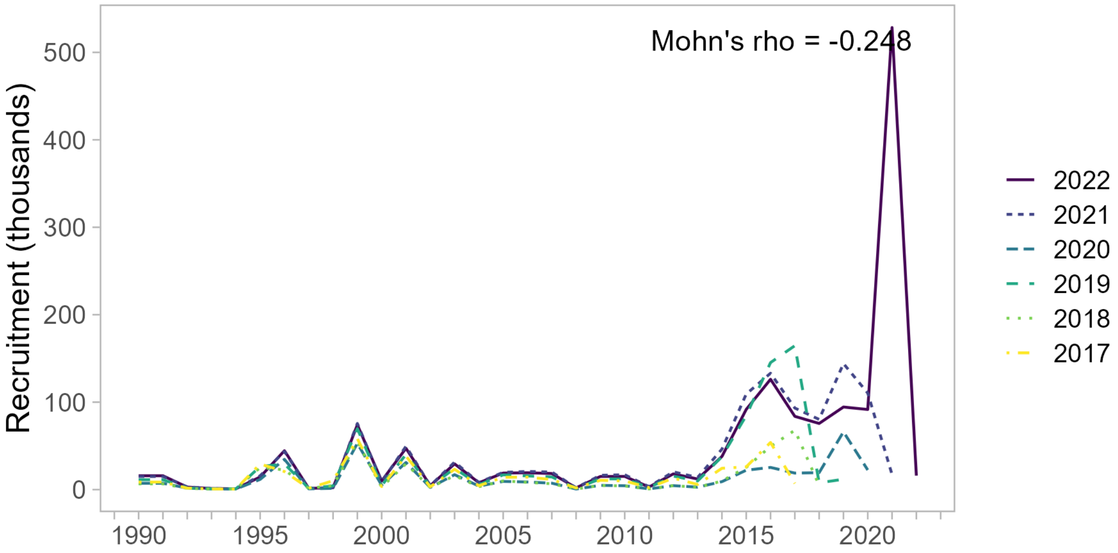

Figure 42: Recruitment estimates (millions) from retrospective analysis of model 23.0a going back to 2017.

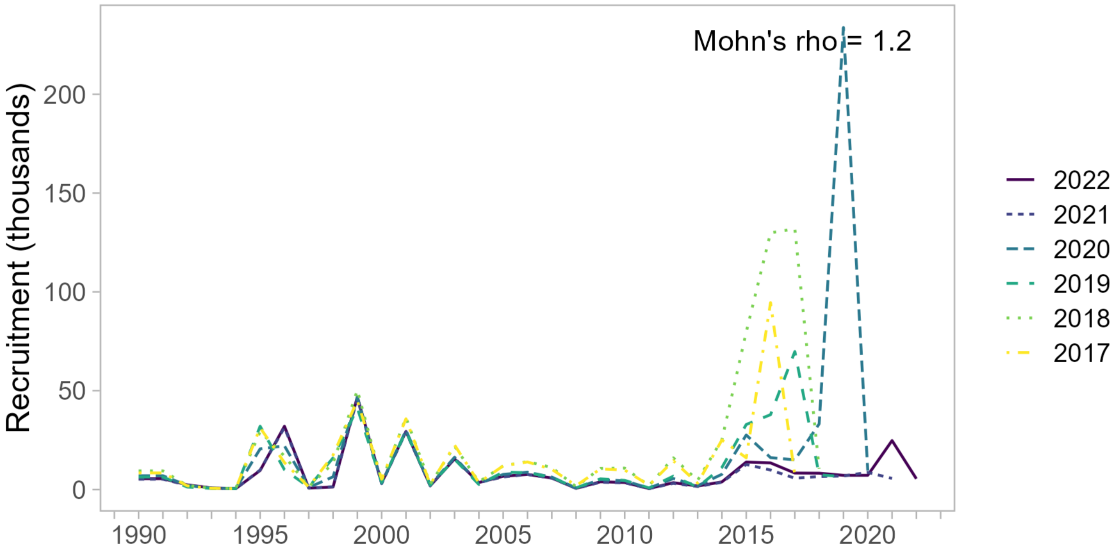

Figure 43: Recruitment estimates (millions) from retrospective analysis of model 23.0a1 going back to 2017.

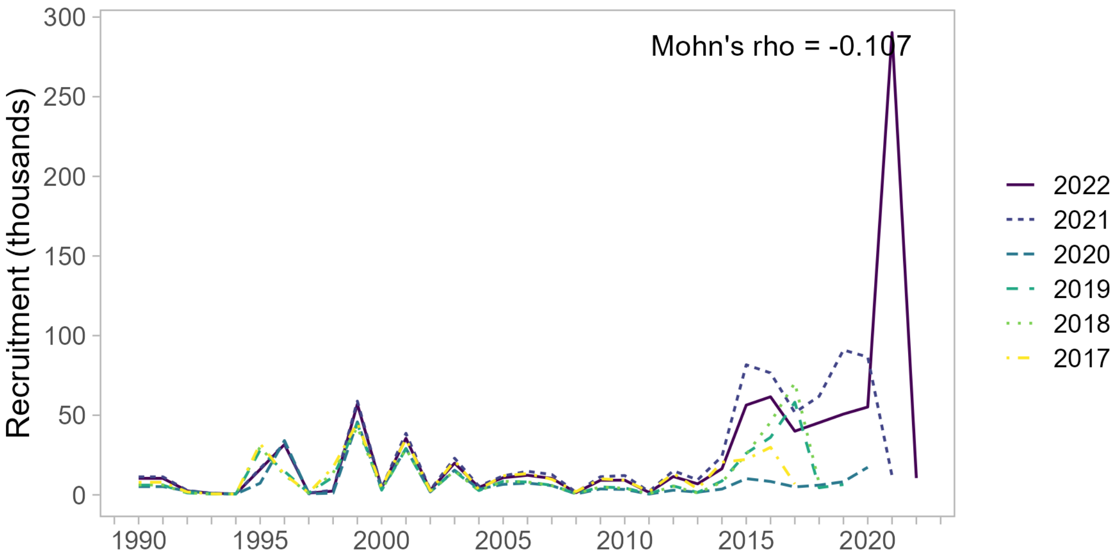

Figure 44: Recruitment estimates (millions) from retrospective analysis of model 23.0a3 going back to 2017.

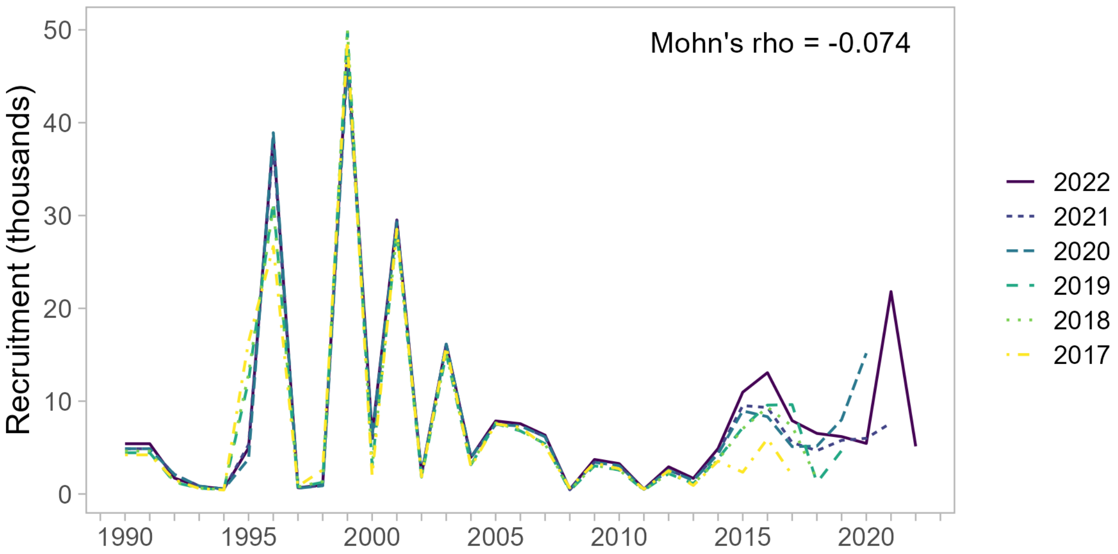

Figure 45: Recruitment estimates (millions) from retrospective analysis of model 23.3 going back to 2017.

Appendix C: Scallop Fishery Catch per Unit Effort Index Standardization

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

March 2023

Purpose

This appendix documents progress in developing a standardized catch per unit effort (CPUE) index based on fishery observer data. This index is used in development of a Stock Synthesis population dynamics model for the Kodiak Shelikof District.

Background

Interpretation of catch per unit effort (CPUE) as an index of abundance is reliant upon a fundamental relationship in fisheries analysis

$$U_t = \frac{C_t}{E_t} = qN_t \tag{1}$$

where C_t is catch at time t, E_t is the effort expended at time t, N_t is abundance at time t, and q is the portion of the stock captured by one unit of effort (Maunder and Punt 2004; Maunder et al., 2006). Provided q is constant over time, CPUE is proportional to abundance, though it is rare that q is constant over the entire exploitation history.

Weathervane scallop CPUE is affected by each vessel's choice of fishing location as well as weather, currents, sea state, captain and crew performance, gear tuning, processing capacity, markets, etc. Standardization of scallop fishery CPUE has been explored in various forms since 2017 (NPFMC 2017). Most recently, a standardized CPUE index was estimated using a generalized additive model (GAM) with gamma distributed error and log link function in the form of

$$(U + \gamma) = f_1(depth\ \cdot\ Bed) + f_2(longitude \cdot\ Bed) + Month + Vessel + Bed + Season + \epsilon \tag{2}$$

where f_i are smoothing functions, and month, vessel, bed, and season are parametric effects. Since all fishery hauls were used (i.e., including zero catching and unobserved hauls), a small modifier (γ) was added to CPUE estimates to avoid zero values. The resulting standardized index in season i was computed as the marginal of season i ($\beta_{j,i}$), back-transformed using

$$\hat{U}_i = e^{\beta_{j,i} + \frac{\sigma_{j,i}}{2}} - \gamma \tag{3}$$

where ($\beta_{j,i}$) and $\sigma_{j,i}$ are the point estimate and standard error of the j^{th} parametric effect (i.e., season) in year i (NPFMC 2022).

This appendix continues efforts to improve development of a standardized CPUE index following Siddeek et al. (2016). Differences from the previous method include 1) the covariate structure, 2) method for fitting non-linear terms, and 3) data used in the analysis.

Core data preparation

There is no minimum legal size for weathervane scallops, and thus retention size is dependent on various factors including vessel, captain, population composition, GHL, and fishery performance, etc. Prior efforts to standardize observer CPUE has only considered retained catch CPUE, partly because such analyses used data from both observed and unobserved hauls. Here, standardized indices for both retained catch and total catch (i.e., retained + discards) CPUE are estimated.

Prior to fitting linear models, observer data were filtered to exclude data not representative of core fishery performance, and therefore abundance. Although catch estimates exist for all commercial dredges since 2009, only observed dredges were included in this analysis. In addition, only dredges started within known scallop bed boundaries were included. There is no regulation specifying a standard dredge width, but paired 13 ft or 15 ft dredges are used by the fleet during the vast majority of the timeseries, therefore only hauls employing those dredge sizes were included in this analysis. Anomalously low (including zero) and high catches were removed from analyses by including only the 2.5% - 97.5% quantiles of CPUE data. Likewise, only dredges within the 2.5% - 97.5% quantiles of depth were included. Total sample sizes per season are listed in (Table 1).

Standardization by General Linear Model

Standardized CPUE $\hat{U}_i$ was estimated using a generalized linear model (GLM) evaluating a range of covariates including depth, month, dredge width, vessel, bed, and season. Since the exact functional relationship between depth and CPUE is unknown, the effect of depth was estimated as a natural spline with 4 degrees of freedom. Appropriate degrees of freedom were evaluated using AIC. The key point of difference between this approach and using a GAM is that degrees of freedom are fixed in a natural spline within GLM, whereas they would be estimated using a penalized maximum likelihood in a GAM.

Forward and backward, stepwise model selection was done with the ‘null’ model containing only a single explanatory variable (i.e., Season),

$$\ln\hat{U}_i = Season_i + \epsilon \tag{4}$$

eventually reaching the ‘full’ model

$$\ln\hat{U}_i = \mathrm{ns}(depth, \mathrm{df} = 4) + DredgeWidth_{d,i} + Vessel_{v,i} + Bed_{b,i} + Month_{m,i} + Season_i + \epsilon \tag{5}$$

Model improvement with the addition of new covariates was evaluated using an approximate R^2 statistic,

$$R^2 = \frac{D_{null} - D_{resid}}{D_{null}} \tag{6}$$

where D_{null} is the null deviance of the model and D_{resid} is the residual deviance of the model. Model improvement was considered insignificant if increase in R^2 was less than 0.01 and Δ AIC was less than two per degree of freedom lost (Anderson 2008; Siddeek et al. 2016). Both gamma (with log link function) and lognormal error distributions were evaluated.

Season coefficients were scaled using

$$\beta_i' = \frac{\beta_i}{\bar{\beta}} \tag{7}$$

where $\bar{\beta}$ is defined as

$$\bar{\beta} = \sqrt[n_j]{\prod_{j=1}^{n_j} \beta_{i,j}} \tag{8}$$

and n_j is the number of coefficients in factor i (i.e., season) (Siddeek et al. 2016). The existing GAM derived index and nominal round weight CPUE index based on retained catch data were scaled using the same method as GLM coefficients.

Results and Discussion

The best retained catch CPUE model included depth, month, dredge width, and season (Table 2), while the best total catch CPUE model only included depth and month (Table 3). The addition of vessel met significance criteria for AIC (Δ df = 3, Δ AIC retained catch = -143, Δ AIC total catch = -143), but not deviance explained. Only two cooperative vessels have fished within the Kodiak Shelikof District since the 2014/15 season and they have maintained similar fishing performance (except in 2016/17 when one other vessel fished). It is unsuprising that the addition of bed met neither significance criteria since the Kodiak Shelikof District only contains one primary bed where most fishing effort occurs and two minor beds that are directly adjacent and only fished sporadically (Table 2 - 3). Bed would likely be more informative in districts with active fishing on multiple beds, like Kodiak Northeast and Yakutat Districts. As with vessel, dredge width met significance criteria for AIC (Δ df = 1, Δ AIC = -163) in the total catch model, but not deviance explained (Table 3). Gamma distributed error appeared to marginally outperform log-normal distributed error based on diagnostic plots (Figures 1 - 4).

The marginal effect of depth suggested a slightly decreasing wave-like curve, with a minor peak around 55 fathoms (Figure 5). Partial residuals indicate that this relationship is particularly noisy. Depth distribution of weathervane scallops is not well understood, and is likely variable among beds, substrate types, and ocean conditions. The marginal effect of month suggested that CPUE is higher in July, similar throughout August - November (Figure 6). Most dredges occurred in July and it is unusual throughout the timeseries for a vessel to fish during more than one month during a given season. Month effect is possibly somewhat confounded by season since that are several years throughout the timeseries were both operating vessels finish only during July. As would be expected, hauls that used two 15 ft dredges (i.e., 30 ft dredge width) tended to have greater CPUE than hauls using two 13 ft dredges (i.e. 26 ft dredge width) in the retained catch model (Figure 7), though this wasn't the case in the total catch model.

The resulting standardized CPUE indices steadily increased for the first three years and then undergo a continuous decline to a timeseries low during the 2016/17. CPUE rebounded drastically after 2016, reaching timeseries highs from the 2019/20 season to present and peak during the 2020/21 season (Tables **??** - **??**; Figure 8). Both nominal and GAM CPUE indices trend closely with CPUE based on the final model GLM until the 2021/22 season, where the GLM suggests minor increase (retained catch CPUE) or decrease (total catch CPUE) while nominal and GAM indices suggest a continued substantial increase (Figure 9). Follow-up analyses indicated this departure was due to the GLM based index omitting anomalously high and low catches.

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Maunder, M.N., J.R. Sibert, A. Fonteneau, J. Hampton, P. Kleiber, S.J. Harley. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science 63(8): 1373–1385. https://doi.org/10.1016/j.icesjms.2006.05.008

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Siddeek, M.S.M., J. Zheng, D. Pengilly. 2016. Standardizing CPUE from Aleutian Islands 0097 Golden King Crab Observer Data. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks. http://doi.org/10.4027/amdlfs.2016.04

Tables

Table 1: Sample size of core commerical dredges by season with the KSH district.

Season	Number of Dredges
2009/10	238
2010/11	398
2011/12	237
2012/13	204
2013/14	254
2014/15	145
2015/16	105
2016/17	92
2017/18	52
2018/19	40
2019/20	45
2020/21	44
2021/22	84
2022/23	77

Table 2: Effective degrees of freedom, approximate R^2, and Δ AIC for the null GLM fit to retained catch CPUE, final GLM, and additional covariates fit with gamma distributed error.

Model	Terms	df	R^2	Δ AIC
Null	$Season$	13	0.4	0
Final	$\text{ns}(depth, \text{df} = 4) + Dredge\ Width + Month + Season$	22	0.45	-136
	Final+Bed	24	0.45	-140
	Final+$Vessel$	25	0.45	-143

Table 3: Effective degrees of freedom, approximate R^2, and Δ AIC for the null GLM fit to total catch CPUE, final GLM, and additional covariates fit with gamma distributed error.

Model	Terms	df	R^2	Δ AIC
Null	$Season$	13	0.43	0
Final	$\text{ns}(depth, \text{df} = 4) + Month + Season$	21	0.47	-132
	Final+Bed	23	0.47	-131
	Final+$Vessel$	24	0.47	-143
	Final+$Dredge\ Width$	22	0.48	-163

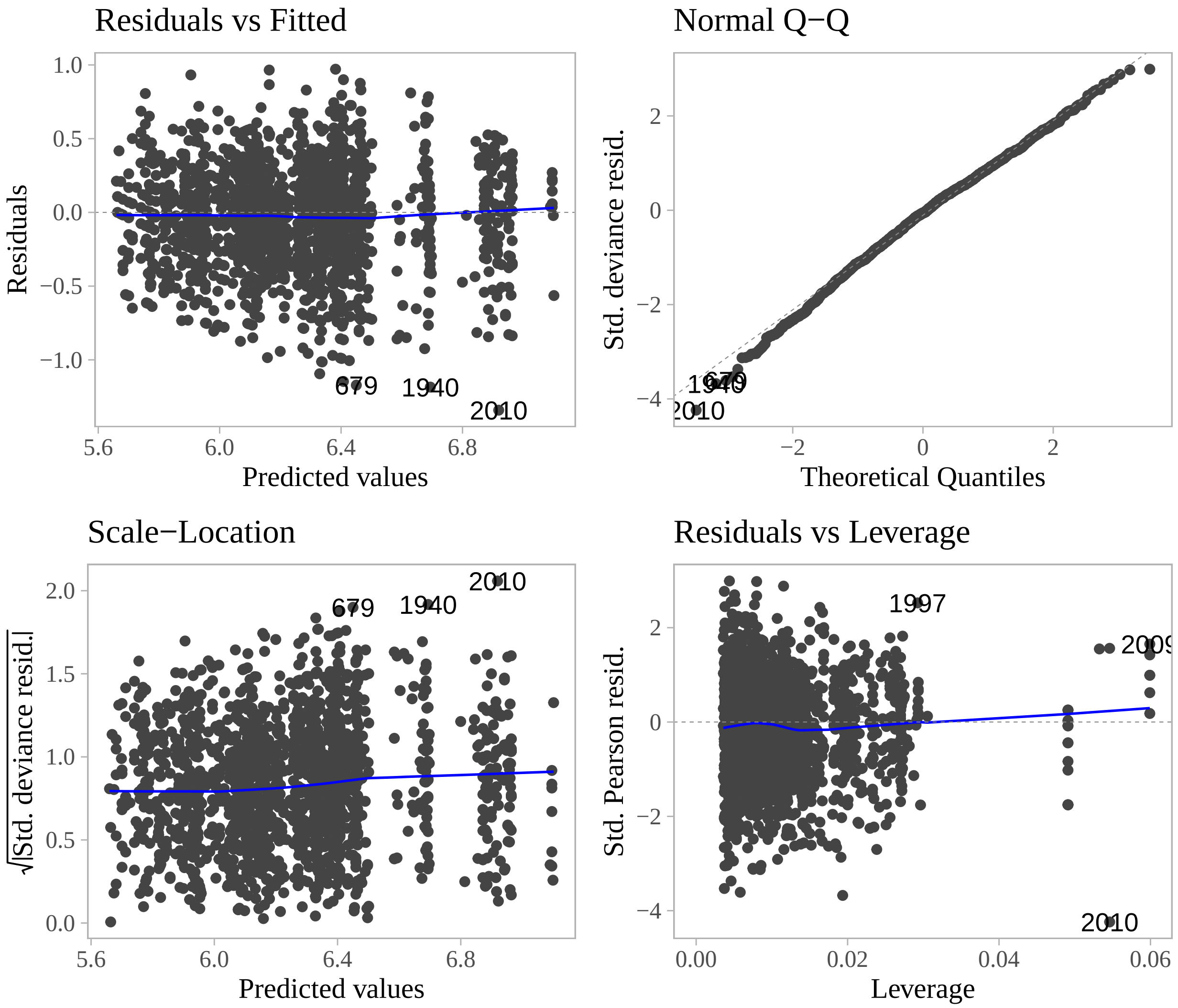
Table 4: Standardized retained catch CPUE index, associated standard error, and CV for Kodiak Shelikof District based on a gamma distributed GLM.

Season	Index	σ	CV
2009	0.88	0.02	0.03
2010	0.95	0.02	0.02
2011	1.01	0.02	0.02
2012	0.88	0.02	0.03
2013	0.73	0.03	0.04
2014	0.67	0.03	0.04
2015	0.66	0.03	0.05
2016	0.56	0.03	0.06
2017	0.74	0.04	0.06
2018	0.92	0.05	0.05
2019	1.28	0.05	0.04
2020	2.02	0.05	0.02
2021	2.10	0.04	0.02
2022	1.98	0.05	0.02

Table 5: Standardized total catch CPUE index, associated standard error, and CV for Kodiak Shelikof District based on a gamma distributed GLM.

Season	Index	σ	CV
2009	0.94	0.02	0.03
2010	1.01	0.02	0.02
2011	1.01	0.02	0.02
2012	0.83	0.03	0.03
2013	0.71	0.03	0.04
2014	0.62	0.03	0.05
2015	0.61	0.03	0.05
2016	0.60	0.03	0.06
2017	0.77	0.04	0.06
2018	1.15	0.05	0.04
2019	1.27	0.05	0.04
2020	1.95	0.05	0.03
2021	1.89	0.04	0.02
2022	1.82	0.04	0.02

Figures



Residuals vs Fitted

Normal Q−Q

Scale−Location

Residuals vs Leverage

Figure 1: Linear model diagnostics for the final model fit to retained catch CPUE with a gamma distributed error.

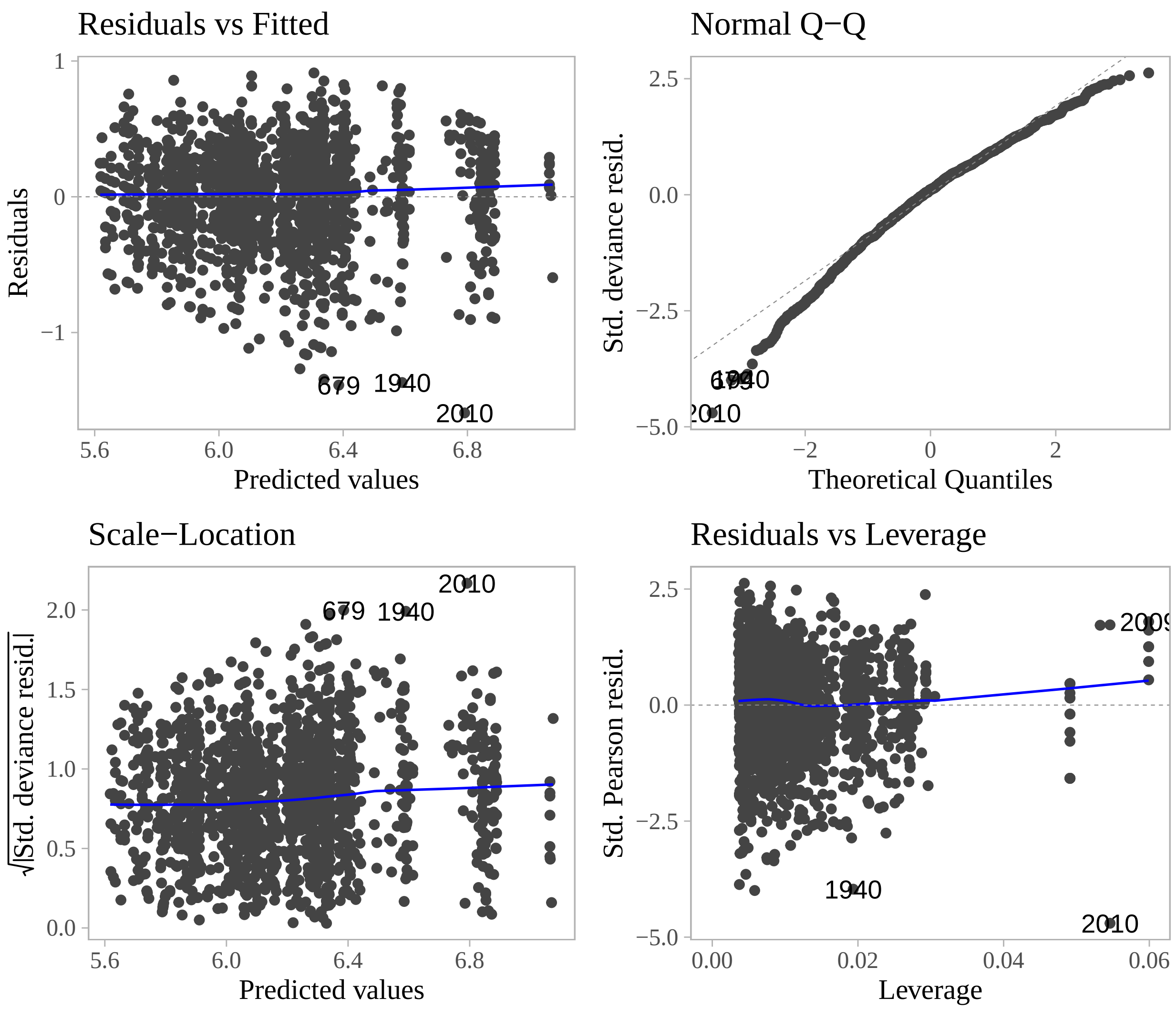


Figure 2: Linear model diagnostics for the final model fit to retained catch CPUE with a lognormal distributed error.

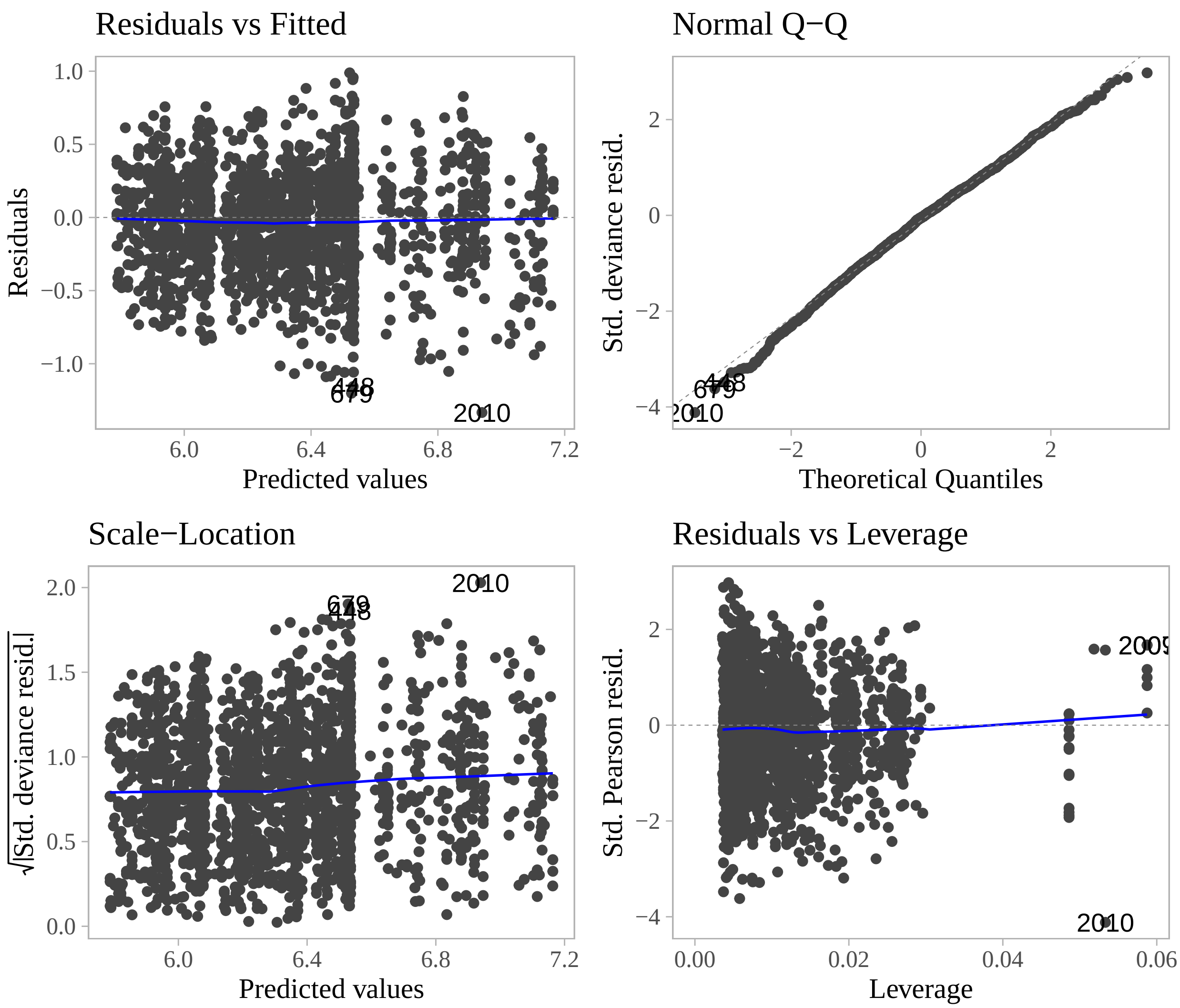


Figure 3: Linear model diagnostics for the final model fit to total catch CPUE with a gamma distributed error.

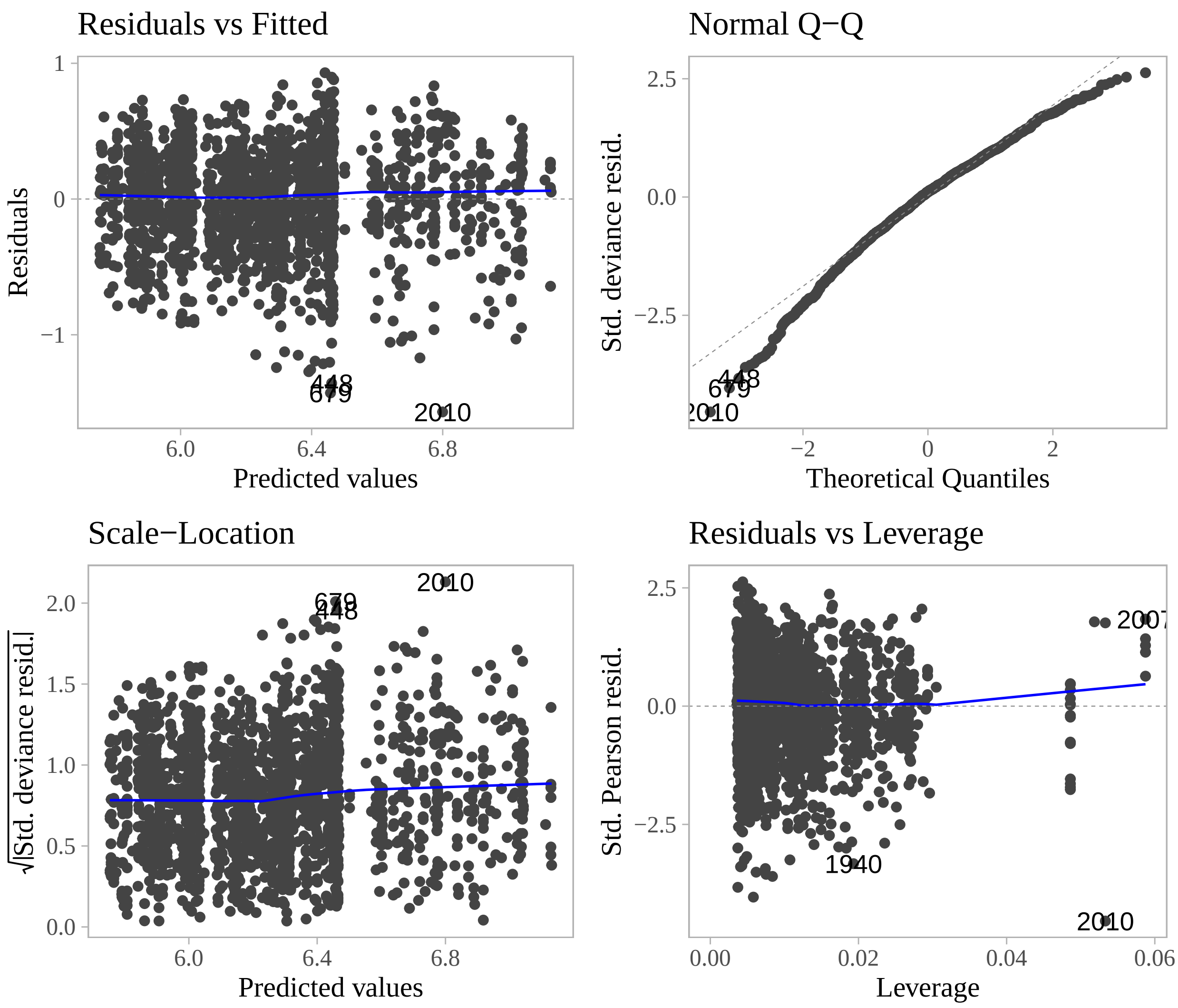


Figure 4: Linear model diagnostics for the final model fit to total catch CPUE with a lognormal distributed error.

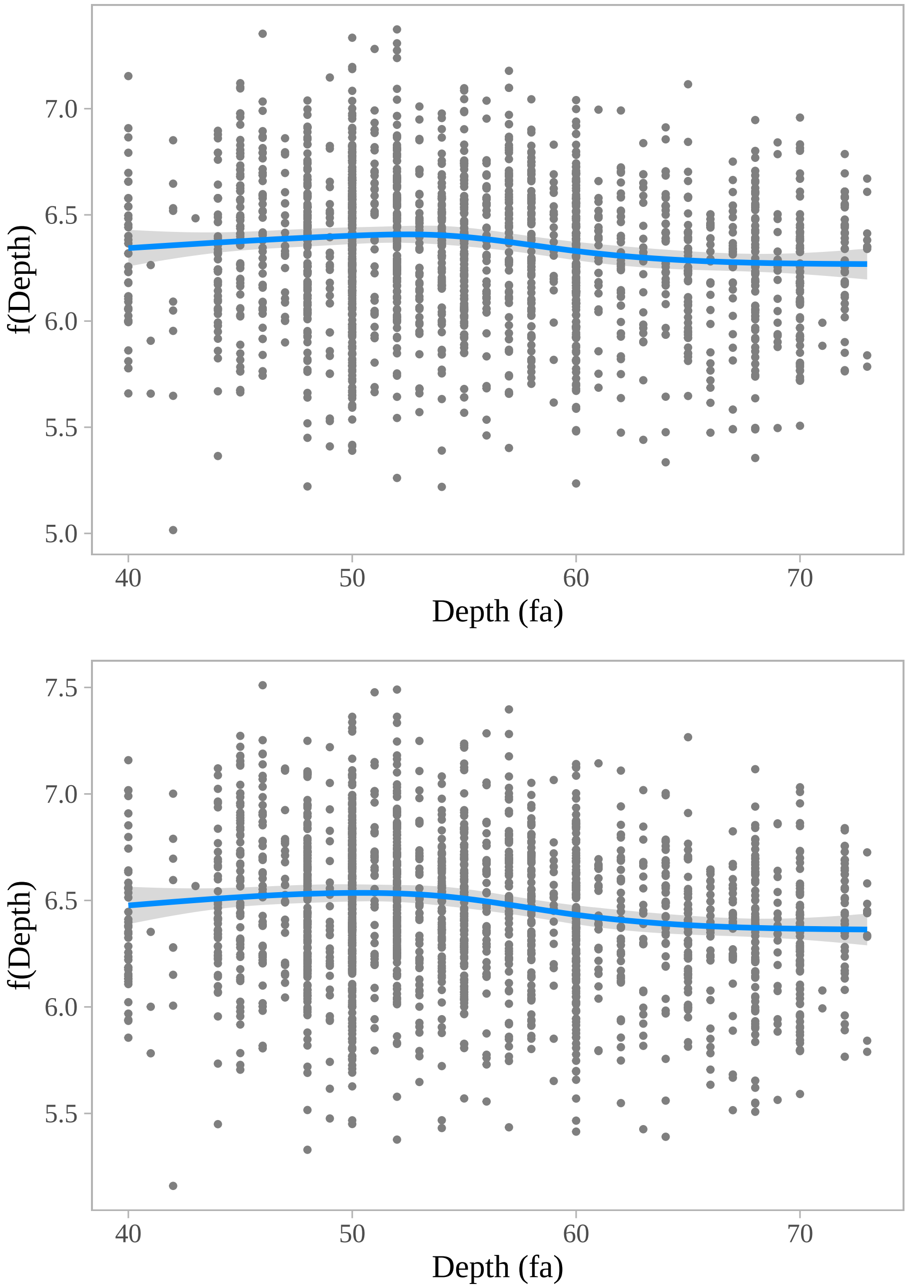


Figure 5: Marginal effect of depth (fa) in the final GLM model fit to retained catch CPUE (top) and total catch CPUE (bottom).

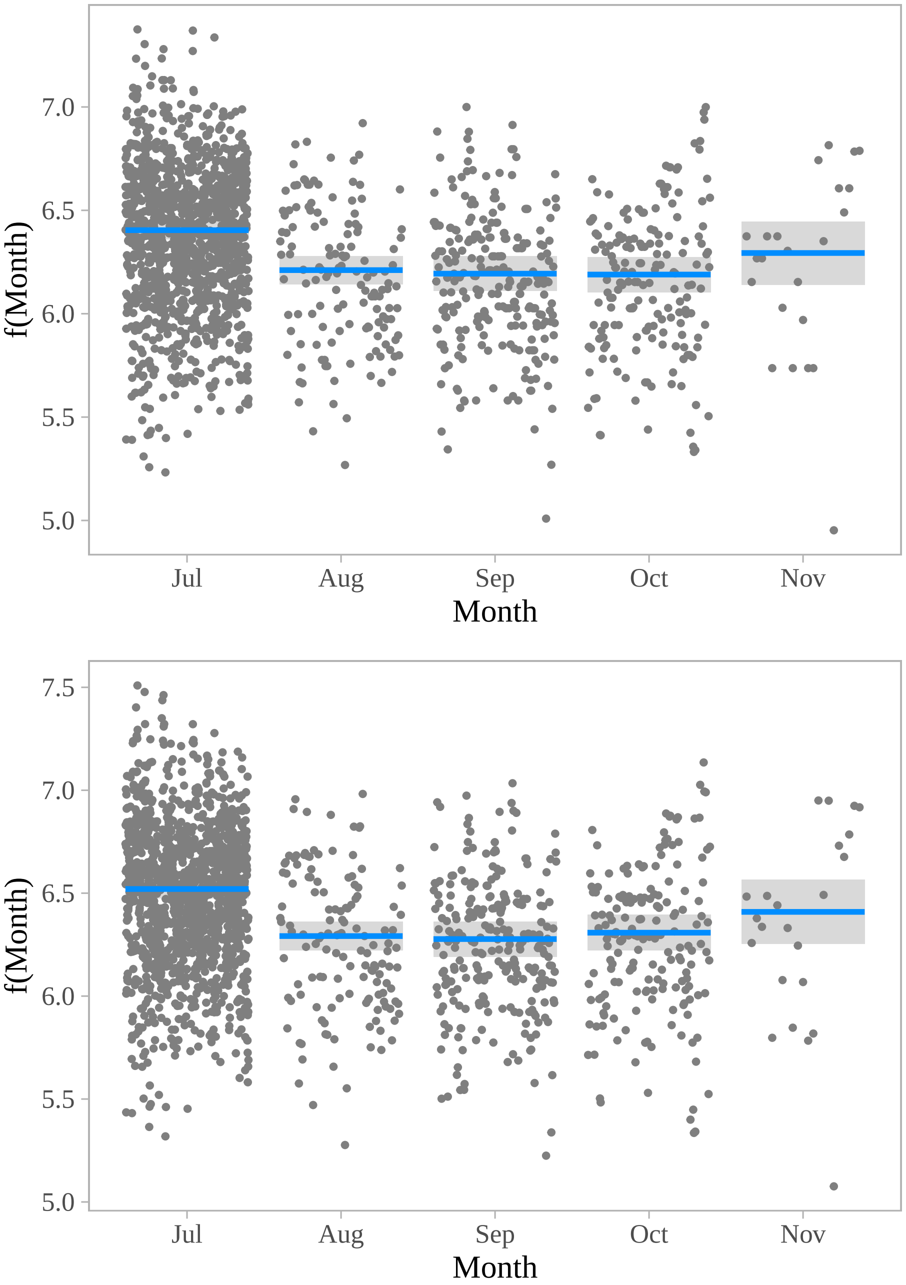


Figure 6: Marginal effect of month in the final GLM model to retained catch CPUE (top) and total catch CPUE (bottom).

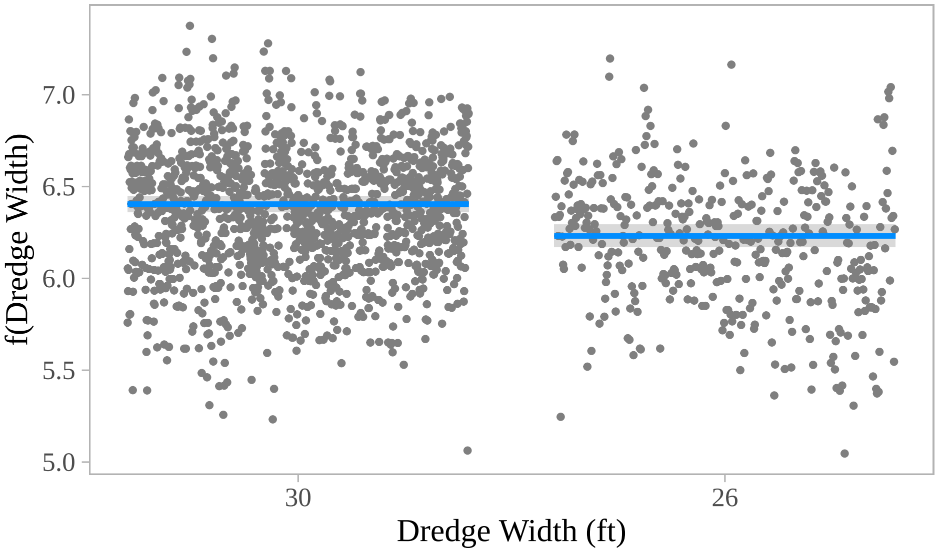


Figure 7: Marginal effect of dredge width (ft) in the final GLM model.

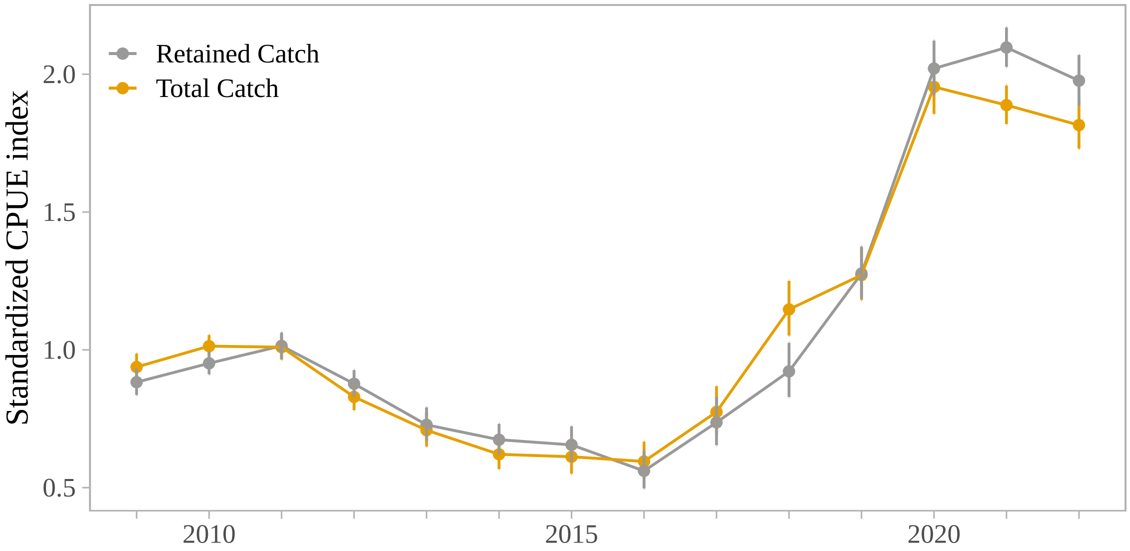


Figure 8: Standardized CPUE index estimated using gamma GLM for the Kodiak Shelikof District.

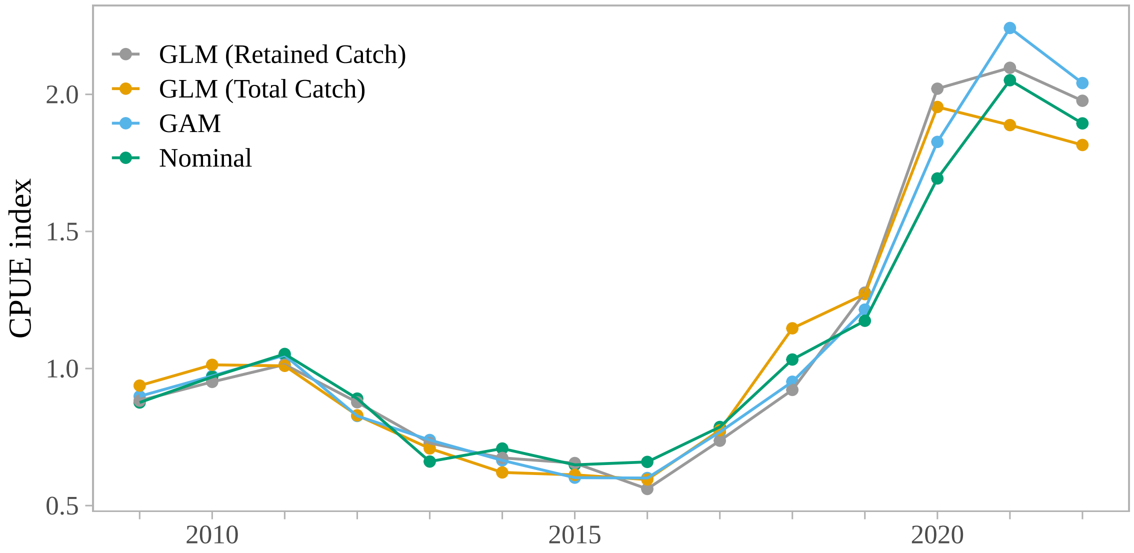


Figure 9: Standardized CPUE index estimated using gamma GLM in comparision to scaled GAM and nominal (round weight / dredge hr) indices for the Kodiak Shelikof District.

Appendix D: Response to Comments

March 2023

SSC April 2022

Comment: "*The FMP requires that a SAFE report be produced annually, and an FMP amendment would be required to accommodate an alternative assessment cycle. The SSC reiterates its support for such an amendment to the extent that it allows greater flexibility in scheduling the SAFE report cycle.*"

Response: Sarah Rheinsmith (NPFMC) has initiated a motion to amend the scallop FMP to allow for setting multi-year specifications.

Comment: "*The SSC requests that in the future, a map be produced of all beds that have been surveyed or fished (even if only historically). From this map, the footprint of the current fishery relative to the extent of the overall historical distribution should be provided in each SAFE.*"

Response: Such a figure will be presented in the next version of the full SAFE (i.e., 2024).

Comment: "*If there is interest in improving the understanding of stock distribution and productivity in order to allow for the potential of an expanded fishery in the future, the SSC recommends that the State consider allocating some portion of the annual survey effort to mapping of scallop beds to better define the boundaries of existing beds.*"

Response: The dredge survey currently uses all of its allocated time to fully sample the major harvest areas (Yakutat, Kodiak Shelikof, and Kodiak Northeast District). The next survey Operational Plan will cover 2024-2026 surveys and ADF&G will take this suggestion under consideration.

Comment: "*The SSC recommends that future modeling efforts be focused on an age-structured model (and/or other models for data-limited situations for comparison) for a single district, perhaps Yakutat where the recent fishery has been active.*"

Response: For now, modelling efforts will continue with the Stock Synthesis framework and be focused on Kodiak Shelikof District. The Shelikof District is an active fishery, with a long history, and has undergone a dynamic trend in harvest and fishery performance. It is currently the second largest contributor to the state-wide GHL behind Yakutat District. Further, it primarily consists of a single bed which has been surveyed five times.

Yakutat District has only been surveyed across all five actively fished beds in 2019 and 2021. Prior to that, only select beds were fished during surveys. In addition, the Yakutat District appears to be a less contiguous population that undergoes somewhat different patterns of recruitment and survival among beds which may complicate model development. Yakutat District will likely be a good subject to further evaluate a population dynamics model developed for Kodiak Shelikof District.

Comment: "*For future age-structured modeling efforts, the SSC has the following recommendations, in addition to those provided by the SPT:*

- *The models should include discard mortality.*
- *If survey dredge efficiency is assumed to be known, include this information as a prior on catchability and force selectivity to be 1.0 for a reasonable range of sizes rather than allowing dredge selectivity to be less than 1.0 across the entire size range.*
- *Consider dropping the westward region large-mesh trawl survey index as it is highly uncertain. If the trawl index is retained, provide justification for the implausibly small log(SE) = 0.01 for several of the observations.*
- *As recommended by the SPT, further work on standardizing the fishery CPUE index will be needed, including a careful evaluation of its suitability as an index of abundance by region or overall.*
- *Provide an explicit basis for data weighting. Recent groundfish assessments may be helpful to assess the range of approaches commonly employed.*
- *Provide a basis for the selection of the variance in recruitment deviations.*
- *Provide a graphical summary of the fits to size-at-age data.*"

Response:

- All 23.x models presented include discard mortality.
- All models presented in this iteration applied dredge efficiency outside of the model and assumed catchability = 1 for the dredge survey. As we gain additional information on dredge efficiency - particularly the new survey dredge - I will evaluate a model using the approach suggested here. Model 23.3 assumes full selectivity throughout the size range, while other models attempt to estimate selectivity across the full size range.
- The Westward Region Trawl Survey data has been dropped from the analysis in all models.
- Additional work on CPUE standardization is presented in Appendix C.
- I will address the basis for data weighting in the next iteration of model development.
- I will address the basis for recruitment variation in the next iteration of model development.
- Fits to size-conditional age data are provided in Appendix B.

Comment: "*Going forward, the SSC recommends that the survey team consider adjusting the survey plan to include key beds in the Yakutat Area annually rather than in alternating years. The goal would be to produce a consistent survey time series to inform the development of an assessment model and allow important comparisons between fishery independent abundance and biomass estimates and fishery-dependent nominal and standardized CPUE estimates. The SSC recognizes that this may limit survey effort in the Cook Inlet and Kodiak regions.*"

Response: The current dredge survey Operational Plan sunsets in 2023, and any changes to District prioritization will be evaluated before the 2024 survey. Although, it is noteworthy that complete surveys of the Kodiak Shelikof, Kodiak Northeast, Kayak Island, and Yakutat Districts are responsive to management needs, and moving between Kodiak and Yakutat areas during a survey presents logistical challenges.

Comment: "*The SSC recommends the SPT and ADF&G survey team consider the value of re-deploying the ADF&G CamSled optical sampling platform relative to the current sampling methods. A recent publication (Batter et al. 2021, Journal of Shellfish Research) demonstrates the efficacy of this sampler to support abundance and biomass estimation. Importantly, the local scallop density and distribution information captured in the seabed imagery would provide independent estimates of abundance and biomass, insights into the planned dredge calibration study, and potentially support direct estimates of natural mortality (e.g., ratio* *of live to dead scallops), as well as support essential fish habitat assessments. If the CamSled tool is deployed, the SSC considers mapping of scallop bed boundaries to allow comparison between scallop distribution and fishing footprint to be a high priority.*"

Response: The SPT acknowledges the utility of the CamSled in augmenting dredge surveys. There has been interest by the ADF&G BSAI crab research program to deploy the CamSled in the Bering Sea for crab related research. If new expertise are gained as part of that effort, we will reconsider use of the CamSled for surveying scallop beds in the future.

Comment: "*The SSC notes the importance of the dredge calibration experiment in interpreting the time series in the near future until the new gear has its own series. The SSC looks forward to seeing the details of the calibration study, including overall catchability and size-selectivity when the experiment is complete.*"

Response: An brief overview of experiment details were presented as part of the 2022 scallop survey results. The primary goal of this experiment during the 2022 survey was to troubleshoot gear configuration and optimal fishing conditions for the new dredge, while the old dredge was used to sample survey stations. The 2023 survey will tow a number of hauls simultaneously in a systematic design across the survey.

Comment: "*The SSC recommends that the survey team consider documenting uncertainty associated with time on bottom for the survey dredge and methods used to estimate area swept.*"

Response: Methods for estimating area swept are documented in the current Operational Plan (Burt et al. 2021) and in section 2.3.2 of the 2022 SAFE (Equation 4). Specifically, distance fished is extracted from the fishing log, whereby the vessel captain records the moment the dredge makes bottom contact by monitoring dredge angle via the Dredgemaster and begins the 1 nmi tow. In the future survey staff plan to facilitate access of Dredgemaster data (2016-present) to directly inform time on bottom. Dredge width is constant (x = 8 ft).

Comment: "*The SSC appreciated the analysts' efforts to examine scallop data collected in the westward region large-mesh trawl survey. Scallop catches in this gear were small and highly variable, likely due to the survey gear not being designed for scallops. The SSC concurs with the SPT's assessment that these data provide little additional information to inform the age-structured modeling work and continued efforts are unlikely to be fruitful. However, examination of scallop catches outside the known beds may provide insights into the locations of scallop beds not currently detected in the fishery or state-wide survey.*"

Response: ADF&G continues to collect information on scallop CPUE and shell height composition as part of the Westward Region large-mesh trawl survey should these data become of interest again in the future.

Comment: "*The SSC recommends that the SPT consider whether the OFL levels are appropriately set using the current reference period from 1990-1997, given the more recent CPUE trends and biological information (e.g., average weight) available.*"

Response: It's likely that a more recent reference period would better represent the current reproductive potential of the stock. An analysis of reference period will be presented in the next full SAFE (2024).

Comment: "*The SSC encourages the continued monitoring of weak meats and supports the SPT recommendation to improve collection of quantitative data for monitoring individual scallop condition indices and stock health trends. The SSC recommends the analysts and SPT consider additional observer training and other more objective sampling protocols to standardize and improve weak meat detection.*"

Response: The ADF&G Shellfish Observer Program will take this recommendation under consideration.

Comment: "*The SSC was pleased to see that CTD data were collected during the 2021 survey reported in the SAFE. To the extent possible, the SSC recommends continuing this sampling in subsequent surveys.*"

Response: ADF&G plans to continue CTD data collection on future surveys.

Comment: "*The SSC encourages continued investigation of trends in meat weight and whether these may be driven by environmental factors, such as temperature, in addition to the timing of the survey.*"

Response: Preliminary analyses suggest that inter-annual differences in meat weight at size are in part driven by timing of gonad development and spawning, which is consistent with what has been observed in Atlantic sea scallops. Meat weight at size data continues to be collected as part of the ADF&G dredge survey and observer program, though it has been difficult to collect area specific data for evaluating intra-annual fluctuation in meat weight and gonad condition, as fisheries typically only span a short window of the fishing season.

Comment: "*Regarding the change in the shell height definition from the 'top shell' to 'outer shell,' the SSC appreciated the brief analysis of paired valve measurements provided. The SSC concurs with the analysts that redefining the shell height from "top valve" to "outer shell margin" is appropriate without using a conversion for survey data, given the mixed history of data collection. The analysts indicated that there are plans to conduct a similar analysis on shells collected during the fishery. The SSC looks forward to seeing this analysis.*"

Response: The ADF&G Shellfish Observer Program collected paired measurements on 351 shells ranging from 8 - 203 mm shell height (top valve). The estimated conversion from top to bottom valve measurements was $L_{bottom} = 1.018L_{top}$ (below), which about the same as what has been estimated based on survey collected shells ($L_{bottom} = 1.02L_{top}$). Observers began collecting shell height measurement of the "outer shell margin" as opposed to "top valve" in the 2022/23 season.

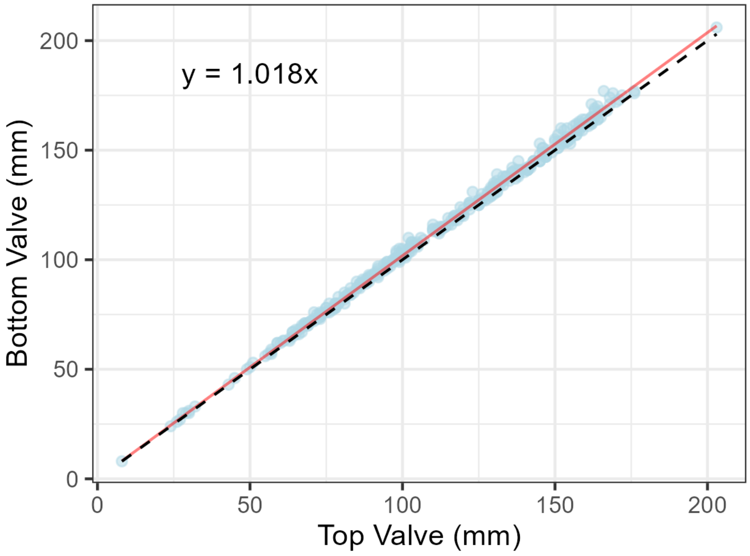


Figure 1: Paired top and bottom valve measurements for observer collected shell height data. The dotted line represent a 1:1 relationship and the solid red line represent the linear fit to the data.

Comment: "*The SSC noted that although the scallop fishery has a small spatial footprint, scallop fishing should be included in future fishing effects modeling because of the bottom-tending characteristics and rigid nature of the gear.*"

Response: The SPT and ADF&G will help facilitate these data being included in fishing effects modelling.

Comment: "*The SSC suggests that the SPT and ADF&G survey team may benefit from a deeper examination of recent and ongoing science and management efforts for Atlantic sea scallops, including development of appropriate survey designs, cooperative survey data collection, and ecosystem interactions and effects, particularly with regard to management in the context of choke species, as well as invasive species such as the tunicate Didemnum vexillum.*"

Response: ADF&G will continue to follow research and management of Atlantic sea scallops to better inform dredge survey design, observer data collection, and management of weathervane scallops.

Comment: "*The SSC recommends that the SPT consider the value of a study on the genetics of scallops to help define stock structure.*"

Response: The SPT agrees there would be value in assessing genetic and population connectivity of weathervane scallops throughout Alaska, particularly among its sub-regions (i.e., Bering Sea, eastern/western GOA).

Comment: "*The SSC supports the SPT recommendations to streamline the SAFE document by including the survey history and methods via references to the appropriate ADF&G documents. In addition, reductions in the area-specific fishery performance sections may also be warranted as these do not directly inform stock status determination. Finally, several minor editorial issues should be reconciled if these sections continue to be included:*

- *Table 2.2 headers missing for 'total' and 'sampled' stations.*
- *Tables 4.4, 4.5, 4.6: why are there no discard mortality estimates?*
- *Table 4.11, 4.12 report an order of magnitude lower discard mortality rates – are these correct? If so, perhaps include a comment on why this is the case.*
- *If trawl data are to be reported, please convert to lb/nm2 instead of kg/km for comparability with dredge data.*
- *Check accuracy of numbers presented for OY and OFL on page 6 section 1.1 and MSST on page 8.*
- *In Table 2.1, separate landings and discards so trends can be discerned.*"

Response: The SPT notes these editorial comments. There will be broader scale changes to the format of the 2024 full SAFE as we determine what information are necessary, or appropriately reported elsewhere. There is also interest in making the scallop SAFE more consistent with the format of crab SAFE documents.

There was error in reporting GHL and fishery harvest in the 2022 SAFE document. Reporting for this and future SAFE documents will be done using Bookdown so that reported statistics can be linked directly to raw data - thus avoiding transcription and addition error.