Appendix D: Preliminary rebuilding projections for eastern Bering Sea snow crab

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Contents

A. Executive summary

A rebuilding analysis was performed for snow crab in the eastern Bering Sea based on the author-preffered model from the 2022 SAFE document (22.1ab). The model was projected to the year 2040 under different scenarios for fishing mortality, recruitment, and natural mortality. Analyses aimed at understanding the relationships between mortality and environmental conditions (included in Appendix B and C) suggest that high temperatures and high densities of crab were key conditions related to mortality events observed in 2018 and 2019. Previous analyses have linked ice cover and the Arctic Oscillation to recruitment. Given projected temperatures and population densities, a scenario in which mortality is close to average and recruitment is low are the most defensible scenarios in the opinion of the author. Under the lower recruitment scenario prioritized by the SSC and the average natural mortality scenario, the stock could rebuild under zero fishing mortality in less than 10 years (i.e. t_{min} would be 10 years). When unobserved mortality was assumed to be small, the state harvest strategy could return the stock to above B_{MSY} within the t_{min} of 10 years.

The potential for unobserved mortality to impact rebuilding outcomes was evaluated by multiplying the time series of input bycatch biomass by 5 and 100 and refitting the model. The refitted models were then projected under the same scenarios as above. The management advice (i.e. the OFL) resulting from models with and without unobserved mortality included were similar. The key difference between the models was how much of the OFL was allocated to the non-directed fisheries. Models with unobserved bycatch included allocated more of the OFL to non-directed fisheries, decreasing the catches of the directed fishery. It is clear that there must be unobserved mortality occurring as a result of crab killed by fishing gear, but not captured and brought to the surface. At the same time, it is difficult to reconcile the potential for unobserved mortality to play a large role in the recent population dynamics of snow crab and the appearance of the largest pseudocohort in the history of the survey in 2015-2018. Given uncertainties around unobserved mortality, similar OFLs under different assumptions about unobserved mortality, and impacts on projected directed fleet catches based allocation of the OFL under different assumptions about unobserved mortality, the author-preferred unobserved mortality scenario for rebuilding projections is the status quo. That said, additional research on unobserved mortality is warranted and non-directed bycatch is most intense around the Pribilof Islands, which would be a potentially useful area in which to focus research.

B. Comments and responses

SSC comment: SSC supports the CPT recommendation to use GMACS as the basis for rebuilding analyses but was not able to select appropriate rebuilding parameters given the information currently available. Therefore, the SSC provided guidance on rebuilding projections and fishing mortality alternatives that should be included in the next iteration of the analysis

The prioritized scenarios were completed with updated data and the author-preferred model from the 2022 SAFE.

SSC comment: The top priority for the rebuilding analysis is to use the tighter prior on M that is consistent with both last year's model and the preferred model recommended for the 2022 harvest specifications cycle by the CPT.

The author-preferred model uses a prior consistent with the previous status quo model.

SSC comment: The SSC recommends a stochastic treatment of M, resampling of annual M values from the same period of years used for recruitment resampling

This functionality was built into GMACS for these rebuilding projections.

SSC comment: To bracket a range of plausible trajectories, four time periods were recommended:

- 1982-2017: This period was recommended by the CPT, and will be similar to the results already provided, except for the use of the tighter prior on M during estimation. The SSC notes that this will likely be the most optimistic case, as it does not include the high estimated M associated with the apparent mortality event in 2018-2019.
- 1982-2019: This period matches the fully observed time series, including the elevated mortality in 2018-2019, but does not reflect the anticipated increased frequency of mortality events due to climate change.
- 1994-2019: This period follows the author's rationale for a break in the recruitment time series, reflecting more recent conditions while still allowing for the possibility of some high recruitment
- 2005-2019: This period corresponds to the most recent period of alternating warm and cool conditions in the Bering Sea and approximates a one in seven chance of an elevated mortality event, consistent with estimates of near-term future temperature variability in the Bering Sea.

Noting the compressed timeline for this rebuilding analysis, the SSC suggests if all of the four projection time-periods cannot be evaluated that the first and fourth would be the highest priority.

Given unexpected issues with the jittering analysis (see main SAFE document), only the prioritized scenarios were performed.

SSC comment: Consistent with the treatment of mortality events for other crab stocks and for GOA Pacific cod, the SSC recommends using only the 'base' mortality rate (not including the 2018-2019 event), for each projection period, along with the resampled recruitments to calculate the BMSY for determining rebuilding parameters

Three B_{MSY}s are presented on each graph and table: one that corresponds to the currently used B_{MSY} with which management advice is set (i.e. average recruitment from 1982-2021), one that corresponds to 1982-2017, and one that corresponds to 2005-2019.

SSC comment: The SSC supports the CPT recommendations of fishing mortality alternatives to include in each projection, with two additions for a total of five alternatives:

- No fishing mortality (F=0)
- Average bycatch over a recent period (including both groundfish and other crab fisheries)

- An approximation of the State of Alaska's Harvest Control Rule (HCR) with recent bycatch
- An approximation of the State of Alaska's HCR without recent bycatch
- F = F_{ABC}

These fishing scenarios were performed for each of the 4 productivity scenarios, but an issue was discovered with the State of Alaska harvest control rule without recent bycatch when writing this document (discussed below). This primarily impacts the unobserved mortality sensitivies because it is related to how the fishing mortality is allocated between among the directed and non-directed fleets capturing snow crab.

SSC comment: The SSC requests that future rebuilding analyses provide a summary of the technical specifications of how the projections are being run (e.g., how many forward simulations, which sources of uncertainty are included, whether Monte-Carlo error has been evaluated and is negligible for the quantities of interest). To aid in specific evaluation and comparison of rebuilding parameters, the SSC also requests that they be provided in tabular format including: Tmin, Tmax, mean generation time, and specific rebuilding times for fishing alternatives (potential Ttarget values).

Each of these points has been addressed below.

C. Projection specifications

The projection model used here was based on the author-preferred model 22.1ab from the 2022 SAFE document. Several points of concern were raised about the model fits for model 22.1ab in the SAFE document. These issues are important to address for tactical management, but for strategic management projections, the issues are less important for several reasons. First, projections use average values for population processes to project forward. Estimates of population processes were similar across models. They key drivers of rebuilding time are the initial status of the stock (i.e. the ratio of current MMB to B_{MSY}) and assumptions about future recruitment and natural mortality. The estimated status from all of the models with the most up-to-date data are in an over-fished state. The purpose of multiple recruitment and natural mortality scenarios is to evaluate the impact of different assumptions about future productivity on rebuilding trajectories. One strong caveat is that the projections models assume that the OFLs and ABCs are set with perfect estimates of the scale of the population, which have been historically uncertain. Still, given similar starting statuses and similar estimated population processes, this projection model is best available framework to evaluate rebuilding trajectories for eastern Bering Sea snow crab.

Projections were performed by starting at the local minima from model 22.1ab. Recruitment and natural mortalities were sampled from the estimated recruitments and natural mortalities based on user input range of years. Four future productivity scenarios were analyzed by crossing the periods 1982-2017 and 2005-2019 for sampling recruitment and natural mortality. The model was projected to 2040 in each of 2000 projections performed for each combination of recruitment and natural mortality scenarios. Five fishing scenarios were performed within those four productivity scenarios based on the SSC requests: zero fishing mortality, only bycatch mortality, an approximation of the State of Alaska's harvest with no bycatch, an approximation of the State of Alaska's harvest including bycatch, and the federally set acceptable biological catch (ABC). Markov Chain Monte Carlo (MCMC) simulations were performed for model 22.1 before discovering the bimodality in management quantities. Once the bimodality was discovered, there was not time to run MCMC, so the starting points of the forward projections do not incorporate stochasticity in parameter estimates or initial conditions.

Bycatch mortality was specified in the model as the average of the estimated bycatch fishing mortality over the last ten years. The State of Alaska's harvest control rule was approximated by averaging the ratio of the total allowable catch (TAC) set by the State and the ABC over the last 10 years (Daly, personal communication). The ratio (equal to 0.40) was used to scale the ABC calculated in the projections; the ABC was based on a 25% buffer of the OFL calculated using the current B_{MSY} proxy.

Three proxies for B_{MSY} were calculated to evaluate rebuilding progress. These target biomasses correspond to the currently used $B_{35\%}$ (recruitment years 1982-2021), a target biomass calculated using expected recruitment based on the years 1982-2017, and a target based on the recruitment estimates for the years 2005-2019. All biomass targets were calculated without incorporating the potential for mortality events to occur (i.e. the base estimate of natural mortality was used in projections).

Sensitivities about the assumptions of unobserved mortality were explored in which the observed time series of bycatch was multiplied by 5 and 100 before the model was fit to the data. The projection methodology described above was then repeated for each of those models.

Estimates of mean generation time from the Kodiak lab were ~ 7 years, based on the approximate time to maturity (Fedewa, personal communication).

D. Projection results

Author-preferred model

Assumed future conditions of recruitment and natural mortality impacted the time to rebuilding under no fishing, as did the target biomass used (Figure 1 & Figure 2). Scenarios in which future recruitment and natural mortality were drawn from 2005-2019 never rebuilt under zero fishing regardless of the target. Scenarios in which future recruitment and natural mortality were drawn from 1982-2017 rebuilt the fastest of the scenarios, rebuilding to the currently used B_{MSY} in 2029 under no fishing and during 2029-2030 while fishing at the State harvest control rule plus bycatch.

Uncertainty around the future population size was larger under recruitment projections sampling from 2005-2019 than from 1982 to 2017 because the 2005-2019 period is comprised of one very large recruitment among many small recruitments, resulting in a smaller standard deviation of recruitment during the years 1982 to 2017 compared to that from 2005-2019. Consequently, although the overall potential scale of the populations under 2005-2019 recruitment is larger, the slope of the rebuilding trajectory is somewhat more shallow than when recruitment is drawn from 1982-2017. The currently used $B_{35\%}$ is lower than both other biomass targets, which can result in faster times to rebuilding if it is used as the rebuilding target.

Unobserved mortality sensitivities

Altering the input bycatch biomasses to represent potential unobserved mortality resulted in changes in the estimates of some population processes. See Figure 7 through Figure 26 for differences in fits and estimated population processes among the models with different assumptions about unobserved mortality. Changes in individual contribution of likelihood component to the objective function and the resulting management advice can be seen in Table 1 and Table 2. Fairly large changes were seen in the scale of the population and resulting estimates of MMB, $B_{35\%}$ and $F_{35\%}$. However, estimates of status of the population and OFLs were less different than the other management quantities.

As with the author-preferred model, assumed future conditions of recruitment and natural mortality impacted the time to rebuilding under no fishing, as did the target biomass used (Figure 3 through Figure 6). The general trends of the timing of rebuilding under a given productivity scenario and zero fishing mortality were similar to the results from modeling when no additional unobserved mortality was modeled. However, there were more scenarios in which the stock never rebuilt with higher unobserved mortality.

An error in the projection model occurs for the 'State - bycatch' scenario and is most apparent in the 100x bycatch scenarios. The 'State - bycatch' scenario should be close to the 'No fishing' line because under these models, the entire allocation of the OFL should be to the bycatch fleets based on current calculations of the OFL. The fishing mortality allocated to the bycatch fleets is an average of the last ten years in the calculation of the OFL, then a fishing mortality for the directed fleet is estimated to allow the remaining portion of the OFL to be caught by the directed fleet. This dynamic would need to be considered more carefully if additional unobserved mortality were to be included in the assessment or projections. Currently, very little bycatch occurs in the author-preferred models, so the allocations to bycatch fleets when calculating the OFL are small. If unobserved mortality is included in the assessment and the OFLs do not change appreciably, it would result in the directed fishery being allocated less of the OFL than historically seen.

If one of the unobserved mortality scenarios are selected, the methodology for calculating the 'State - bycatch' scenario will need to be revised.

E. Author recommendations

Scenario selection

Selection t_{min} is the first step in developing a rebuilding plan and to do that, probable scenarios for future conditions must be established. Appendix B and C detail analyses aimed at understanding the dynamics of mortality for snow crab over time. One of the conclusions from the draft manuscript was that the mortality events in 2018 and 2019 appear to have been a result of high population-wide caloric demand as a result of high temperatures and high densities of crab. Bottom temperatures in the Bering Sea are projected to warm as ice cover is less of a permanent feature of the ecosystem (Jones et al., 2020). However, densities of crab will likely not be high in the short- and medium-term future (e.g. the next ten years), based on the current status of the population. Temperatures occupied by mature crab in 2003 were similar to temperatures in 2018 and 2019 as a result of similarly small cold pools (figure 1; Appendix B). However, estimated mortalities were not exceptional in 2003, potentially because of low densities of mature crab (figure 2: Appendix B). In light of these observations, more average natural mortalities may be an appropriate assumption over the projection period because, even though the Bering Sea is likely to be warm, densities of crab will be low.

Models predicting and projecting recruitment for crab in the eastern Bering Sea were published by Szuwalski et al. (2020) and linked estimated recruitment for snow crab to ice cover (positive relationship) and the Arctic Oscillation (AO; a negative relationship). Linking these recruitment models to projections of ice and the AO from global climate models produced declining trajectories of recruitment under warming scenarios. Consequently, the author-preferred projection of recruitment for the rebuilding analyses is the lower average recruitment scenario prioritized by the SSC (i.e. 1982-2017). That said, lower recruitment than this scenario projects is possible, which would impact rebuilding timelines.

Unobserved mortality

It is clear that there is some unobserved mortality on snow crab in the Bering Sea imposed by non-directed fleets; Rose et al.'s studies demonstrated that a small fraction of the crab in the path of groundfish fisheries are caught and brought to the surface (see Dr. Rose's May 2022 CPT meeting presentations for a summary). However, it is difficult to make a case for large impacts of non-directed fisheries on the recent population dynamics of snow crab. If the non-directed fisheries were a large driver of population dynamics, it is hard to explain how the largest pseudo-cohort ever observed would have occurred recently and developed through the size ranges that are impacted by the non-directed fleets. Still, managers only have two levers for impacting the population dynamics of snow crab in the Bering Sea: adjusting fishing mortality in the directed fishery or adjusting fishing mortality in the non-directed fleets. The other apparent drivers of snow crab dynamics (e.g. sea ice) are outside of the control of managing bodies. Consequently, it is important to carefully consider potential effects of the non-directed fisheries on the dynamics and rebuilding prospects of snow crab.

Given uncertainties around unobserved mortality, similar OFLs under different assumptions about unobserved mortality, and impacts on projected directed fleet catches based allocation of the OFL under different assumptions about unobserved mortality, the author-preferred unobserved mortality scenario for rebuilding projections is the status quo.

Future research aimed at understanding unobserved mortality could be focused on two areas. First, trawl bycatch is most intense around the Pribilof Islands (Figure 27) and this area has been suggested to be important to reproductive dynamics (e.g. Parada et al., 2010). This area would be a good candidate for research aimed at evaluating the impacts of potential modifications of non-directed fishery bycatch on snow crab population dynamics. Second, evaluation of the potential impacts of incorporating unobserved mortality into the assessment and management would be useful. If incorporating unobserved mortality results ultimately similar OFLs in a given year, the current methodology of allocating an average recent fishing mortality in the calculation of the OFL to the non-directed fleet then solving for the fishing mortality in the directed fleet that 'completes' the OFL could result in unanticipated impacts on the OFL allocated to the directed fleet.

F. References

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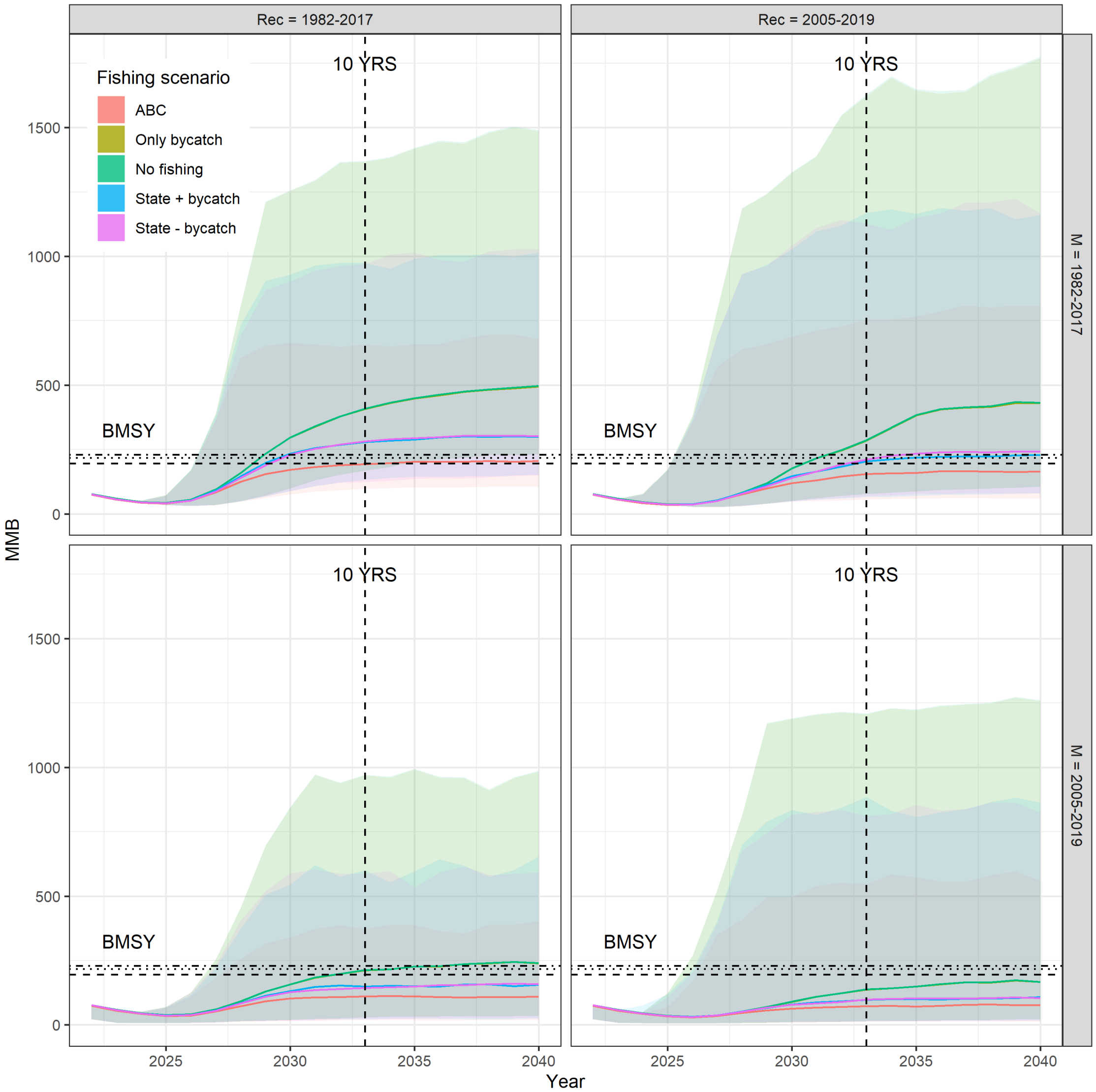

Figure 1: Projections of rebuilding trajectories under different productivity scenarios (recruitment and mortality), fishing strategies, and target biomasses (three horizontal lines corresponding to 1982-2021, 1982-2017, and 2005-2019, in ascending order). Bycatch time series are those used in the status quo assessment.

Fishing	Recruitment	Natural mortality	BMSY_sq	BMSY_17	BMSY_19
No fishing	Rec = 1982-2017	M = 1982-2017	2029	2029	2029
No fishing	Rec = 1982-2017	M = 2005-2019	2032	2035	2037
No fishing	Rec = 2005-2019	M = 1982-2017	2031	2032	2032
No fishing	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 1982-2017	M = 1982-2017	2034	Inf	Inf
ABC	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 1982-2017	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
bycatch	Rec = 1982-2017	M = 1982-2017	2029	2029	2029
bycatch	Rec = 1982-2017	M = 2005-2019	2032	2035	2037
bycatch	Rec = 2005-2019	M = 1982-2017	2031	2032	2032
bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 1982-2017	M = 1982-2017	2029	2030	2030
State + bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 2005-2019	M = 1982-2017	2033	2035	Inf
State + bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 1982-2017	M = 1982-2017	2030	2030	2030
State - bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 2005-2019	M = 1982-2017	2033	2034	2035
State - bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf

Figure 2: Table of time to rebuild under different productivity scenarios (recruitment and mortality), fishing strategies (fishing), and target biomasses (right three columns). BMSY.sq uses recruitment from 1982-2021, BMSY.17 uses recruitment from 1982-2017, BMSY.19 uses recruitment from 2005-2019.

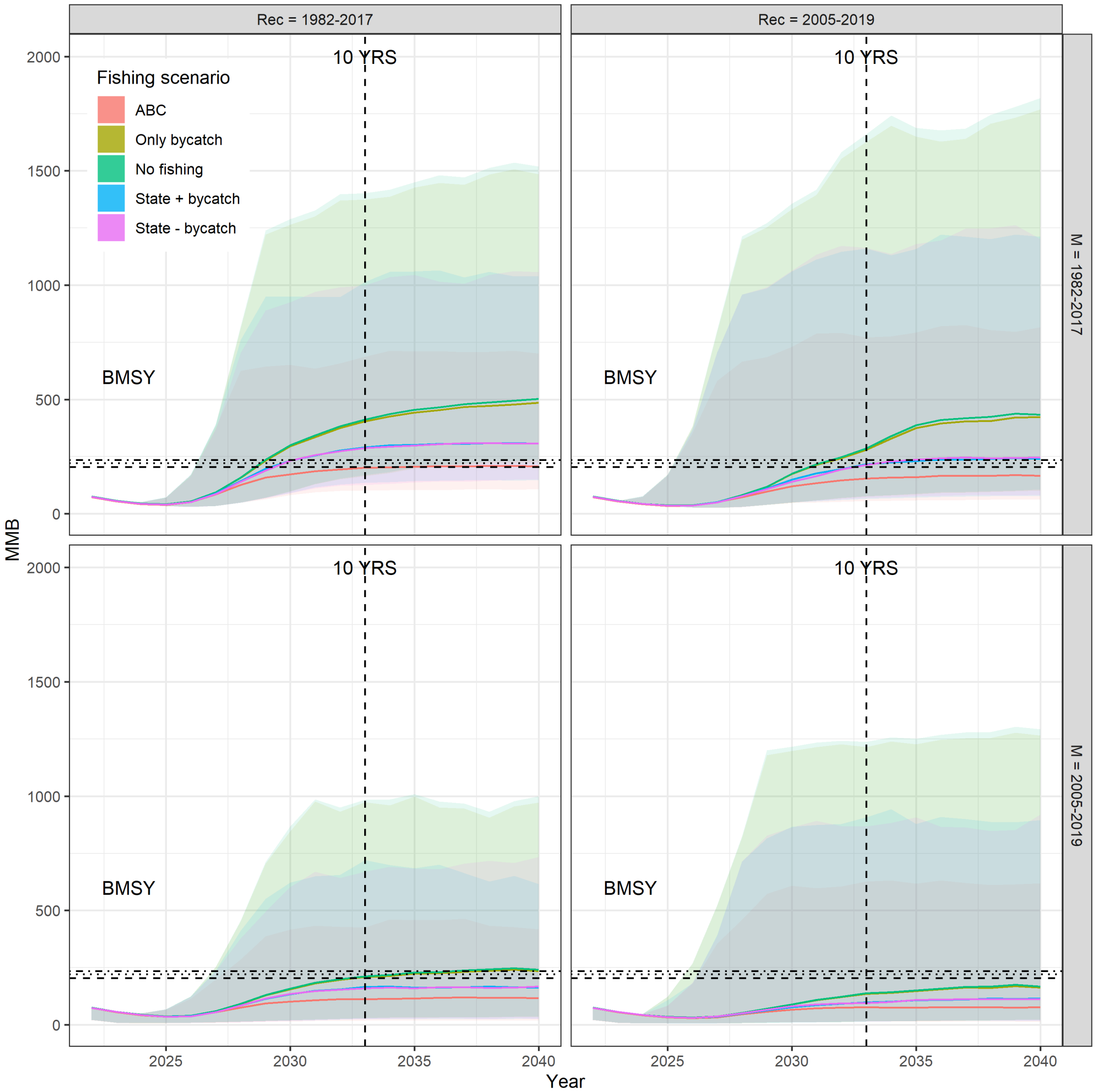

Figure 3: Projections of rebuilding trajectories under different productivity scenarios (recruitment and mortality), fishing strategies, and target biomasses (three horizontal lines corresponding to 1982-2021, 1982-2017, and 2005-2019, in ascending order). Bycatch time series are 5x those used in the status quo assessment.

Fishing	Recruitment	Natural mortality	BMSY_sq	BMSY_17	BMSY_19
No fishing	Rec = 1982-2017	M = 1982-2017	2029	2029	2029
No fishing	Rec = 1982-2017	M = 2005-2019	2033	2035	2037
No fishing	Rec = 2005-2019	M = 1982-2017	2031	2032	2032
No fishing	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 1982-2017	M = 1982-2017	2035	Inf	Inf
ABC	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 1982-2017	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
bycatch	Rec = 1982-2017	M = 1982-2017	2029	2029	2030
bycatch	Rec = 1982-2017	M = 2005-2019	2033	2035	2038
bycatch	Rec = 2005-2019	M = 1982-2017	2031	2032	2032
bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 1982-2017	M = 1982-2017	2030	2030	2031
State + bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 2005-2019	M = 1982-2017	2033	2034	2036
State + bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 1982-2017	M = 1982-2017	2030	2030	2031
State - bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 2005-2019	M = 1982-2017	2033	2034	2035
State - bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf

Figure 4: Table of time to rebuild under different productivity scenarios (recruitment and mortality), fishing strategies (fishing), and target biomasses (right three columns). Bycatch time series are 5x those used in the status quo assessment. BMSY.sq uses recruitment from 1982-2021, BMSY.17 uses recruitment from 1982-2017, BMSY.19 uses recruitment from 2005-2019.

