Evaluating the impact of a lack of recent survey data in Alaska Fisheries Science Center groundfish and crab stock assessment models

by

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Introduction

Several bottom trawl surveys in the Bering Sea and Aleutian Islands (BSAI) were cancelled in 2020 due to the COVID-19 pandemic. The purpose of this analysis was to understand the impact of not having fishery-independent data in the most recent year in our stock assessment models. We were specifically interested understanding potential bias and uncertainty in the main assessment outcomes and management advice, and identifying the assessments that may be most impacted by this loss of data.

Methods

We conducted two retrospective analyses for several groundfish and crab species to quantify uncertainty in assessment model quantities and management advice (Table 1). The first was a standard retrospective analysis performed to provide the basis for our comparison. This type of analysis evaluates how the assessment model estimates change with the addition of new data (Mohn 1999), and whether there is a consistent change. The assessment models were run over a 7-10 year time period, depending on the species, while sequentially removing the most recent year of data (known as a peel). Model projections were also done for each peel to provide biological reference points, overfishing limit (OFL), and acceptable biological catch (ABC) estimates.

The second retrospective analysis was conducted similarly to the standard approach. The key difference was that the survey biomass and composition likelihood contributions were down-weighted so that the survey was effectively removed from the assessment's terminal year for each peel. This analysis was conducted with models using annual surveys (Eastern Bering Sea (EBS) Pacific cod, BSAI yellowfin sole, BSAI northern rock sole, BSAI flathead sole, BSAI Greenland turbot, EBS Tanner crab, and EBS snow crab), and also for models using biennial surveys, Gulf of Alaska (GOA) Pacific cod, BSAI Atka mackerel, and BSAI Pacific ocean perch (POP) (Table 1). For the assessments where a biennial survey is the main fishery-independent data source, the most recent survey was removed from the assessment, even if the survey occurred in the year before the terminal year of the assessment. For example, if 2018 was the terminal year of the retrospective peel and was an off year for the survey, 2017 would represent the most recent survey data and would be removed from the assessment model.

There were a few caveats to the methodology applied here. First, BSAI northern rock sole, flathead sole, and Greenland turbot are on a biennial assessment cycle and this analysis assumes that the assessments are done annually. The second caveat is that the projections for EBS Pacific cod used the Alaska Fisheries Science Center's Tier-3 projection model to get reference points, OFL, and ABC estimates, which deviates from what is done in practice. Lastly, in 2019, the EBS Pacific cod ABC was derived from an ensemble modeling approach and the ABC in this exercise was derived from a single model.

Measures of uncertainty

Several measures of uncertainty were calculated and evaluated to understand the impact of missing the most recent survey. They included:

1. Model estimated CV of spawning stock biomass (SSB) and recruitment, which measures the estimated precision of the assessment model.

2. Mohn's rho, $\rho = \left(\frac{X_{Y-p} - X_{Y-p,full}}{X_{Y-p,full}}\right)$, where *p* represents the retrospective peel, *full* is the assessment model with the full time series of data, and *X* is the quantity of interest (Mohn 1999, Hurtado-Ferro et al. 2015). Mohn's ρ is a measure of relative bias in quantities estimated from models with a reduced time series and the model with the full time series. Mohn's rho was calculated for the two retrospective analyses separately to determine how bias differs when the most recent survey is missed.

3. $\sigma_{Ralston} = \sqrt{\frac{1}{\sum_{p=1}^{P} p - 1} \sum_{y} \left(ln\left[X_{Y-p,i}\right] - ln\left[X_{Y-p,ref}\right] \right)^2}$, where *i* represents the retrospective analysis (i.e., standard or without survey) and *ref* represents the last accepted assessment model (Ralston et al. 2011). The σ statistic assumes the most recent stock assessment is the best representation of the stock and is a measure of uncertainty in log space with respect to the best representation. This statistic accounts for bias and variability in our estimates and would be expected to be larger for assessments that exhibit either greater bias or annual variability.

4. Additional variance, $\sigma^2 = \frac{\sum_{y=0}^{Y} \left(\frac{X_{no\ survey,y} - X_y}{X_y} \right)^2}{Y-1}$, where *y* is year, *Y* is the total number of years used in the retrospective analysis, X_y is the quantity from the standard retrospective, and $X_{no\ survey,y}$ is the quantity from the retrospective without the survey data. This variance term provides a measure of the additional uncertainty due to dropping a survey assuming the standard model represents the true dynamics.

Results

Biennial surveys: Aleutian Islands bottom trawl survey and Gulf of Alaska bottom trawl survey

The BSAI Pacific ocean perch and Atka mackerel stock assessments use the Aleutian Islands bottom trawl survey as a primary source of fisheries-independent information. The distributions of the spawning stock biomass CV in the terminal year for POP and Atka mackerel, shown in Figure 1, indicate that the uncertainty is greater (CV is larger) when the model does not have the most recent survey information. This is also true for the distributions of the recruitment CV for POP (Figure 2). Uncertainty, as measured by $\sigma_{Ralston}$ and additional variance statistics, for POP SSB and recruitment is greater when the most recent survey is missed (Tables 2 and 3). Mohn's rho and the retrospective plots indicate that the POP model underestimates SSB relative to the full model (Table 2, Figures 3 and A1) and when the most recent survey is removed from the assessment model, the terminal estimates of SSB, total biomass, and management quantities are generally lower than the standard retrospective (Figures 3).

Both retrospective analyses exhibited positive bias in Atka SSB and recruitment and this bias was greater when the most recent survey data were removed from the Atka assessment model (Tables 2 and 3, Figure A2). The terminal estimates of Atka recruitment, SSB, and total biomass differed more with the last assessment over peels -8, -9, and -10 (Figure 4). The estimates were generally similar between the retrospective analyses with the greatest difference between peels 5-7 (Figure 4). This was also true for the management quantities. Uncertainty in Atka SSB was also greater when the most recent survey data were not included in the model, but to a lesser extent than POP (Table 2).

The Gulf of Alaska Pacific cod stock assessment model uses data from several surveys, but here we focused on the GOA bottom trawl survey. The distributions of model estimated, terminal year spawning stock biomass CV and terminal year recruitment CV were similar between the two retrospective analyses (Figures 1 and 2). The GOA Pacific cod assessment model has a small bias towards overestimating SSB and recruitment for both retrospective analyses (Table 2, Figure A3). The bias increased for SSB and declined for recruitment when the survey data were removed from the assessment model than the standard retrospective (Table 2). The terminal estimates of recruitment were similar between the two retrospectives, but SSB and total biomass were subtly different between the two analyses, mainly between 2014 and 2018 (Figure 5). This difference between the two between 2014 and 2018 is also evident in the management quantities (Figure 5). The model has a time block on natural mortality (M) to account for a change in M due to the GOA heat wave during this time period, where M was estimated to be lower when the most recent survey data was not included in the model. Uncertainty expressed by $\sigma_{Ralston}$ in GOA Pacific cod SSB was greater when the most recent survey data were not included in the model than the standard retrospective (Table 2). The σ^2 statistic also indicates that there is some difference between the two analyses (Table 2, Figure 5).

Eastern Bering Sea shelf bottom trawl survey

The assessment models for several groundfish species, Tanner crab, and snow crab include the Eastern Bering Sea shelf bottom trawl survey data. This is the only survey data included in the yellowfin sole and northern rock sole stock assessment models. The flathead sole model includes a combined EBS trawl survey and Aleutian Islands survey index and the EBS Pacific cod stock assessment model used to provide OFL advice has included a combined EBS and northern Bering Sea (NBS) index since 2018. The crab assessment models use sex-specific biomass estimates from the EBS bottom trawl survey in their models.

Model estimated uncertainty (CV) for spawning stock biomass in the terminal year was generally similar between the standard retrospective and the retrospective without the survey (Figures 1 and 2). The two retrospective analyses, indicate that the spawning stock biomass CV is slightly higher when the most recent survey data are not included in the assessment model (Figure 1). EBS Pacific cod and BSAI northern rock sole exhibited the largest differences in model estimated SSB CV between the two analyses (Figure 1, Figures A4 and A6).

Bias measured by Mohn's rho was similar between the standard retrospective and the retrospective without survey data for BSAI northern rock sole (positive bias) and flathead sole (negative bias) and EBS Tanner crab (negative bias; Table 2, Figures A6, A7, and A9). The EBS Pacific cod model exhibits a small negative bias that becomes more negative when the most recent survey data are removed from the model (Table 2, Figure A4). The BSAI yellowfin sole and EBS snow crab models exhibit a positive bias that becomes more positive when the most recent survey data were not included in the assessment model (Table 2, Figures A5 and A10). Uncertainty in SSB or crab mature male biomass (MMB) with respect to the last accepted assessment model ($\sigma_{Ralston}$) was greater when the most recent survey data was not included in the model for most BSAI species, except for flathead sole and Tanner crab (Table 2). The difference in uncertainty between the standard retrospective and the retrospective without the most recent survey data was greatest for EBS Pacific cod and EBS snow crab (Table 2). EBS Pacific cod SSB from the standard retrospective was more similar to the last assessment and consistently larger than SSB estimates from the retrospective missing the most recent survey data, which helps explain greater uncertainty as measured by $\sigma_{Ralston}$ (Figure 6). The retrospective estimates of snow crab SSB were consistently greater than the last assessment and the SSB estimates from the retrospective missing recent survey data were generally larger than from the standard retrospective (Figure 12). The terminal estimates of SSB, MMB, and total biomass were generally similar between the retrospective analyses for all other BSAI groundfish species and Tanner crab (Figures 7-11).

The estimates of terminal year recruitment CV also showed similarities between the two retrospectives for most species (Figure 2). However, the terminal year recruitment CV was larger when the data were not included in the BSAI northern rock sole assessment as compared to the standard retrospective (Figure 2). Bias in recruitment was greater for EBS Pacific cod, Tanner crab and snow crab and less for BSAI yellowfin, northern rock sole, flathead sole, and Greenland turbot when the most recent survey data was missing from the assessment model (Table 2). Uncertainty ($\sigma_{Ralston}$ and σ^2) in recruitment was also greater when the most recent survey data were removed from the Tanner crab and snow crab assessment models. The greatest differences in the terminal estimates of recruitment between the standard retrospective and the retrospective missing the most recent survey data is apparent for EBS Pacific cod, BSAI Greenland turbot, EBS Tanner crab, and EBS snow crab (Figures 6, 10, 11, and 12).

The management advice for EBS snow crab exhibited the biggest difference between the retrospective analyses (Figure 12). This is emphasized when expressed as the proportional difference (no survey retrospective – standard retrospective) in OFL, where the snow crab OFL would be overestimated assuming the standard retro was true (Figure 13). The management quantities were generally similar between the two retrospective analyses for most BSAI species (Figures 6-11). Assuming the standard retrospective was true, the tendency would be to underestimate BSAI yellowfin sole and EBS Pacific cod overestimate BSAI northern rock sole and Greenland turbot (Figure 13). Of the groundfish species reliant on a biennial survey, BSAI Pacific ocean perch would be underestimated and the estimates were generally similar between the retrospectives for BSAI Atka mackerel and GOA Pacific cod, but there would be a slight tendency to overestimate OFL.

Discussion

A key finding of this analysis is that the assessments with the consistent retrospective patterns, EBS snow crab and BSAI Pacific ocean perch, exhibited the greatest uncertainty in stock assessment outputs and management quantities when the most recent survey data were not included in the assessment model. Other than the historical retrospective pattern in existing models, it is difficult to identify other significant explanatory factors contributing to uncertainty when there is a lack of recent survey data. Survey frequency may be a contributing factor. Although the majority of assessments with annual surveys had a slight increase in uncertainty, they seemed to be relatively insensitive to missing the most recent year of assessment data. EBS snow crab and EBS Pacific cod are exceptions. The biennial Aleutian Islands bottom trawl survey is an informative source of data for the BSAI Pacific ocean perch and BSAI Atka mackerel assessments and the GOA bottom trawl survey is an important source of information for the GOA Pacific cod assessment. The loss of the most recent survey data led to an increase in the CV of spawning stock biomass, a subtle increase in $\sigma_{Ralston}$, and a moderate difference between the retrospective analyses as measured by σ^2 for BSAI Atka mackerel. Although to a lesser extent, the results indicate that uncertainty was greater in the spawning stock biomass estimates for GOA Pacific cod when the most recent survey data were not included in the model.

BSAI Pacific ocean perch and EBS snow crab exhibit the strongest retrospective patterns of all the species evaluated. The estimated uncertainty in the stock assessment and management quantities for these two species is driven by their strong retrospective patterns. The strong retrospective pattern exhibited by the BSAI Pacific ocean perch model is partially due to assuming time-invariant selectivity and catchability for the Aleutian Islands bottom trawl survey and explorations where catchability was assumed to be time-varying improved this retrospective pattern (Spencer et al. 2018). Bias in the BSAI Pacific ocean perch assessment indicates the model systematically underestimates biomass. Although

Mohn's rho improved when the survey data were removed from the model, estimated biomass in the terminal years of each peel was much less than the last full assessment (Figure A1). Survey biomass from the biennial Aleutian Islands bottom trawl survey has been increasing for this species and the model cannot adequately predict the increase when missing the most recent year of survey data. This leads to greater uncertainty when the most recent survey is missed and the management advice is lower than when survey data are available. Simplifying assumptions such as time-invariant catchability also helps to explain the persistent retrospective pattern in the EBS snow crab model (Szuwalski et al. 2019). Also the 2014 survey observation of MMB, relative to surrounding observations, is quite large without an indication of a large incoming recruitment event and produces a strong retrospective. This pattern makes this assessment more reliant on consistent annual survey observations.

The EBS Pacific cod assessment is relatively unbiased; however, uncertainty was greater when the most recent survey data were removed from the assessment model. Survey biomass has varied, with strong increases and declines, over the retrospective years (Figure A4). Depending on where the retrospective peel fell with respect to the direction of change in survey biomass, the model may have over- or underestimated the change in biomass with respect to the last accepted assessment model leading to greater uncertainty.

BSAI Atka mackerel, similar to BSAI Pacific ocean perch, relies on the biennial Aleutian Islands bottom trawl survey as the main source of fisheries-independent data and the GOA Pacific cod stock assessment uses the biennial GOA bottom trawl survey as an informative source of data in the assessment. Both assessment models become more positively biased (i.e.,overestimates biomass) and uncertainty in terminal year estimates of biomass is greater, when the most recent survey data are removed from the assessment as compared to the standard retrospective. Although the increase in bias helps to explain the increase in uncertainty for these species, differences between the retrospective models for Atka mackerel can also be explained by the high variability in the survey biomass, and the assumption of time invariant selectivity over the retrospective years. Differences between the retrospective models for GOA Pacific cod also can be attributed to the time block on natural mortality. The time block was placed on natural mortality to account for the heat wave between 2014 and 2018. When the most recent survey data are not included in the assessment model, natural mortality is underestimated resulting in a larger difference with the reduced model and the last accepted assessment and increased uncertainty.

Survey data are an important component of all stock assessment models. This analysis indicates that the magnitude of uncertainty is species specific, dependent on assessment model specification and historical retrospective patterns, and to some degree survey frequency. It should be noted that this analysis was reliant on existing survey data and does not take into account the unknown stock dynamics for 2020. Climate change is underway in Alaskan waters and is likely to result in changes to the ecosystem and commercially targeted groundfish and crab stocks. As an example, the 2017 Gulf of Alaska, eastern Bering Sea, and Northern Bering Sea surveys showed unprecedented shifts in the abundance of Pacific cod, larger than had been observed during the entire NMFS survey time series. This underscores the need for research surveys when they can be safely conducted.

References

Barbeaux, S.J., Aydin, K., Fissel, B., Holsman, K., Laurel, B., Palsson, W. Rogers, L., Shotwell, K., Yang, Q., Zador, S. 2019. Assessment of the Pacific cod stock in the Gulf of Alaska. *In* Plan Team for Groundfish Fisheries of the Gulf of Alska, Stock Assessment and fishery evaluation report for groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Bryan, M.D., Barbeaux, S.J., Ianelli, J., Nichol, D., Hoff, J. 2018. Assessment of the Greenland turbot stock in the Bering Sea and Aleutian Islands. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands, Stock Assessment and fishery evaluation report for groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Hurtado-Ferro, F., Szuwalski, C. S., Valero, J. L., Anderson, S. C., Cunningham, C. J., Johnson, K. F., Licandeo, R., McGilliard, C. R., Monnahan, C. C., Muradian, M. L., Ono, K., Vert-Pre, K. A., Whitten, A. R., and Punt, A. E. Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. ICES Journal of Marine Science 72: 99–110.

Lowe, S. Ianelli, J. Palsson, W., Fissel, B. 2019. Assessment of the Atka mackerel stock in the Bering Sea and Aleutian Islands. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands, Stock Assessment and fishery evaluation report for groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

McGilliard, C.M., Nichol, D., Palsson, W. 2018. Assessment of the Flathead sole-Bering Sea flounder stock in the Bering Sea and Aleutian Islands. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands, Stock Assessment and fishery evaluation report for groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. Ices Journal of Marine Science 56: 473-488.

Ralston, S., Punt, A.E., Hamel, O.S., DeVore, J.D., Conser, R.J. 2011. A meta-analytic approach to quantifying scientific uncertainty in stock assessments. Fishery Bulletin 109: 217-231.

Spencer, P.D., Ianelli, J. Assessment of the Pacific ocean perch stock in the Bering Sea/Aleutian Islands. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands, Stock Assessment and fishery evaluation report for groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Spies, I., Wilderbuer, T.K., Nichol, D.G., Ianelli, J. 2019. Assessment of the yellowfin sole stock in the Bering Sea and Aleutian Islands. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands, Stock Assessment and fishery evaluation report for groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Stockhausen, W.T. 2019. Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2019 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.

Szuwalski, C. 2019. A stock assessment for eastern Bering Sea snow crab. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2019 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.

Thompson, G.G., Thorson, J.T. 2019. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands, Stock Assessment and fishery evaluation report for grounfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Wilderbuer, T., Nichol, D., Ianelli, J. 2018. Assessment of the northern rock sole stock in the Bering Sea and Aleutian Islands. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands, Stock Assessment and fishery evaluation report for grounfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Tables

Table 1. Focal species, year of last full stock assessment, model used to conduct the analyses, survey of interest, and time period of analysis.

Species	Year of last full stock assessment	Bottom trawl survey	Time period	Number of peels
EBS Pacific cod	2019 Thompson and Thorson (2019)	Bering Sea shelf	2009-2019	10
EBS Yellowfin sole	2019 Spies et al. (2019)	Bering Sea shelf	2009-2019	10
BSAI Northern rock sole	2018 Wilderbuer et al. (2019)	Bering Sea shelf	2008-2018	10
BSAI Flathead sole	2018 McGilliard et al. (2018)	Bering Sea shelf	2008-2018	10
BSAI Greenland turbot	2018 Bryan et al. (2018)	Bering Sea shelf	2008-2018	10
BSAI Pacific Ocean perch	2018 Spencer and Ianelli (2018)	Aleutian Islands	2010-2018	8
BSAI Atka mackerel	2019 Lowe et al. (2019)	Aleutian Islands	2008-2018	10
GOA Pacific cod	2019 Barbeaux et al. (2019)	Gulf of Alaska	2009-2019	10
EBS Tanner crab	2019 Stockhausen et al. (2019)	Bering Sea shelf	2010-2019	9
EBS snow crab	2019 Szuwalski et al. (2019)	Bering Sea shelf	2012-2019	7

Table 2. Measures of bias and uncertainty for the terminal estimate of spawning stock biomass and mature male biomass (MMB) for Tanner crab and snow crab.

	Mohn rho (ρ)		Ralston		Additional
Species	Survey	No survey	σ Survey	σ No survey	σ^2
BSAI POP	-0.391	-0.358	0.487	0.789	0.101
BSAI Atka mackerel	0.114	0.202	0.242	0.264	0.085
GOA Pacific cod	0.118	0.173	0.246	0.265	0.013
EBS Pacific cod	-0.037	-0.097	0.062	0.238	0.021
BSAI yellowfin sole	-0.209	-0.237	0.332	0.359	0.003
BSAI northern rock sole	0.107	0.106	0.113	0.137	0.001
BSAI flathead sole	-0.046	-0.048	0.069	0.055	0.001
BSAI Greenland turbot	0.098	0.117	0.107	0.112	0.002
EBS Tanner crab	-0.098	-0.107	0.139	0.129	0.001
EBS Snow crab	0.635	1.075	0.459	0.629	0.094

Table 3. Measures of bias and uncertainty for the terminal estimate of recruitment.

	Mohn rho (ρ)		Ralston		Additional
Species	Survey	No survey	σ Survey	σ No survey	σ^2
BSAI POP	-0.480	-0.566	1.110	1.320	0.092
BSAI Atka mackerel	0.463	0.391	0.577	0.541	0.011
GOA Pacific cod	0.709	0.597	0.683	0.669	0.010
EBS Pacific cod	0.261	0.454	1.067	0.834	1.117
BSAI yellowfin sole	0.193	0.179	0.535	0.528	0.001
BSAI northern rock sole	2.051	1.988	1.415	1.444	0.006
BSAI flathead sole	-0.232	-0.206	0.579	0.558	0.001
BSAI Greenland turbot	3.216	2.540	1.527	1.644	0.094
EBS Tanner crab	0.810	83.536	0.694	2.769	18101.739
EBS Snow crab	0.745	4.921	1.371	1.402	102.889

Figures

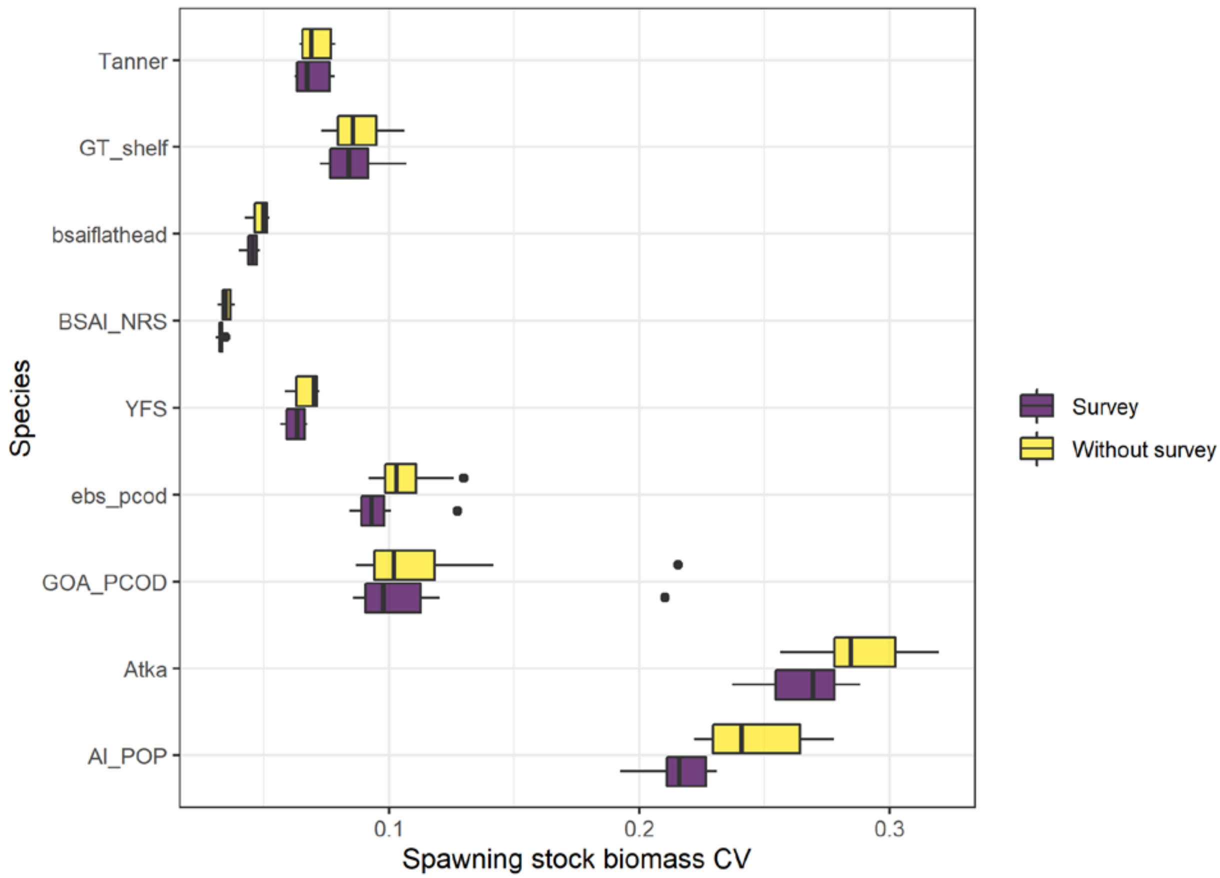

Figure 1. Distribution of terminal year SSB CV estimates across retrospective peels. The box represents the interquartile range (IQR, 25th - 75th percentiles), whiskers are no larger than 1.5*IQR and outliers are values beyond 1.5*IQR. CV estimates were not available for EBS snow crab when this report was written.

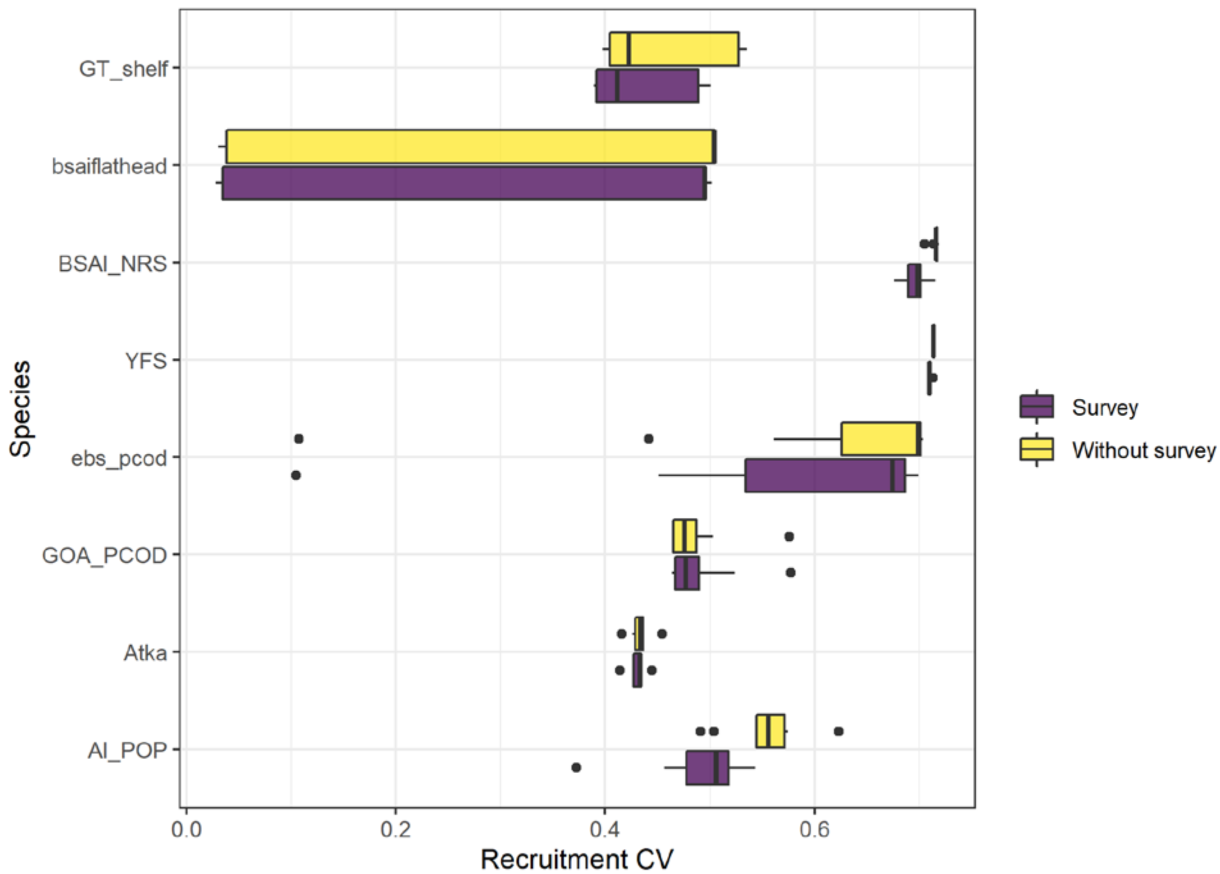

Figure 2. Distribution of terminal year recruitment CV estimates across retrospective peels. