PSC Chinook Technical Committee

TO: Chinook Interface Group
FROM: Chinook Technical Committee co-chairs
DATE: February 25, 2022
SUBJECT: Imputing missing tag codes due to COVID-19 for Exploitation Rate Analysis
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COVID-19 impacted hatchery operations in 2020, and as result, several Chinook indicator stocks were released without coded-wire tags (CWTs) or adipose-fin-clip marks, while others were released with insufficient tagging levels. The Chinook Technical Committee (CTC) provided details about this and other impacts of COVID-19 in memos dated September 30, 2020 and January 6, 2022 to the Commission. The intent of this memo is to inform the Chinook Interface Group of the CTC's plans to address technical issues associated with these tagging shortfalls.

Chinook salmon from BY 2019 were released without CWTs in 2020, recruited into fisheries, and showed up in escapement as two-year-olds in 2021. These releases were from the sub-yearling indicator stocks Atnarko (ATN), Big Qualicum (BQR), Chilliwack (CHI), Harrison (HAR), Middle Shuswap (MSH), Puntledge (PPS), Robertson Creek (RBT), and Lower Shuswap (SHU). To address this information gap in the CTC's exploitation rate analysis (ERA) and the PSC Chinook Model calibration, members of the Analytical Work Group (AWG) developed and presented a statistical method to estimate the stock- and fishery-specific age-2 CWT recoveries that would have occurred had the 2019 broods been released with CWTs and adipose fin clips (i.e., pseudo-recoveries) to the CTC. A technical report documenting the method to produce age-2 pseudo-recoveries has been completed (Attachment I). The performance of this method was evaluated using data from 2017–2020, and the CTC intends to undertake additional evaluations after the 2021 pseudo-recoveries are incorporated into the ERA, including examination of ERA results with and without age-2 pseudo-recoveries to assess their contribution to the analysis. Furthermore, the CTC plans on documenting all instances pseudo-recoveries are used in its ERA and Model calibration reports.

The contribution of age-2 fish to the ERA is small compared to older ages. It is anticipated that the impact to this year's PSC Chinook Model calibration will be small because age-2 fish minimally impact inputs to the Model. The contribution of older ages is comparatively larger than age-2 fish, and the impact to the ERA and PSC Chinook Model is anticipated to be greater in future years. The cumulative impact of missing a BY will affect both AABM fisheries in future Model Calibrations through inputs such as maturation and harvest rates, and will also affect the evaluation of ISBM fisheries through the Calendar Year Exploitation Rate (CYER) metric; hence the importance of addressing gaps in CWT recovery data. Based on this, the CTC plans to continue reviewing and investigating potential improvements to the methodology used to produce pseudo-recoveries and explore alternative approaches to address the impacts of missing BY on CTC products, all of which could require other types of data and analyses.

The CTC does not anticipate any major obstacles in the completion of the ERA and PSC Chinook Model calibration in 2022. Looking a year ahead, there will be a need to employ this or another approved method to impute recoveries for other stocks. Specifically, those released without CWTs such as Kitsumkalum sub-yearling (KLM) and Kitsumkalum yearling (KLY), which start recruiting into fisheries and showing up in escapement at age-3. In addition, a similar exercise is planned for Hanford Wilds (HAN) in 2023, with the one year delay owing to the additional one-year lag for Southern U.S. exploitation rate indicator stocks. This stock does not contribute to any PSC Chinook Model inputs but is an Attachment I indicator stock. Additionally, Little Port Walter (LPW) fish from brood year2018 were released without tags in 2020. However, the method for imputing recoveries will not be applied for this stock. This hatchery stock is part of the Southern Southeast Alaska (SSA) indicator stock and the absence of tags may be influential to the ERA.

Exploration of Methods To Extrapolate Recoveries From Untagged Releases

11 February, 2022

Introduction

In the absence of a tagged component in the 2020 releases (2019 brood), no age two recoveries in 2021 fisheries can be directly estimated for numerous exploitation rate (ER) indicator stocks. This change impacts ER estimates for the Canadian ER indicator stocks: ATN, BQR, CHI, HAR, KLM, MSH, PPS, RBT, and SHU. This document explores some statistical methods available, using historical data, to extrapolate run year 2021 age two recoveries, by stock, to the resolution of fine scale and Exploitation Rate Analysis (ERA) fisheries. A retrospective evaluation of model forecast performance is used to support model selection. Additionally, to confirm no anomalously large forecasts are calculated with these models, the 2019 and 2020 forecasts are compared to estimated quantiles of the historical recoveries. This method of model selection and validation could be applied to identify best approaches for extrapolating recoveries of the 2019 brood in future return years (2022–2024).

The final section of this document includes a proposed method to identify *pseudo-codes* for the untagged releases of the above-mentioned stocks. This additional step is necessary to fulfill association between recoveries and releases during the ERA.

Methods

Model Structure

Model structure fits into two general categories, linear regression methods and ratio scalers.

Regression methods

Two forms of multivariate regressions were fitted to forecast unknown recoveries: linear models and linear mixed-effects models. In both forms the dependent variable, age two recovery rate (i.e. recoveries relative to brood year tagged releases), is a function of three covariates: age three recovery rate (recoveries relative to its own brood year tagged releases), and categorical variables for stock and fishery. Both the dependent variable age two and covariate age three recovery rates are estimated from the same calendar year, thus the age three rate is from a separate brood year. Thus, unlike a sibling regression this model attempts to account for the calendar year marine influence on return rates. Representing the dependent and independent variables as rates removes release size influences. As these are rates, the values were logit transformed before fitting.

The main difference between model forms is the treatment of the categorical variables. The variable $\omega_{a,y,k,F}$ represents recoveries by age in calendar year of a stock k in a fishery F, and variable $R_{b,k}$ represents the tagged releases by brood year of that stock. While the linear regression is required to fit a separate intercept for each level of the categorical variables, the linear mixed effects model comprises a fixed part (β_1, and β_2), and a random part ($\alpha_k + \alpha_F + \sigma_{kF}$). The random component does not require estimation of parameters.

$$\frac{\omega_{a=2,y,k,F}}{R_{b=y-2,k}} = \beta_1 + \beta_2 * \frac{\omega_{a=3,y,k,F}}{R_{b=y-3,k}} + \alpha_k + \alpha_F + \sigma_{kF}$$
$$\alpha_k \sim N(0, \sigma_k^2)$$
$$\alpha_F \sim N(0, \sigma_F^2)$$
$$\sigma_{kF} \sim N(0, \sigma^2)$$

The following variations to the rate-based regressions were also explored:

- models were fitted using recovery counts instead of rates
- the age 3 recovery rate covariate was replaced with the sum of age 2 and age 3 recovery rates (from a common brood year)
- a third categorical variable was added to identify pre-terminal and terminal fisheries
- within the mixed-effects fits, the model was tested having stock as a dummy variable (similar to a multivariate regression) and then as a random effect (fishery is always treated as a random effect).

Age Ratio Scalers

The age ratio scaler methods all rely on an average ratio of previous age two CWT recovery estimates relative to age three. The sections below identify how this ratio of age two to age three CWT estimates can be calculated for individual fishery or all fisheries for a given stock. Furthermore, these scalars can be based on both ages occurring the same run year or originating from the same brood year.

Fishery and Stock Specific Age Ratio Scaler The Fishery and Stock specific age ratio method is based on the weighted average of the predicted age two estimate to base age three estimate for a finescale fishery and stock over the previous five years.

$$\omega_{a=2,F,y} = \frac{\sum_{i=y-n}^{n} \omega_{a=2,F,i}}{\sum_{i=y-n}^{n} \omega_{a=3,F,i}} * \omega_{a=3,F,y}$$

with ω representing the CWT estimates for a specific age (a), finescale fishery (F), and run year (y) over a the previous five (n) years.

Stock Specific Age Ratio The Stock specific age ratio is the weighted average of the age two / age three weighted by the age three estimate for all fisheries by stock for the previous five years. The stock CWT Estimate

$$\omega_{a=2,F,y} = \frac{\sum_{i=y-n}^{n} \omega_{a=2,i}}{\sum_{i=y-n}^{n} \omega_{a=3,i}} * \omega_{a=3,F,y}$$

with ω representing the CWT estimates for a specific age (a), finescale fishery (F), run year (y).

Model Selection

Model selection is based on ranking performance measures of precision and uncertainty as estimated from retrospective forecasting.

Retrospective Forecasting

Model performance was evaluated using cross validation with testing years 2017–2020. Training years varied depending on model structure. Regression models were fit using an expanding window starting in 2000, such that 2017 was forecast using a model fit to 2000–2016; 2018 was forecast using a fit to 2000–2017, etc. The ratio models scaler was calculated using the five years prior to each forecast year.

Permformance Metrics

All models' forecast errors were compared using a common set of fishery-stock-year combinations (n=484). No single model produced a forecast for all 484 combinations, but in order to estimate performance statistics equitably, a balanced number of forecasts from each model was required. If a model lacked a forecast for a specific fishery-stock-year, that forecast was set to zero (equivalent to the real case of zero recoveries in the covariate).

Five performance measures (PM's) were evaluated, two of them being scale-dependent measures (mean raw error: mre, root mean squared error: rmse) and three being percentage errors (mean percent error:

mpe, mean absolute percent error: mape, mean relative percent difference: mrpd). Care should be taken when comparing models with scale-dependent measures:

> *Due to the varying numerical scale of results, scale-dependent measures should not be used when comparing performance of models across multiple sets of dependent data (such as comparing recruitment forecast models across stocks of varying size).*[1]

Percent based PM's are useful when evaluating models that are desired to perform equally well at forecasting both relatively small and large values (thus avoiding the limitation of scale-dependent measures). As the metric is a percentage, errors in forecasting large and small values are treated with equal weight. However, some models can forecast recoveries in fishery-years that had no actual recoveries. For these cases, the percentage based metrics result in division by zero and those forecast errors must be excluded from the averaging calculations (mpe & mape). Excluding division by zero cases will lead to a misrepresentation of precision and accuracy of models that have forecasts >0 when actual recoveries was zero. The relative percent difference[2] (rpd) metric attempts to avoid this problem by having a denominator that is the mean of both the forecasted and true value. While the mpe can range $c(-\infty, \infty)$, the rpd is constrained to $c(-200, 200)$.

Model Ranking

The ranking of models is done in two stages. First, models were ranked by each PM using a relative scale (Folkes et al 2018)[1], which preserves PM detail. The second step is to calculate average rank, by model, using a select representation of PM ranks. As indicated earlier, if comparing performance of models when true values substantially vary (e.g. ≥ 2 orders of magnitude), percent-based PM's should be prioritized. If there is no need to equally weight small and large forecasts (e.g. one acceptably correct forecast of a large value can outweigh numerous erroneous small forecasts, which may be desirable) then scale-based PM's can be included or even prioritized.

Forecast Validation

In addition to evaluating model performance, the top ranked model for each forecast requirement (fisheries only and escapement only) was validated by comparing recovery forecasts during 2019 and 2020 to the quantiles of historical recoveries from years 2000–2020. This comparison was done at two levels of aggregation, first by stock and fishery, then by stock summed across all fisheries. Results are presented as

[1] Folkes, M.J.P., Thomson, R.E., and Hourston, R.A.S. 2018. Evaluating Models to Forecast Return Timing and Diversion Rate of Fraser Sockeye Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/021. vi + 220 p.

[2] https://stats.stackexchange.com/a/201864

frequency histograms, which include lines defining the lower (2.5%) and upper (97.%) quantiles. As not all fisheries have stock-specific age 2 recoveries for all historical years, records were added with recovery value equal zero for fishery-stock-years missing values. This assures the likely best estimates of sample statistics. The quantiles are estimated both as sample estimates and as population level estimates (by first estimating mean and SD of the sample).

Forecast values within the range of quantile estimates could be considered representative of historical recoveries and acceptable as plausible forecasts.

Data

This evaluation was carried out with seven Canadian ER indicator stocks: BQR, CHI, HAR, MSH, PPS, RBT, and SHU. Cowichan was not included in this evaluation as tags were applied to 200,000 of the 351,000 releases in 2020. ATN has had no age 2 fishery recoveries since run year 2016, which limits the utility of the performance evaluation for this stock, thus ATN was excluded from the evaluation. KLM was also excluded as ERA recoveries commence with age 3.

Recoveries

Age 2 recoveries of the seven evaluated ER indicator stocks has, on average, occurred in 20 of the 80 ERA fisheries (2000–2020). Two types of recovery estimates exist in the CTC-CAMP database: *EstimatedNumber* and *AdjustedEstimatedNumber*. For the set of Canadian indicator stocks, since year 2000 there are 18 records where the *AdjustedEstimatedNumber* is capped at 50 and the *EstimatedNumber* exceeds 50. This analysis is done using the *EstimatedNumber* field. Recoveries are represented as the summed value (across all available tag codes in CAMP), by age, stock, finescale fishery, and recovery year.

Table 1: Count of ERA fisheries with age 2 recoveries, by ER Indicator stock.

	BQR	CHI	HAR	MSH	PPS	RBT	SHU	Total
2001	3	7	1	0	2	1	1	15
2002	2	4	1	0	1	1	1	10
2003	4	9	2	0	2	2	0	19
2004	2	5	3	0	2	3	1	16
2005	3	6	3	0	1	3	2	18
2006	1	4	0	0	1	1	1	8
2007	5	12	2	0	3	5	4	31
2008	1	3	4	0	1	1	2	12
2009	1	10	9	0	2	2	1	25
2010	1	8	3	0	1	3	2	18
2011	2	8	1	0	1	1	4	17
2012	2	7	7	4	1	2	4	27
2013	5	10	4	2	1	1	1	24
2014	3	7	1	2	1	3	6	23
2015	2	3	4	0	1	3	1	14
2016	2	10	4	2	3	4	5	30
2017	2	9	3	0	2	4	1	21
2018	3	10	2	3	1	6	8	33
2019	3	6	1	1	1	5	3	20
2020	1	7	2	3	2	3	4	22

Releases

Table 2: The 2020 releases of 2019 Brood year indicating the extent of untagged releases.

ERA Stock ID	Program	Stage	Tags Applied	Unmarked
ATN	Atnarko R	Smolt 0+	0	1924871
BQR	Big Qualicum R	Smolt 0+	0	3418046
CHI	Chilliwack R	Smolt 0+	0	2231008
COW	Cowichan R	Smolt 0+	200170	151000
HAR	Harrison	Smolt 0+	0	365653
KLM	Kitsumkalum	Fed Fry	0	253000
PHI	Phillips R	Smolt 0+	83217	8381
PPS	Puntledge R	Smolt 0+	0	264239
QUI	Quinsam R	Smolt 0+	237414	2457452
RBT	Robertson Cr	Smolt 0+	0	6397220
SHU	Shuswap R Low	Smolt 0+	60223	493377
MSH	Shuswap R Middle	Smolt 0+	0	169200

Results

While nine stocks were considered for evaluation, due to absence of age 2 and 3 recoveries for ATN during 2016–2020 and as KLM has ERA start age of 3, these stocks cannot be forecasted using any method. Pseudo-recoveries for Kitsumkalum Chinook age 3 and older can be generated starting the next ERA cycle. The appendix section includes plots of stock-specific forecast errors across the four retrospective testing years. As recovery level varies by orders of magnitude across stocks, separating the plots by stock allows for better representation of results close to the plots' origins.

Age Ratio Methods

Within this section, the predicted age two compared to observed estimates is show for each finescale fishery, stock, and run year combination for the 2017 to 2020 run years. The first two figures show the comparison using the fishery and stock specific age ratio (figure @ref(fig:runyearageratio) left side) and a single stock specific age ratio (figure @ref(fig:runyearageratio) right side) from both ages in the same run year. The next two figures show the comparison on the same fishery specific (figure @ref(fig:broodyearageratio) left side) and stock specific (figure @ref(fig:broodyearageratio) right side) age ratio based estimates, except with the age ratios aligned to brood years instead of run years. This allows the two ages in the ratio to align to the same cohort instead of two different cohorts.

As figure @ref(fig:runyearageratio) shows, the use of the age ratio method based on both ages from the same run year did produced a more uncertain relationship between predicted and estimated age two CWT recoveries. The alignment of age data based on brood year provided more consistent linear relationship between observed estimates (figure @ref(fig:broodyearageratio)).

When comparing the fishery and stock specific age ratio method to the single stock specific ratio method, it appears that the fishery and stock specific method produced less biased estimates (figure @ref(fig:broodyearageratio)) as the blue line is closer to the one-to-one line.

Table 3: Comparison of predicated and observed age two estimated CWTs using the age ratio methods

Method	r2	Slope	Intercept	RMSE	n
Fishery & Esc. by Stock Age Ratio (Run Year)	0.53483	0.96899	8.4882	138.270	423
Stock Age Ratio (Run Year)	0.51821	0.73214	14.6440	108.010	423
Fishery & Esc. by Stock Age Ratio (Brood Year)	0.56086	0.76404	6.4507	94.735	507

Method	r2	Slope	Intercept	RMSE	n
Stock Age Ratio (Brood Year)	0.53422	0.60320	10.6130	78.927	507

Regression Models

Diagnostic plots of the regression models (not included) indicated consistent heteroscedasticity in the count-based fits. Additionally, the count-based models possessed the undesirable trait of having negative y-intercepts. It is not possible to force the intercept to zero in multiviarate regressions having categorical data. Based on these model limitations, the counts-based models were excluded from performance evaluation. In general, the mixed-effects models performed better than the standard multivariate regression models. Within the range of model structures, including all categorical variables (fishery, stock, pre-terminal/terminal) as random intercepts (vs. just fishery) indicates marginal improvements.

A special note should be made regarding the mixed-effects regression models used in forecasting just escapement. As there is just one level of fishery categorical variable (escapement) it cannot be included as a random effect. Thus only stock is included as a random effect when fitting escapement recovery models.

Model Ranking

Based on a preliminary results in which models were fitted using all fisheries and escapement, it was decided to also fit new models separately considering fisheries and escapement. Thus, results of the performance measure ranking are described in four sections:

- forecasting at the level of fine scale fishery
- forecasting at the level of ERA fishery (including escapement)
- forecasting at the level of ERA fishery (excluding escapement)
- forecasting escapement

Within each section the first rank table is based on all PM's while the second table considers just percent-based PM's. Eleven models were evaluated when considering fine scale fisheries. In the remaining three sections fewer models were considered due to constraints of the categorical variables in regression models.

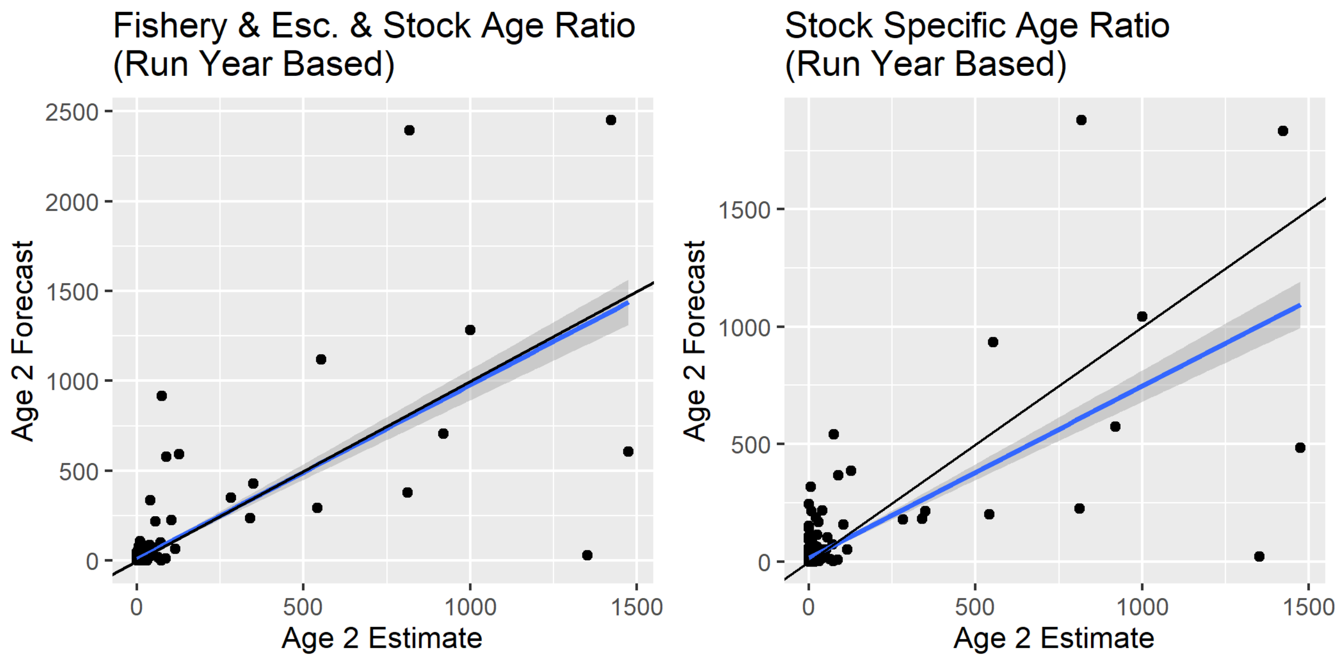

Figure 1: (#fig:runyearageratio) Comparison of predicted and observed age two CWT estimates using the age ratio method based on a finescale fishery and stock run year. Both ages used in the age ratio are from the same run year.Each point is a run year, finescale fishery, and stock specific age two estimate from 2017 to 2020. The solid black line is a one-to-one slope and the blue line is the linear regression between the two values.

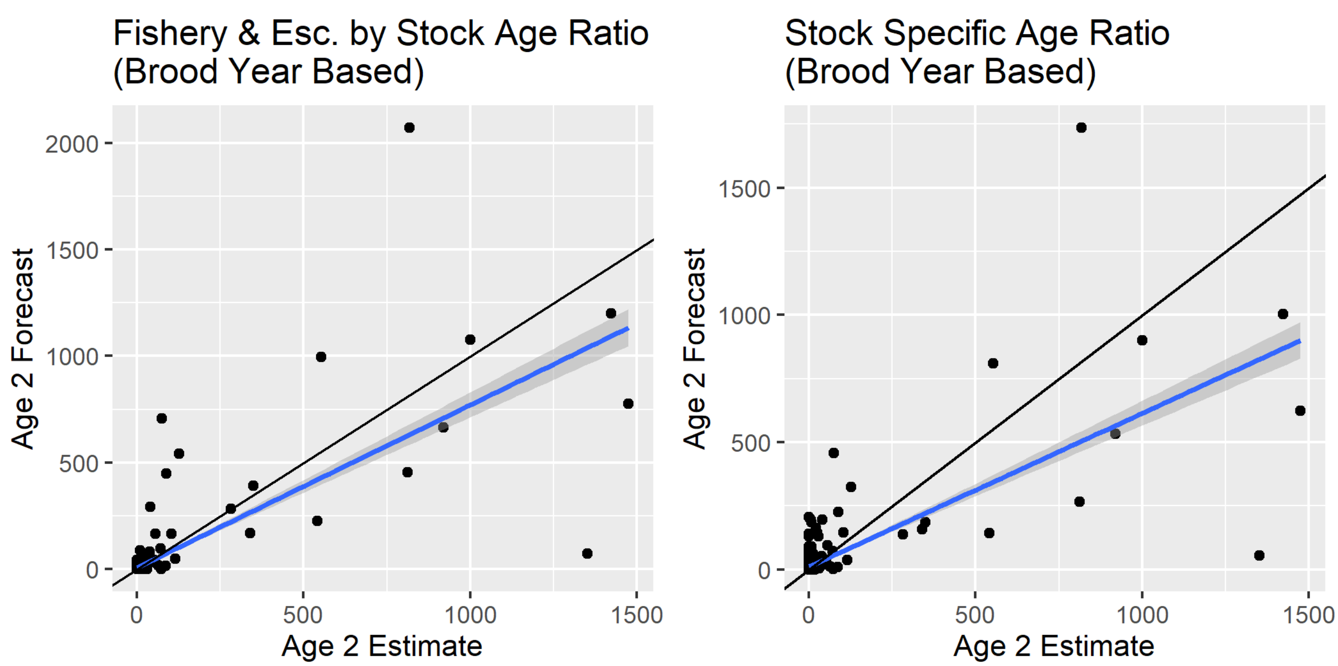

Figure 2: (#fig:broodyearageratio) Comparison of predicted and observed age two CWT estimates using the age ratio method based on a fishery and stock brood year. Each point is a run year, finescale fishery, and stock specific age two estimate from 2017 to 2020. The solid black line is a one-to-one slope and the blue line is the linear regression between the two values.

Fine scale fishery ranking

All the regression methods have a tendency, on average, to underestimate cases where recoveries are typically in the 100's (or larger) - these are conditions that influence the mre estimate. Conversely the age ratio methods have a tendency to (slightly) overestimate at all sizes, while three of the four age-ratio methods substantially overestimate at low recovery fisheries. Considering all PM's, the *fishery/stock-brood year age ratio* method ranked as the best likely option. Additionally, considering just percent-based PM's, the top eight methods are all quite closely ranked (1.14–1.98 out of a possible rank 1–11), and the *fishery/stock-brood year age ratio* is in that top eight. While the uncertainty of that method at low recovery sizes is greater than that of the regression methods (as indicated by mape), the difference in percentages (~91% vs ~114%) is presumably marginal. Thus, whether ranking on all PM types, or just the percent-based methods, the *fishery/stock-brood year age ratio* method is the best likely option. The remaining three age-ratio methods have notably worse performance so should not be considered comparable (or alternative) methods in forecasting recoveries. A secondary method for consideration is the mixed-effects regression that relies on age-3 recovery rate and includes three categorical variables (stock, fishery, preterminal/terminal) as random intercepts.

Table 4: Model ranking based on forecasting recoveries by fine scale fishery using all five performance metrics.

	mre	rmse	mpe	mape	mrpd	forecasts.n	average.rank
ratio_fishery_broodYr	0.80	102.63	24.99	114.55	25.47	484	1.88
glmm.rate2.age3	-11.84	105.85	29.98	91.21	-3.13	484	3.54
lm.rate.age3	-11.65	105.61	29.89	94.77	-3.93	484	3.55
glmm.rate.age3	-11.68	105.81	31.68	94.09	-3.32	484	3.57
glmm.rate2pt	-12.03	106.39	34.32	90.82	-2.05	484	3.65
glmm.rate2	-11.97	106.30	36.54	91.83	-1.91	484	3.67
lm.rate	-11.77	106.07	37.09	96.08	-2.82	484	3.69
glmm.rate	-11.83	106.33	38.31	94.77	-2.15	484	3.71
ratio_fishery_runYr	6.44	129.49	58.73	146.02	25.27	484	5.42
ratio_stock_broodYr	1.46	98.13	127.67	193.54	164.92	484	5.71
ratio_stock_runYr	6.31	107.25	183.17	247.95	165.75	484	8.56

Table 5: Model ranking based on forecasting recoveries by fine scale fishery using only percentage-based metrics.

	mpe	mape	mrpd	forecasts.n	average.rank
glmm.rate2.age3	29.98	91.21	-3.13	484	1.14
glmm.rate2pt	34.32	90.82	-2.05	484	1.20
lm.rate.age3	29.89	94.77	-3.93	484	1.23
glmm.rate.age3	31.68	94.09	-3.32	484	1.24
glmm.rate2	36.54	91.83	-1.91	484	1.27
glmm.rate	38.31	94.77	-2.15	484	1.37
lm.rate	37.09	96.08	-2.82	484	1.39
ratio__fishery__broodYr	24.99	114.55	25.47	484	1.98
ratio__fishery__runYr	58.73	146.02	25.27	484	3.36
ratio__stock__broodYr	127.67	193.54	164.92	484	8.66
ratio__stock__runYr	183.17	247.95	165.75	484	11.00

ERA fishery, including escapement, ranking

This evaluation aggregated recoveries to the level of ERA fisheries. Therefore models were fit and forecasts were made at the ERA fishery level. Recoveries summed to the ERA fishery are mostly represented by recoveries in just one or two fine scale fisheries (there are cases of recoveries in 3-4 fine scale fisheries, but rare). Thus ranking results match the order as presented in the prior tables. The PM values changed due to the reduced number of forecasts contributing to those statistics (fewer ERA fisheries than fine scale fisheries). Conclusions drawn from this evaluation are similar to those from the fine scale fishery forecasting models. Specifically, it appears that the ratio methods are more biased and uncertain when forecasting fishery recoveries having historically low to no recoveries. This supports the need to evaluate models of fishery recoveries and escapement recoveries separately.

Table 6: Model ranking based on forecasting recoveries by ERA fishery, using all five performance metrics.

	mre	rmse	mpe	mape	mrpd	forecasts.n	average.rank
ratio__era__all__fishery__broodYr	0.95	115.68	25.14	114.22	28.07	381	1.70
glmm.rate2.age3	-15.37	119.33	25.67	94.36	-6.09	381	3.16
glmm.rate.age3	-15.20	119.26	26.90	96.86	-6.38	381	3.18
lm.rate.age3	-15.23	119.23	27.71	99.12	-6.68	381	3.21
glmm.rate2pt	-16.08	120.84	34.82	97.68	-4.09	381	3.42
glmm.rate2	-15.96	120.76	39.06	100.66	-3.76	381	3.47

	mre	rmse	mpe	mape	mrpd	forecasts.n	average.rank
lm.rate	-15.74	120.61	41.78	106.81	-4.54	381	3.53
ratio_era_all_fishery_runYr	8.03	145.94	62.43	147.84	28.74	381	4.80
ratio_era_all_stock_broodYr	1.66	111.31	149.16	219.21	153.71	381	5.22
ratio_era_all_stock_runYr	7.76	121.93	215.63	284.61	154.83	381	7.76

Table 7: Model ranking based on forecasting recoveries by ERA fishery, using only percentage-based metrics.

	mpe	mape	mrpd	forecasts.n	average.rank
glmm.rate2.age3	25.67	94.36	-6.09	381	1.05
glmm.rate.age3	26.90	96.86	-6.38	381	1.12
lm.rate.age3	27.71	99.12	-6.68	381	1.17
glmm.rate2pt	34.82	97.68	-4.09	381	1.21
glmm.rate2	39.06	100.66	-3.76	381	1.32
lm.rate	41.78	106.81	-4.54	381	1.47
ratio_era_all_fishery_broodYr	25.14	114.22	28.07	381	1.80
ratio_era_all_fishery_runYr	62.43	147.84	28.74	381	2.93
ratio_era_all_stock_broodYr	149.16	219.21	153.71	381	7.90
ratio_era_all_stock_runYr	215.63	284.61	154.83	381	10.00

ERA fishery, excluding escapement, ranking

Limiting model fits to only fishery recovery data (i.e. excluding large escapement values) substantially reduces the numerical scale of values that each model must be fitted to and forecast from. Under these constraints the mixed-effects regression models, based on only age 3 recovery rates are likely to have better performance. Interpreting these results requires some care. While the top eight models, on average, have minimal bias (values ranging -1 to 1) there is still a moderate amount of uncertainty among all methods. The mpe PM suggests over-estimation by the regression methods, however as indicated previously, this metric fails to account for cases of forecasts produced when no recoveries actually existed (a division by zero error). The limitation is partially addressed by the mrpd metric. As noted in prior evaluations, the larger mrpd values seen for the ratio methods indicate a pattern of forecasting recoveries in fisheries that had no actual recoveries.

Table 8: Model ranking based on forecasting recoveries by ERA fishery - excluding escapement in fit and forecast, using all five performance metrics.

	mre	rmse	mpe	mape	mrpd	forecasts.n	average.rank
glmm.rate2.age3	-1.01	14.28	24.13	85.84	-3.83	353	1.37
glmm.rate.age3	-1.01	14.33	23.11	87.74	-4.18	353	1.39
ratio__era__fisheryonly__broodYr	-0.21	12.90	-27.75	84.52	28.43	353	1.41
lm.rate.age3	-0.99	14.54	24.77	90.51	-4.40	353	1.43
lm.rate	-0.98	14.24	40.89	98.60	-2.51	353	1.54
glmm.rate2pt	-1.04	14.07	44.91	98.11	-1.80	353	1.55
glmm.rate2	-1.01	14.09	47.19	98.87	-1.53	353	1.57
ratio__era__fisheryonly__runYr	0.90	14.70	9.97	116.50	28.69	353	1.77
ratio__era__fisheryonly__stock__broodYr	8.59	29.47	196.89	270.92	166.37	353	7.99
ratio__era__fisheryonly__stock__runYr	10.82	35.35	284.71	359.43	167.05	353	10.00

Table 9: Model ranking based on forecasting recoveries by ERA fishery - excluding escapement in fit and forecast, using only percentage-based metrics.

	mpe	mape	mrpd	forecasts.n	average.rank
glmm.rate2.age3	24.13	85.84	-3.83	353	1.21
glmm.rate.age3	23.11	87.74	-4.18	353	1.23
lm.rate.age3	24.77	90.51	-4.40	353	1.28
lm.rate	40.89	98.60	-2.51	353	1.51
glmm.rate2pt	44.91	98.11	-1.80	353	1.53
glmm.rate2	47.19	98.87	-1.53	353	1.56
ratio__era__fisheryonly__broodYr	-27.75	84.52	28.43	353	1.68
ratio__era__fisheryonly__runYr	9.97	116.50	28.69	353	1.84
ratio__era__fisheryonly__stock__broodYr	196.89	270.92	166.37	353	8.06
ratio__era__fisheryonly__stock__runYr	284.71	359.43	167.05	353	10.00

Escapement only, ranking

As mentioned previously, on average, the regression models underestimate escapement recoveries to a greater extent than do the ratio methods. Uncertainty (rmse) could be considered roughly similar across all methods. However, similar to results seen in methods that considered both fishery and escapement data (thus a large data range), we again see an indication that the ratio methods tend to over-forecast values on the lower end of the range of escapement (mpe PM). While regression methods also over-forecast low escapement recoveries, the average error is an order of magitude smaller (mpe 6.5 for regression vs. 50-72 for ratio). As escapement recovery counts will almost always be greater than zero, there is nearly no risk of forecasting recoveries when none were documented. Thus the role of the mrpd PM to indicate overestimation is less critical.

Table 10: Model ranking based on forecasting recoveries by ERA fishery - including only escapement in fit and forecast, using all five performance metrics.

	mre	rmse	mpe	mape	mrpd	forecasts.n	average.rank
ratio__era__esconly__stock__broodYr	-85.78	397.05	50.19	111.96	-5.91	28	2.44
ratio__era__esconly__stock__runYr	-30.83	431.89	72.34	129.40	0.80	28	2.53
glmm.rate2.age3	-178.42	422.64	6.50	86.81	-39.57	28	3.96
lm.rate.age3	-173.14	423.70	4.83	86.23	-42.10	28	3.99
glmm.rate2	-179.14	423.34	6.23	87.30	-40.43	28	4.00
lm.rate	-174.10	425.03	5.11	87.67	-43.05	28	4.06
ratio__era__esconly__broodYr	15.57	424.25	134.84	175.84	23.53	28	4.11
ratio__era__esconly__runYr	98.01	535.82	171.23	212.85	29.41	28	6.85

Table 11: Model ranking based on forecasting recoveries by ERA fishery - including only escapement in fit and forecast, using only percentage-based metrics.

	mpe	mape	mrpd	forecasts.n	average.rank
ratio__era__esconly__stock__broodYr	50.19	111.96	-5.91	28	2.39
ratio__era__esconly__stock__runYr	72.34	129.40	0.80	28	2.74
glmm.rate2.age3	6.50	86.81	-39.57	28	3.18
glmm.rate2	6.23	87.30	-40.43	28	3.23
lm.rate.age3	4.83	86.23	-42.10	28	3.28
lm.rate	5.11	87.67	-43.05	28	3.36
ratio__era__esconly__broodYr	134.84	175.84	23.53	28	5.73
ratio__era__esconly__runYr	171.23	212.85	29.41	28	7.25

Forecast Validation

The two top ranked models for fishery-only then escapement-only forecasting were evaluated relative to recent estimated recoveries. The top ranked fishery-only model is identified as: *glmm.rate2.age3* meaning it is a generalized linear multivariate mixed-effects regression, where the *2* indicates both fishery and stock are treated as random effects and the recovery rate covariate is only age 3 (not age 3 +age 2). The top rank escapement-only model is named *ratio_era_esconly_stock_broodYr*, which is a stock specific estimate of the recent five year average of age-2:age-3 recovery ratio (escapement only), originating from the same brood year.

Included in each histogram are two separate estimates of both the 2.5 and 97.5 percentiles. The initial estimate represents the recovery count value at +/- 1.95 standard deviations under the normality assumption. As all the recovery distributions are *like* log-normal, recoveries were log-transformed (with addition of 1 to avoid log zero errors). The population estimates of the 2.5 and 97.5 percentiles were estimated from the mean and standard deviation of the log transformed recoveries. The antilog (minus 1) of these percentiles were plotted. These estimates are the equivalent location to the -1.96 and 1.96 standard deviations. Forecasts within this range indicate results are within an acceptable range of uncertainty based on the historical data. However, as previously indicated, the distributions are *like* log-normal, and not all log-transformations resulted in normal distributions. Several cases were found with negatively skewed distributions of the log-transformed values (CHI escapement, being one case). These conditions could result in over-estimation of both the mean and SD as well as the 97.5 percentile.

To avoid estimating comparative benchmarks (ie the percentiles) that may be insufficiently stringent, we have included 2.5 and 97.5 percentiles estimated directly from the samples of recoveries (fishery-stock, years 2000-2020). Typically, with small samples sizes, the ranges of sample estimated quantiles will be narrower (and thus more stringent) than population quantiles estimated from the mean and SD of a sample. It should be noted that not all cases comply with this description. Some estimates of the sample 97.5 percentile are beyond the 97.5 population percentile. However, by including these additional benchmarks the forecasted values are frequently being evaluated by a more conservative range.

Plots are included in the appendix section *Forecasts 2019-2020 and historic recovery quantiles.* Across the combination of seven stocks, two forecast years (2019, 2020), numerous fisheries and escapement, 35 forecasts (having values >0) were produced. Except for five cases, all combinations of fishery-stock-forecast year have forecasts that are within the range of the most stringent percentiles. This suggests all these cases are forecasts well within an acceptable range. Of the remaining five cases, four forecasts are between the separately estimated 97.5 percentiles (i.e. sample estimate and population estimate). Those four forecasts are for MSH in *T FRASER FS*, CHI in *T FRASER TN*, RBT in *WCVI AABM S*, and CHI in *ESCAPEMENT*. This too suggests that these forecasts are likely within a tolerable range. One forecast falls outside the upper limit of both 97.5 percentiles, that being a single forecast for RBT in *CBC S*. It should be noted that the other year forecasted for RBT in *CBC S* remains within the most stringent range.

Discussion

Model Comparison

Selection of the most appropriate model will be defined by several criteria, accuracy vs. precision *in general*, and comparable performance across all possible recovery sizes (0~1000). Initial results, evaluated at the fine scale fishery level indicated that all models' uncertainty might improve by aggregating data to the ERA fishery level, thus reducing uncertainty in small recovery counts due to sampling error. However, most ERA fishery recoveries are typically represented by recoveries in 1-2 fine scale fisheries. Thus the summation did not dramatically increase each fishery estimate. However, the number of stock-fishery combinations being forecasted dropped from 484 (fine scale) to 381 (ERA). This represents the denominator in the PM average and the smaller denominator resulted in increased rmse estimates.

The second exercise was to forecast fishery recoveries and escapement recoveries based on independent models. This approach did produce notably improved forecast uncertainty for fishery recoveries (as expected due to the substantially lower scale of the data). Performance metrics indicate, on average, similar bias and uncertainty, however it was demonstrated that the ratio methods are at risk of forecasting fisheries recoveries for cases when no actual recoveries occurred. This single attribute is cause for concern. Considering the escapement-based methods, the two top ranking models tended to overestimate cases with low escapement recoveries.

Ranking of statistical models at the ERA fishery level revealed a best model, *glmm.rate2.age3* (generalized linear multivariate mixed-effects regression, where the *2* indicates both fishery and stock are treated as random effects and the recovery rate covariate is only age 3) for forecasting of fishery pseudo-recoveries. The top rank escapement-only model is named *ratio_era_esconly_stock_broodYr*, which is a stock specific estimate of the recent five year average age-2:age-3 recoveries ratio (escapement only), originating from the same brood year.

Estimation of recoveries from the 2020 releases will be necessary for fisheries in 2022–2024. This analysis has not evaluated extrapolation methods for the three additional age classes. However it is likely that similar models, accounting for the age shift, can be evaluated under this same approach.

Validating forecasts to historical recoveries

This validation exercise suggests the top-ranking regression and ratio models, for both *fishery only* forecasts and *escapement only* forecasts) have produced forecasts that are not only within a tolerable range of uncertainty (as estimated by 2.5 and 97.5 percentiles), but predominantly in the lower 50% of historical recoveries. This suggests that the risk of forecasting recoveries exceeding values historically estimated is minimal.

Additionally it is understood that the relative contribution of age 2 recoveries to estimation of ER is low. Based on 2020 recoveries, age two contributed on average 5.8% to estimated recoveries for these stocks.

Pseudo-Release/Recovery Data Reporting

The extrapolation of unknown recoveries is one half of the requirements to the ERA. Extrapolated recoveries must be associated with a release group identified by a specific tag code. The current cases do not allow for such a link as all indicator releases were unmarked and no tag codes exist. As such, a protocol to construct pseudo-release codes is described below.

Pseudo Coded-Wire-Tag Format

To link pseudo-recoveries to a stock and associated release, a common pseudo-release coded-wire-tag (CWT) is needed to identify the associated stock. As the identified methods are meant to infill a single brood year for a particular indicator stock, the combination of agency, stock code, and brood year should uniquely identify the pseudo-release. To provide a similar look to other released CWTs from the same agency, the pseudo-release code begins with a common tag code prefix used by the reporting agency. The pseudo-CWT format is provided below.

AASSSYYYY

AA = Agency tag code prefix

SSS = Stock Code

YYYY = Brood Year

So for example, a Chilliwack (CHI) stock pseudo-release record for the 2019 brood year would have a the release CWT of “18CHI2019”.

Release Total

For the pseudo-release, a release cohort size is informative to identify the general size release and calculated marine survival of the stock. The methods identified to infill missing stock brood year recoveries relies on recoveries of the stock over recent run years. As recoveries of recent stock releases are used to infill missing brood years, the average coded-wire-tag (CWT) release size by brood year for a particular stock will be used as the CWT release total of the pseudo-release. As non-CWT fish do not inform the age infill methods, no fish without a CWT will be reported with the pseudo-releases.

Currently the CTC ERA is based on adipose clipped released and recovered fish with CWTs. Because of this, pseudo-releases will be limited to adipose clipped fish. The release size of the pseudo-release will be reported as the average release size of the recently released stocks.

Auxiliary Recovery Format

To generate auxiliary age two recovery records for each finescale fishery that needs to be infilled, default PSC fishery ID and recovery location code will be associated to those records.

Retrospective Plots

Stock-specific retrospective forecasts, by model type, for fine scale fisheries

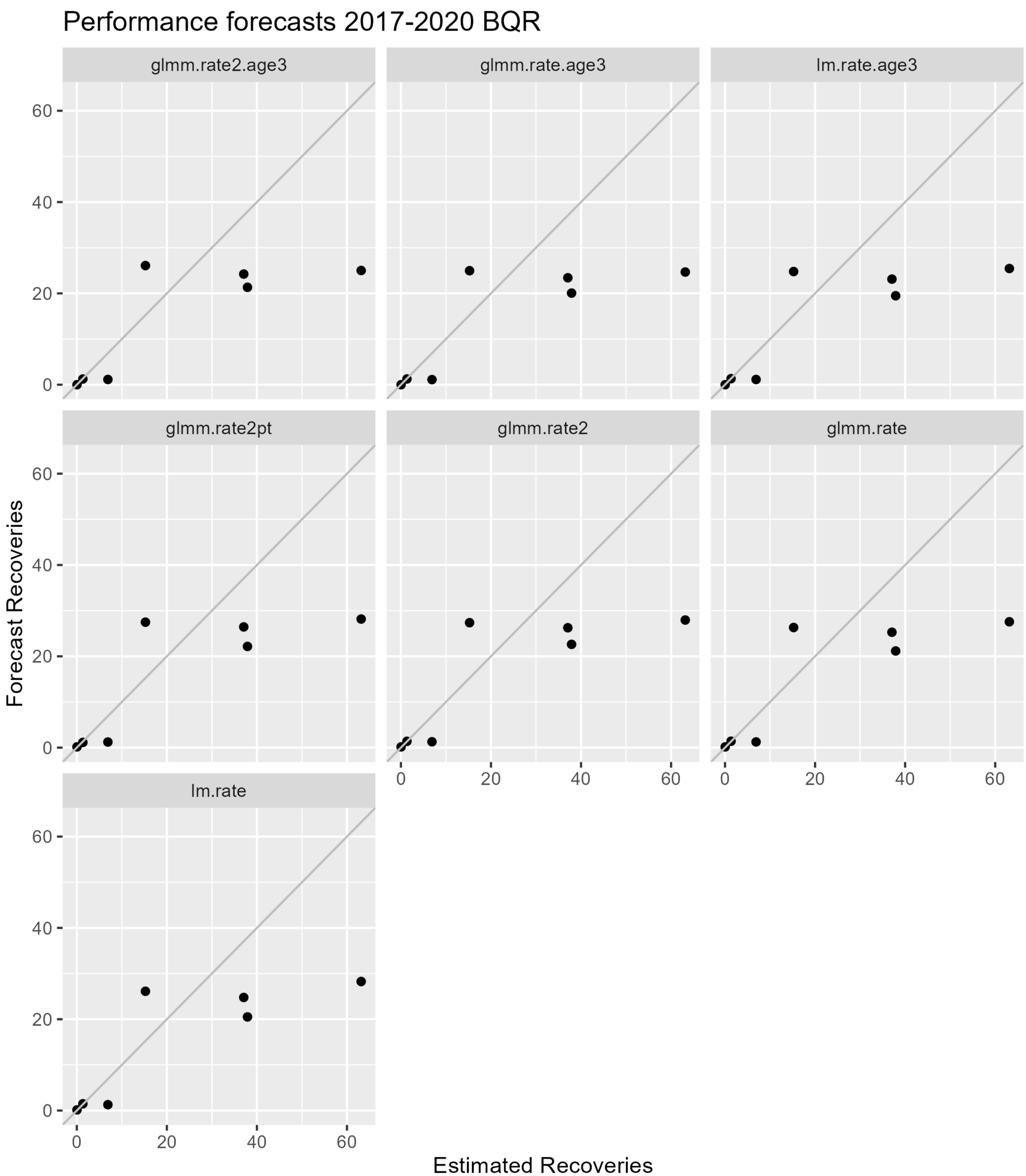

Figure 3: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all fine scale fisheries that are forecasted. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

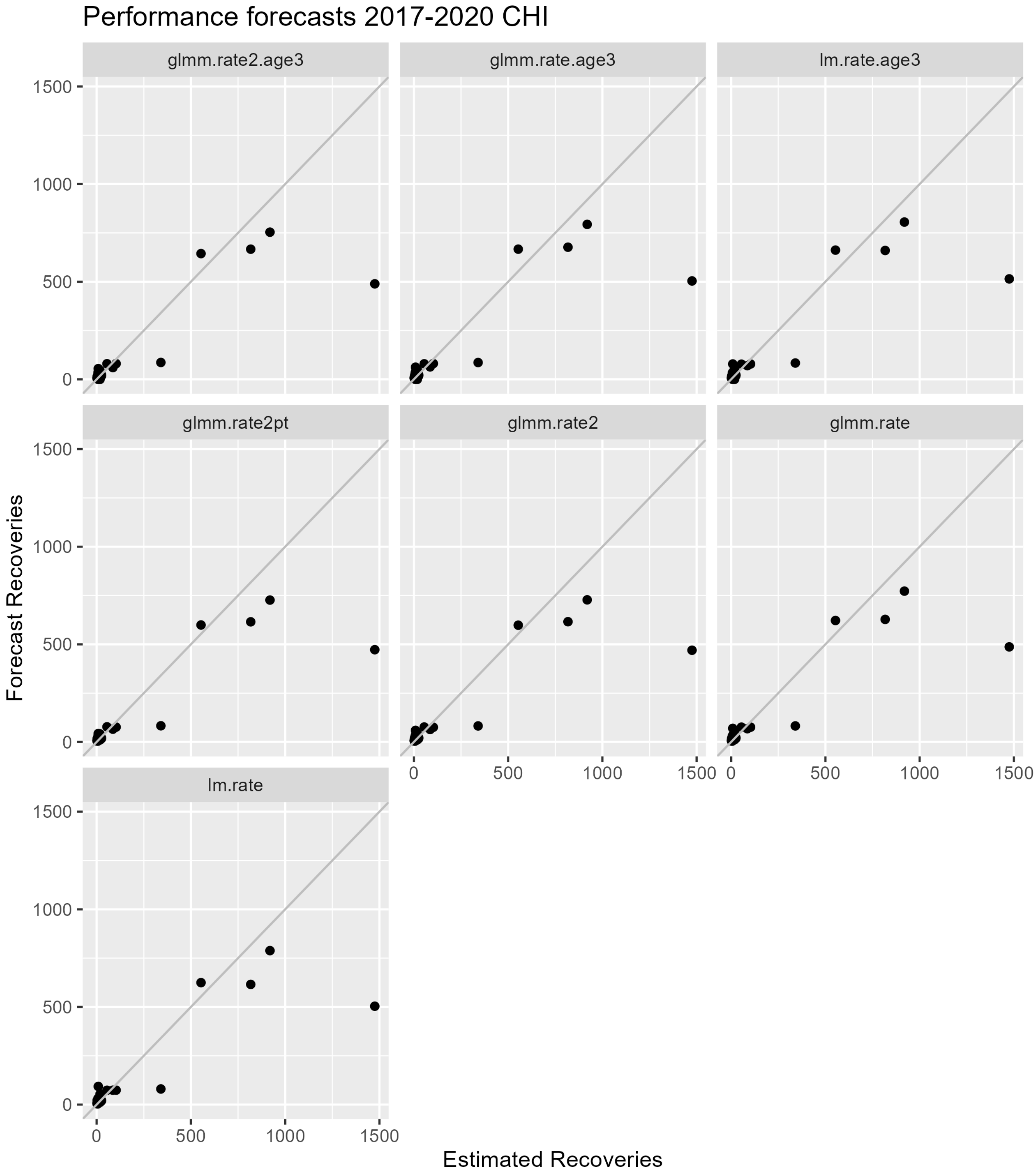

Figure 4: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all fine scale fisheries that are forecasted. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

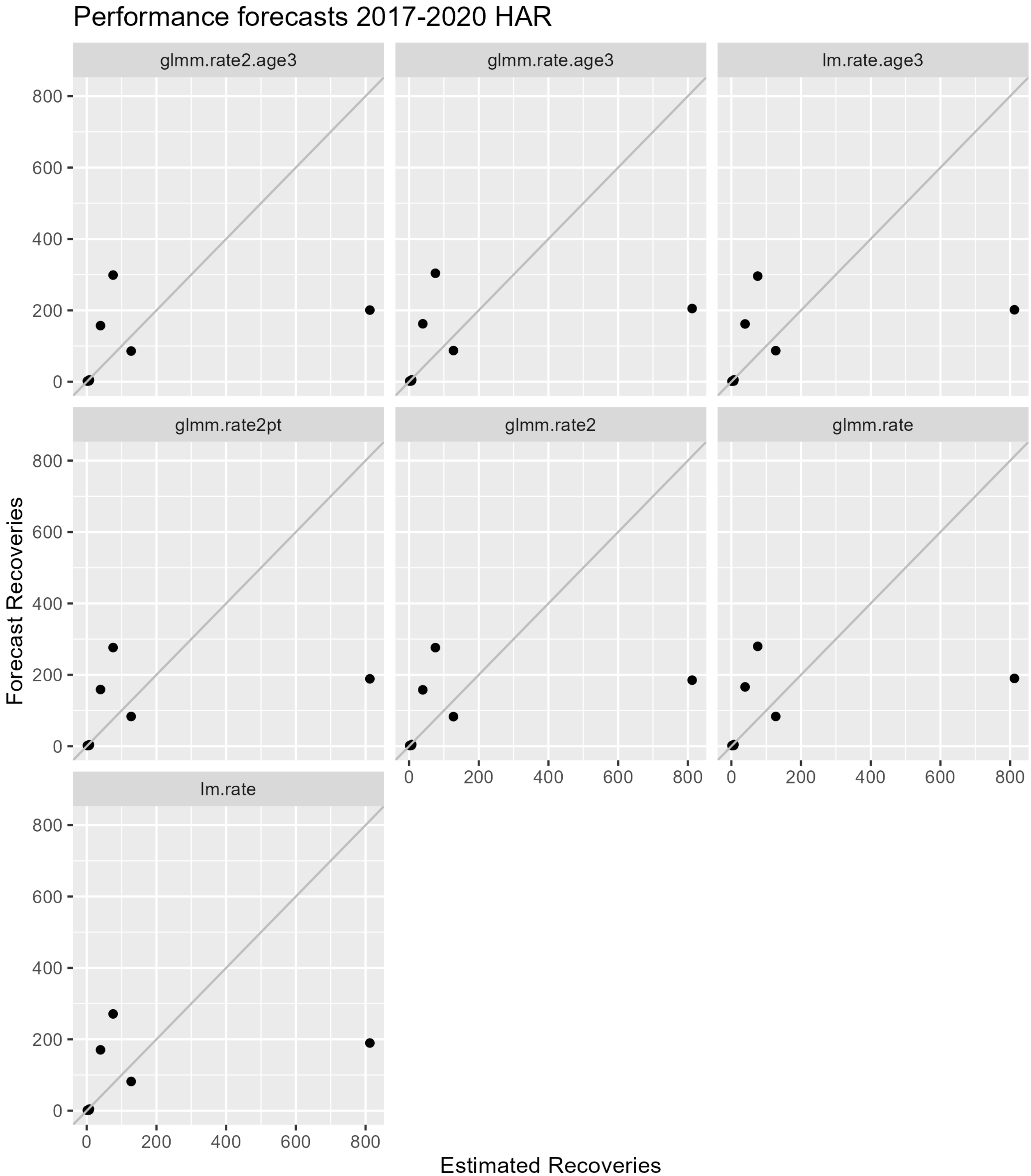

Figure 5: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all fine scale fisheries that are forecasted. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

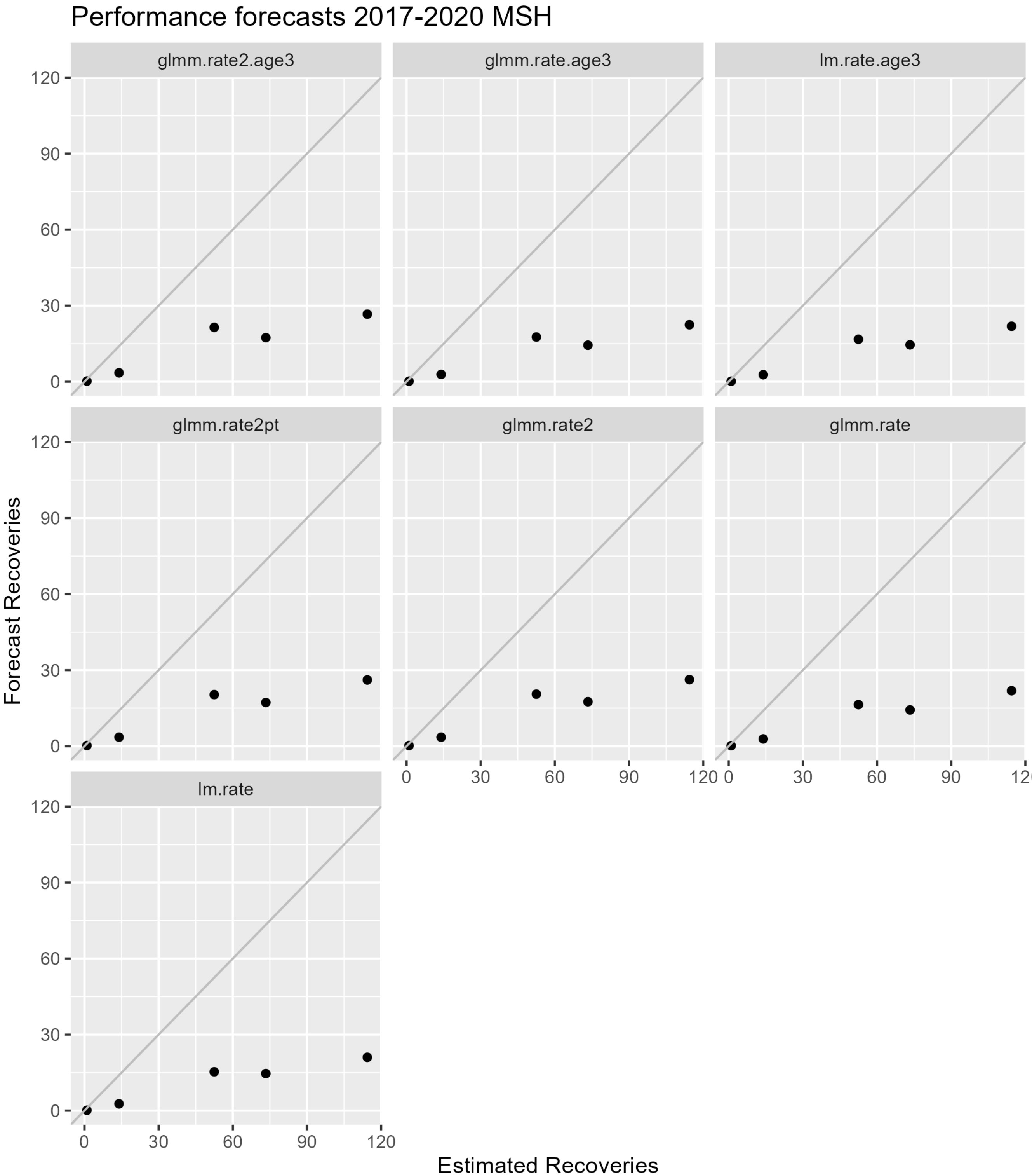

Figure 6: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all fine scale fisheries that are forecasted. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

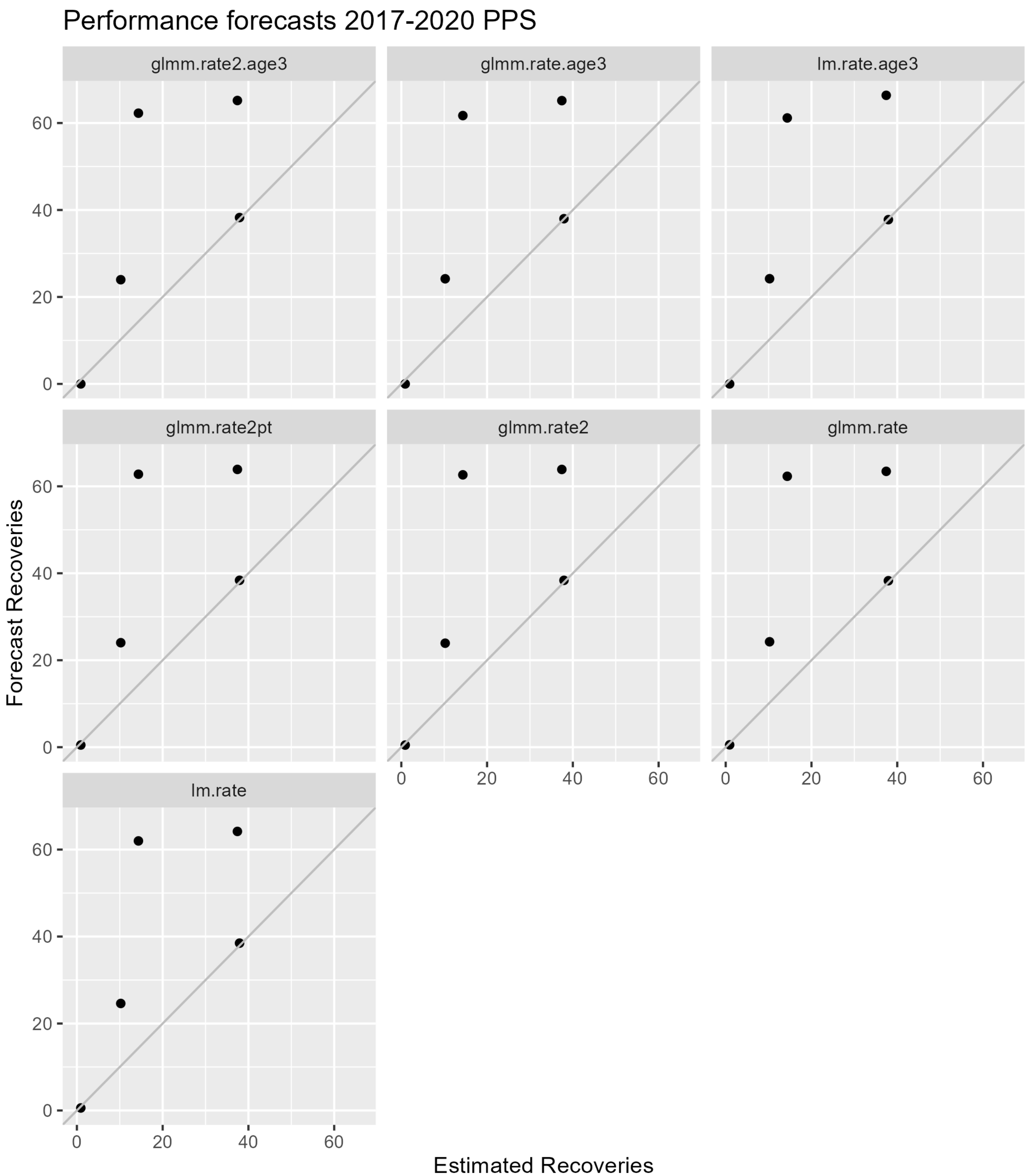

Figure 7: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all fine scale fisheries that are forecasted. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

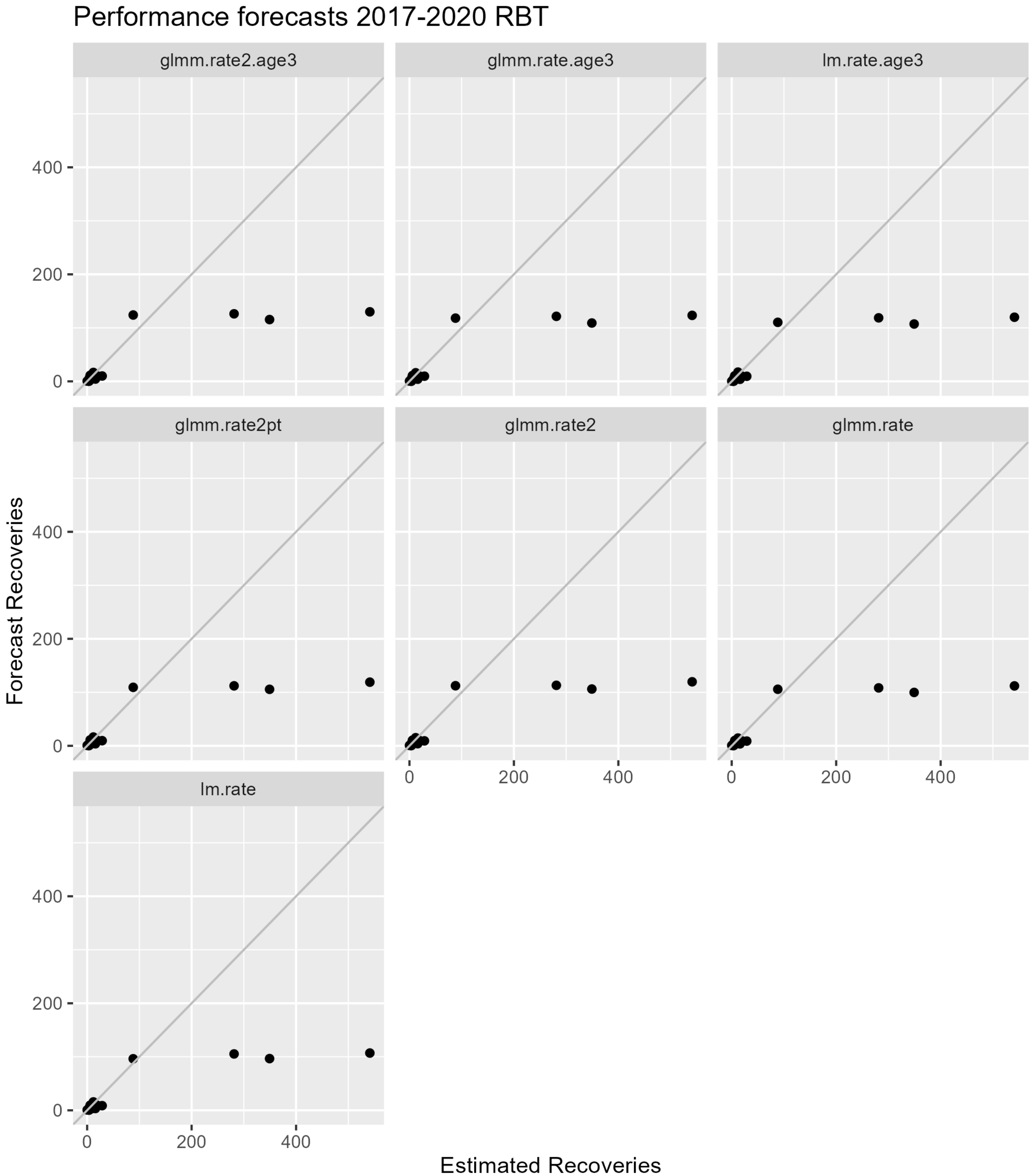

Figure 8: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all fine scale fisheries that are forecasted. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

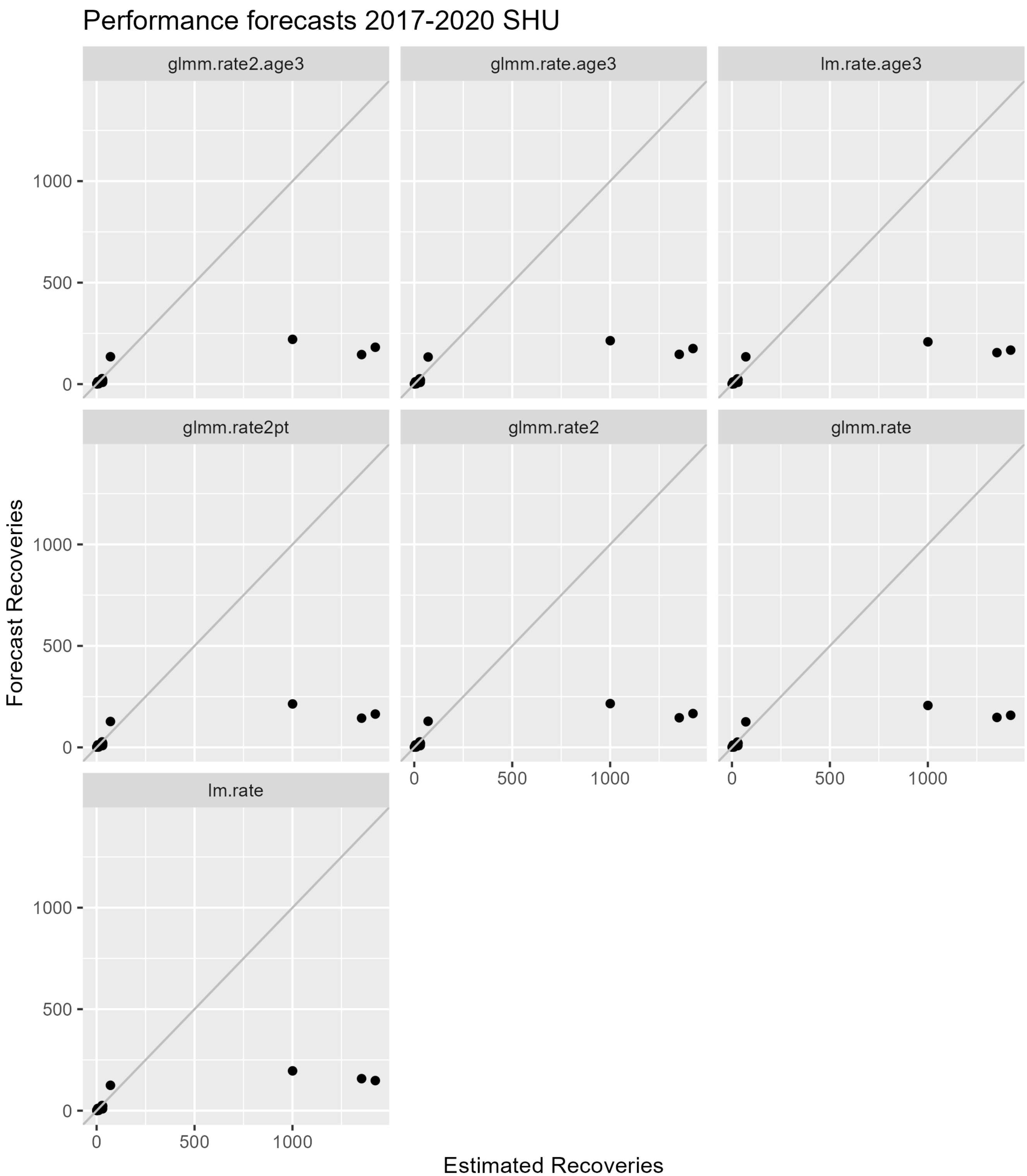

Figure 9: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all fine scale fisheries that are forecasted. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

Stock-specific retrospective forecasts, by model type, for ERA fisheries including escapement

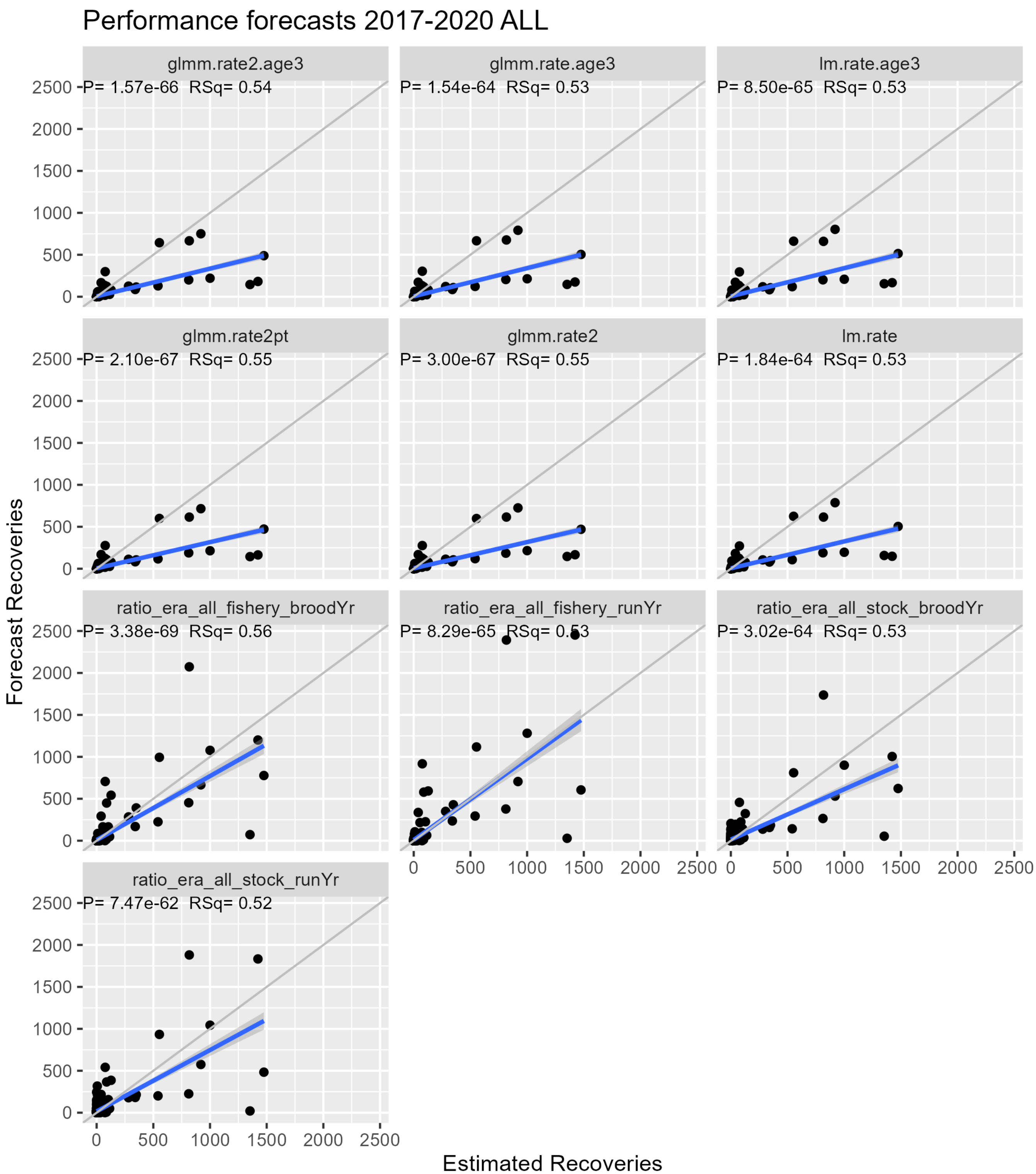

Figure 10: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

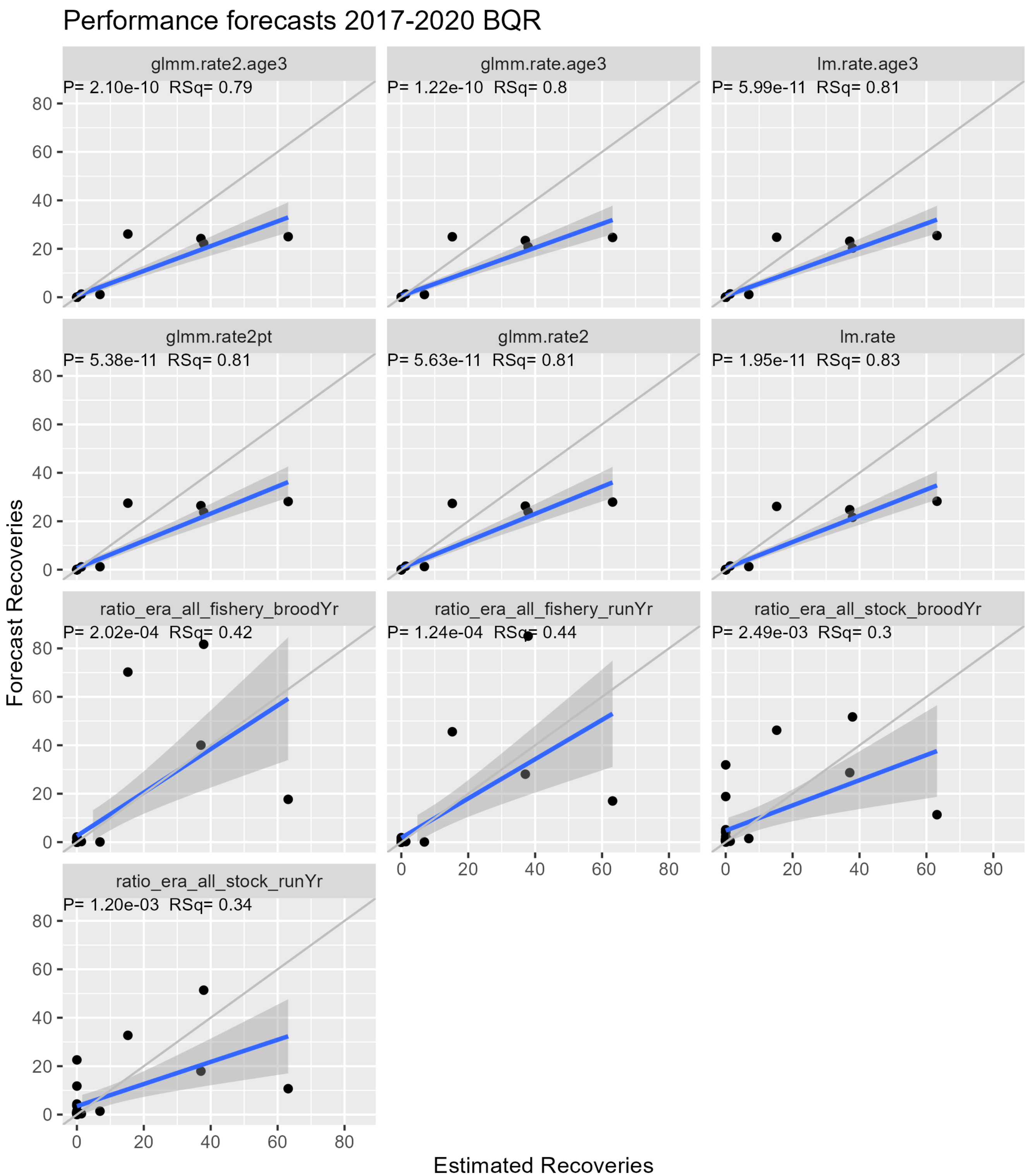

Figure 11: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

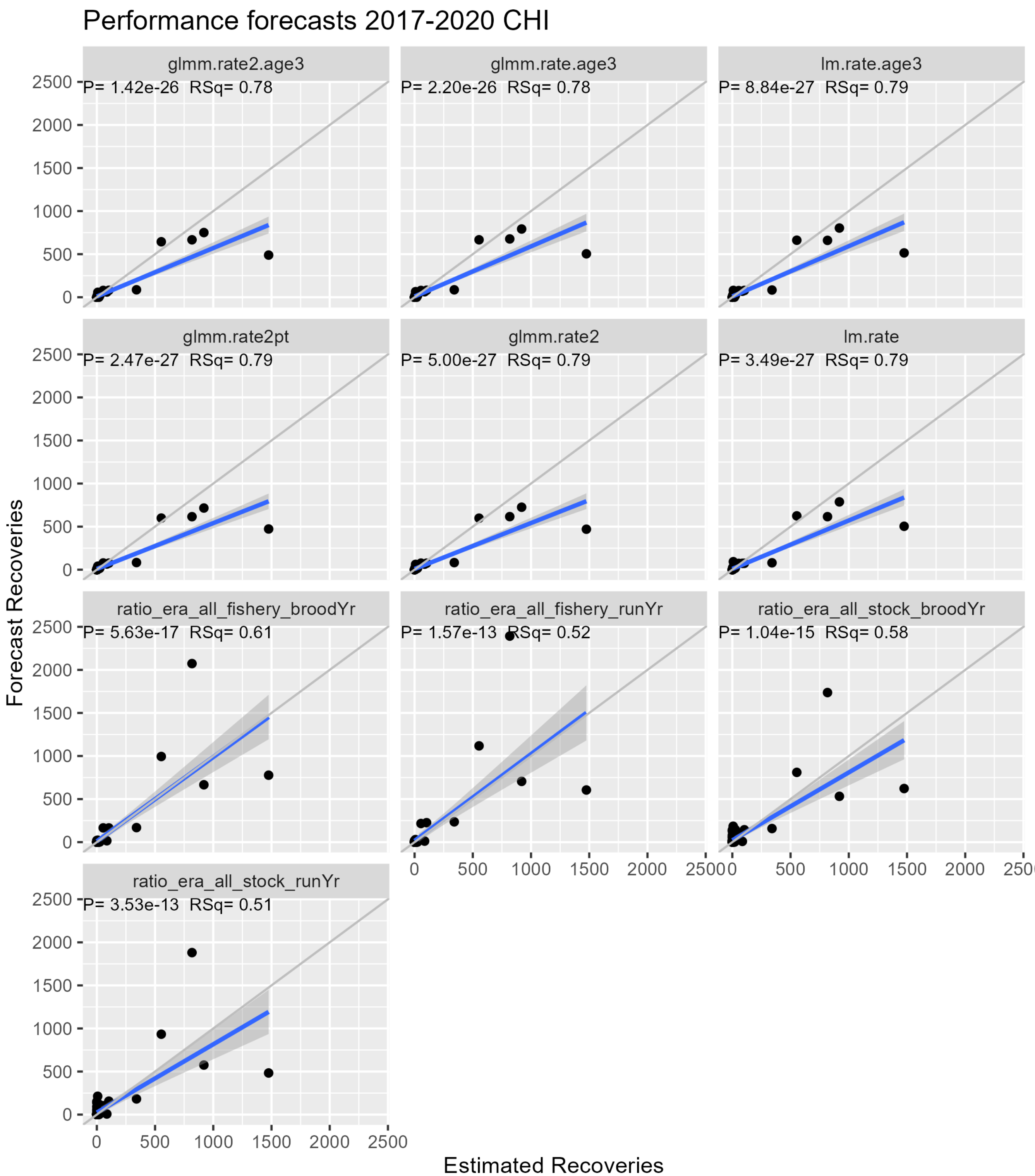

Figure 12: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

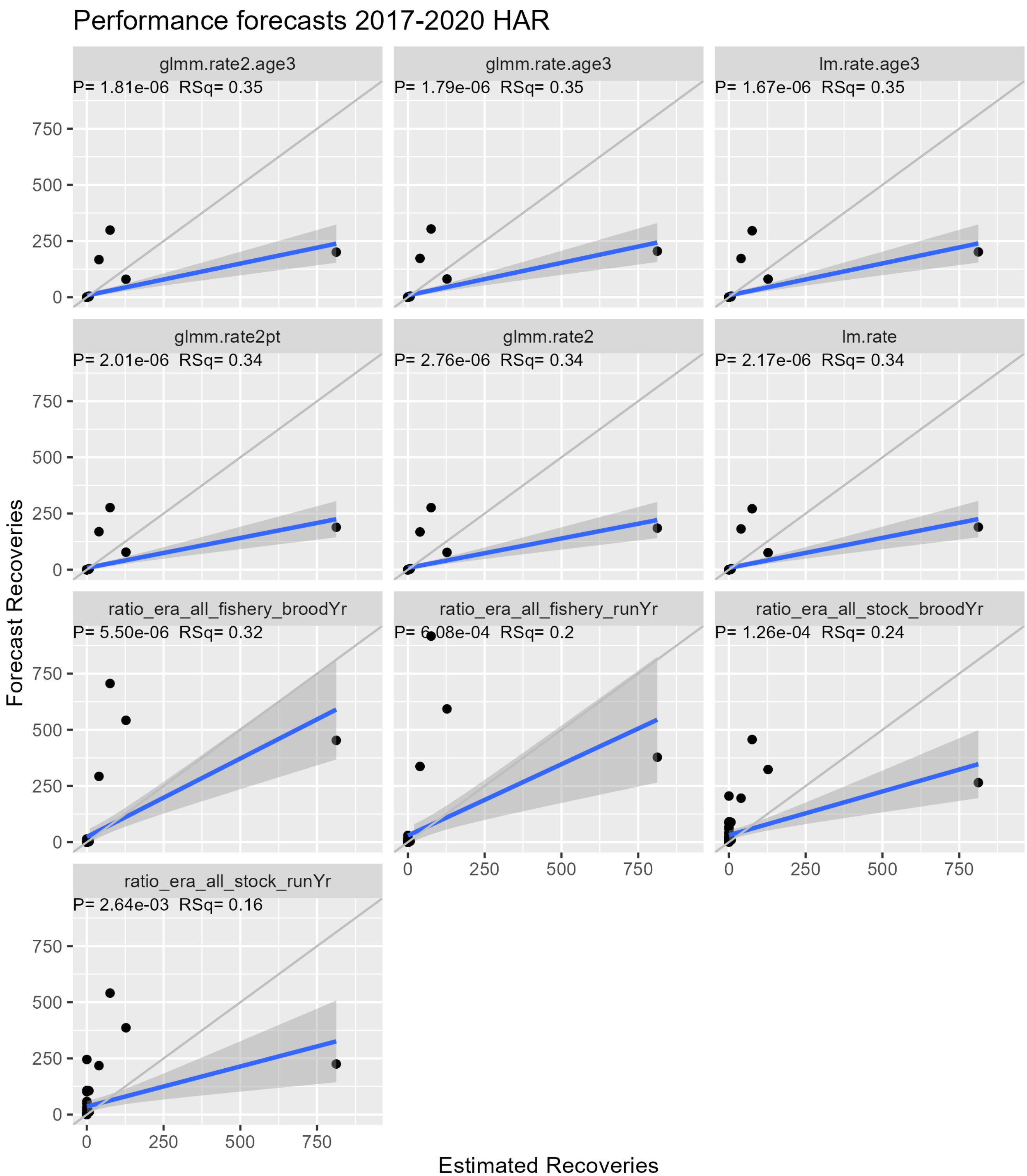

Figure 13: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

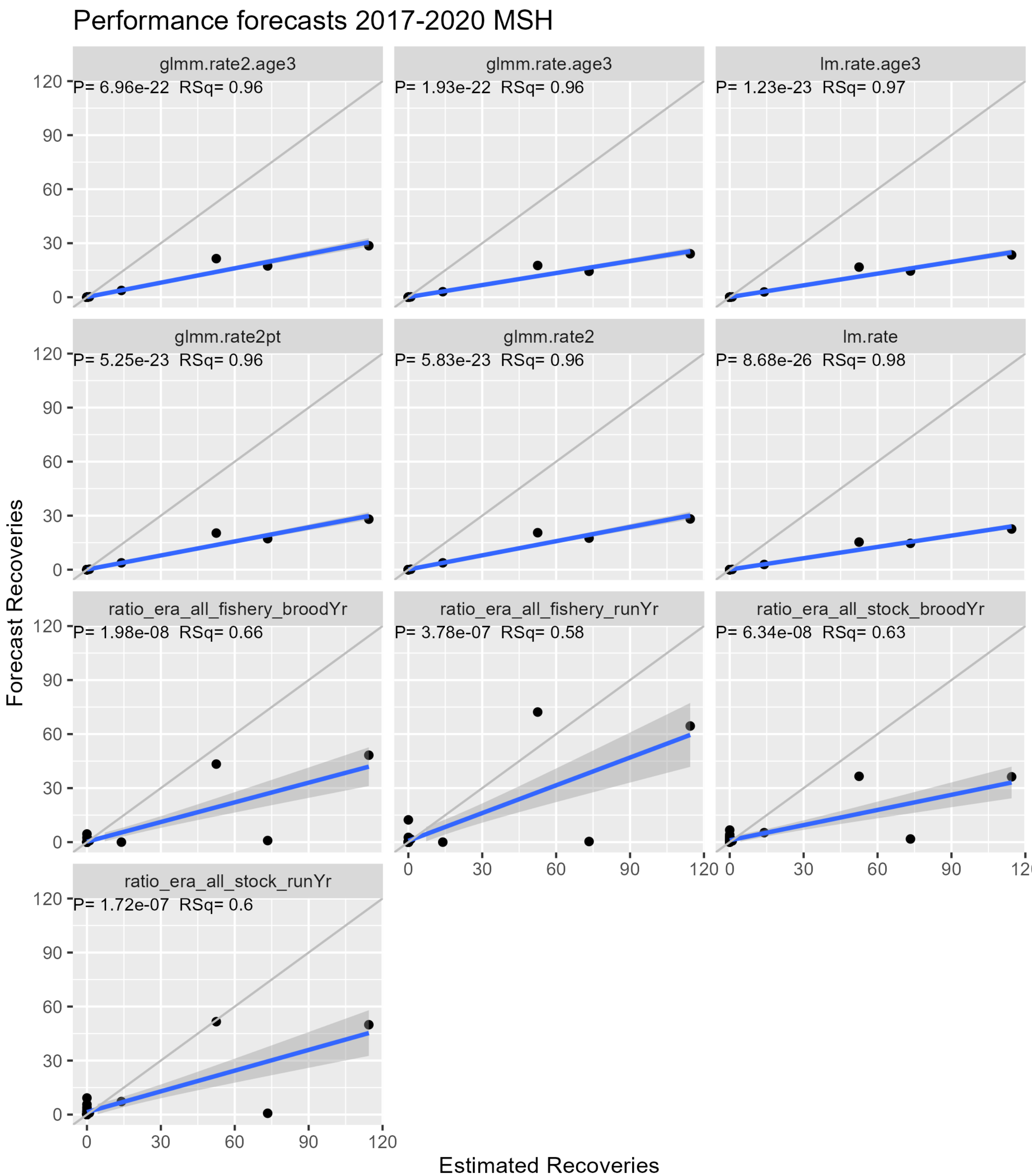

Figure 14: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

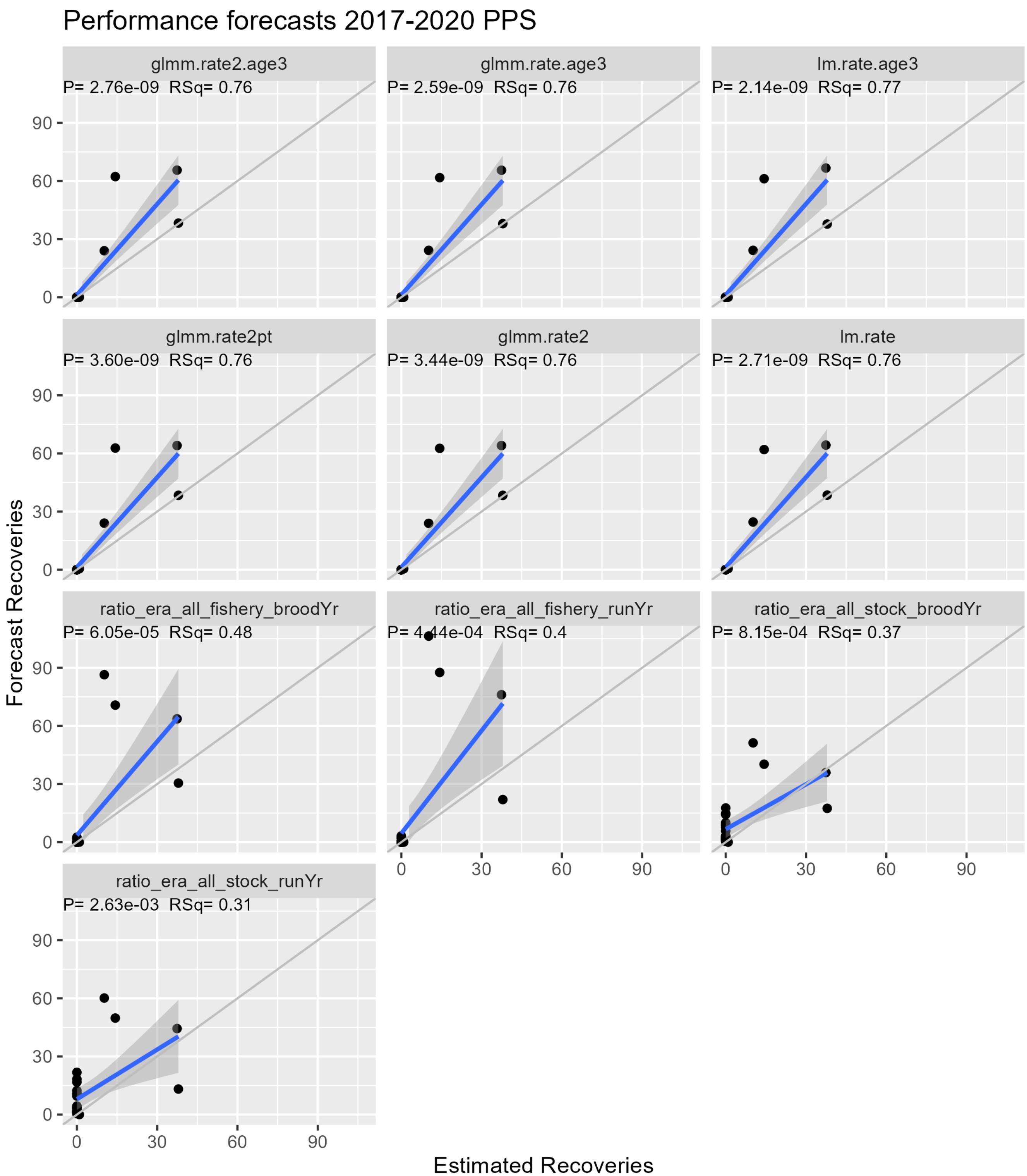

Figure 15: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

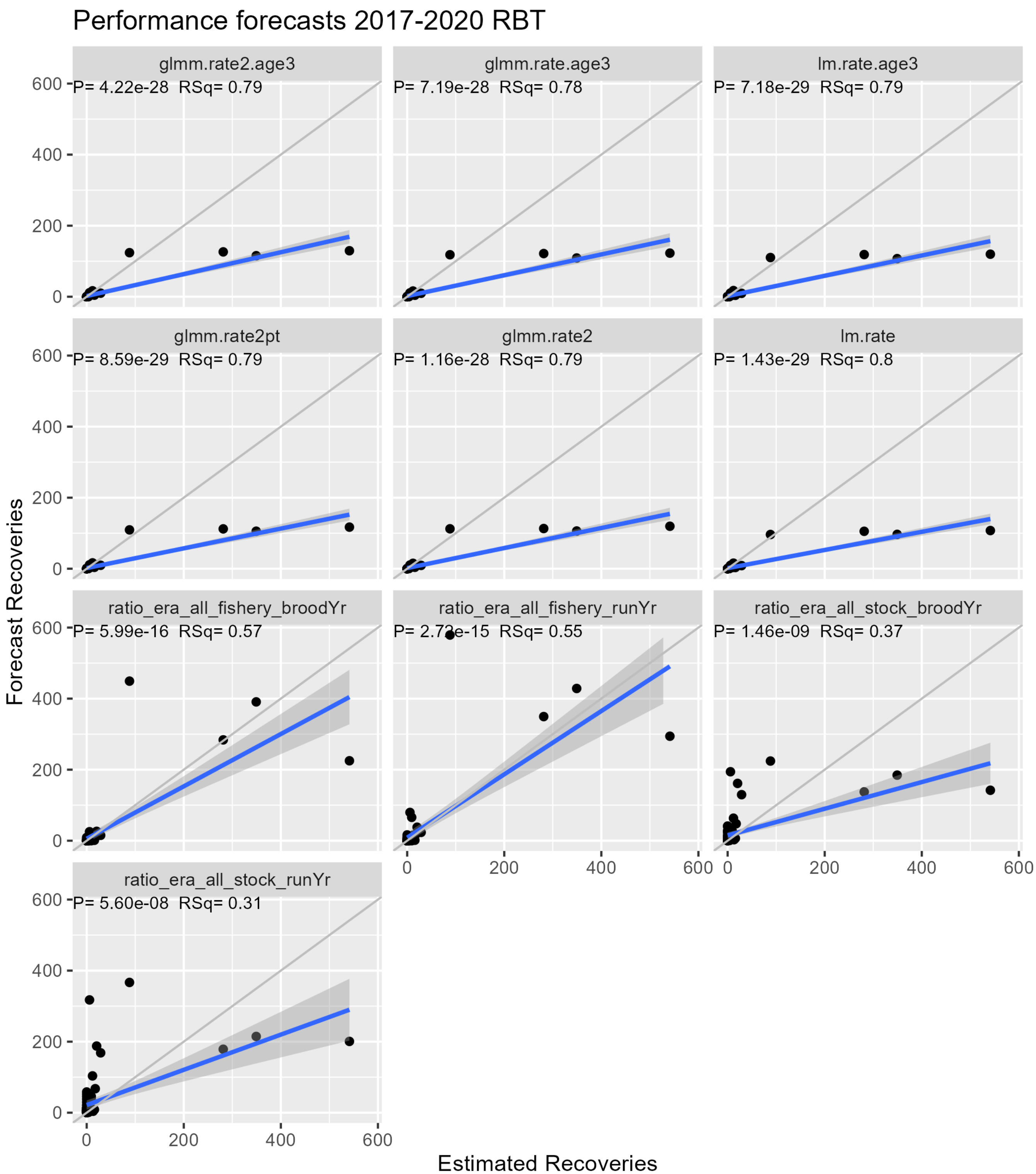

Figure 16: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

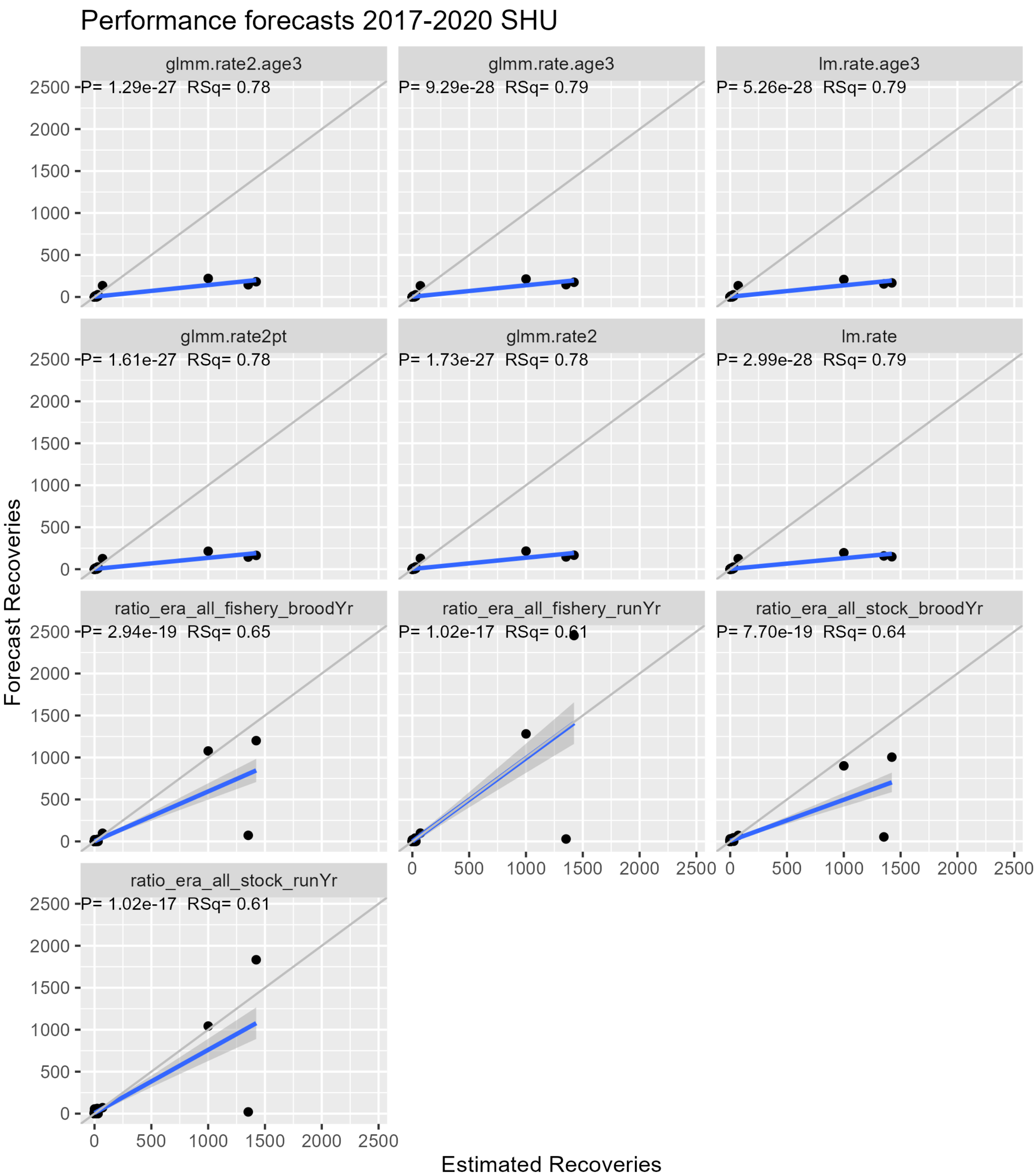

Figure 17: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries and escapement that are forecasted together. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

Stock-specific retrospective forecasts, by model type, for ERA fisheries excluding escapement

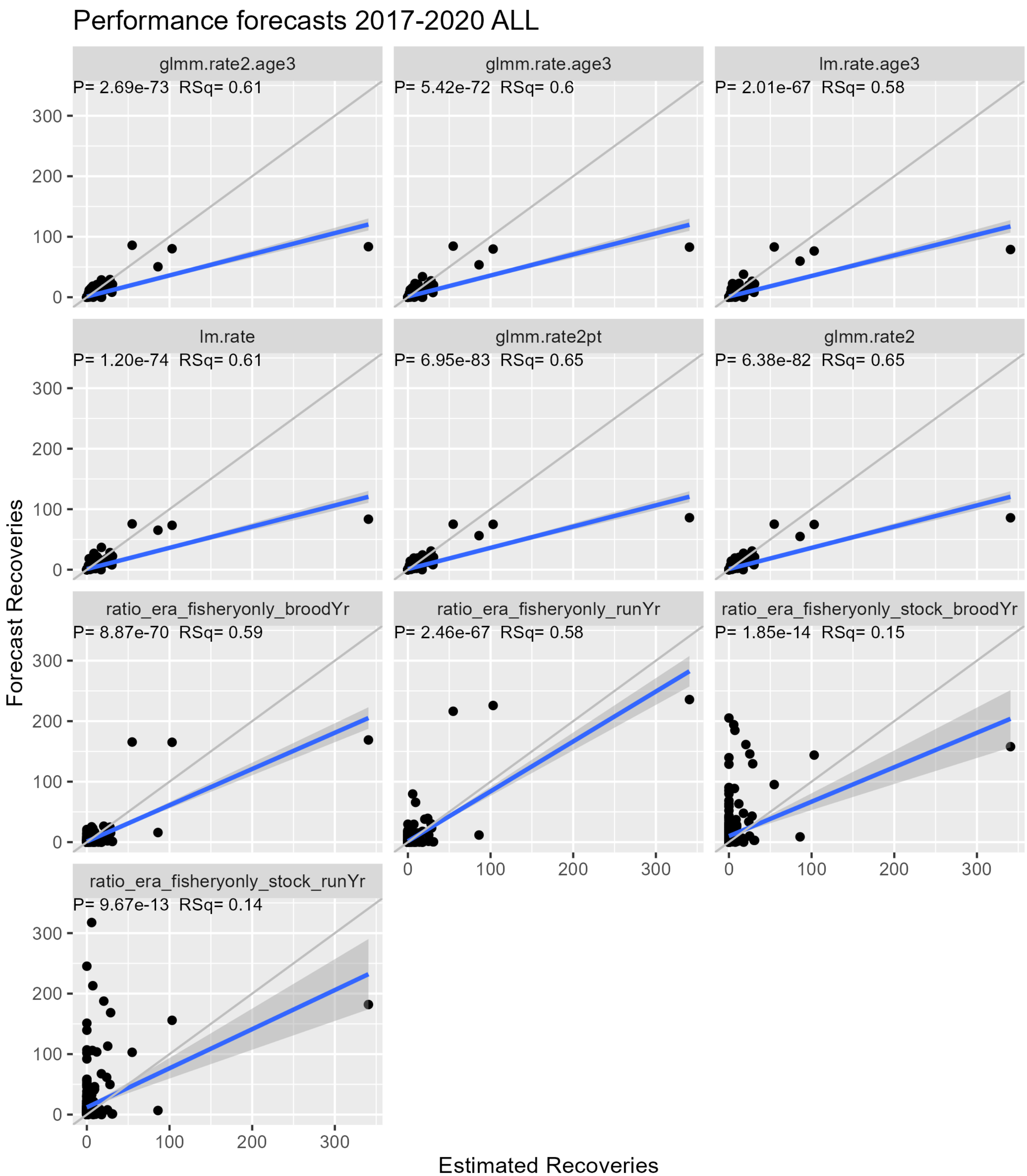

Figure 18: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

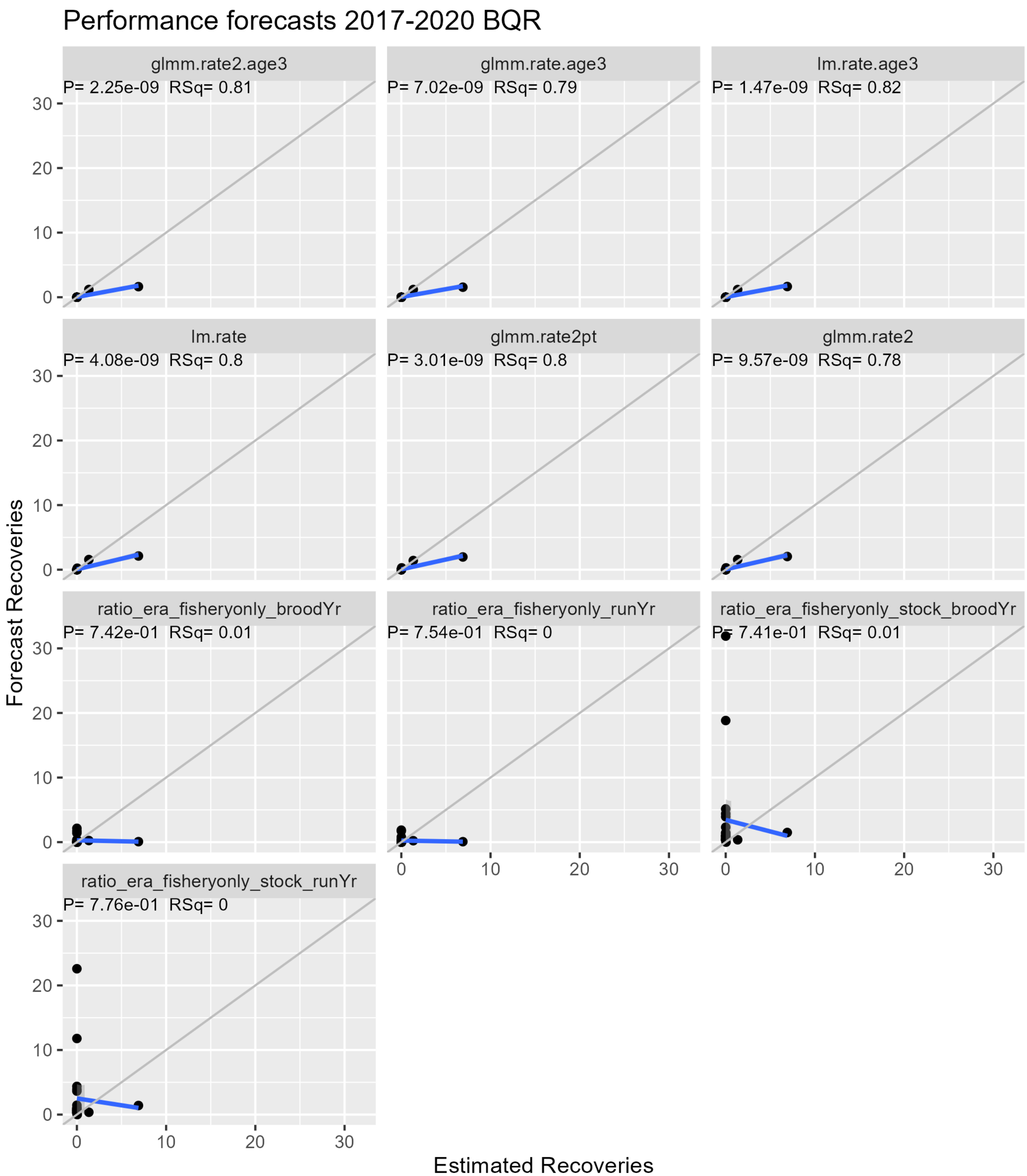

Figure 19: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

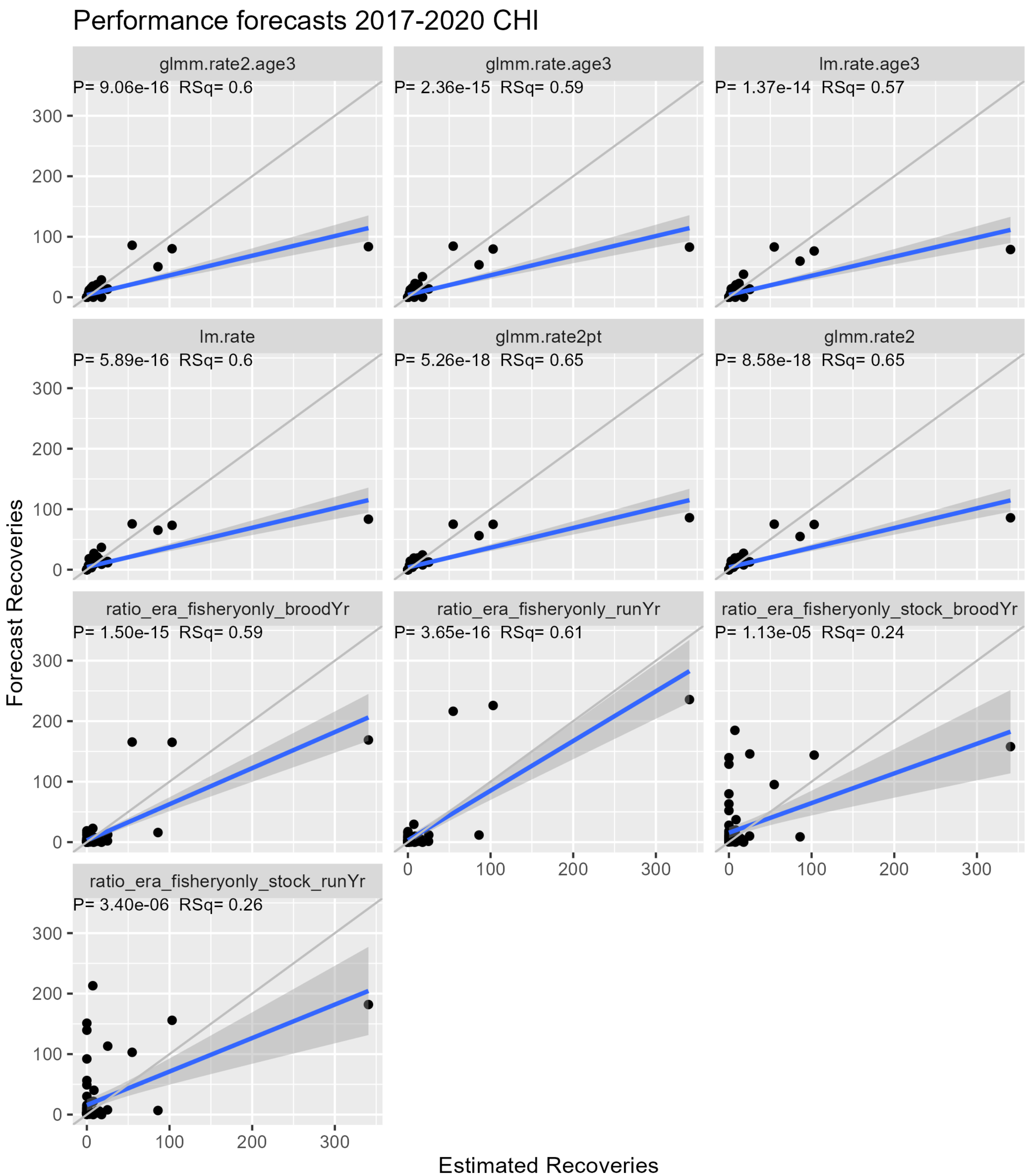

Figure 20: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

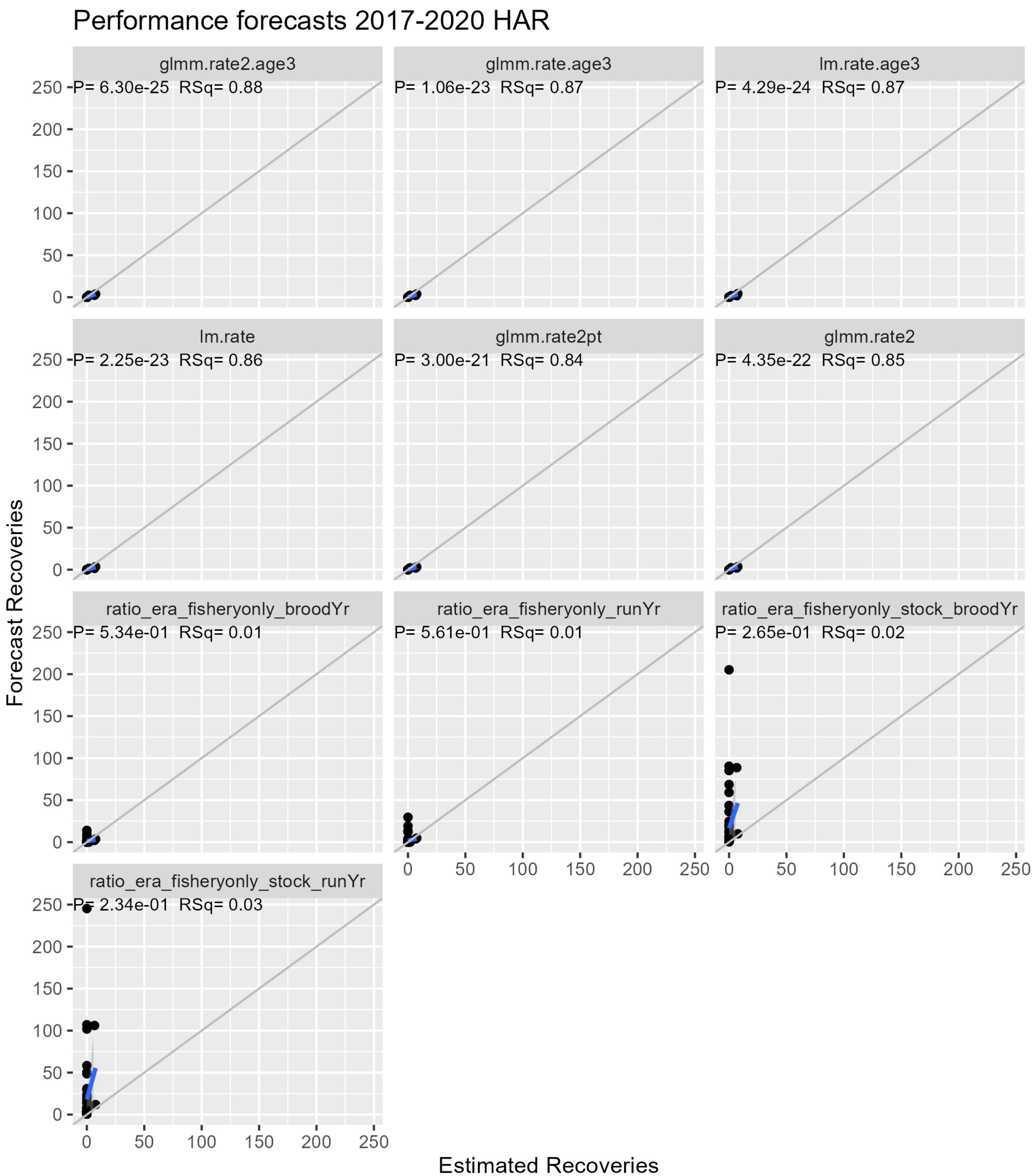

Figure 21: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

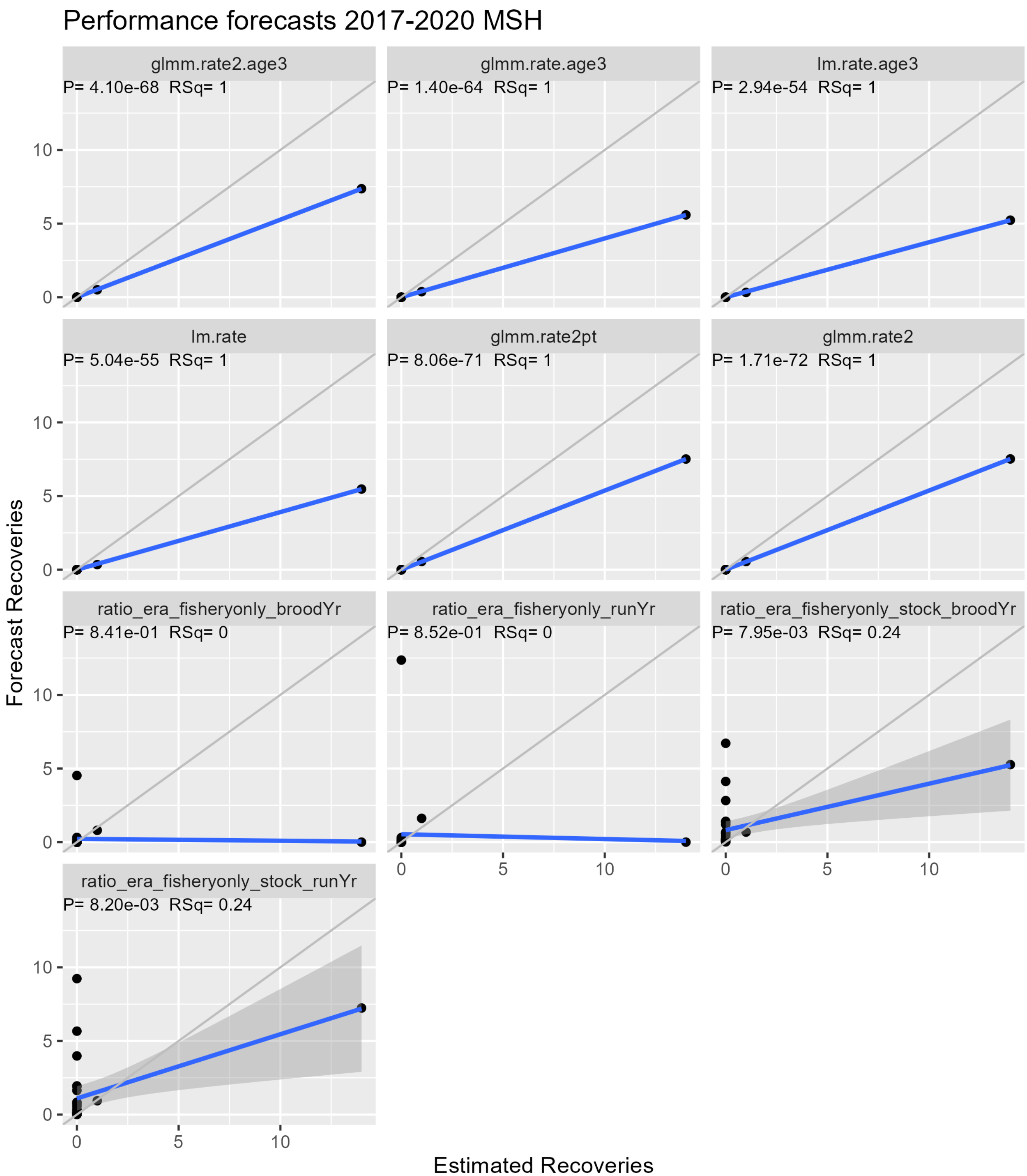

Figure 22: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

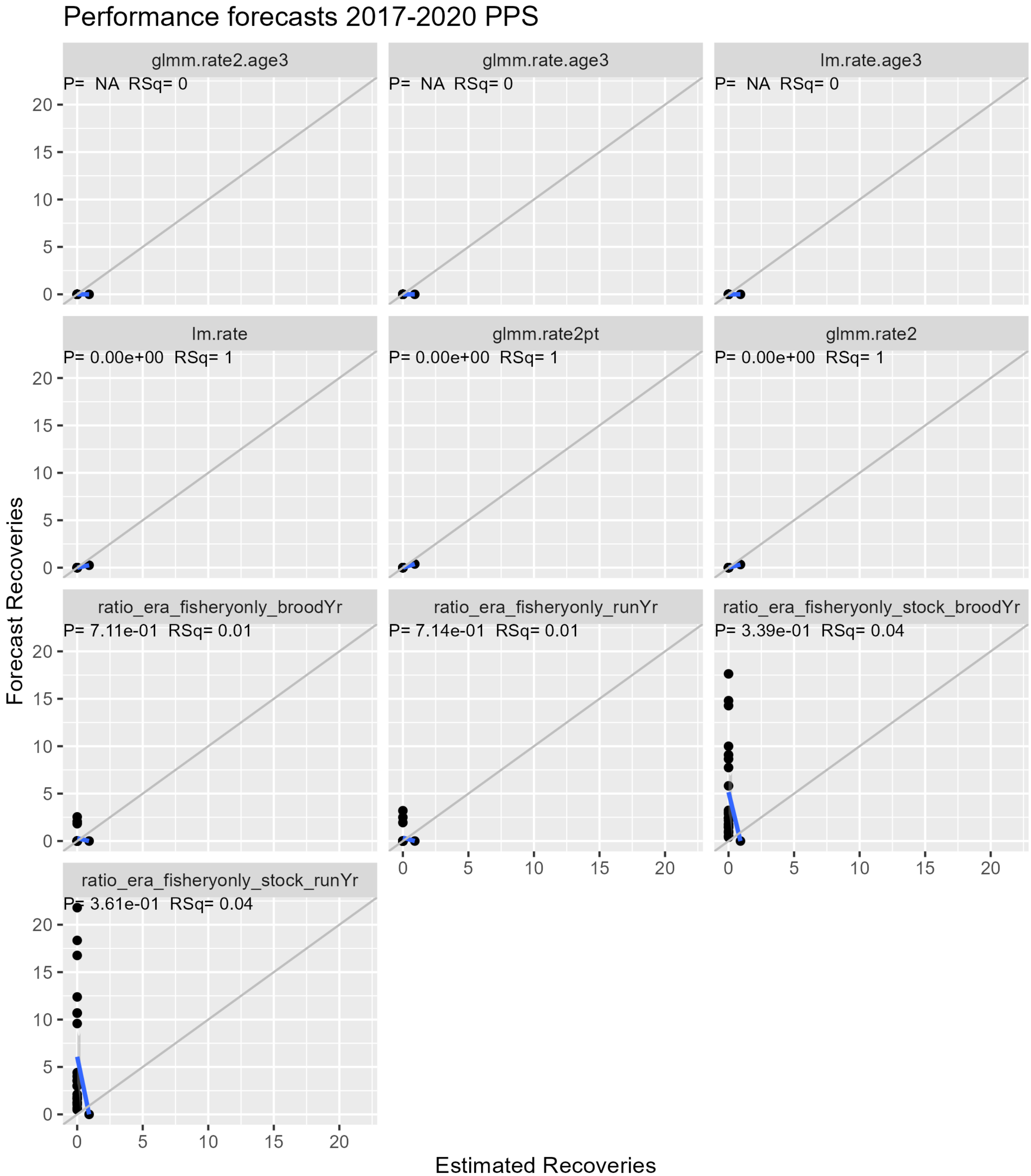

Figure 23: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

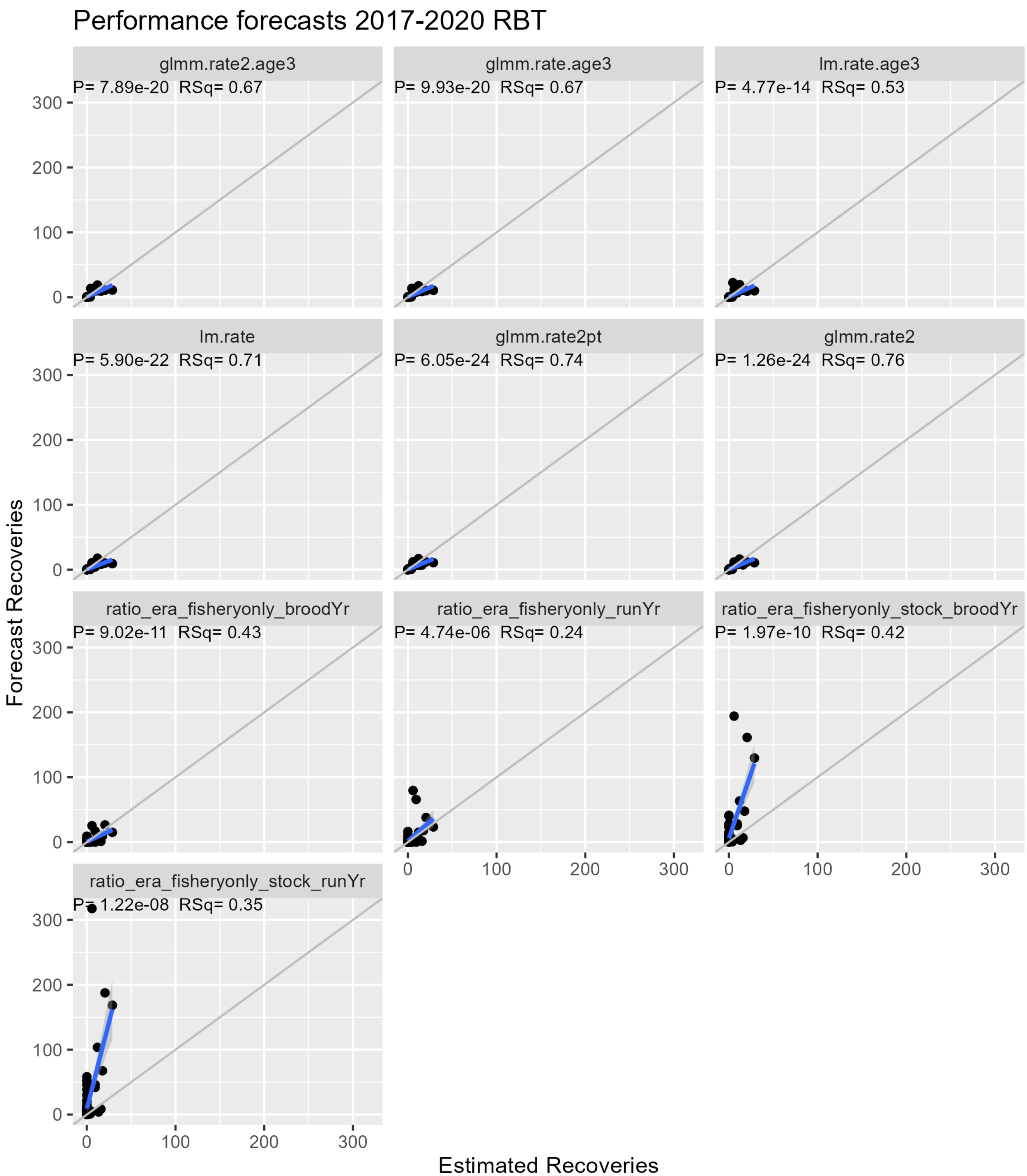

Figure 24: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

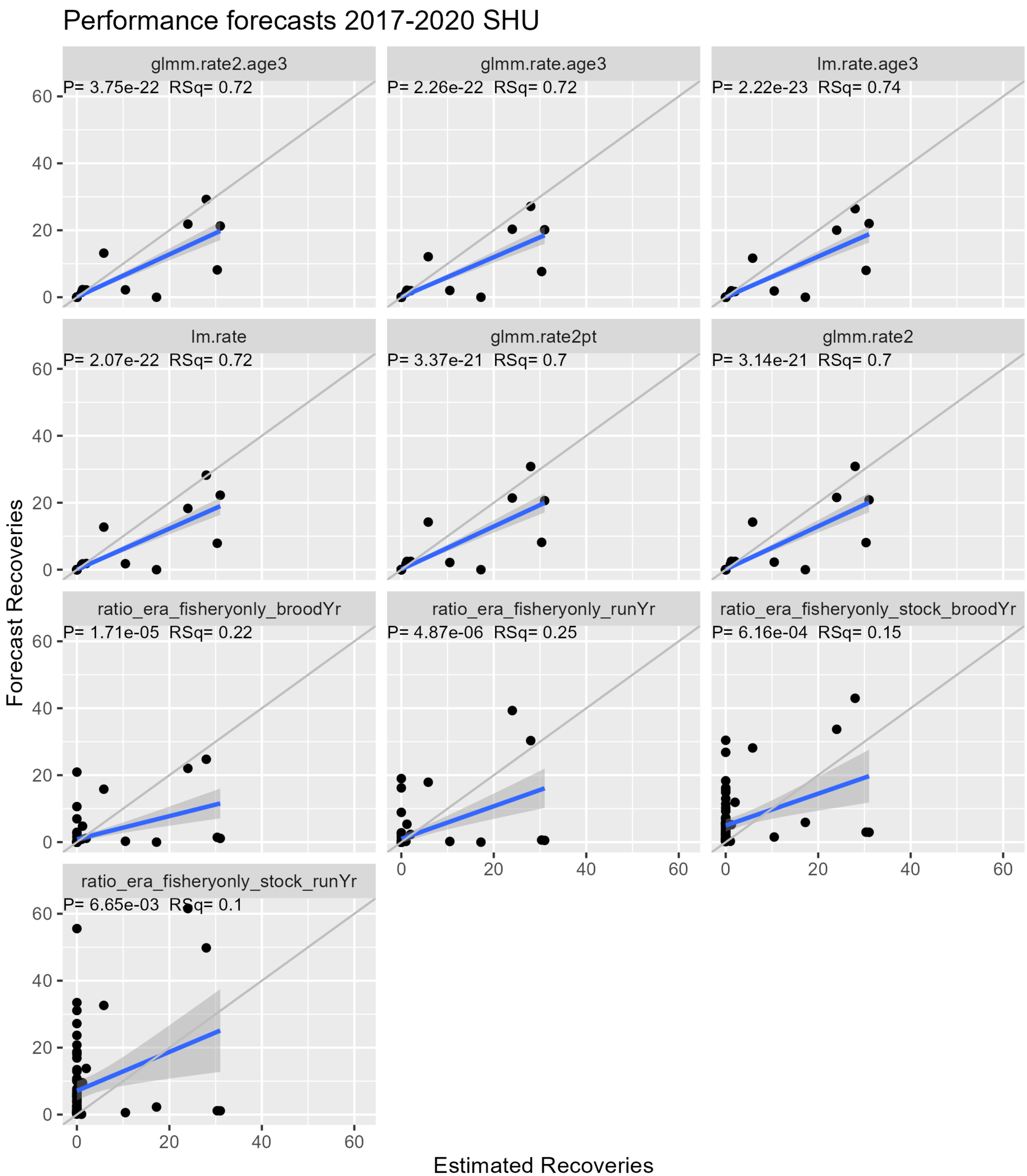

Figure 25: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for all ERA fisheries, excluding escapement. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

Stock-specific retrospective forecasts, by model type, for escapement only

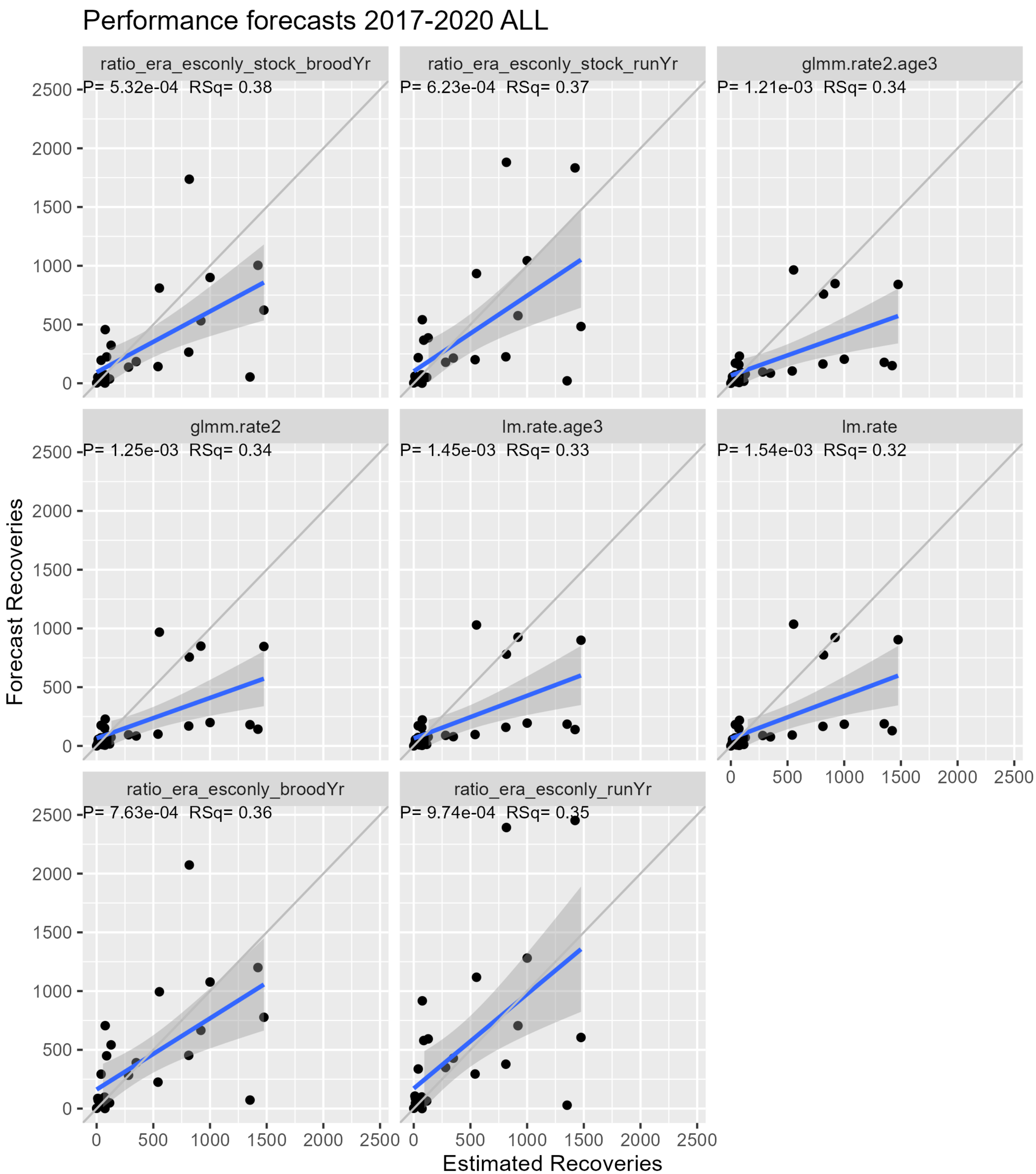

Figure 26: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

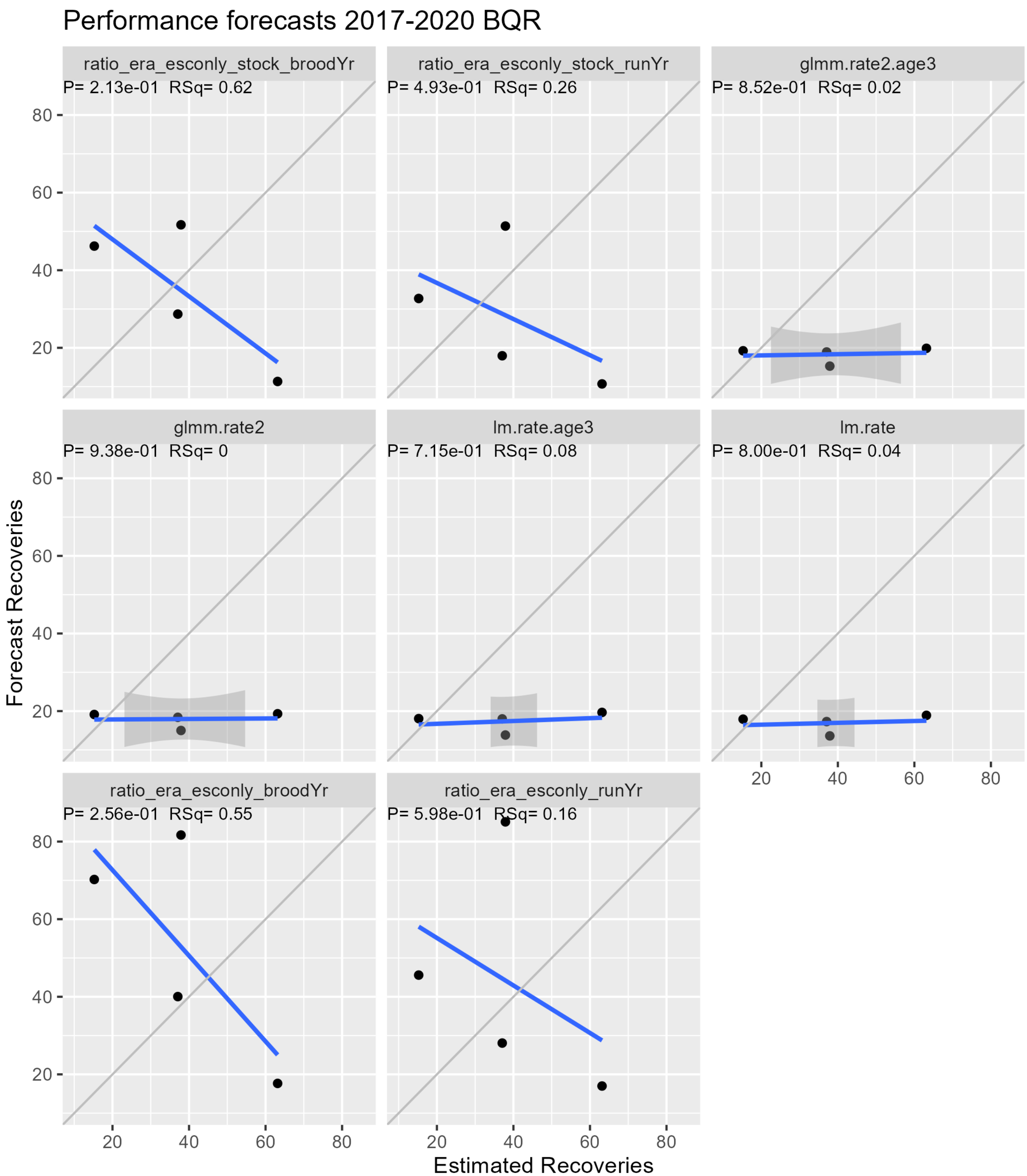

Figure 27: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

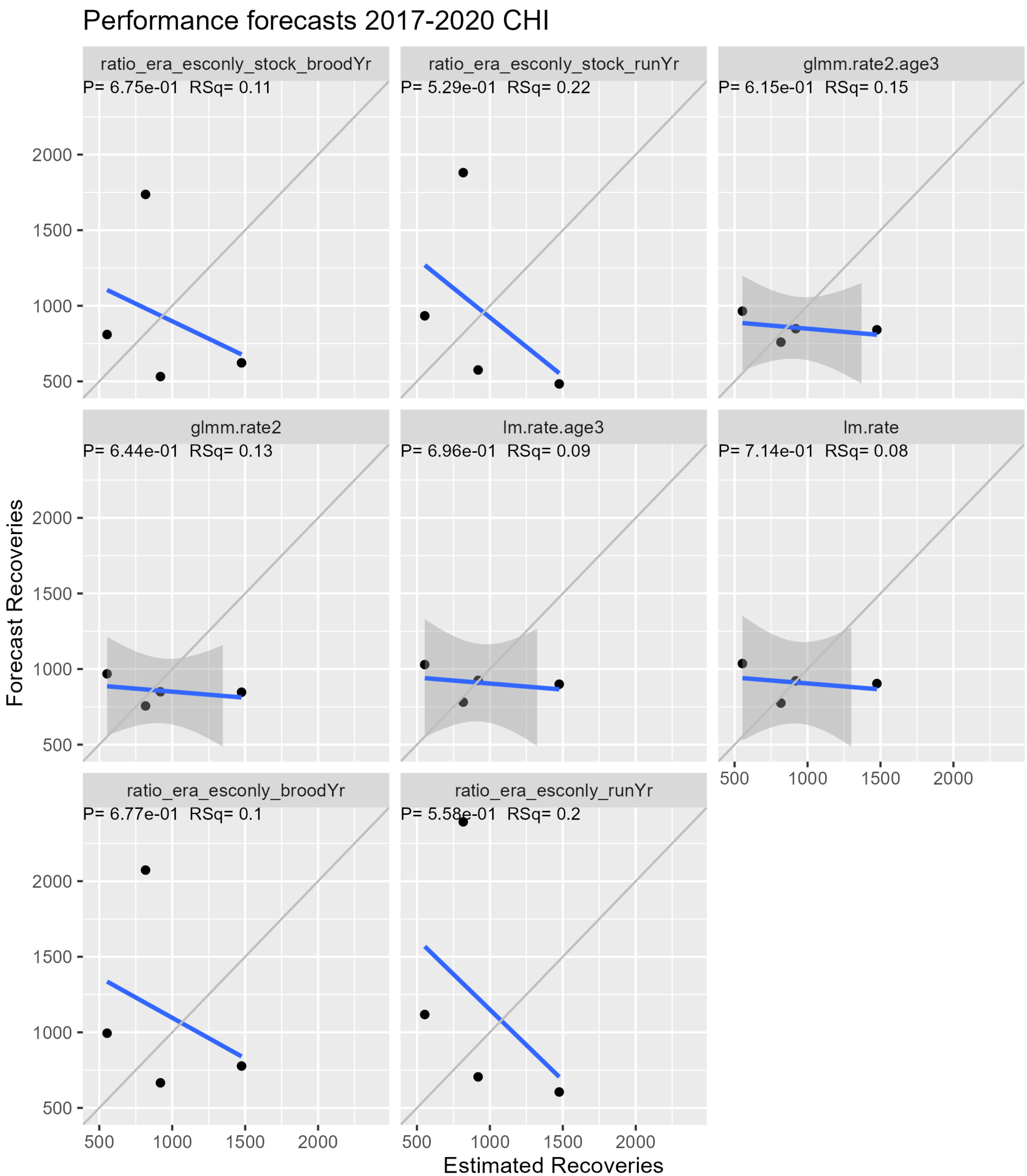

Figure 28: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

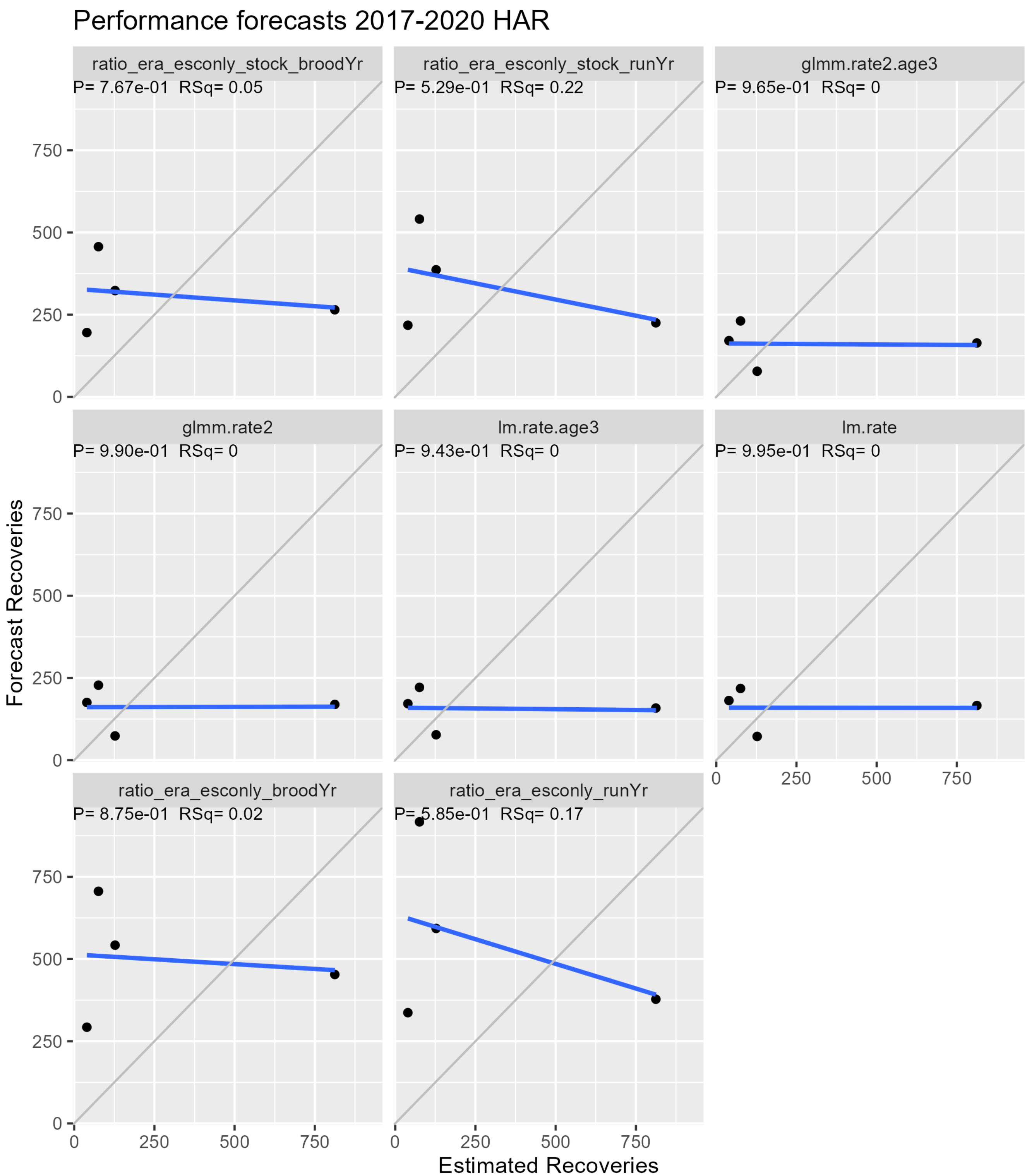

Figure 29: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

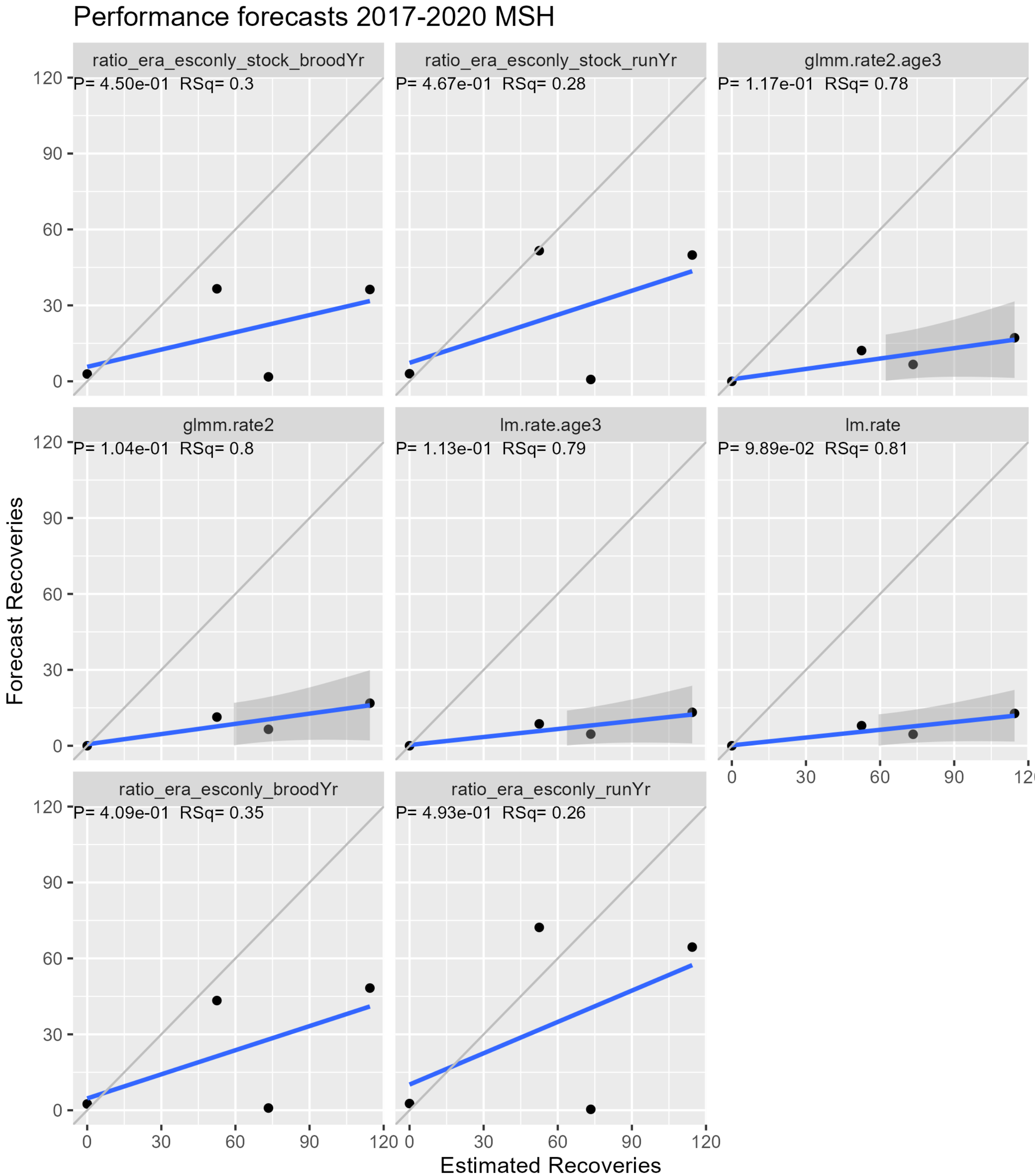

Figure 30: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

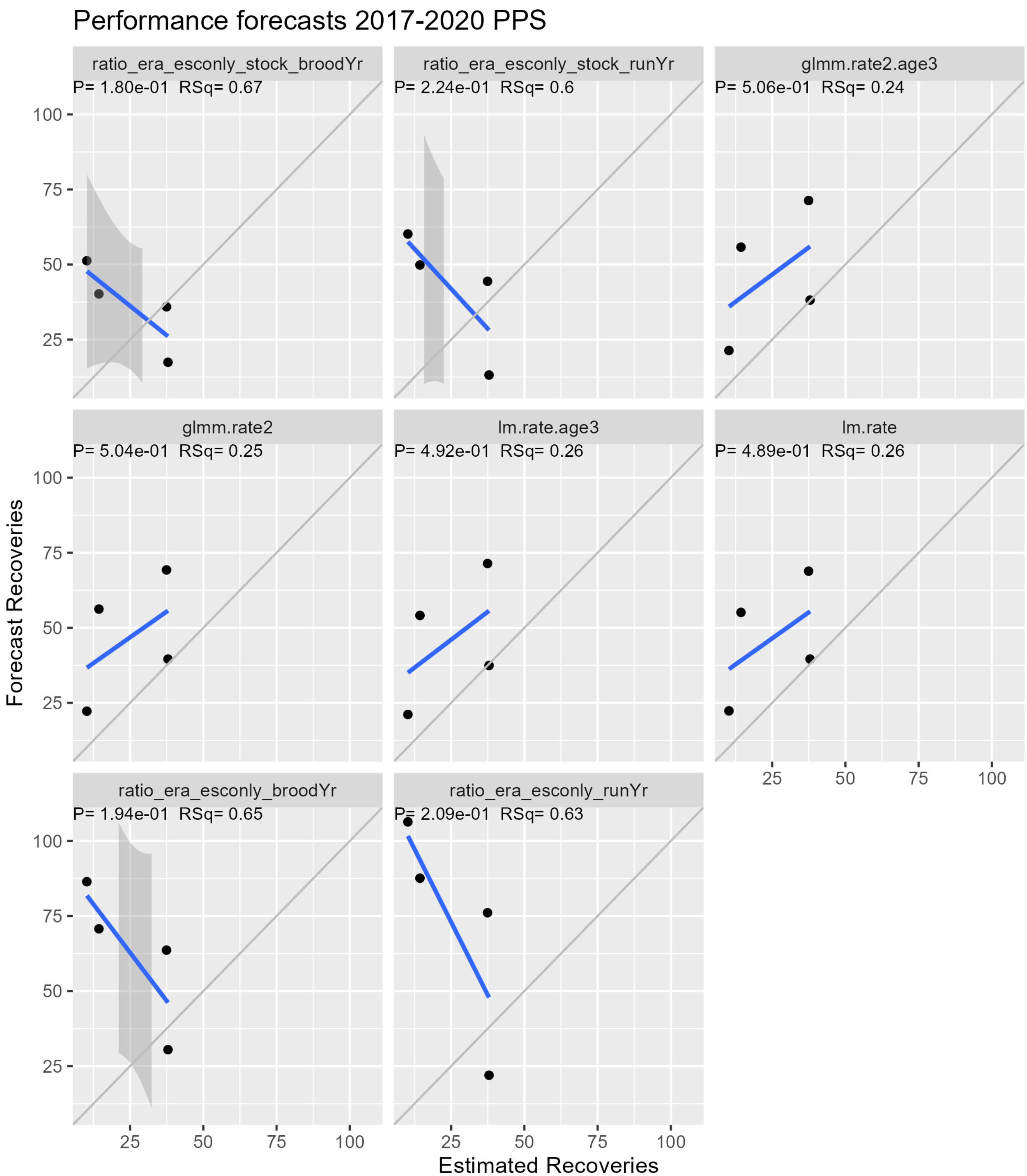

Figure 31: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

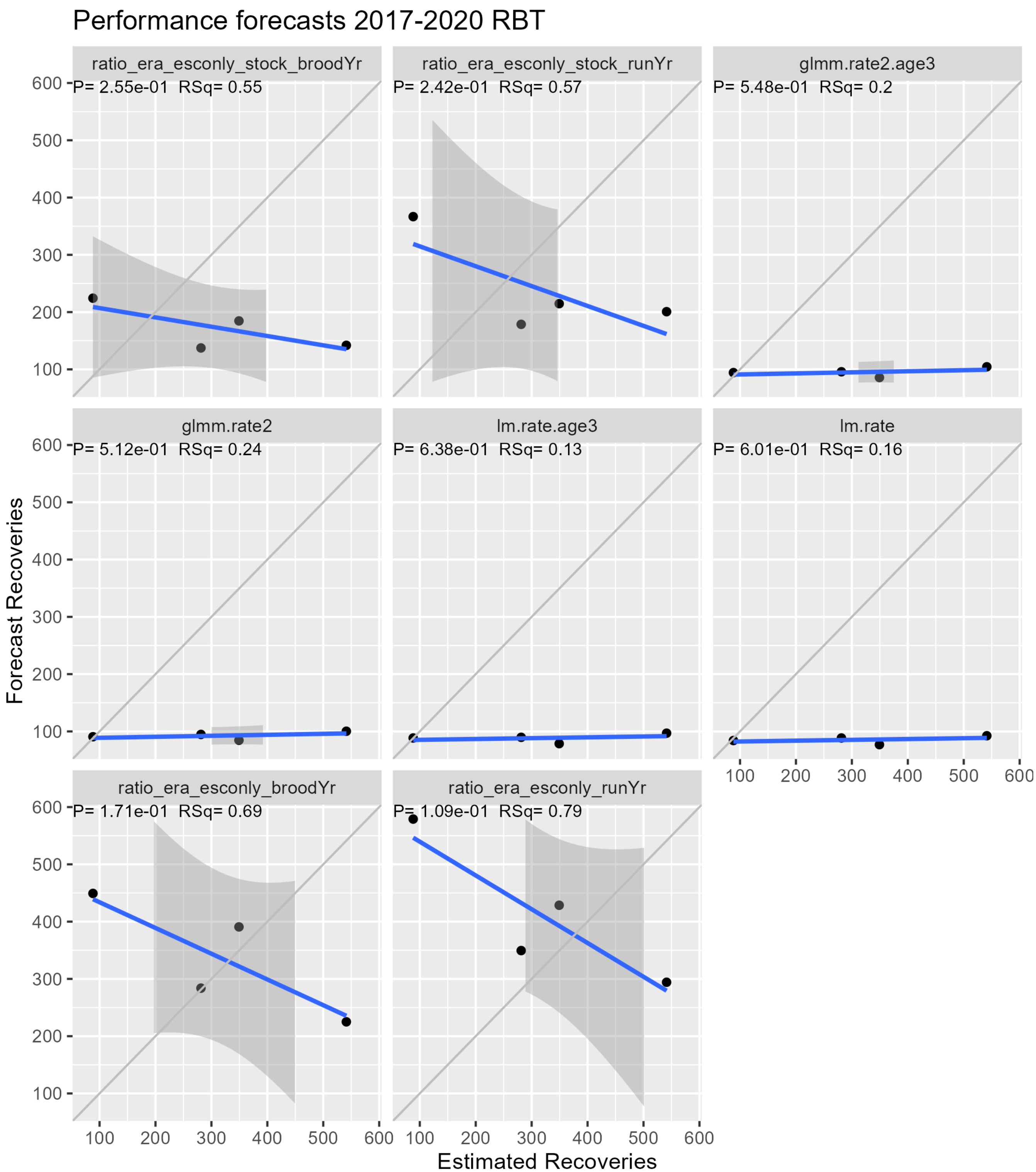

Figure 32: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

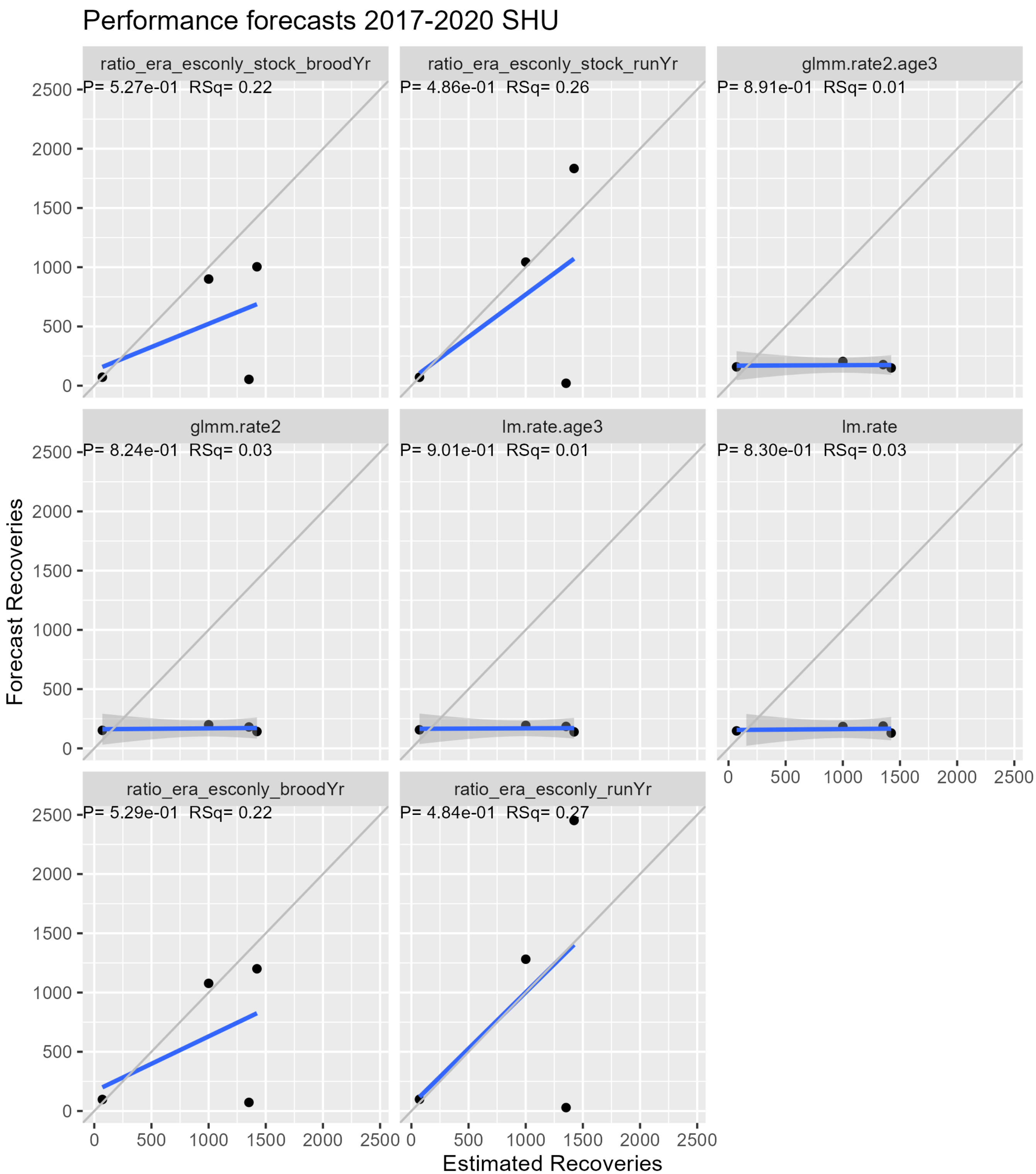

Figure 33: Comparison of predicted and observed age two CWT estimates from retrospective evaluation for years 2017–2020. Each page represents one stock, for escapement only. Each panel is a forecasting model, identified by its name. Each grey line has a slope of one, and points falling close to the line represent better forecasts.

Forecasts 2019-2020 and historic recovery quantiles

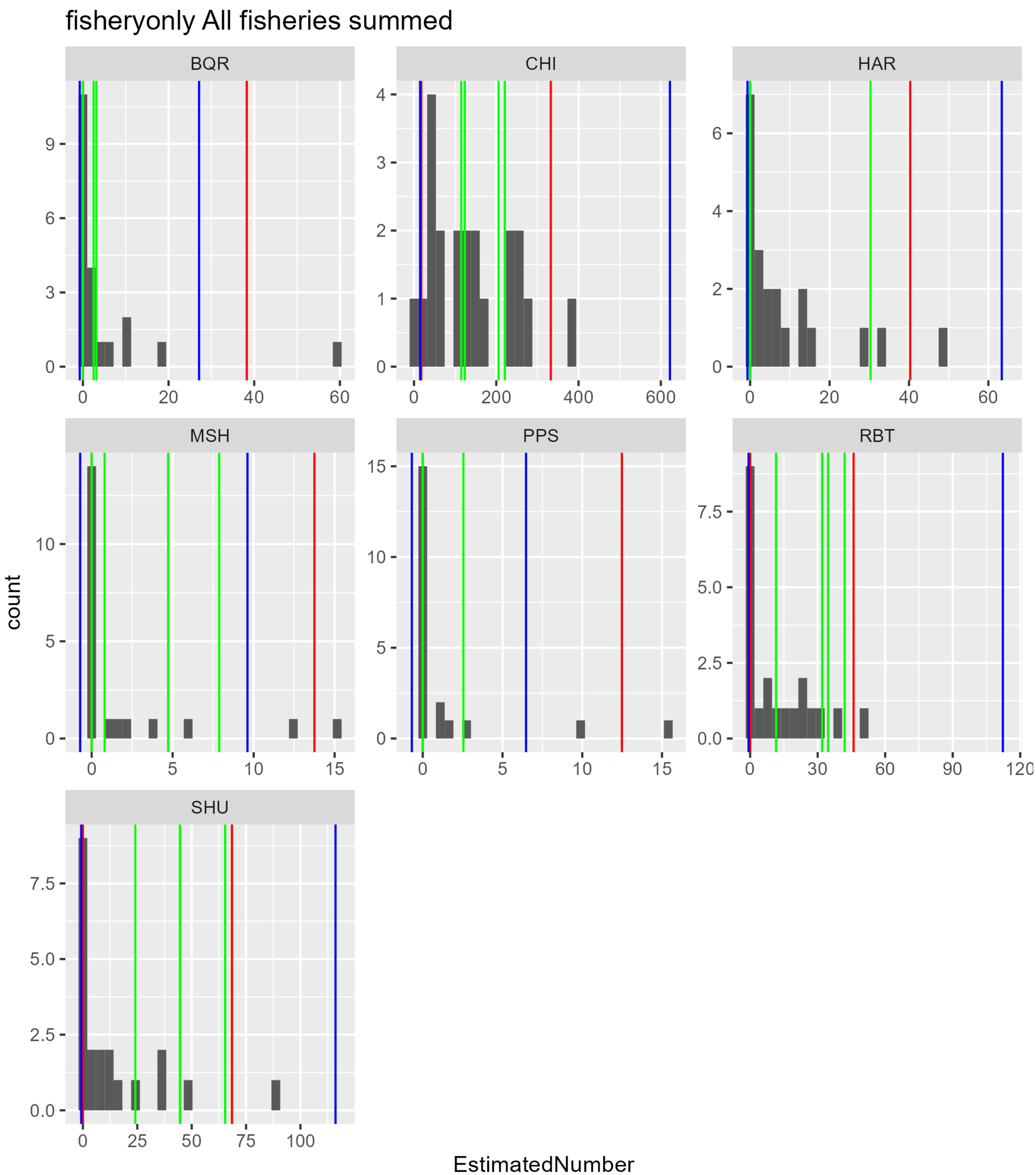

Figure 34: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Fishery recoveries are summed by stock. To allow for comparison, the stock-fishery specific forecasts are also summed across fisheries. Each panel is recoveries of a stock for all fisheries. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

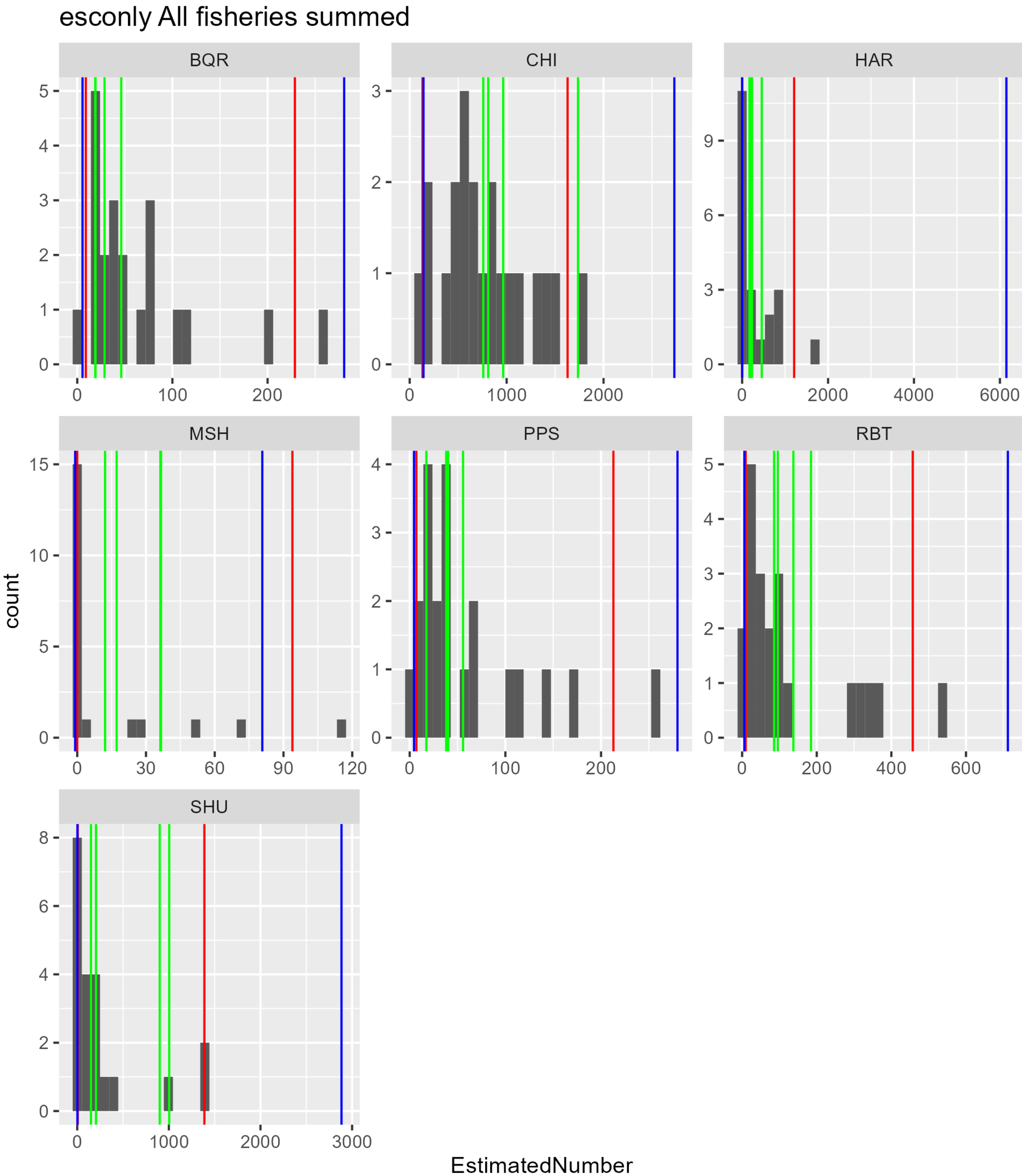

Figure 35: Comparison of 2019 and 2020 escapement recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated escapement recoveries during 2000–2020 (black bars). Each panel is for recoveries of a stock in escapement. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

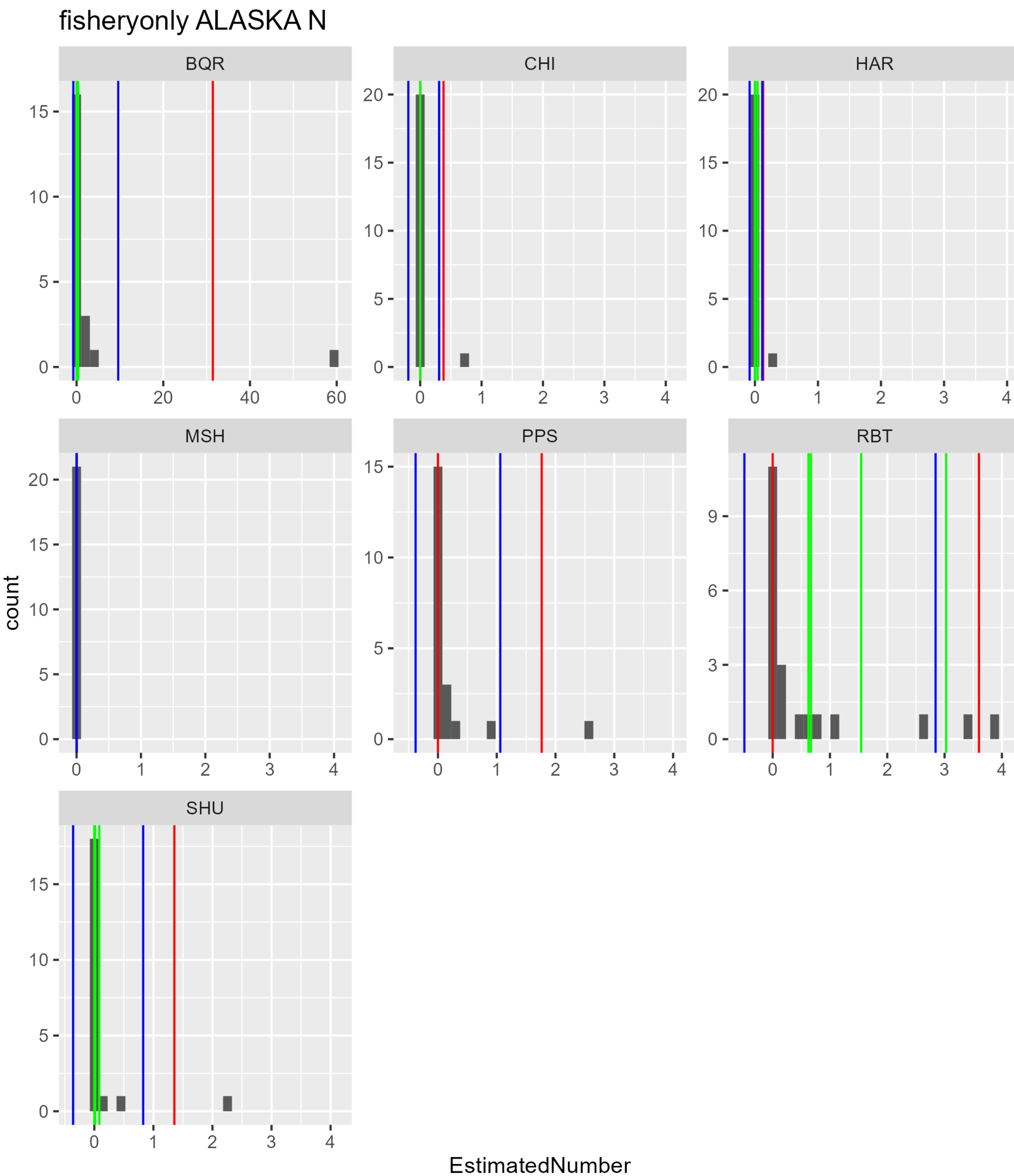

Figure 36: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

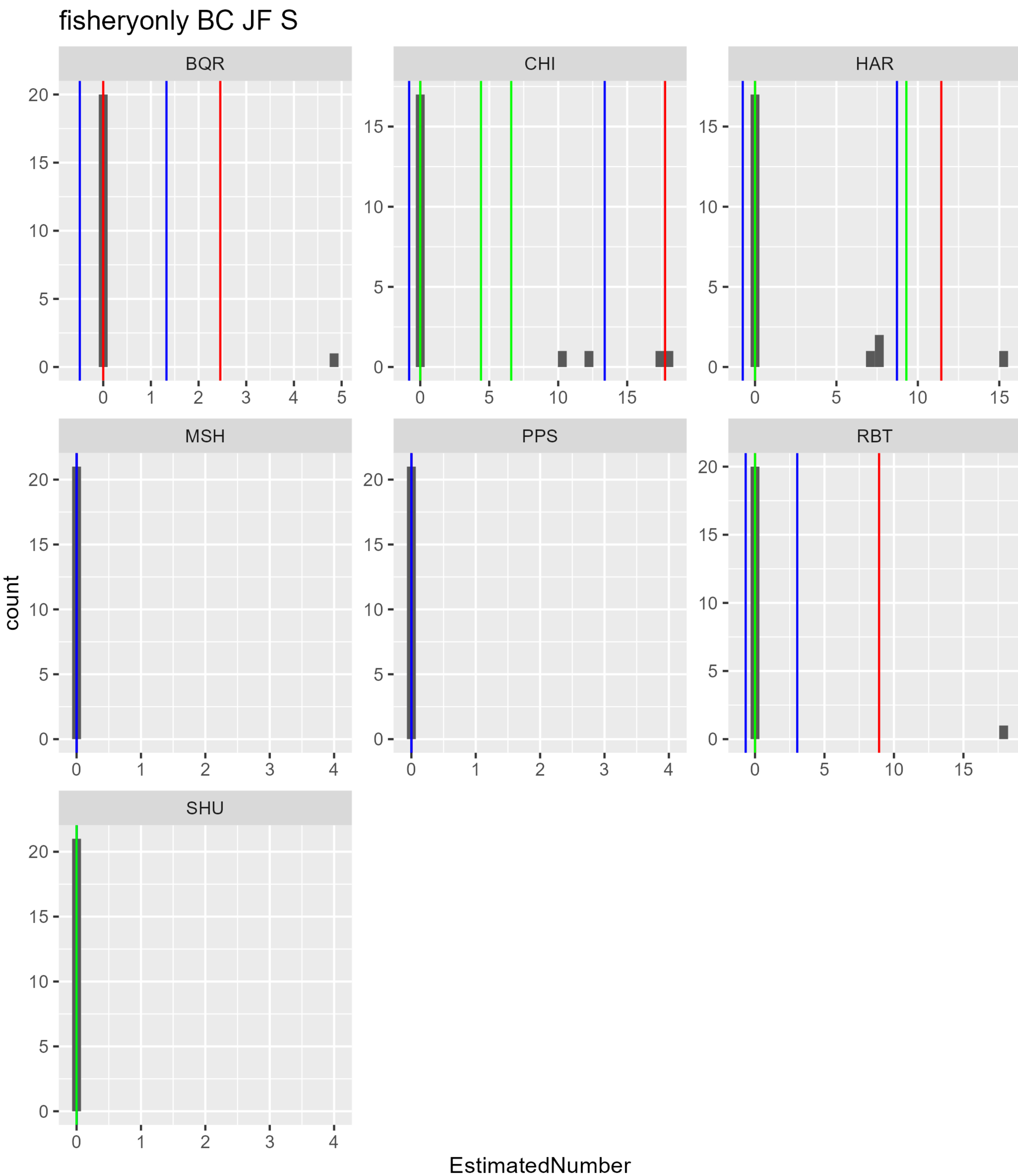

Figure 37: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

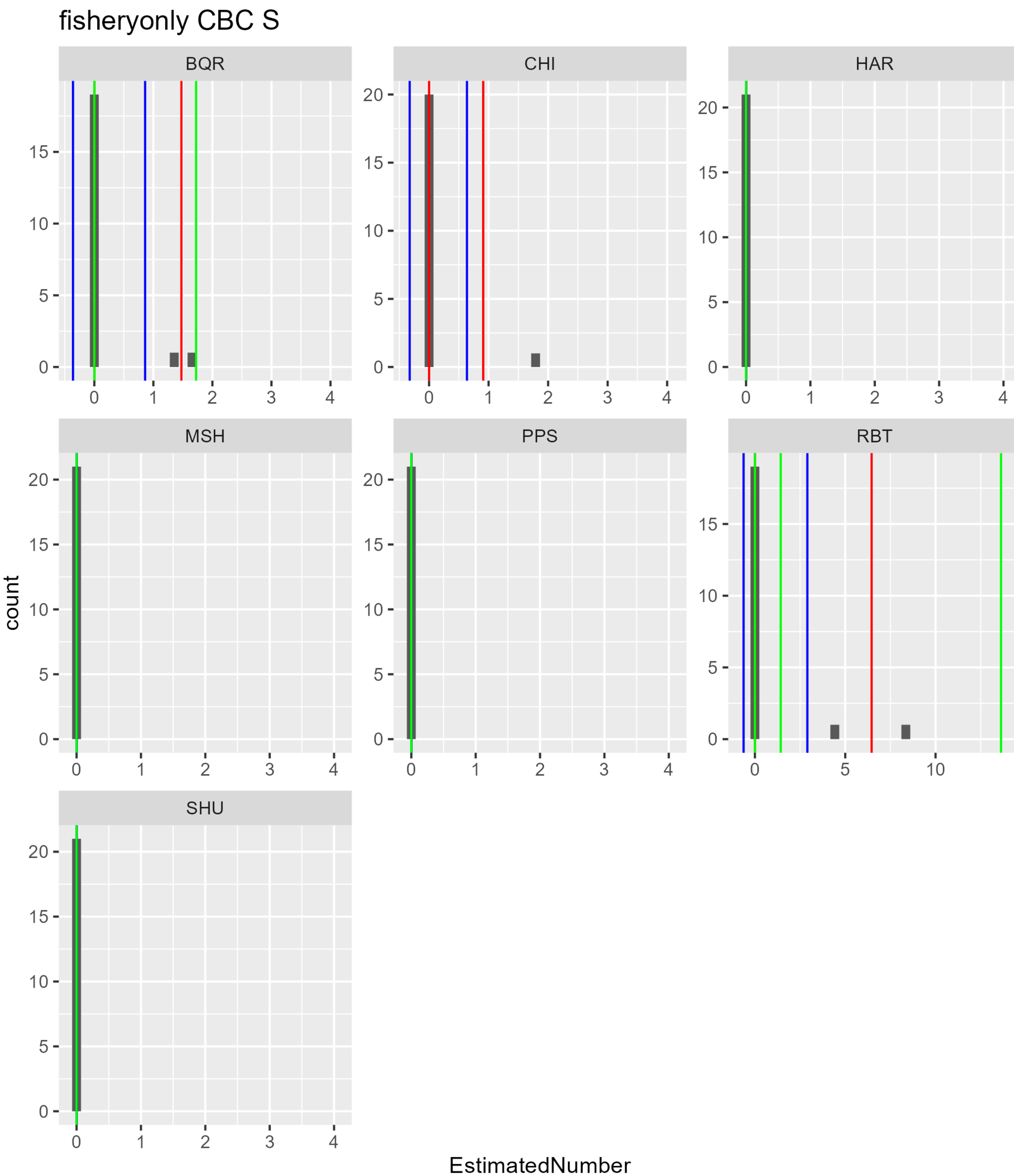

Figure 38: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

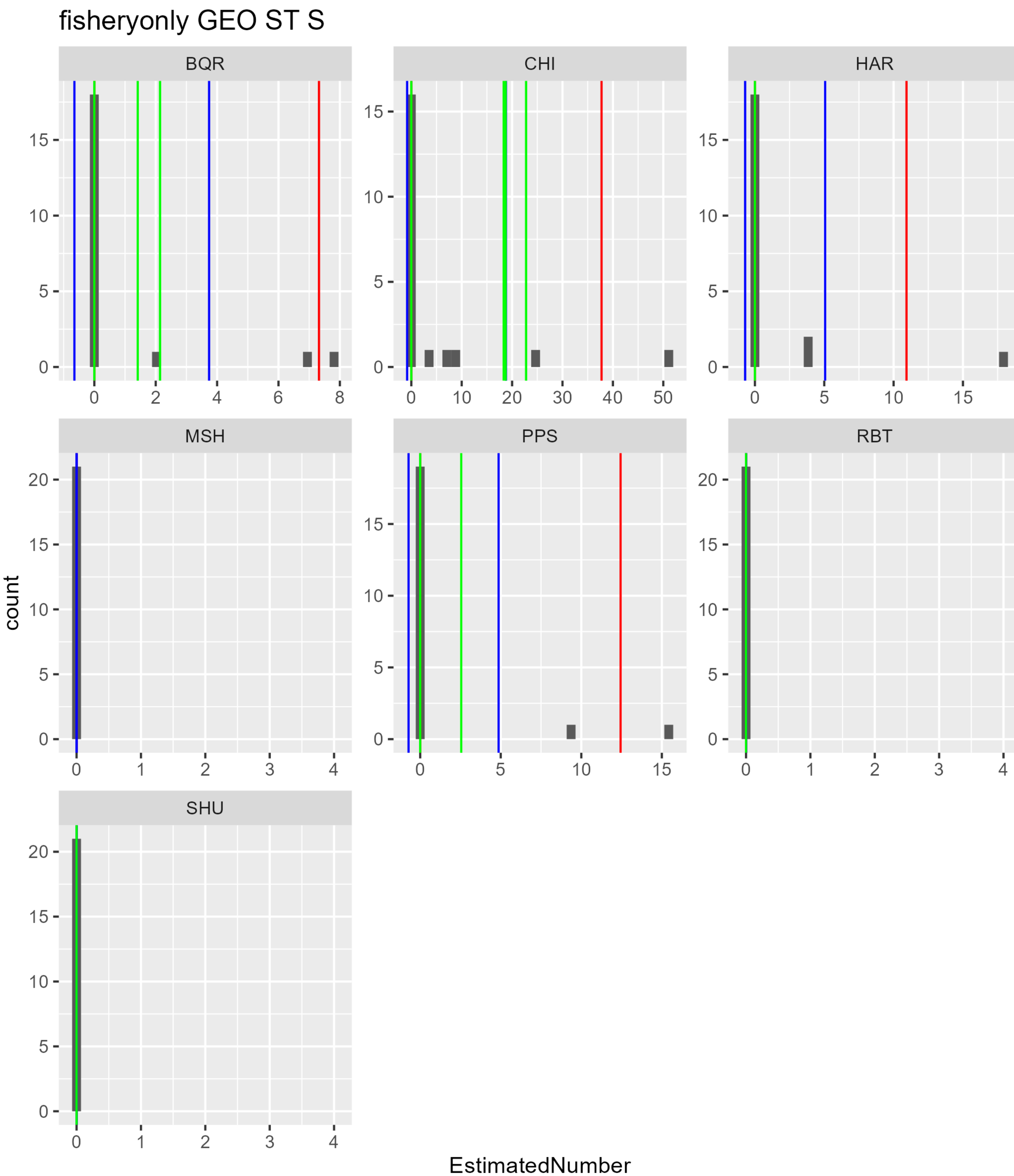

Figure 39: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

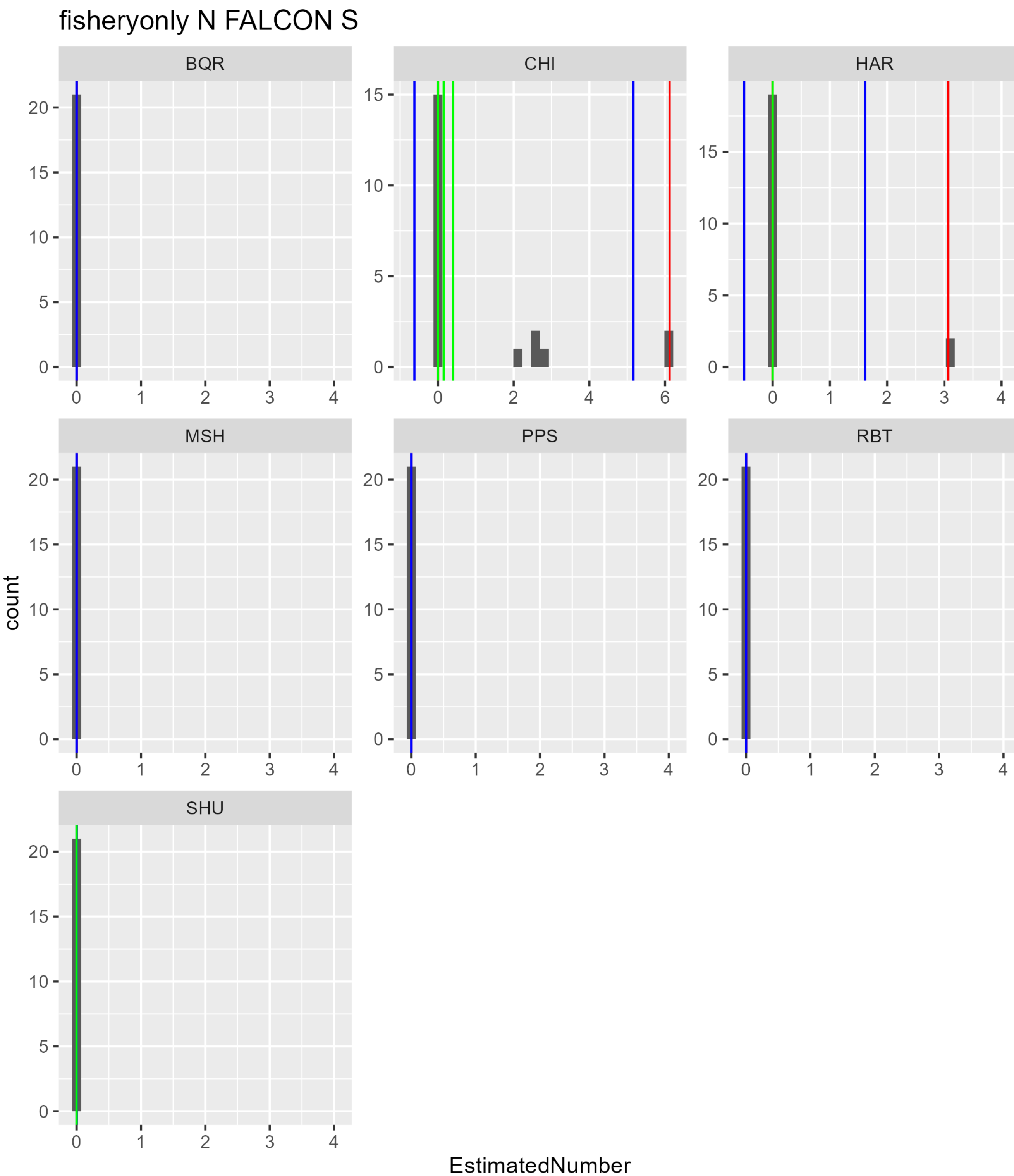

Figure 40: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

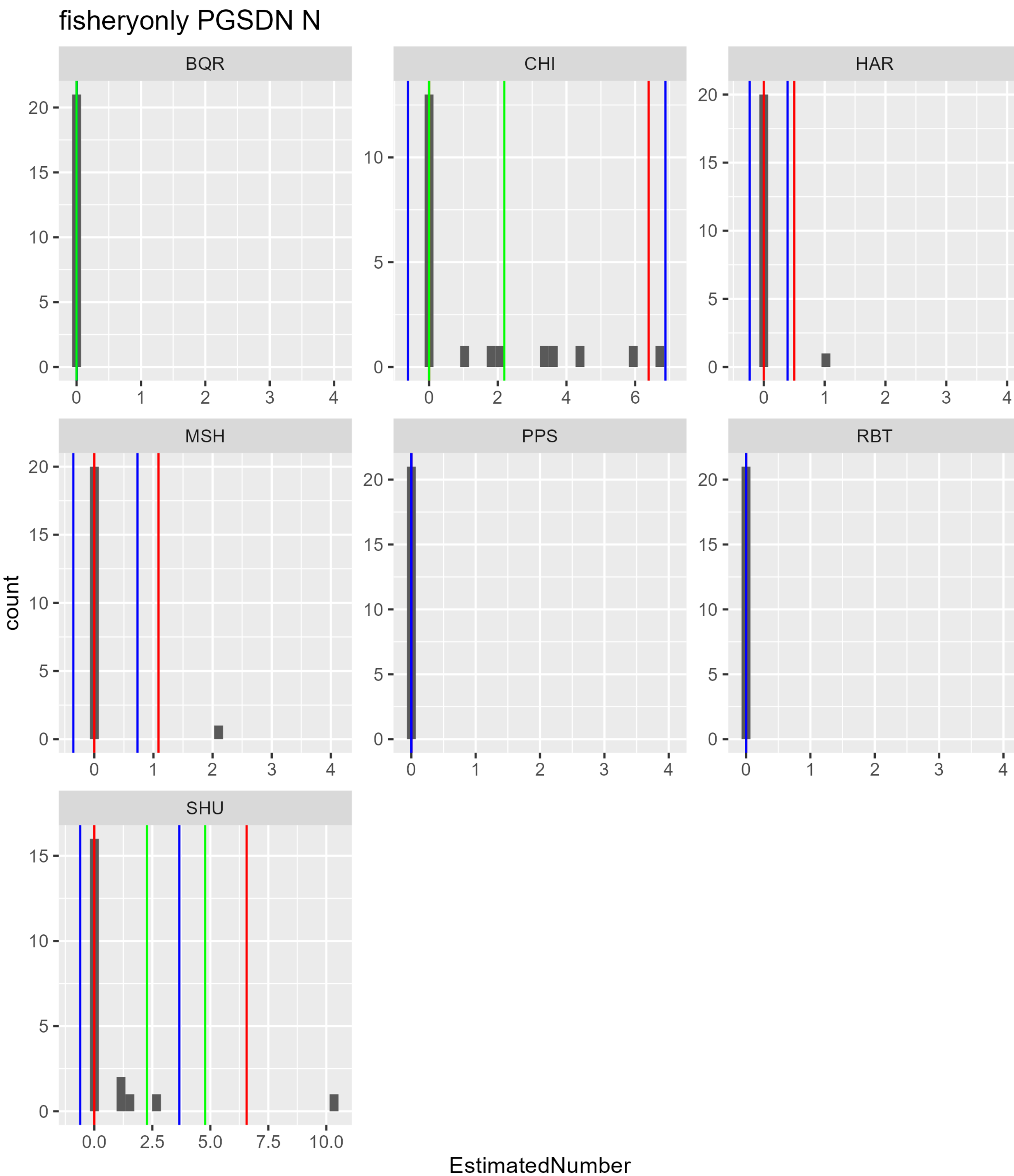

Figure 41: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

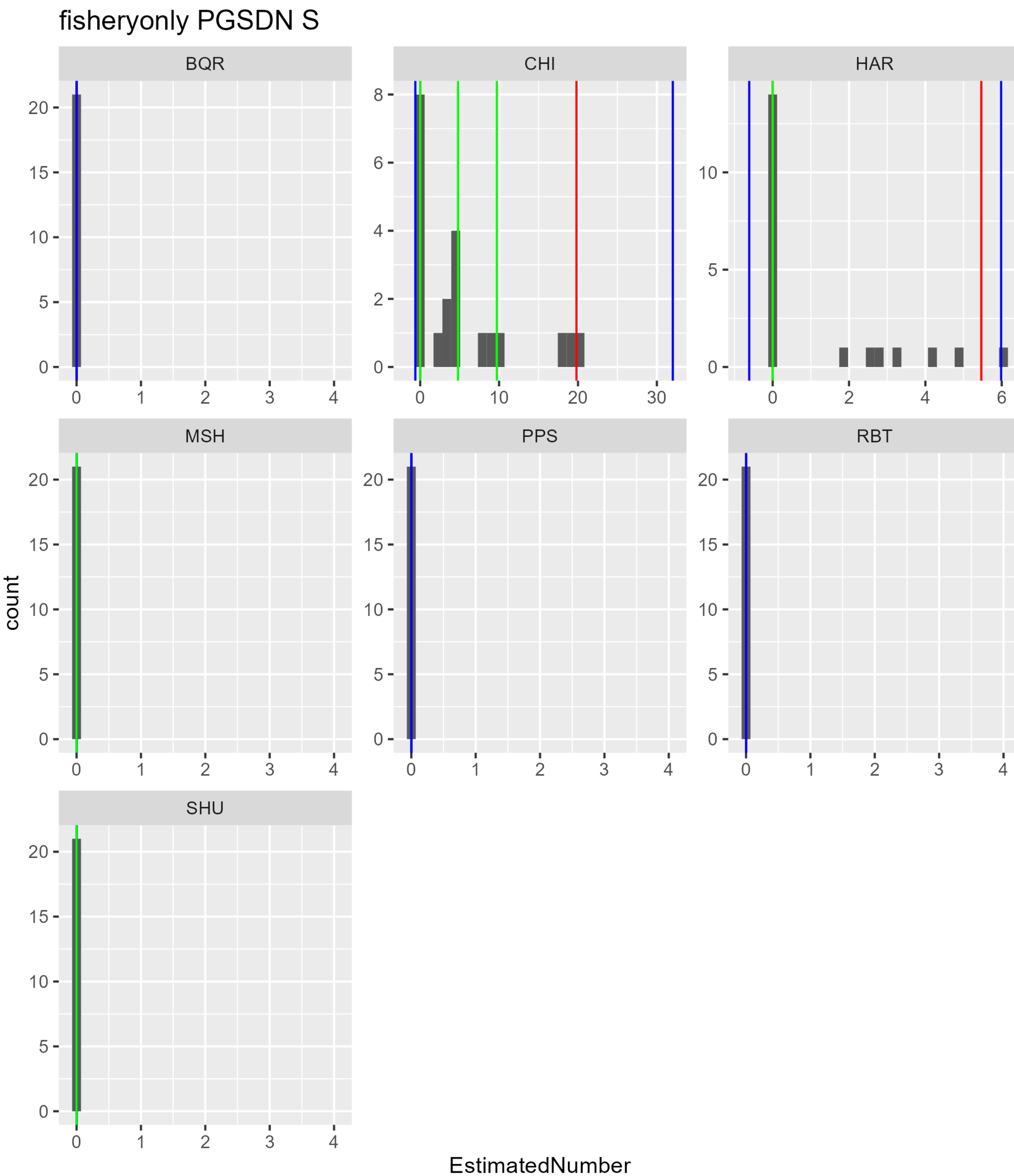

Figure 42: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

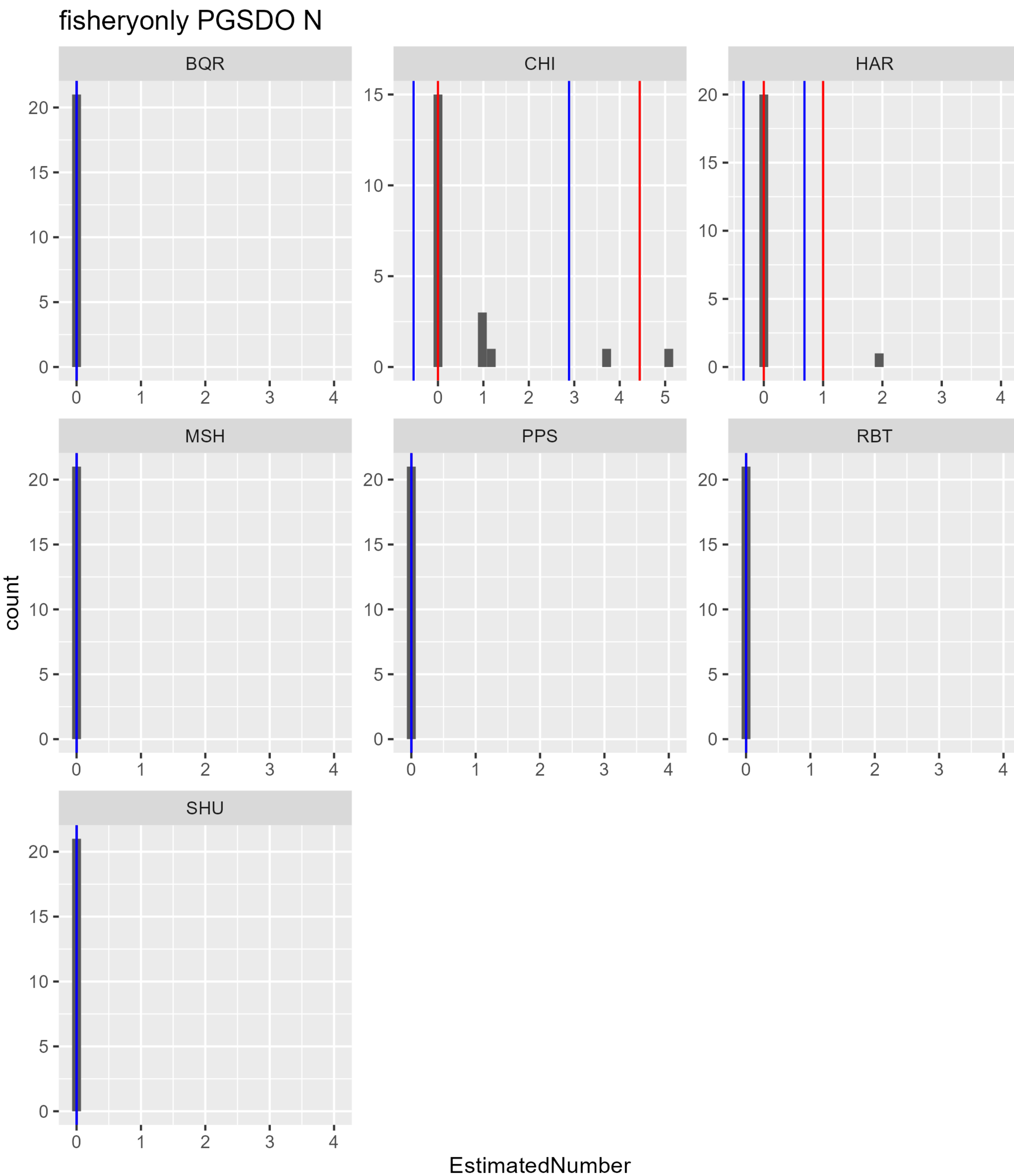

Figure 43: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

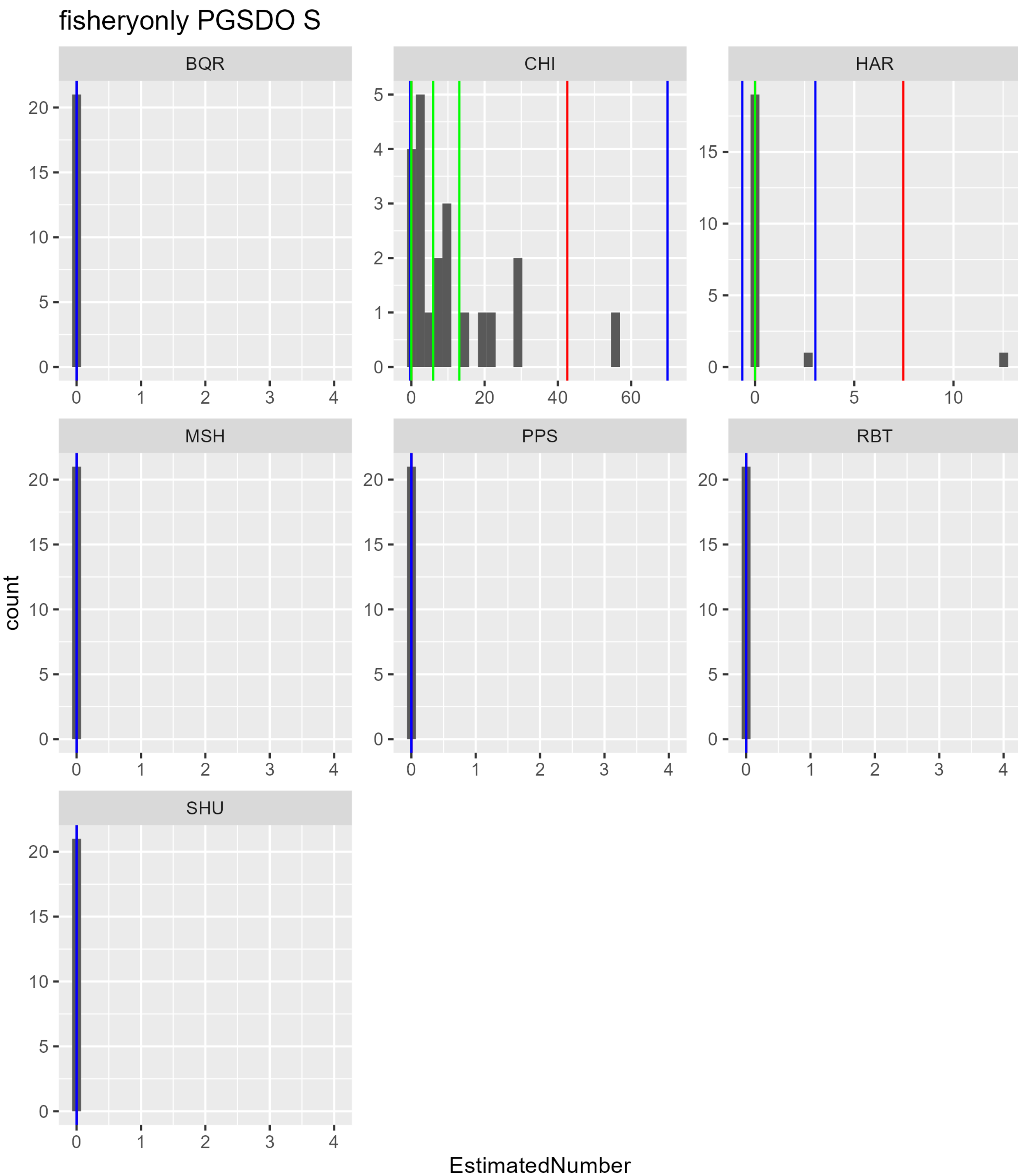

Figure 44: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

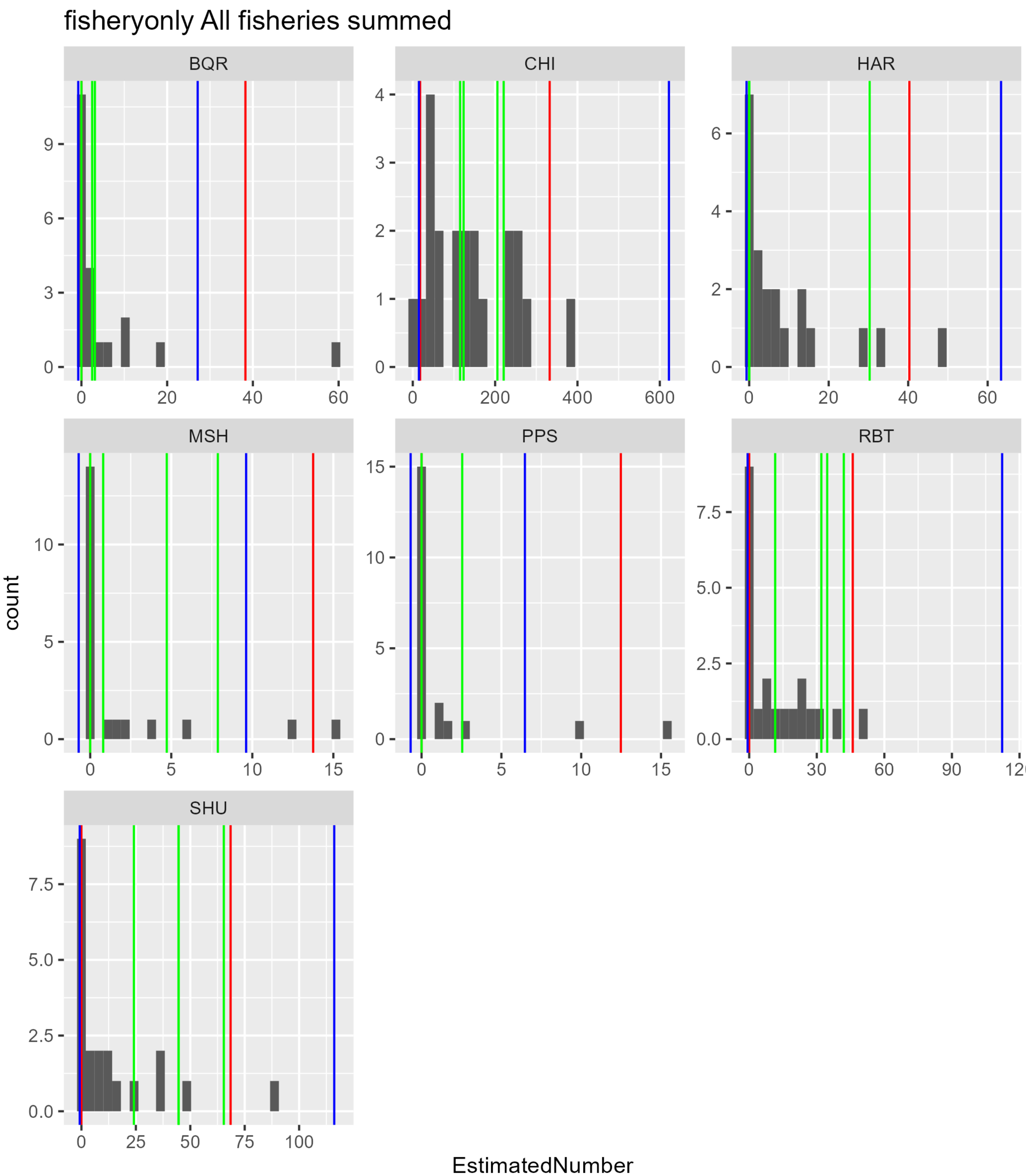

Figure 45: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

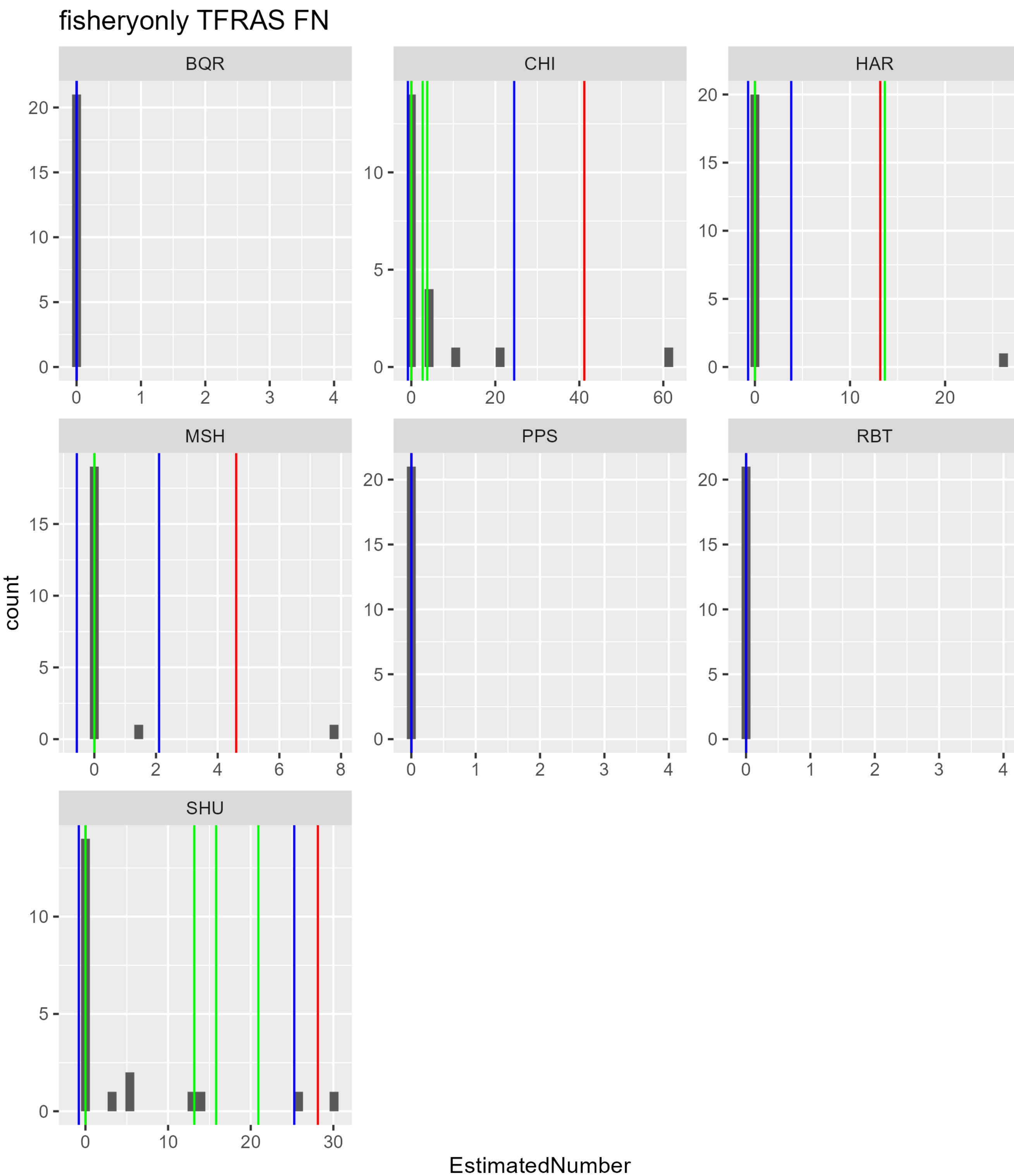

Figure 46: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

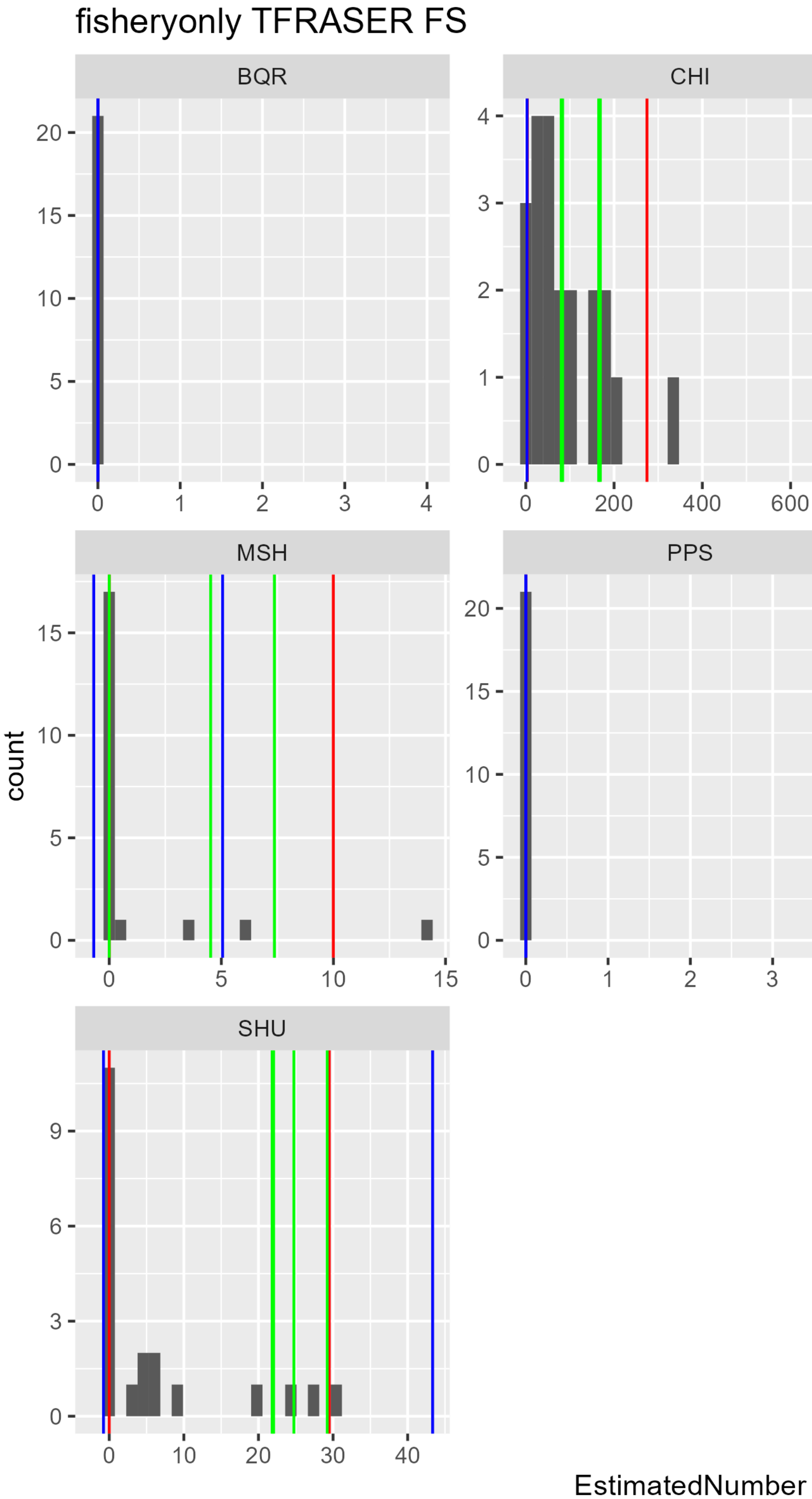

Figure 47: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

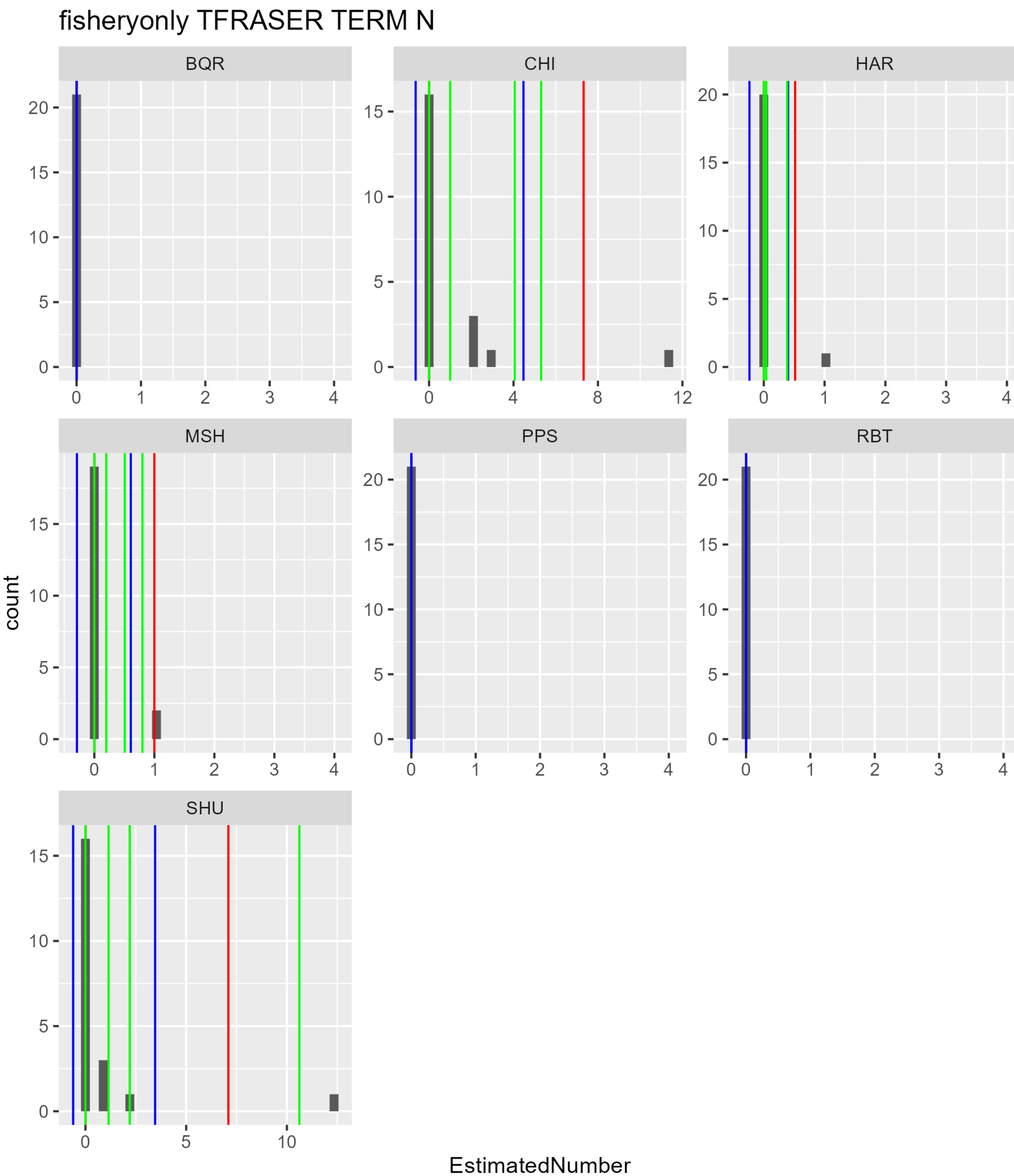

Figure 48: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

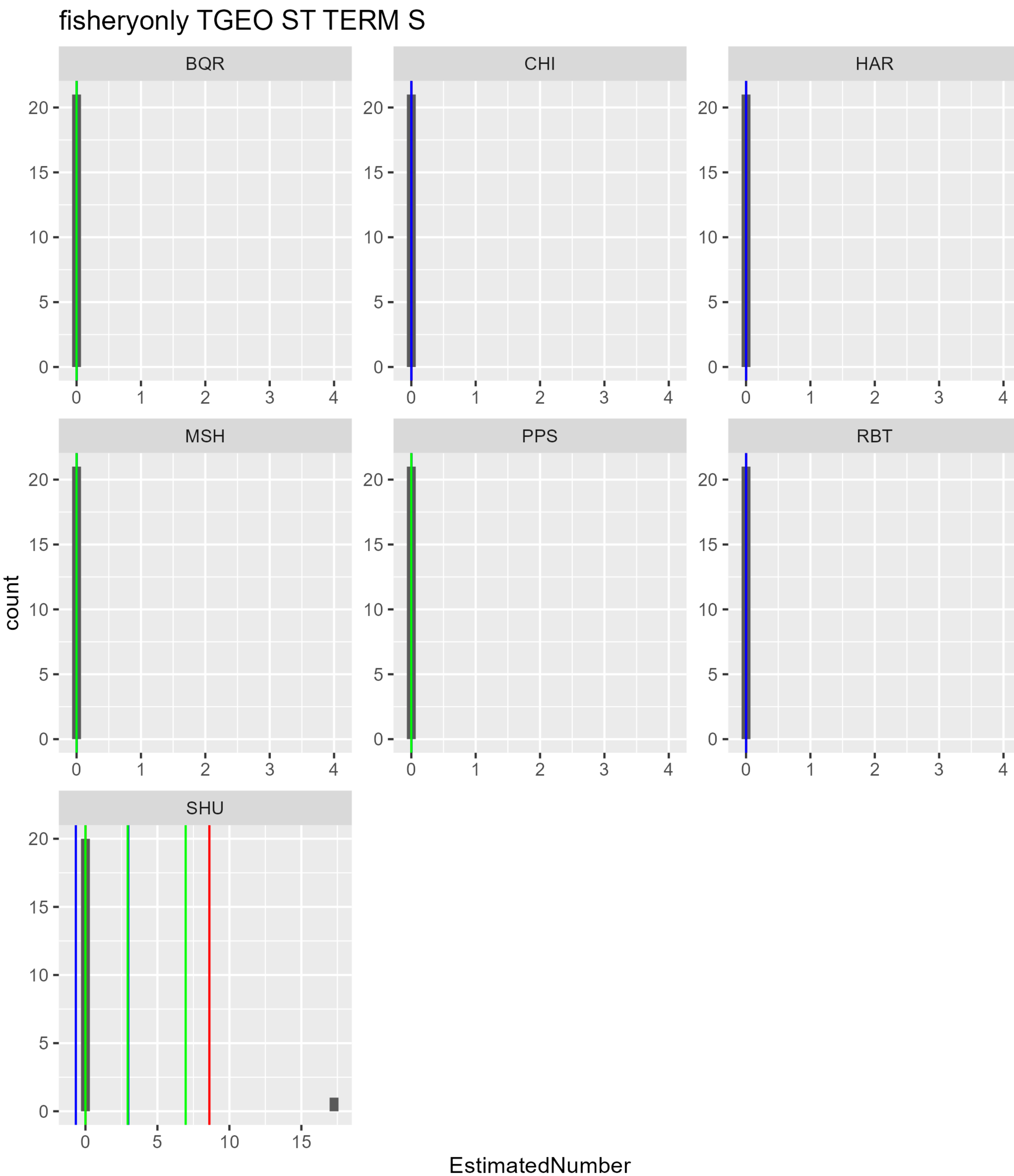

Figure 49: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

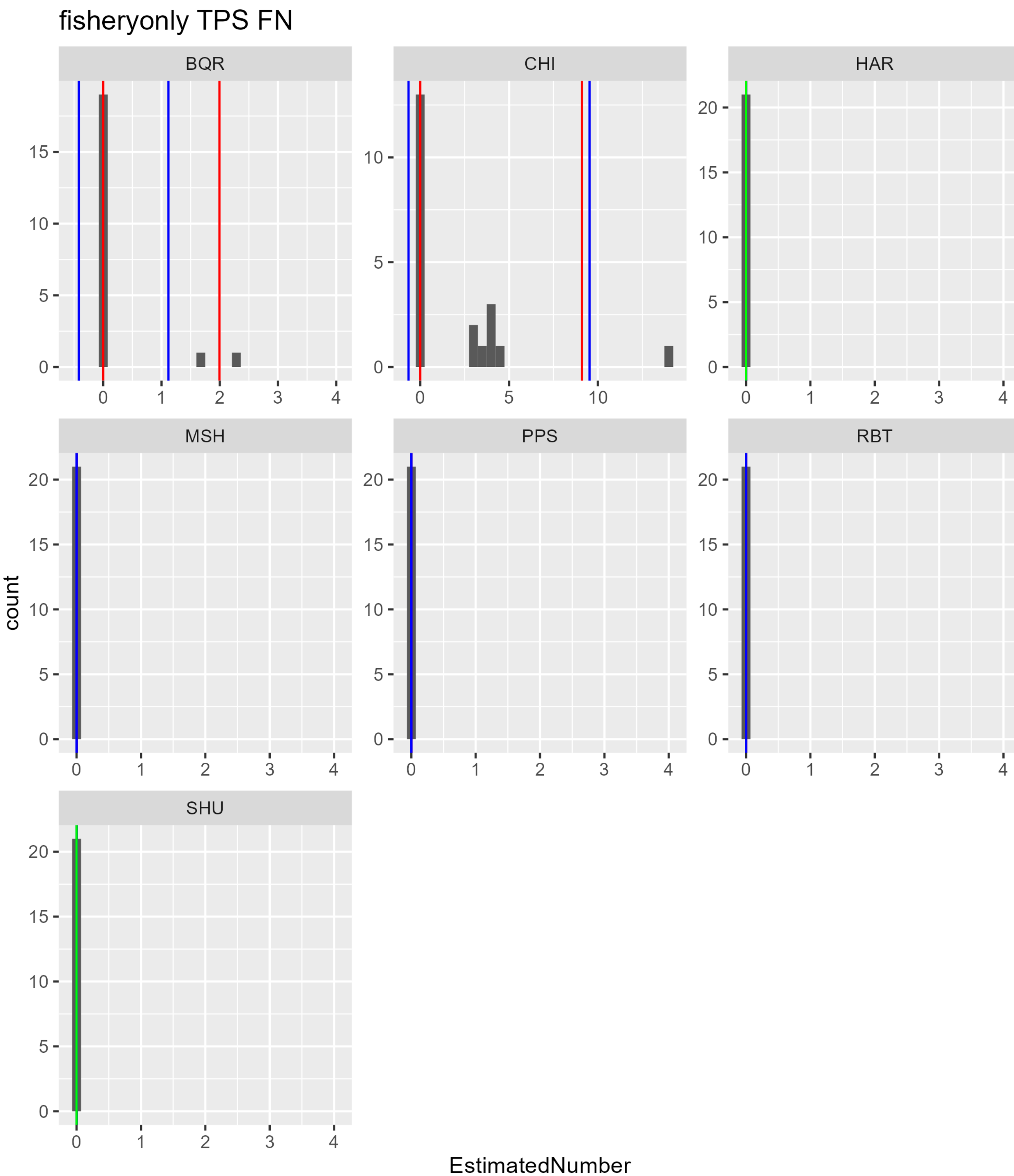

Figure 50: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

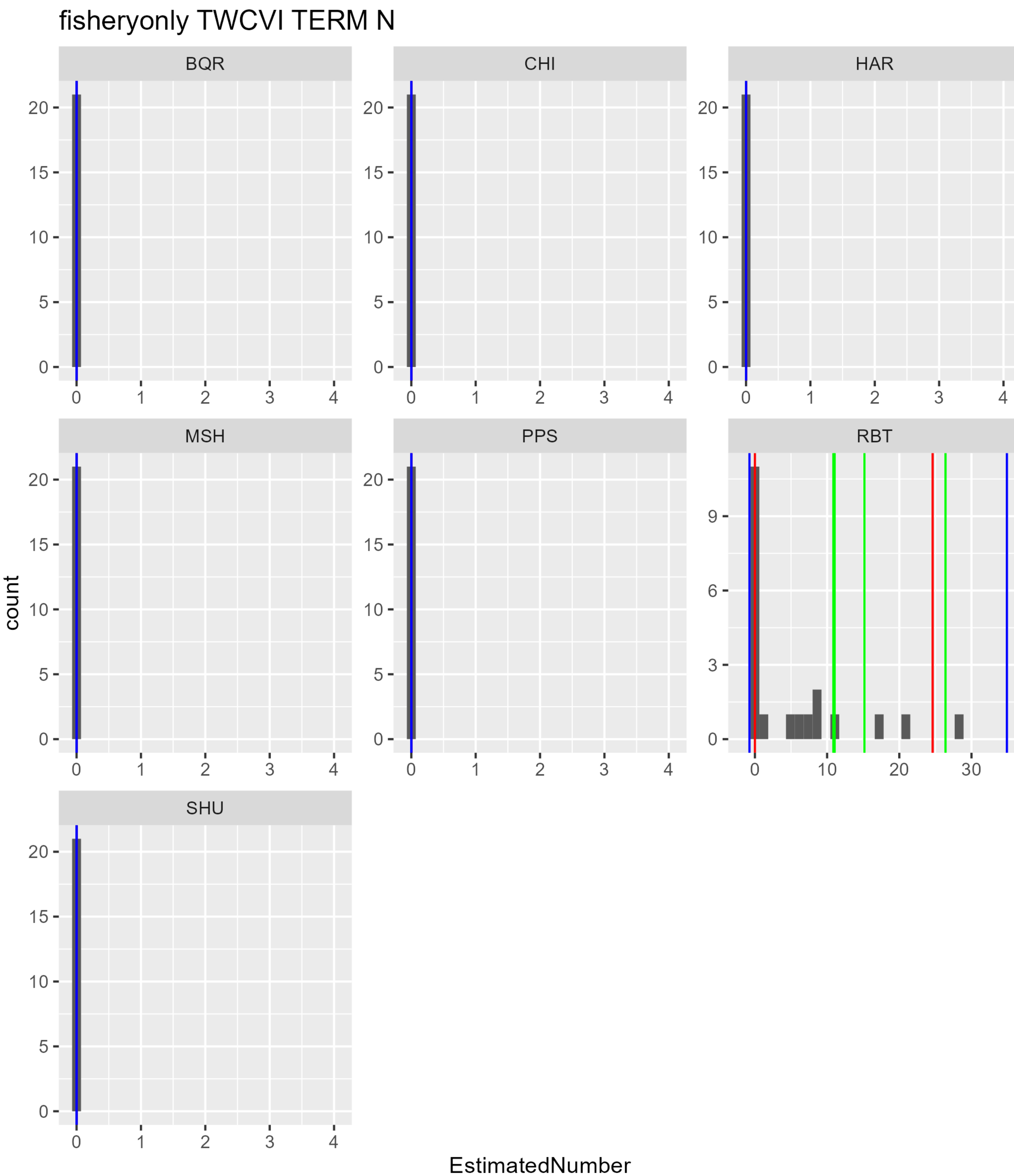

Figure 51: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

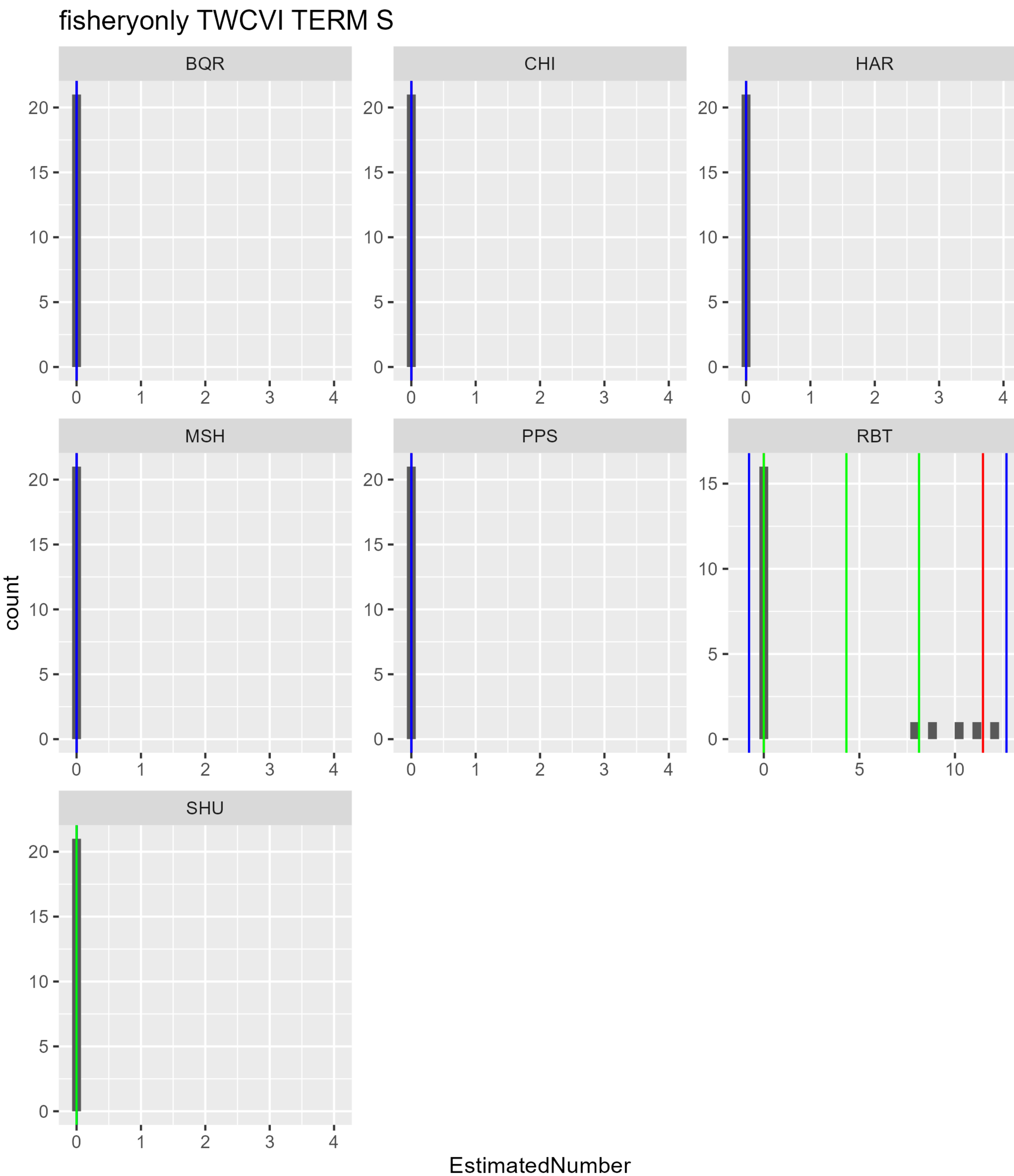

Figure 52: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

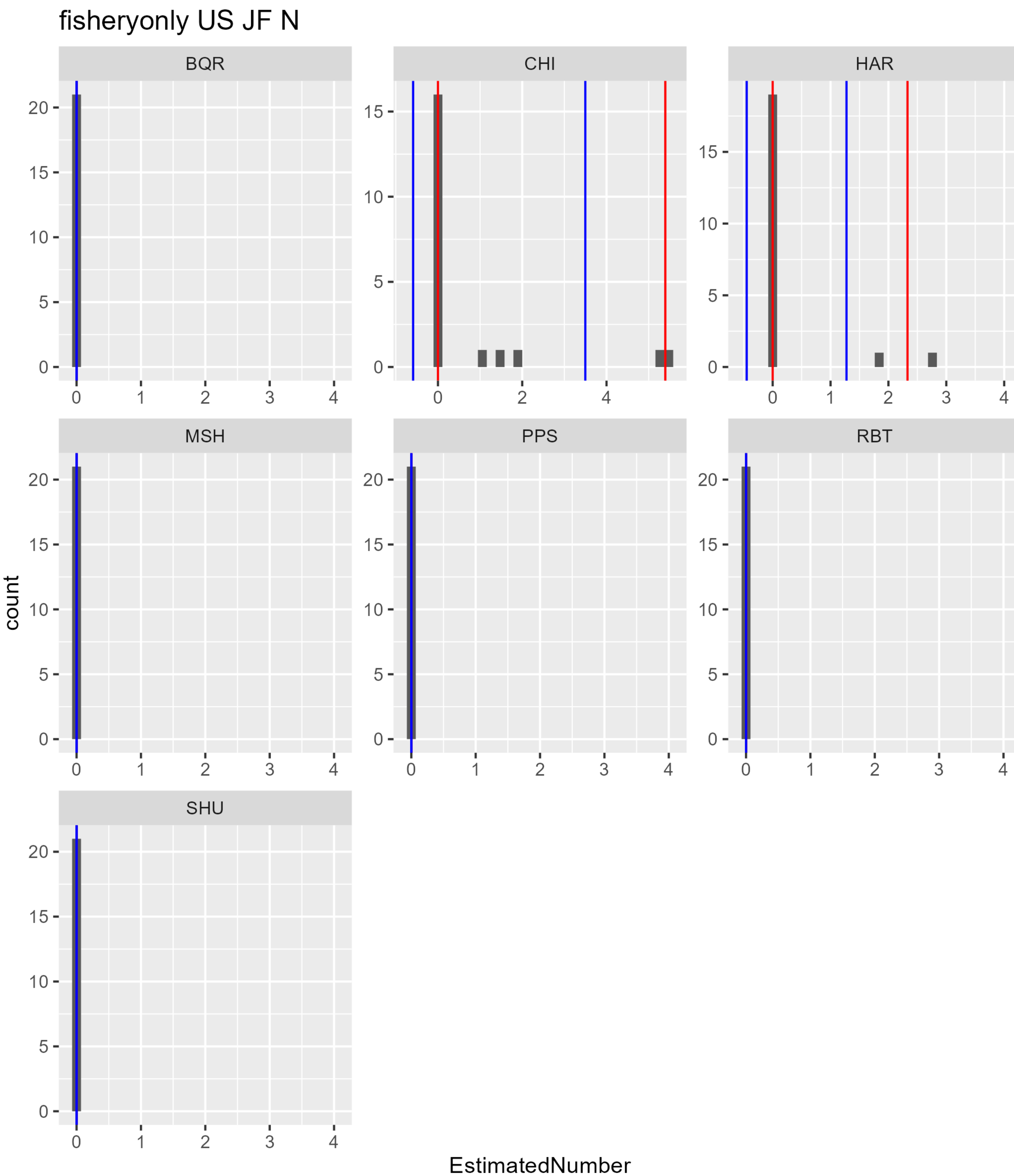

Figure 53: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

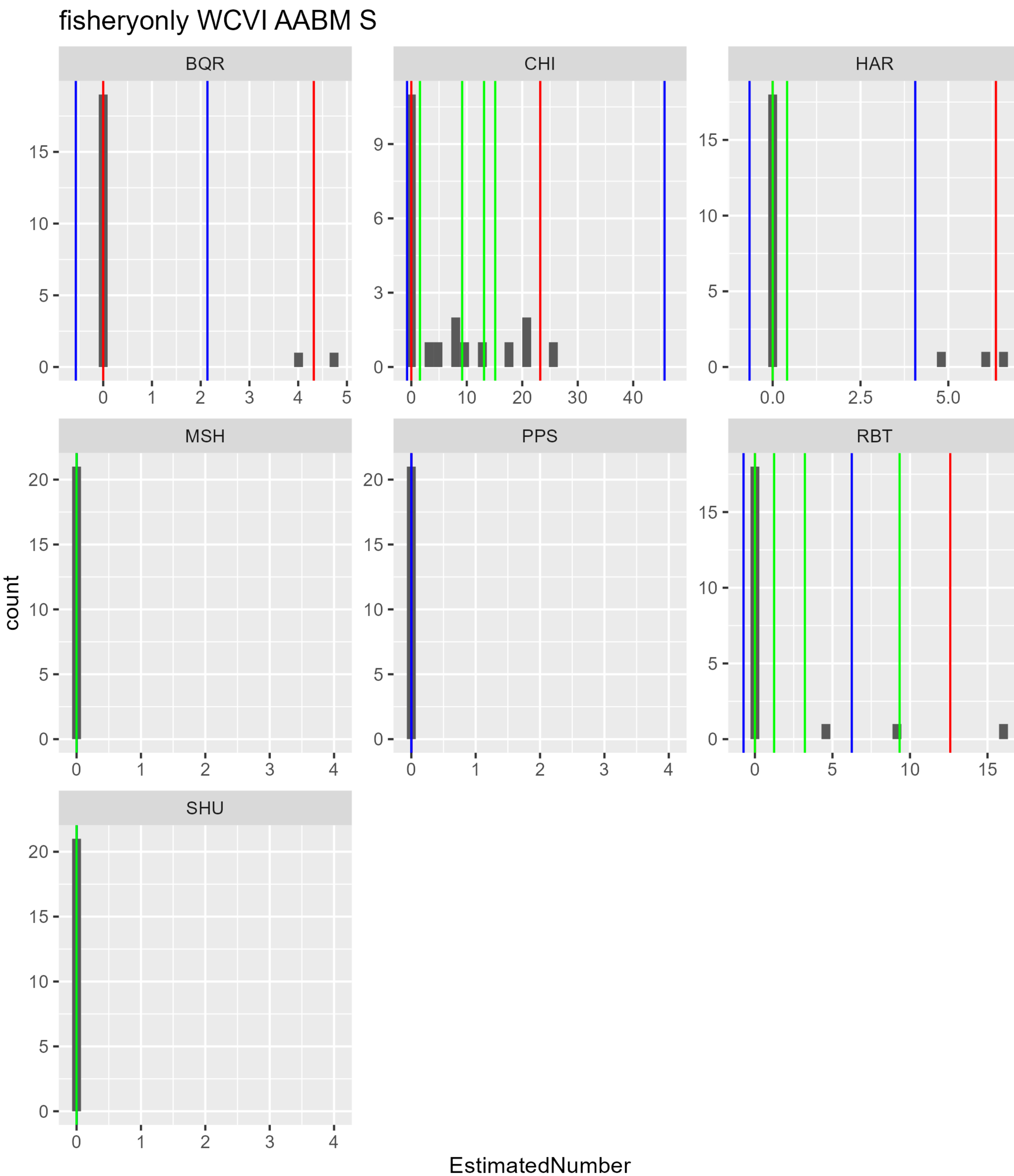

Figure 54: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

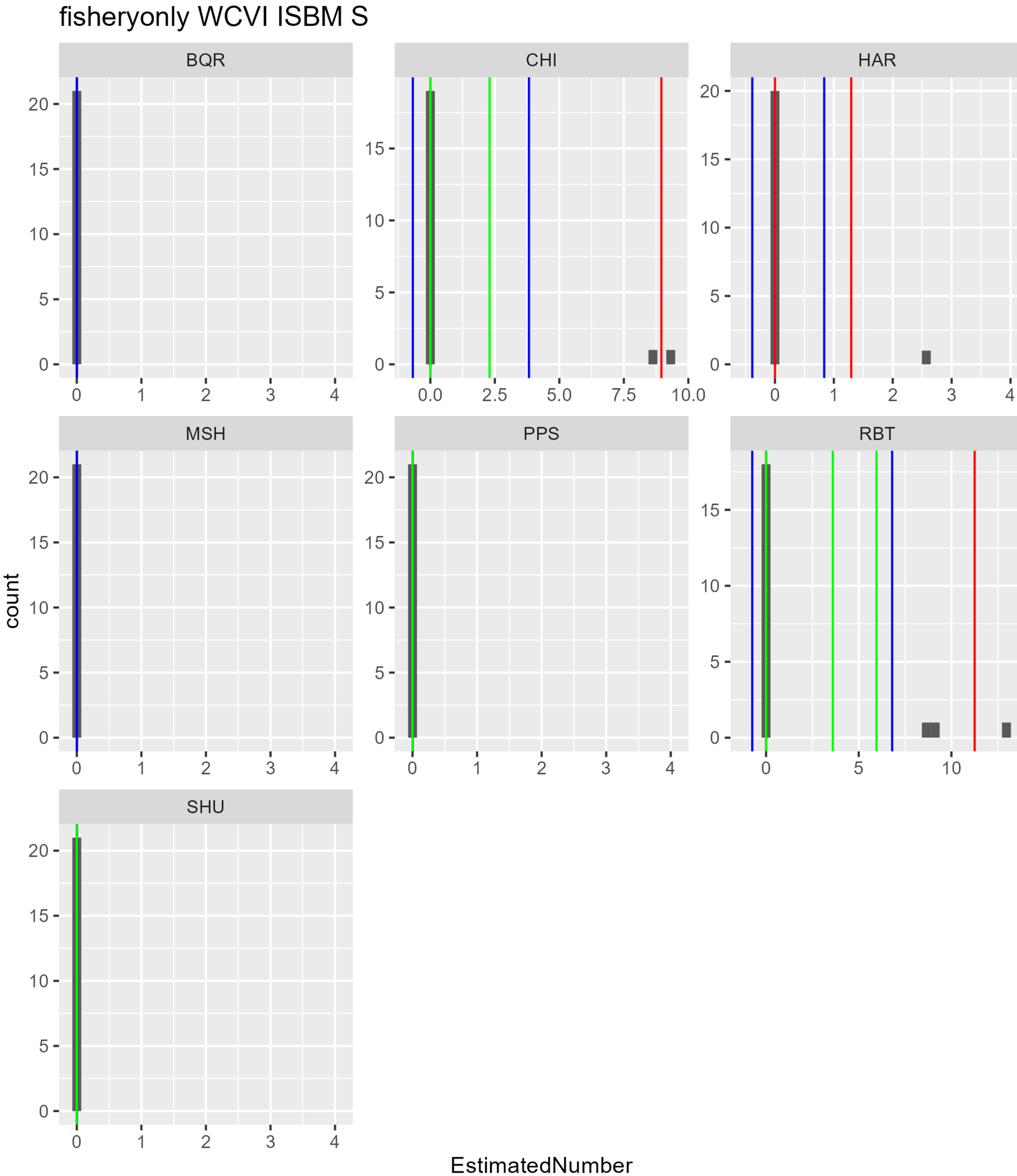

Figure 55: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.

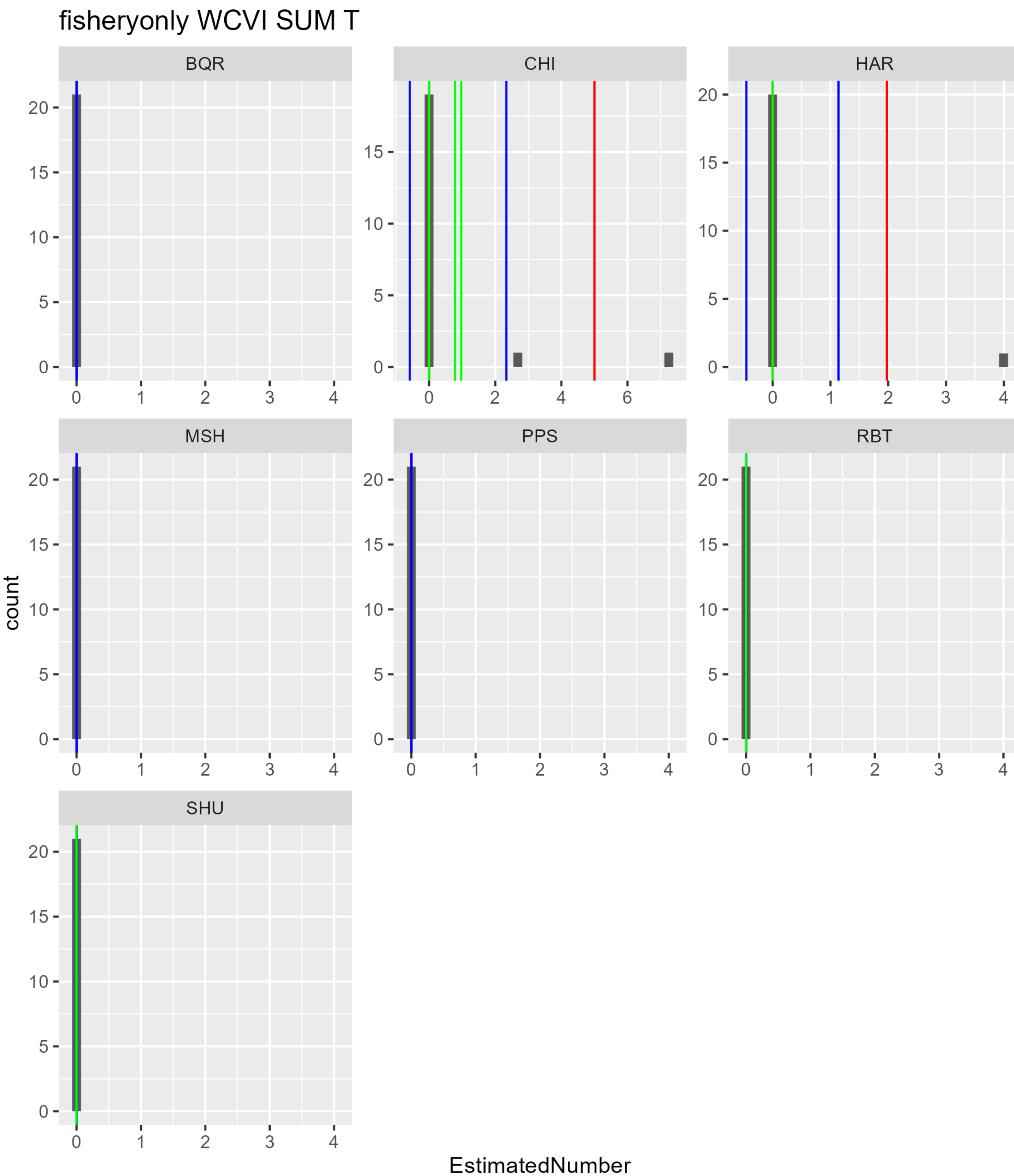

Figure 56: Comparison of 2019 and 2020 fishery recovery forecasts, derived from both the top-ranked regression model and age ratio model (green lines) to age 2 estimated recoveries during 2000–2020 (black bars). Each page represents one fishery, identified at the top of each plot. Each panel is recoveries of a stock in that fishery. Panels lacking a green forecast line indicate the stock was not forecasted for that fishery. The blue lines represent the 2.5 and 97.5 percentiles, as estimated from the mean and standard deviation of the log-transformed recoveries (equivalent location to the -1.96 and 1.96 SD). The red lines are the 2.5 and 97.5 percentiles of the sample.