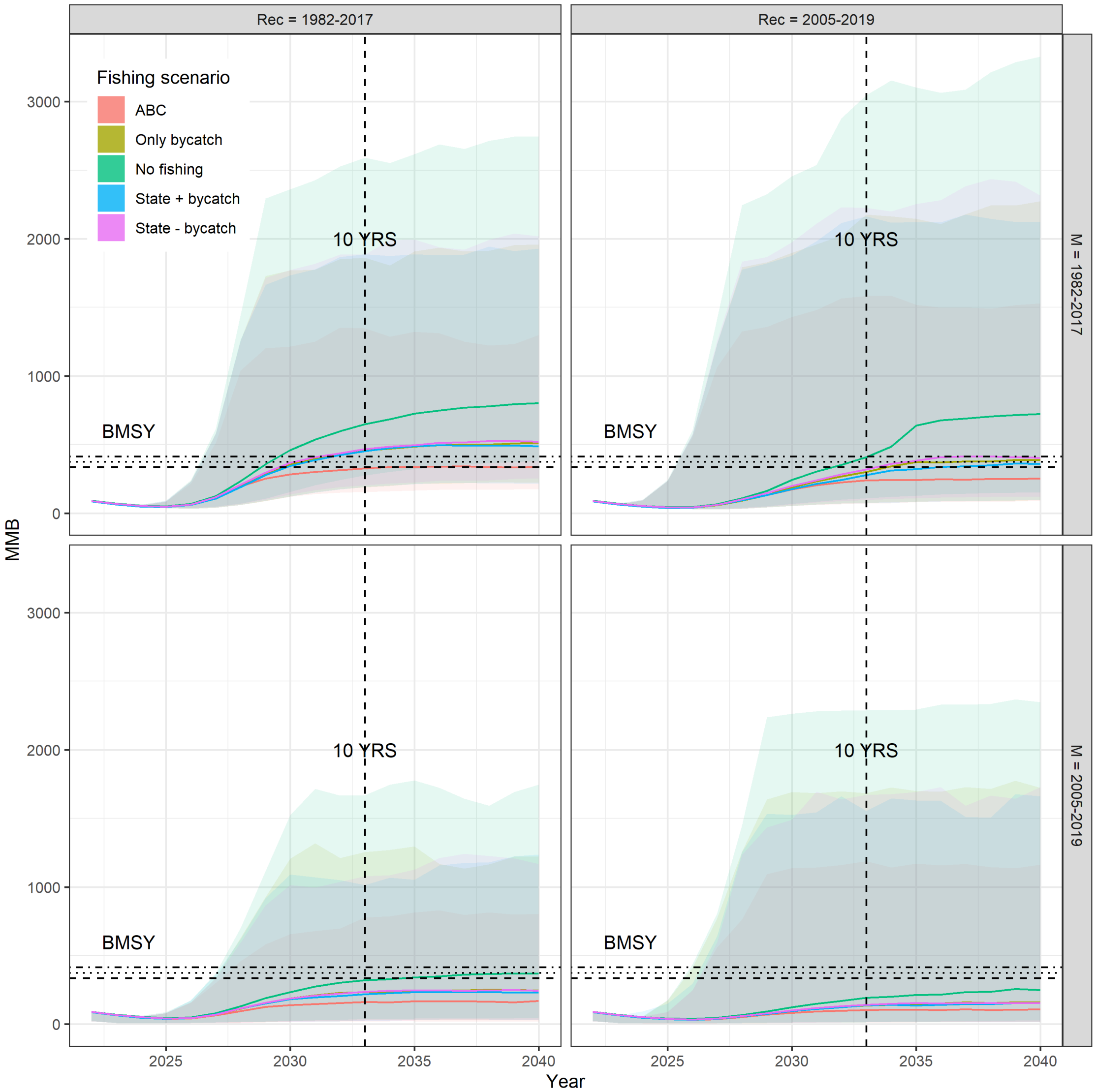

Figure 5: Projections of rebuilding trajectories under different productivity scenarios (recruitment and mortality), fishing strategies, and target biomasses (three horizontal lines corresponding to 1982-2021, 1982-2017, and 2005-2019, in ascending order). Bycatch time series are 100x those used in the status quo assessment.

Fishing	Recruitment	Natural mortality	BMSY_sq	BMSY_17	BMSY_19
No fishing	Rec = 1982-2017	M = 1982-2017	2029	2030	2030
No fishing	Rec = 1982-2017	M = 2005-2019	2035	Inf	Inf
No fishing	Rec = 2005-2019	M = 1982-2017	2032	2033	2034
No fishing	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 1982-2017	M = 1982-2017	2035	Inf	Inf
ABC	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 1982-2017	Inf	Inf	Inf
ABC	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
bycatch	Rec = 1982-2017	M = 1982-2017	2030	2031	2032
bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
bycatch	Rec = 2005-2019	M = 1982-2017	2034	2037	Inf
bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 1982-2017	M = 1982-2017	2030	2031	2032
State + bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State + bycatch	Rec = 2005-2019	M = 1982-2017	2036	Inf	Inf
State + bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 1982-2017	M = 1982-2017	2030	2031	2032
State - bycatch	Rec = 1982-2017	M = 2005-2019	Inf	Inf	Inf
State - bycatch	Rec = 2005-2019	M = 1982-2017	2034	2035	Inf
State - bycatch	Rec = 2005-2019	M = 2005-2019	Inf	Inf	Inf

Figure 6: Table of time to rebuild under different productivity scenarios (recruitment and mortality), fishing strategies (fishing), and target biomasses (right three columns). Bycatch time series are 100x those used in the status quo assessment. BMSY.sq uses recruitment from 1982-2021, BMSY.17 uses recruitment from 1982-2017, BMSY.19 uses recruitment from 2005-2019.

Table 1: Contribution to the objective function by individual likelihood component by modeling scenario.

Component	Fishery	22.1a	22.1ab	22.1ab__100x	22.1ab__5x
catch	Retained	-8.8231	-9.1501	-16.8981	-25.4244
catch	Discard (male)	139.3299	122.0342	103.3297	88.7727
catch	Discard (female)	-69.6608	-69.6607	-69.661	-69.6607
catch	Trawl	-50.6439	-50.6438	-41.187	-50.6248
cpue	NMFS survey (era 1; females)	43.9095	43.6293	40.457	43.6963
cpue	NMFS survey (era 2, females)	-30.8034	-31.2336	-30.7698	-29.3823
cpue	NMFS survey (era 1, males)	31.6677	29.7573	18.6982	27.8424
cpue	NMFS survey (era 2, males)	8.022	-5.4007	21.7178	-3.617
cpue	BSFRF 2009	-0.5799	-0.6052	-0.512	-0.6105
cpue	BSFRF 2010	-1.9527	-3.6876	-3.93	-3.0414
growth__inc	1	1021.2552	1016.8876	1015.4424	1018.2729
growth__inc	2	0	0	0	0
rec__dev	1	0.7575	0.7575	0.7575	0.7575
rec__dev	2	0	0	0	0
rec__dev	3	89.1284	91.2242	92.4832	92.3561
size__comp	Retained males	-3701.8747	-3699.7386	-3713.192	-3632.6982
size__comp	Survey mature females (1982-1988)	-688.4905	-688.4737	-687.6832	-688.553
size__comp	Survey mature females (1989-present)	-3071.9284	-3070.3273	-3075.6692	-3071.0868
size__comp	Survey mature males (1982-1988)	-595.4243	-596.1709	-594.2792	-594.2116
size__comp	Survey mature males (1989-present)	-2741.4501	-2721.3733	-2718.848	-2708.4459
size__comp	BSFRF 2009	-176.1576	-176.4514	-176.2182	-175.8758
size__comp	NMFS 2009	-184.5963	-184.6168	-184.606	-184.3002
size__comp	BSFRF 2010	-173.4927	-173.4626	-174.274	-168.3816
size__comp	NMFS 2010	-170.3836	-171.7761	-171.2706	-174.2002
size__comp	Total males	-2711.7745	-2688.7734	-2704.6184	-2549.1906
size__comp	Discard females	-2282.6251	-2282.1564	-2289.3986	-2284.9493
size__comp	Trawl bycatch (females)	-2467.1116	-2466.9757	-2472.3342	-2464.0533
size__comp	Trawl bycatch (male)	-2358.0865	-2333.903	-2293.4968	-2336.6351
size__comp	Survey immature females (1982-1988)	-623.0579	-624.694	-625.071	-623.5216
size__comp	Survey immature females (1989-present)	-2876.5912	-2878.3031	-2876.8664	-2888.0398
size__comp	Survey immature males (1982-1988)	-577.3463	-577.3848	-582.7908	-570.1027
size__comp	Survey immature males (1989-present)	-2733.1505	-2755.917	-2749.2228	-2753.6437
Total	Total	-26961.9354	-26956.5897	-26959.9115	-26778.5526

Table 2: Changes in management quantities for each scenario considered. Reported management quantities are derived from maximum likelihood estimates. Reported natural mortality is for mature males, average recruitment is for males, and status and MMB were estimates for February 15 of the completed crab year.

	Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
1	21.sq	26.74	153.42	1.43	0.37	7.50	0.27	106.14	0.17
3	22.1a	41.21	183.15	1.50	0.32	10.32	0.28	164.02	0.23
4	22.1ab	96.67	196.38	2.26	0.67	3.98	0.29	180.36	0.49
5	22.1ab_5x	83.31	204.62	1.49	0.35	2.79	0.28	181.00	0.41
6	22.1ab_100x	115.65	336.36	1.12	0.19	4.79	0.28	265.29	0.34

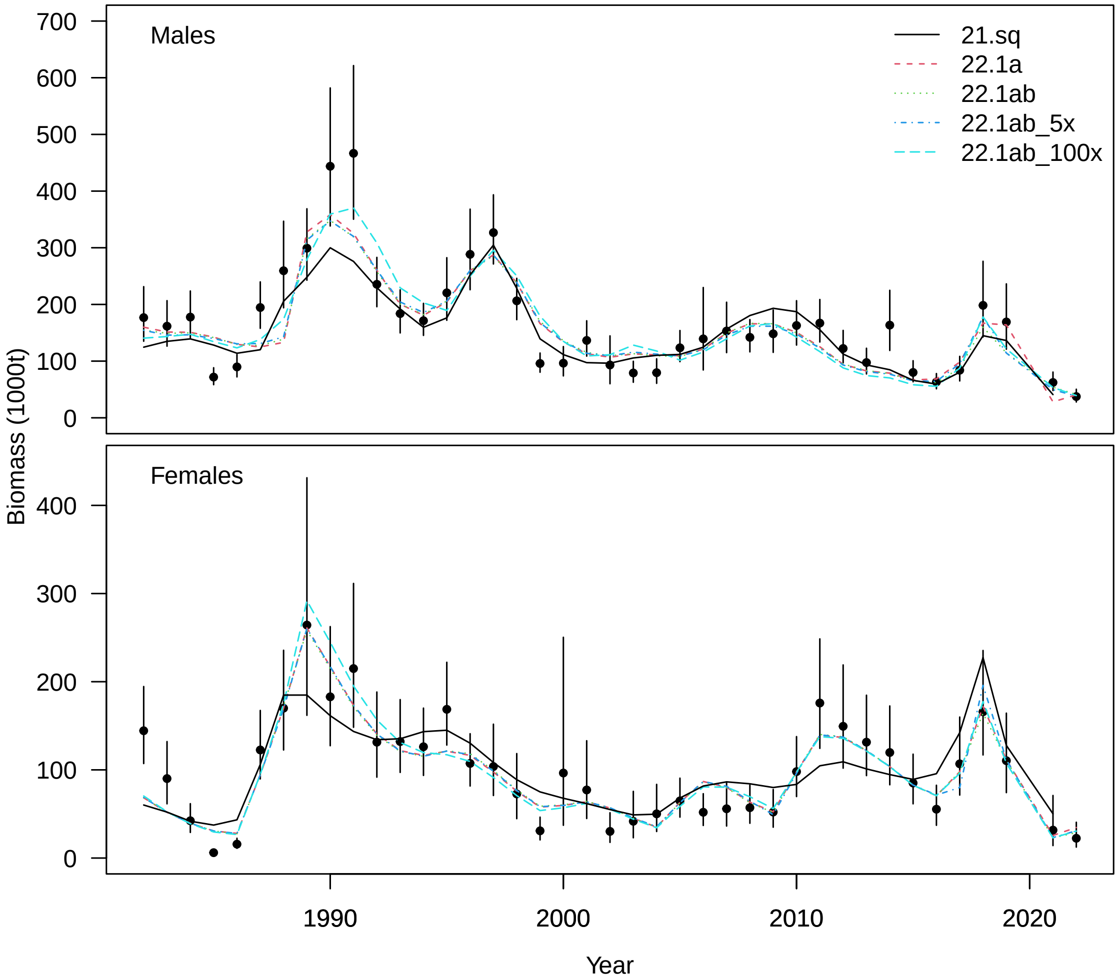

Figure 7: Model fits to the observed mature biomass at survey

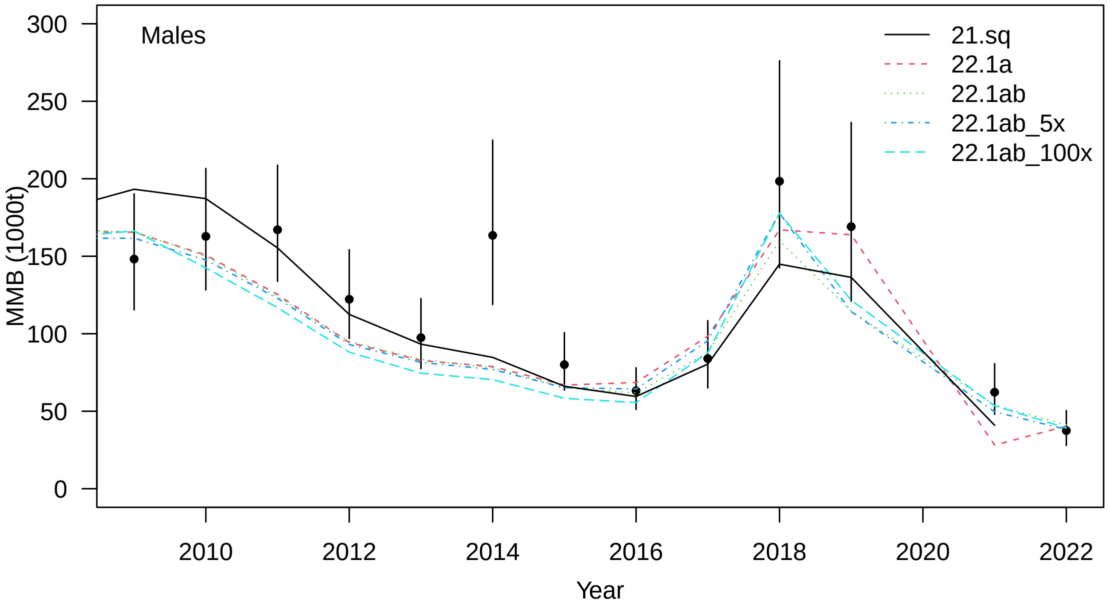

Figure 8: Model fits to the observed mature biomass at survey 2009-present

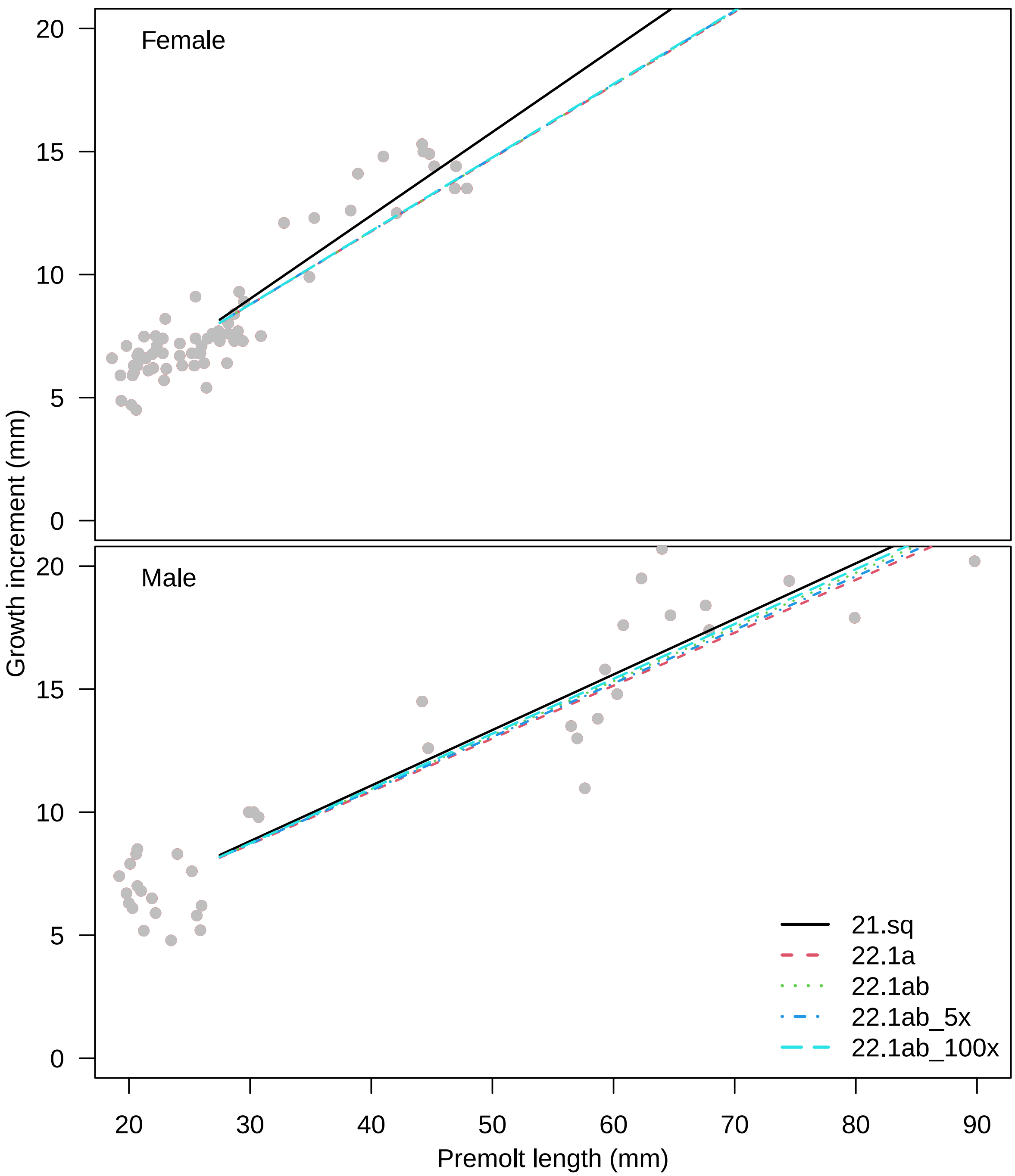

Figure 9: Model fits to the growth data

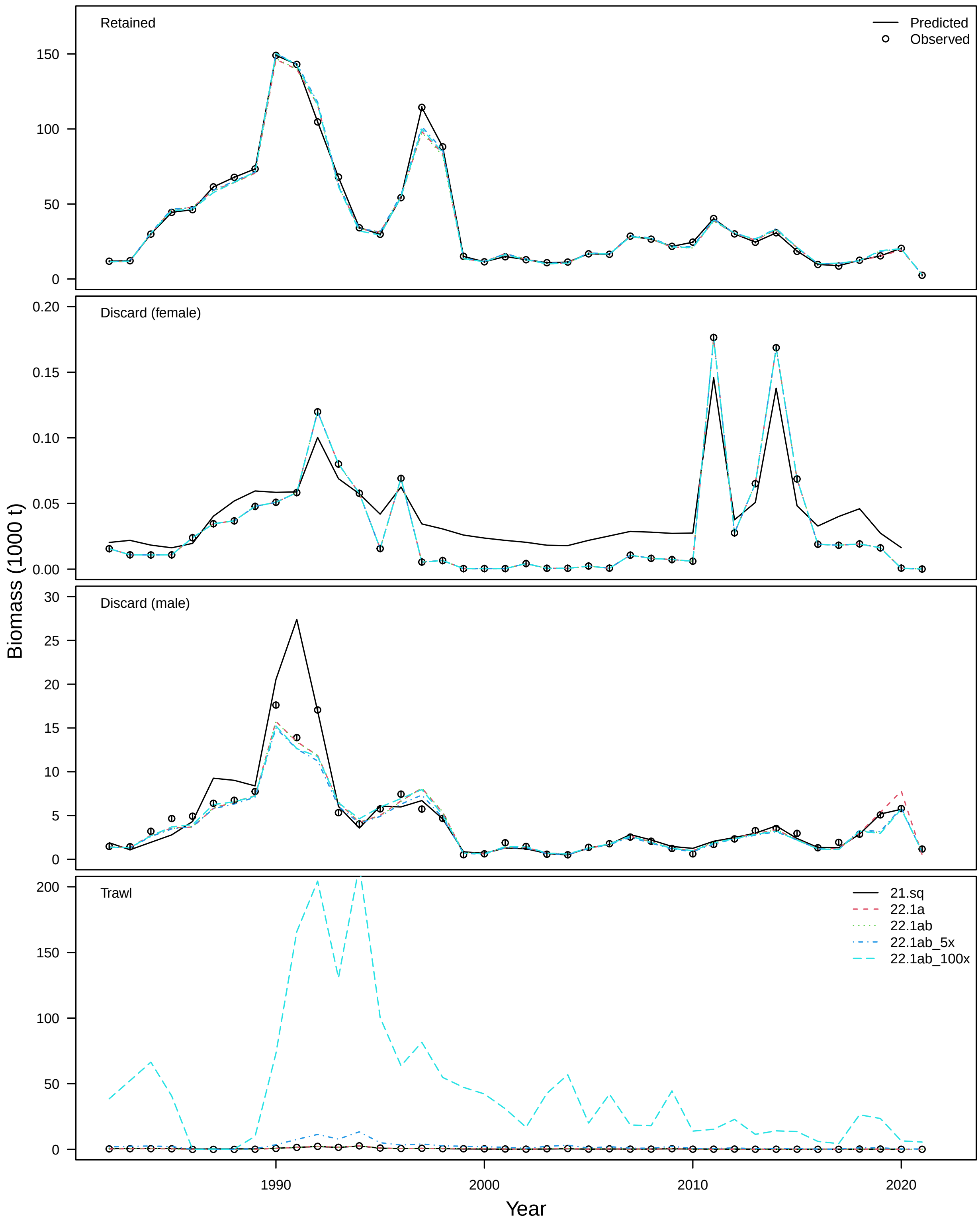

Figure 10: Model fits to catch data

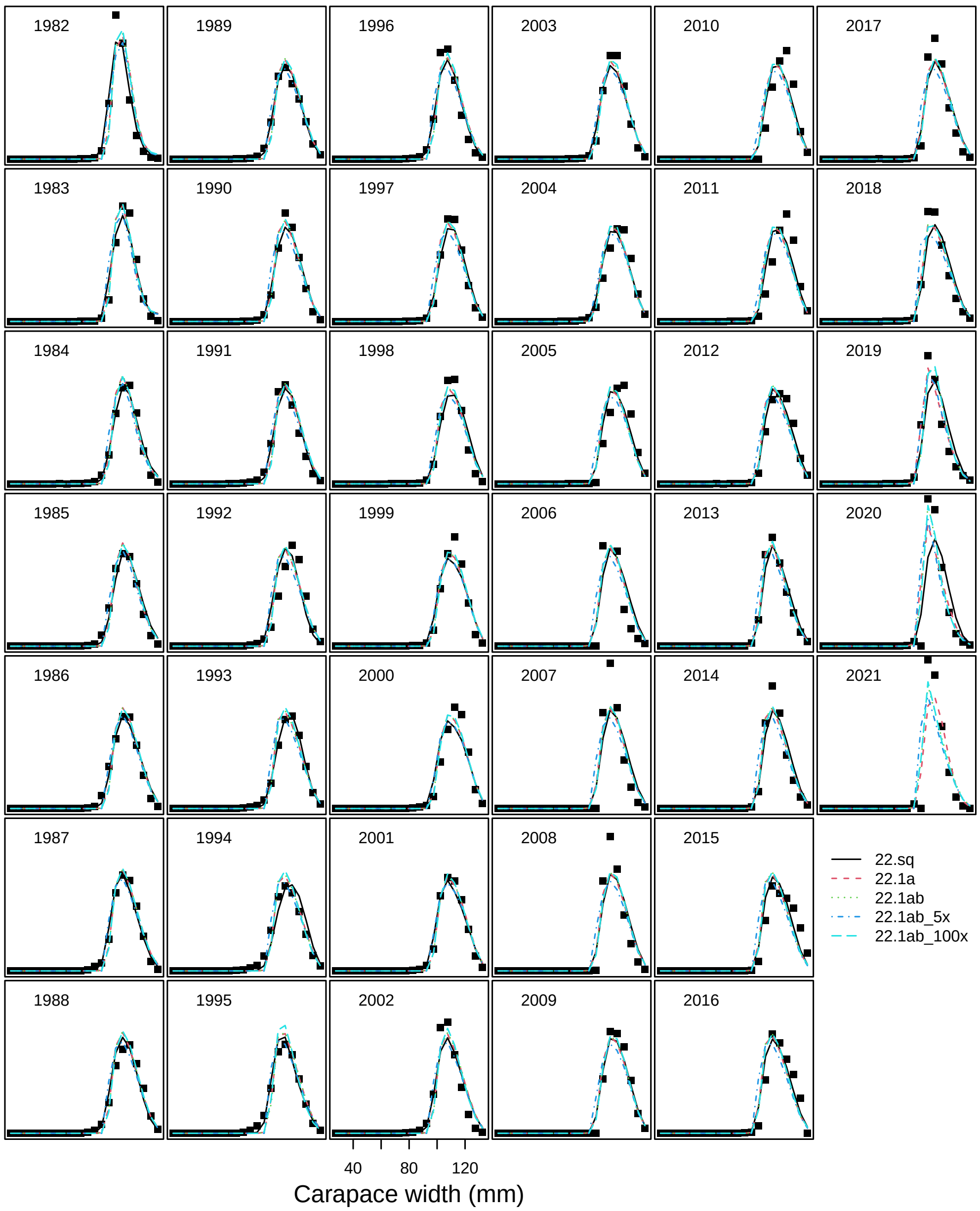

Figure 11: Model fits to retained catch size composition data

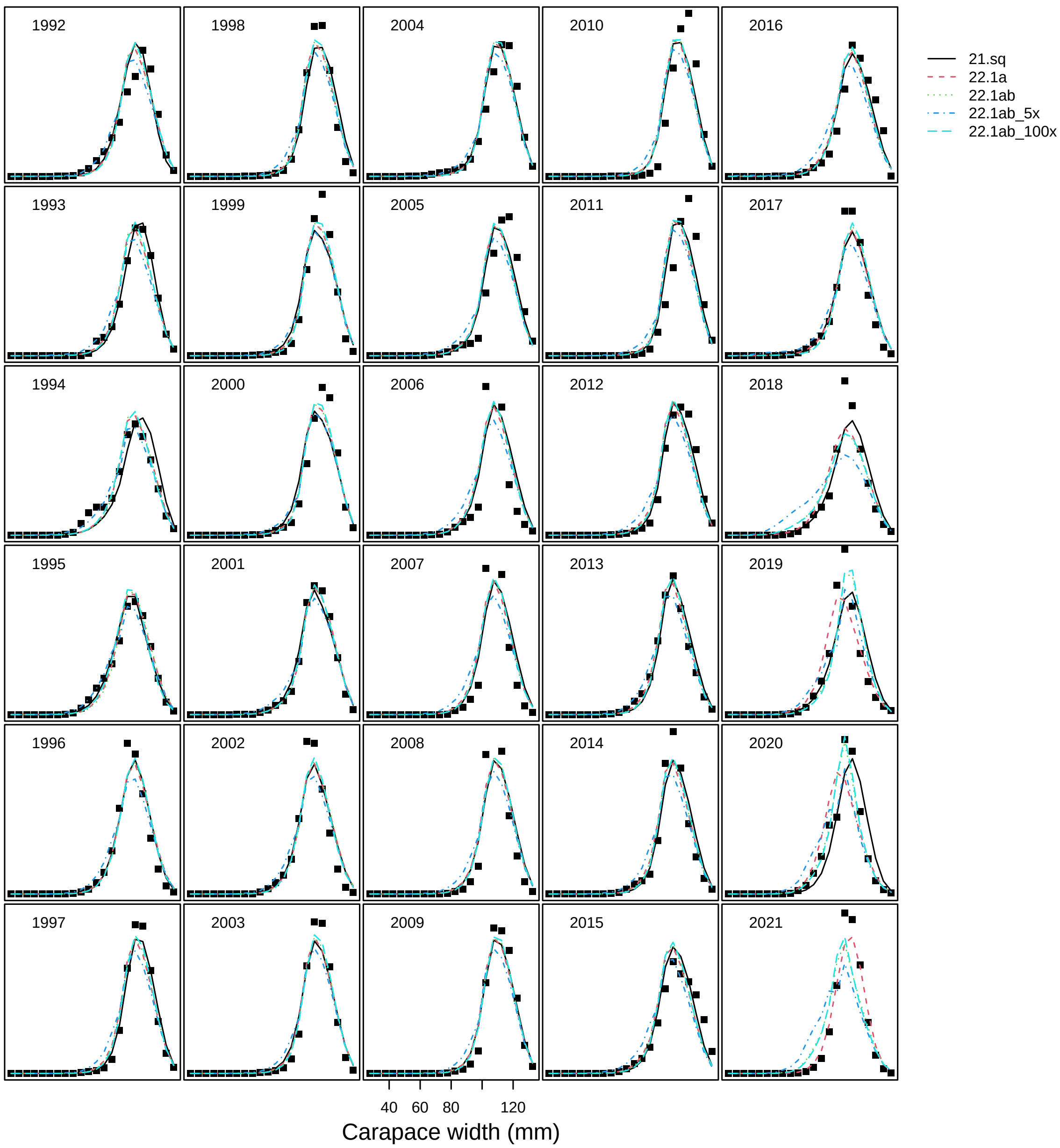

Figure 12: Model fits to total catch size composition data

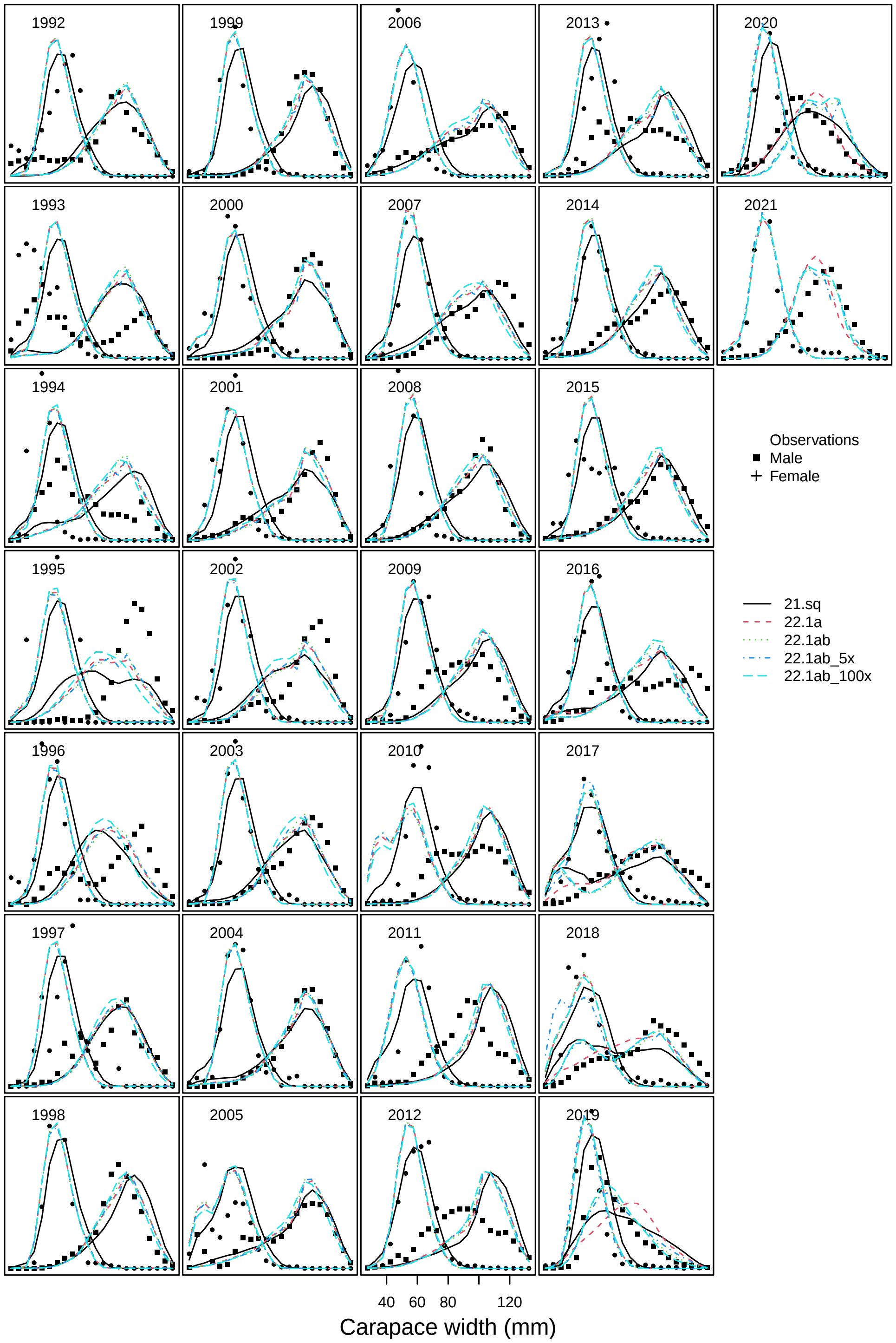

Figure 13: Model fits to trawl catch size composition data

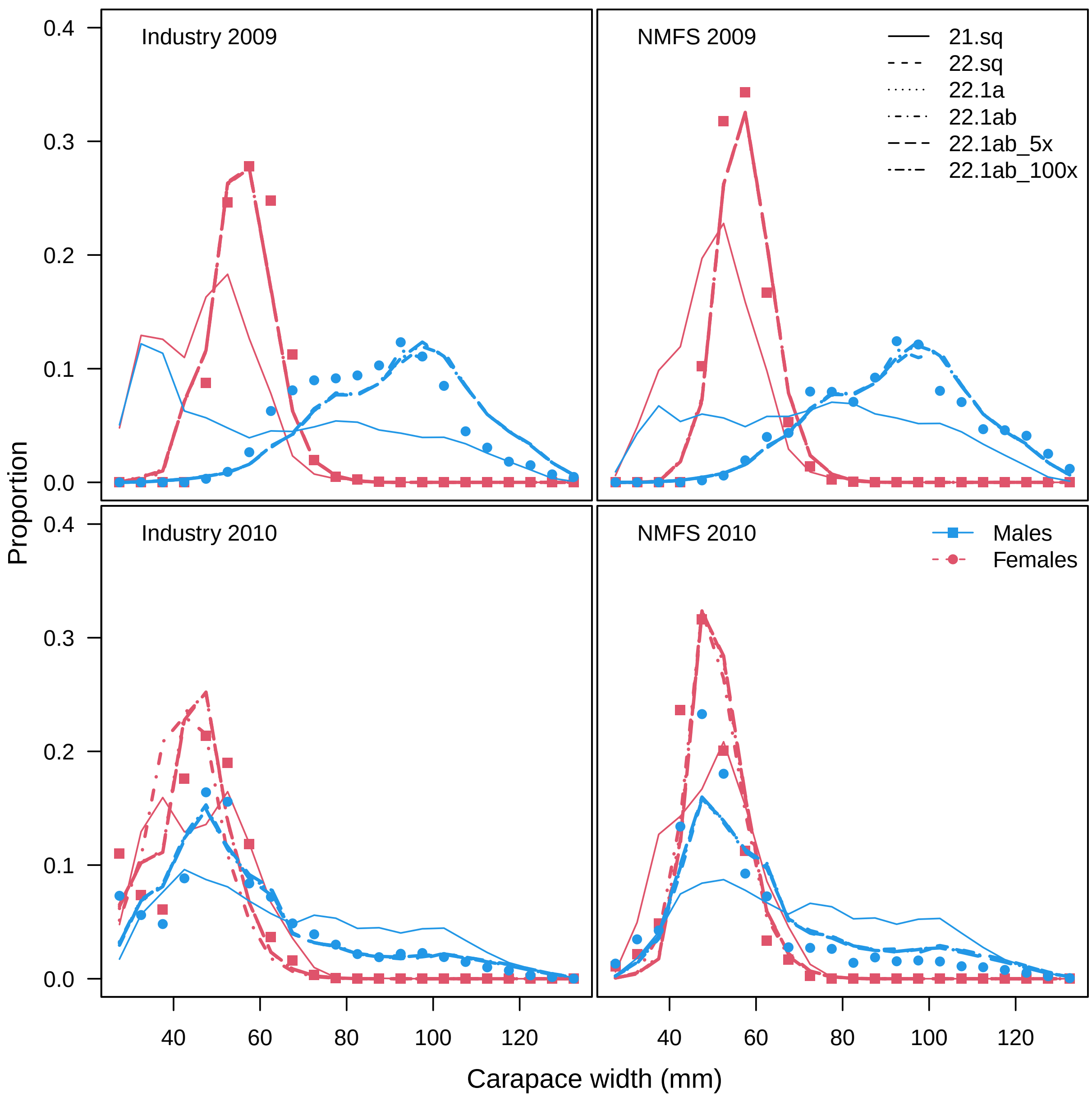

Figure 14: Model fits to size composition data from summer survey experiments (2009 & 2010)

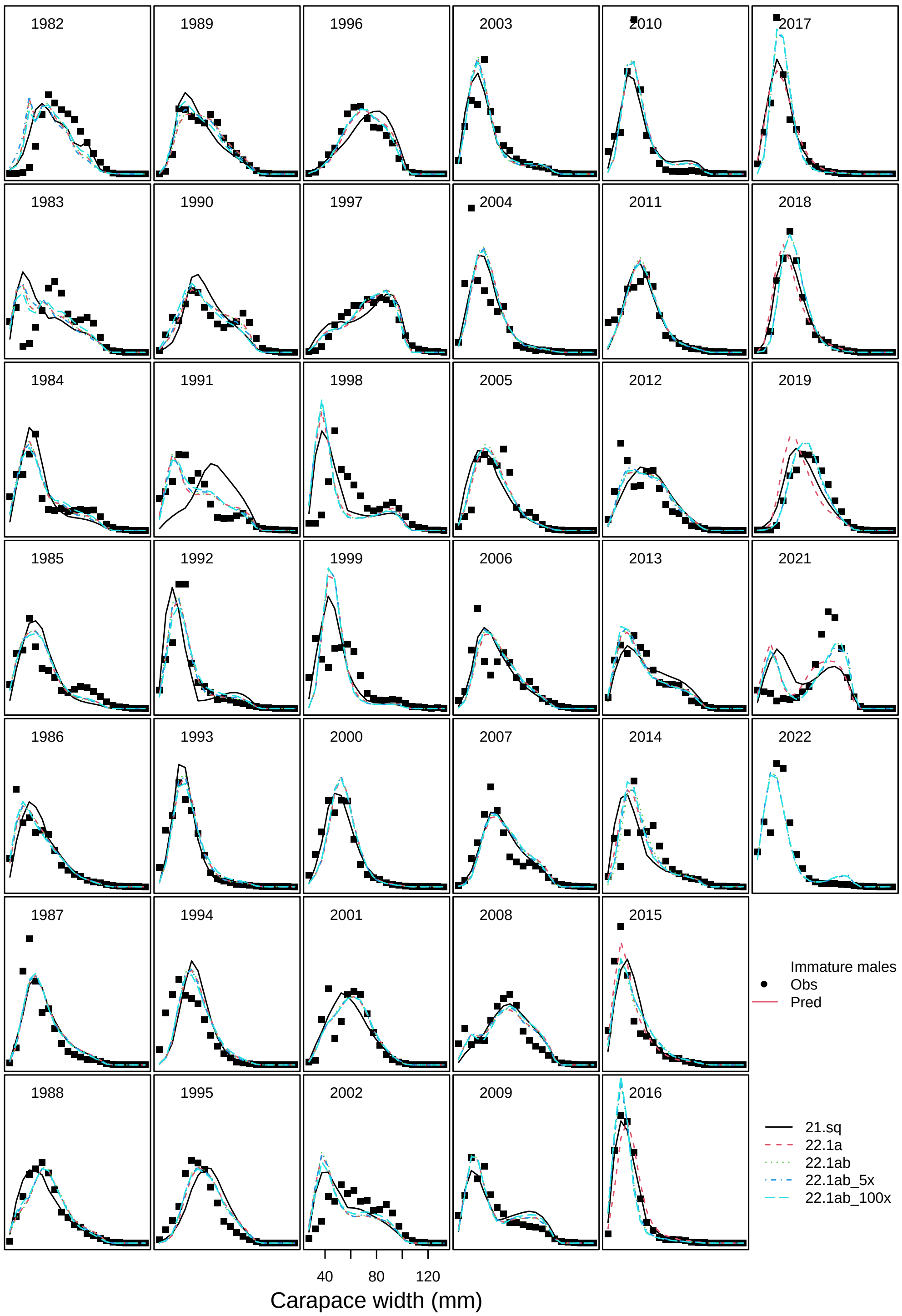

Figure 15: Model fits to immature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

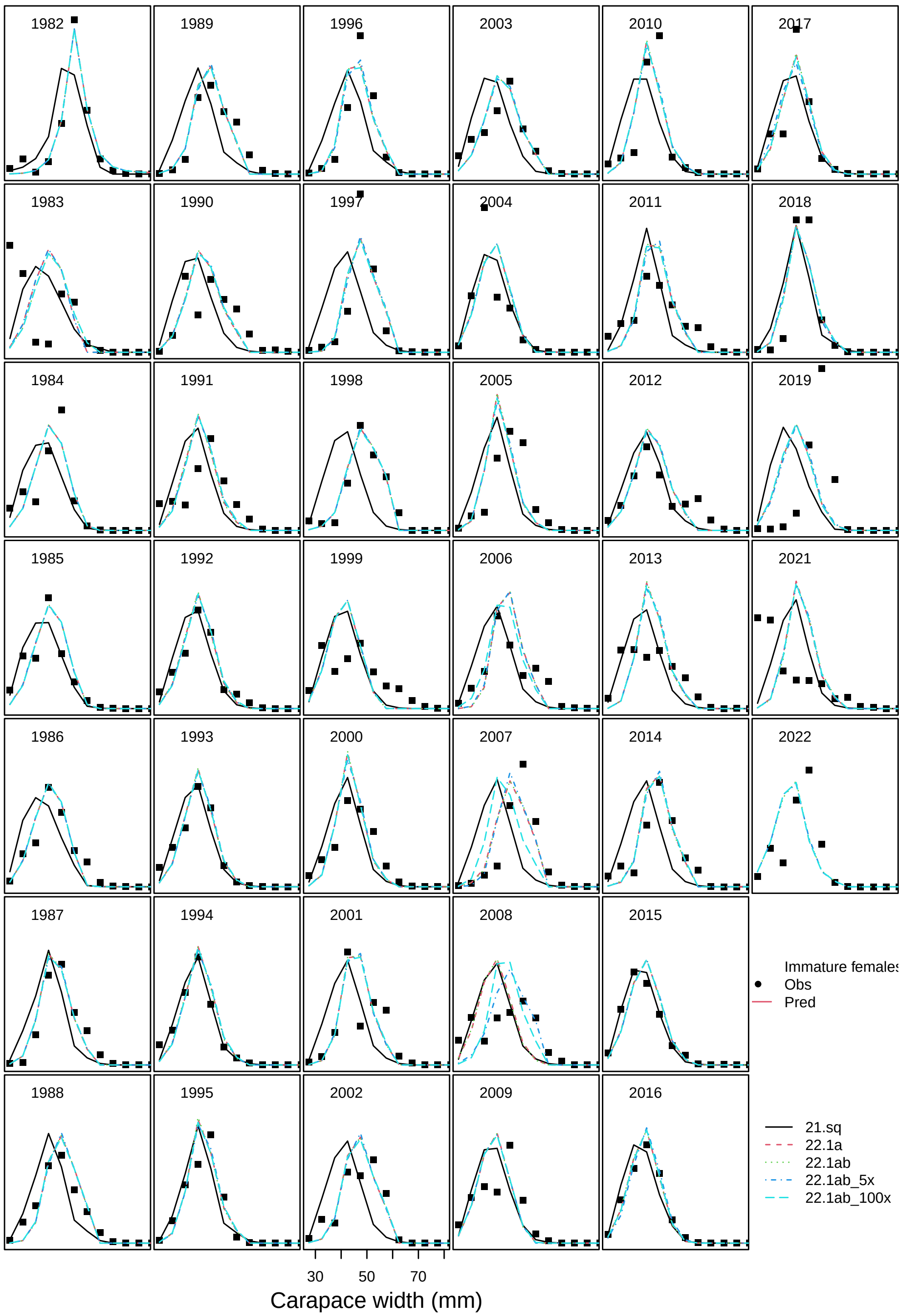

Figure 16: Model fits to immature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

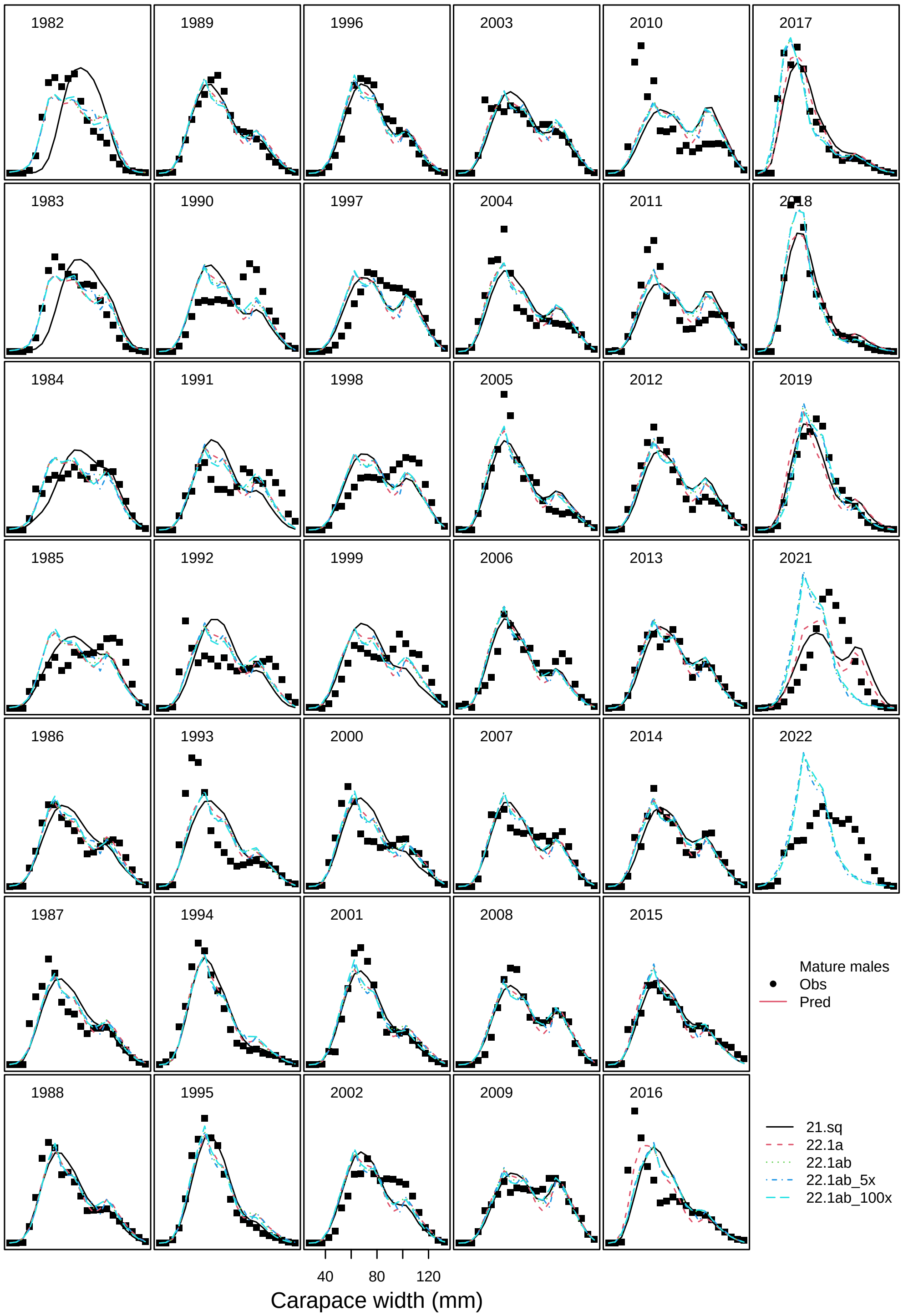

Figure 17: Model fits to mature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

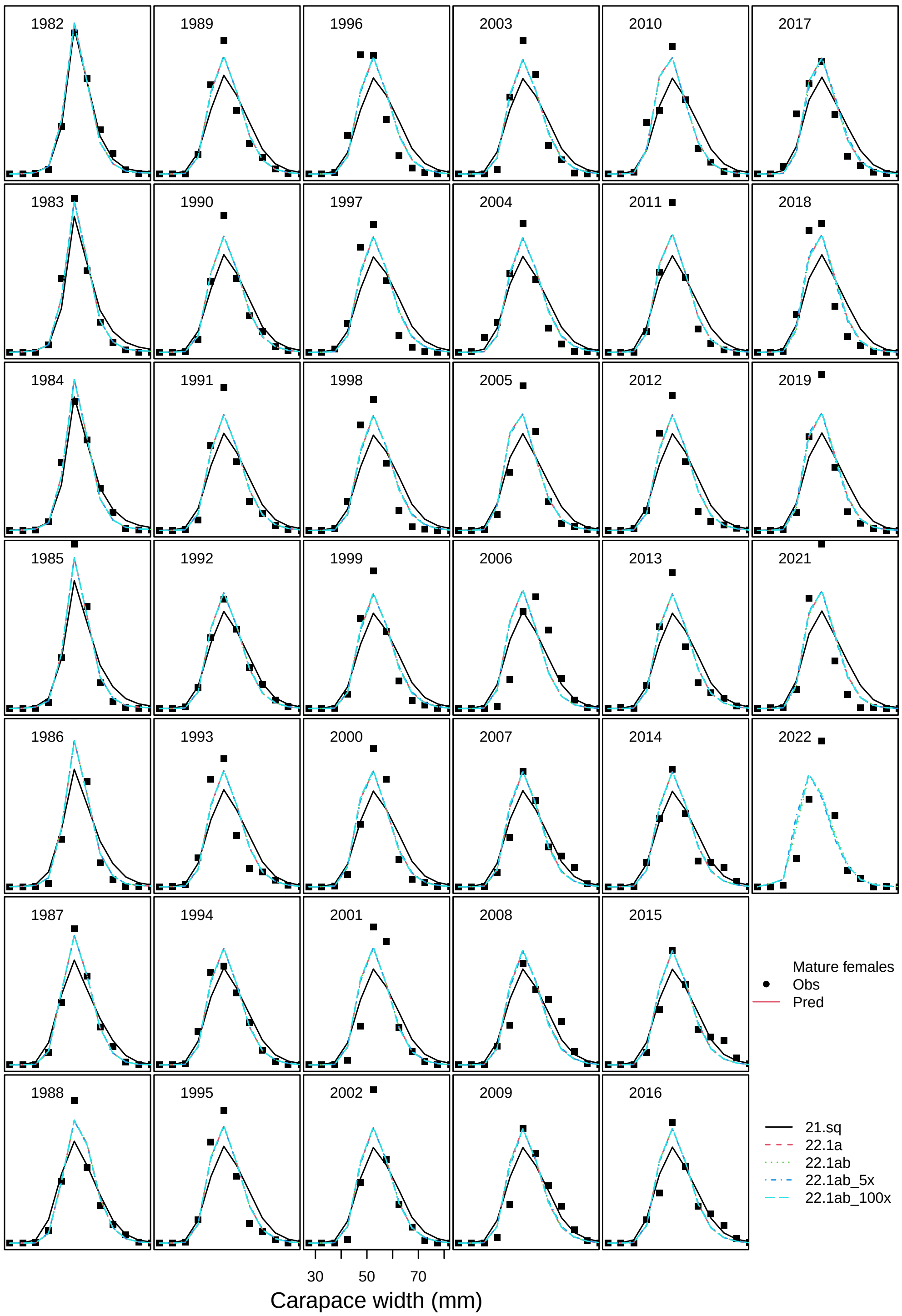

Figure 18: Model fits to mature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

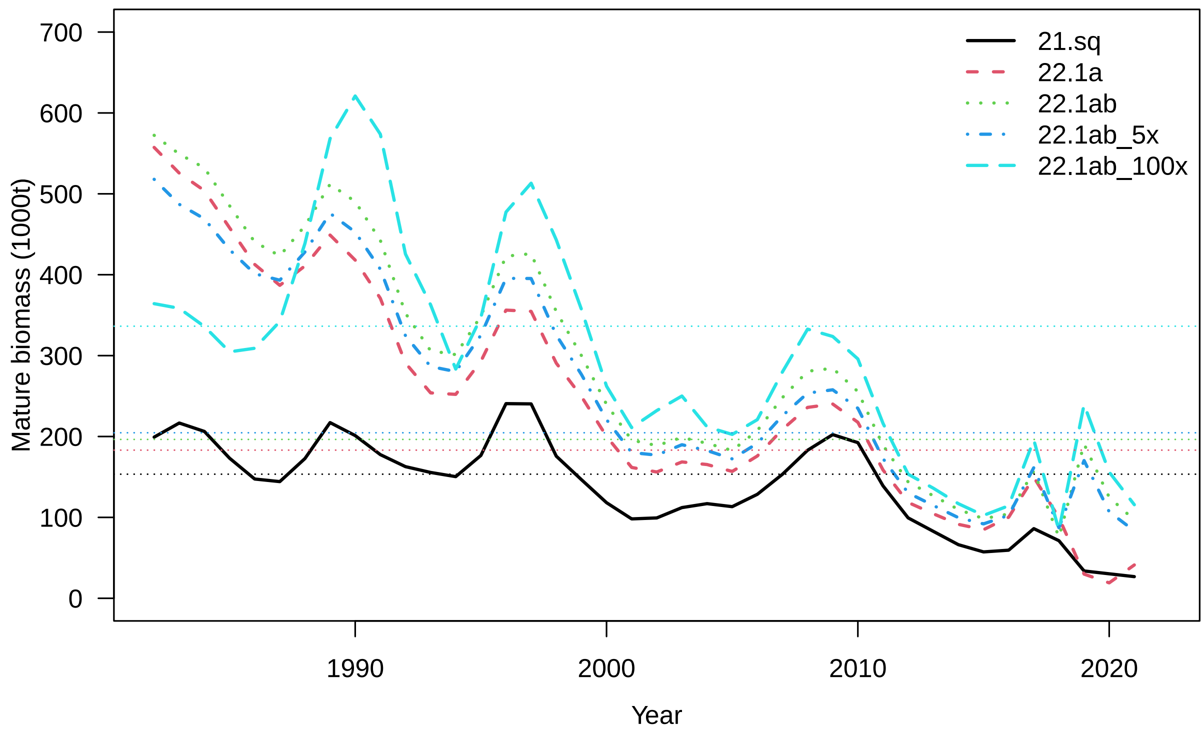

Figure 19: Model predicted mature biomass at mating time. Dotted horizontal lines are target biomasses.

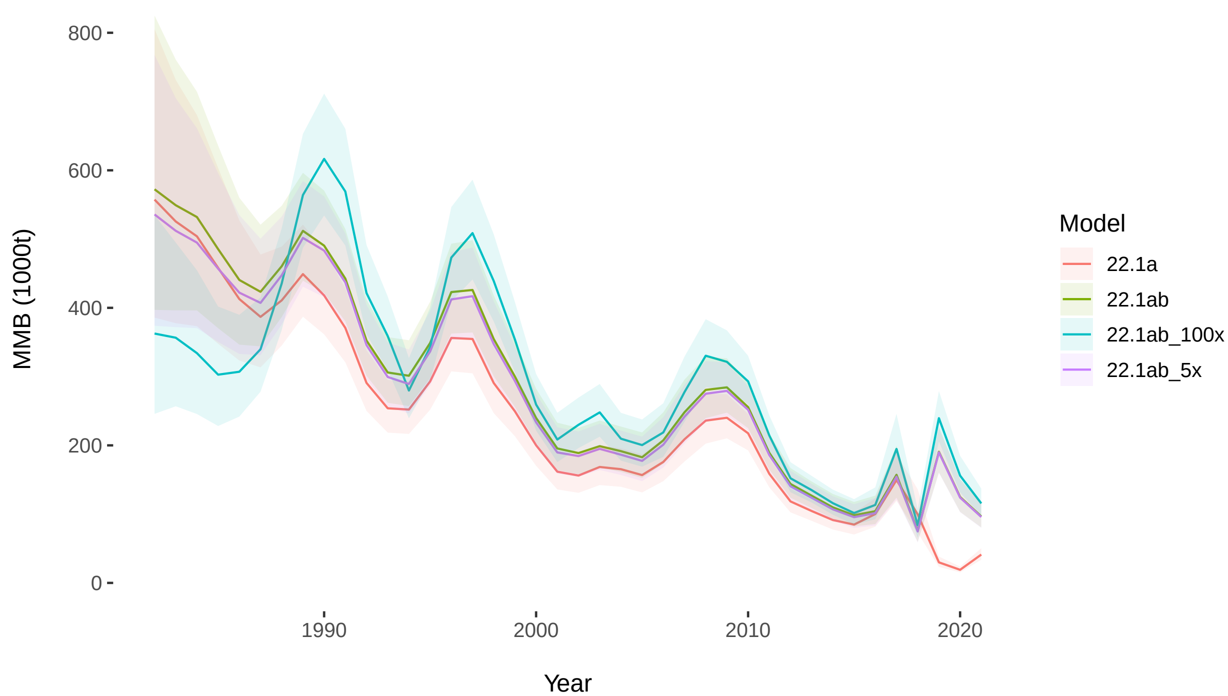

Figure 20: Trajectories of estimated MMB at the time of mating with 95% log-normal confidence intervals.

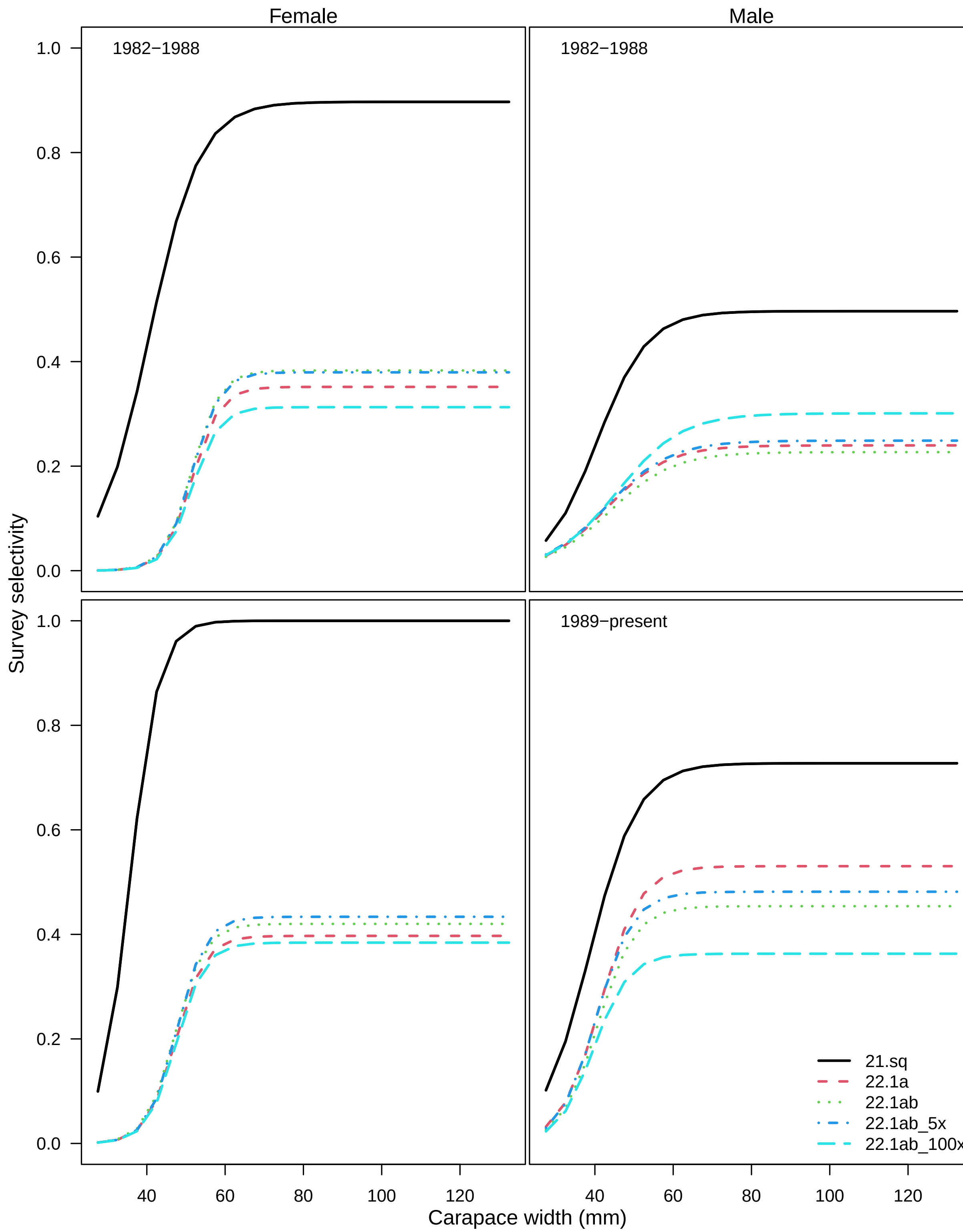

Figure 21: Estimated survey selectivity

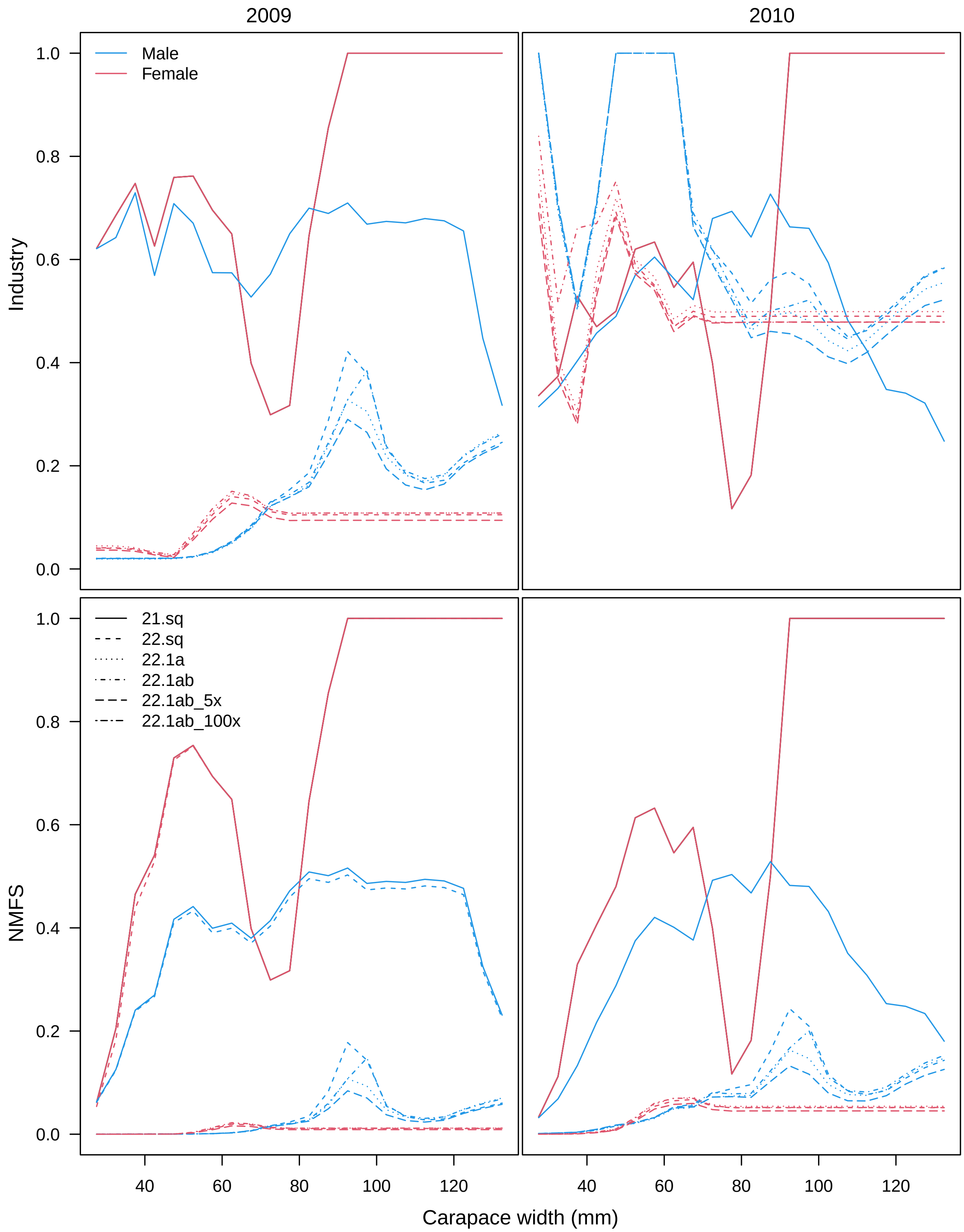

Figure 22: Estimated or specified availability (top row) and estimated experimental survey selectivity (availability * survey selectivity; bottom row).

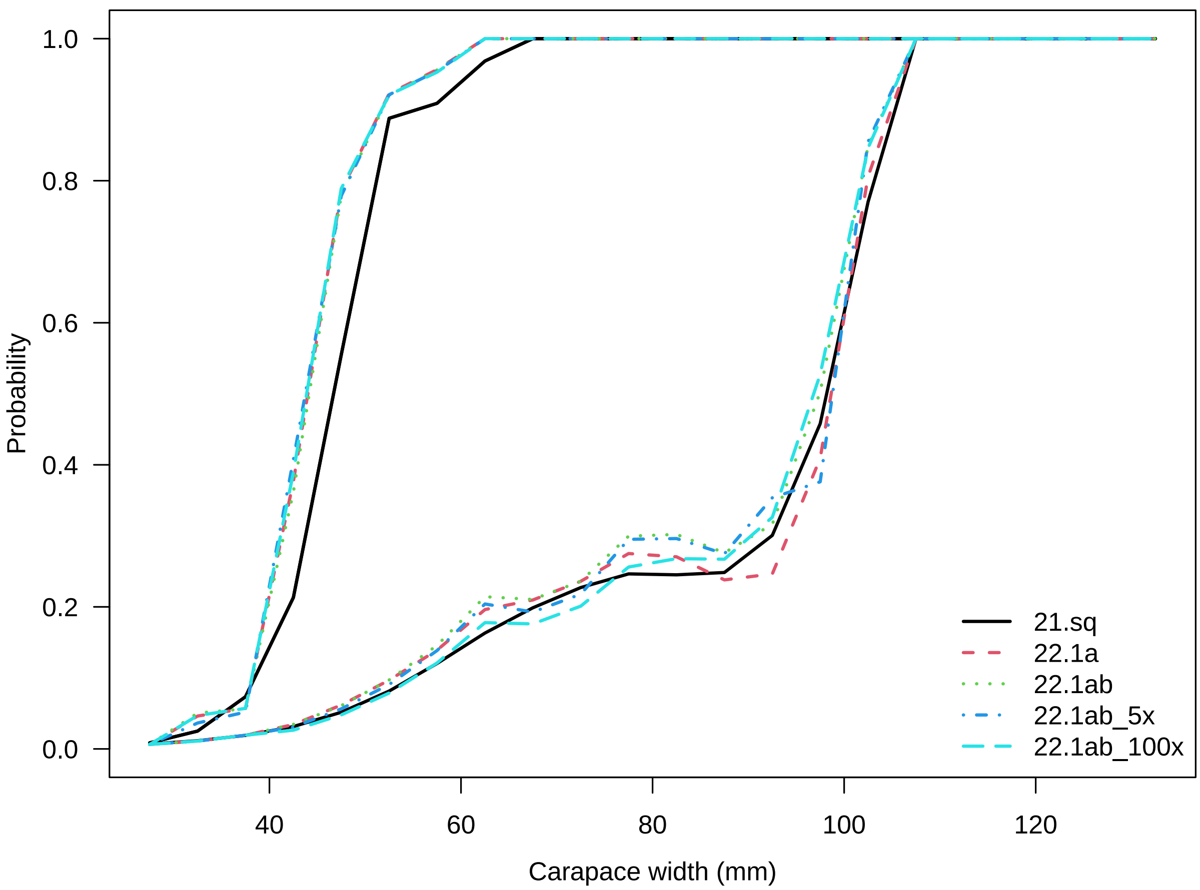

Figure 23: Estimated probability of maturing

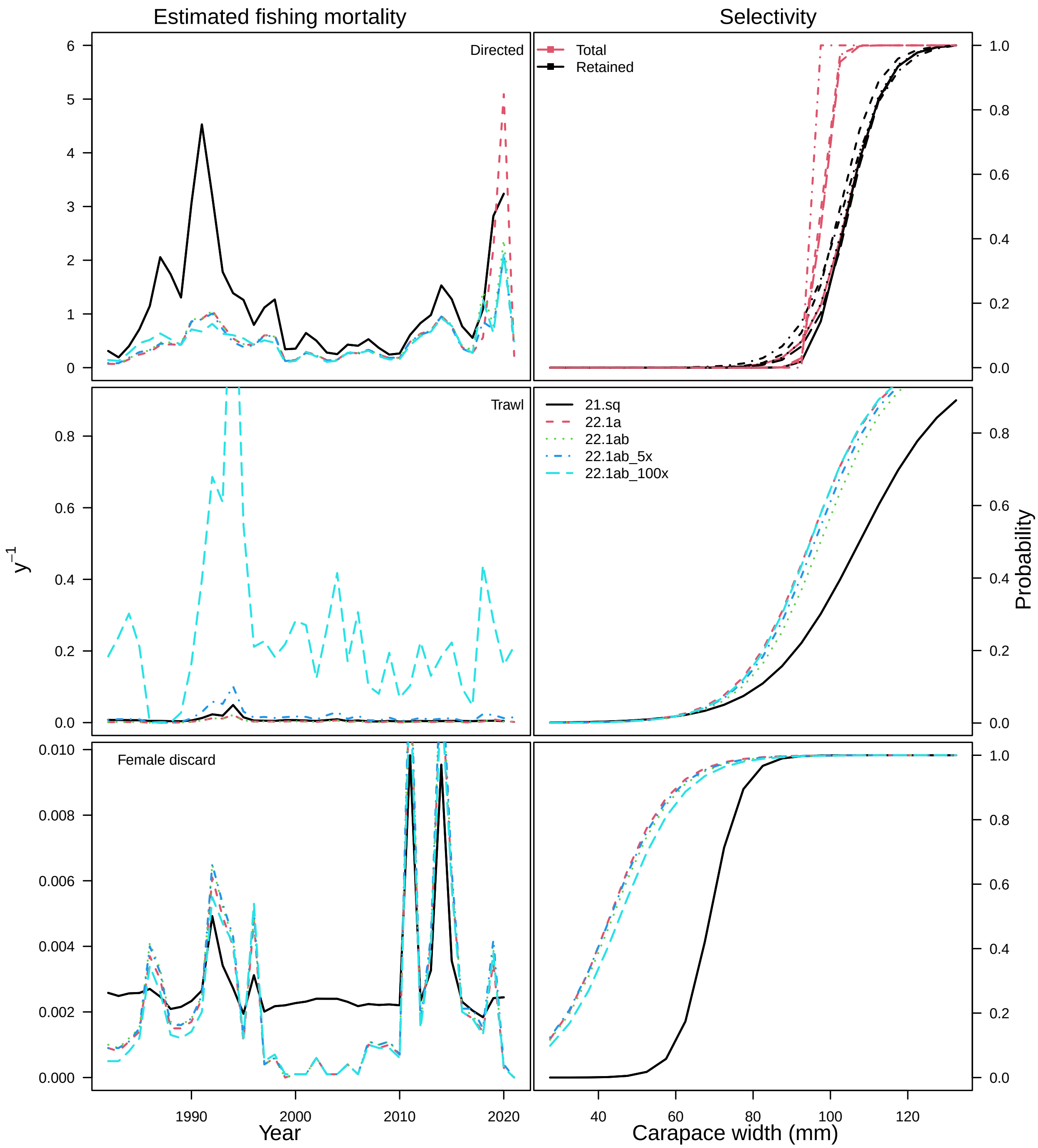

Figure 24: Model predicted fishing mortalities and selectivities for all sources of mortality

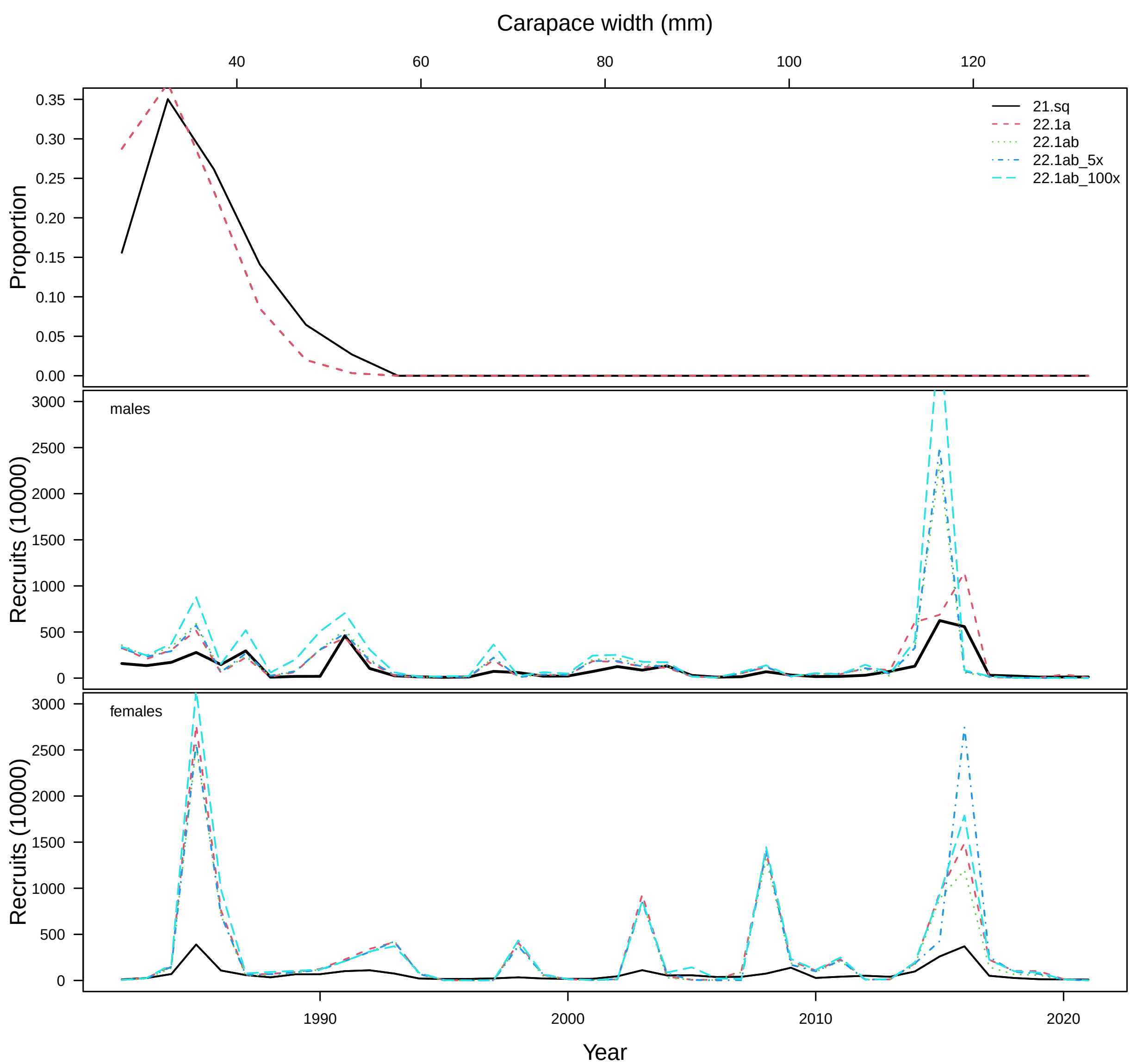

Figure 25: Estimated recruitment and proportions recruiting to length bin.

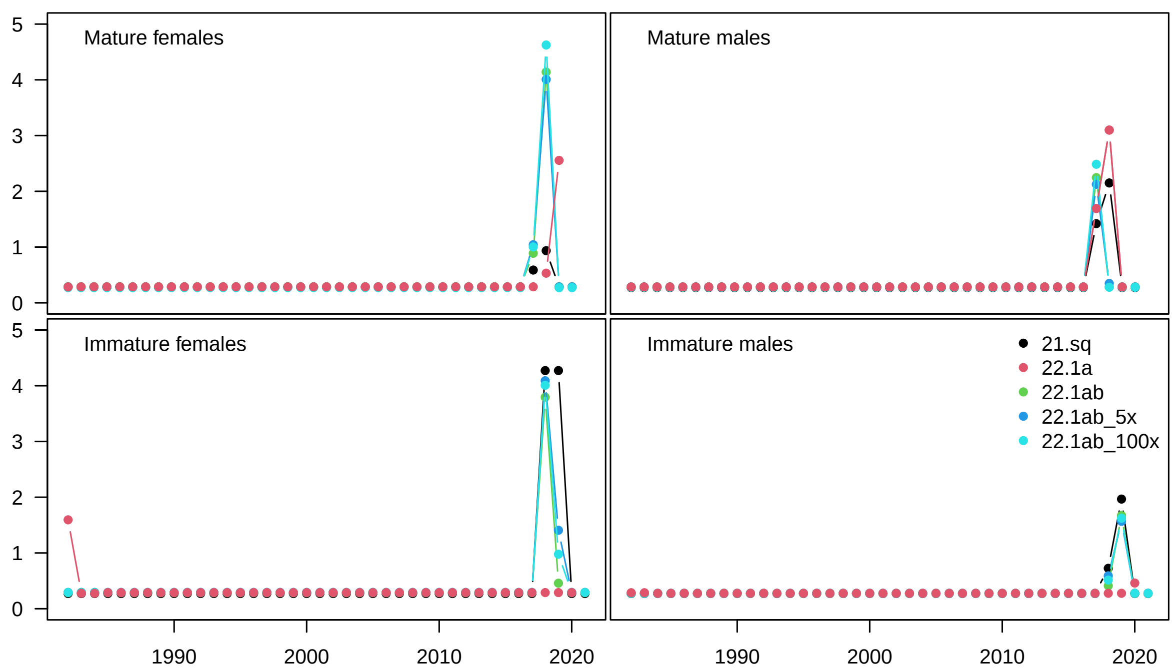

Figure 26: Estimated natural mortality by sex and maturity state.

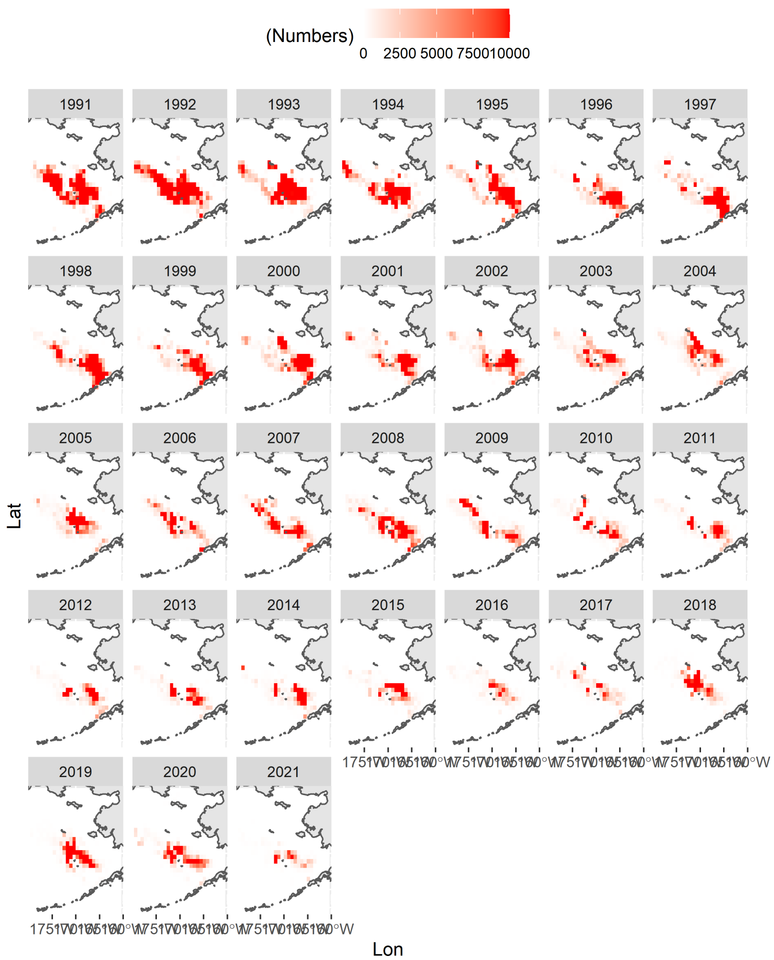

Figure 27: Spatial distribution of observer bycatch in non-directed fisheries over tim.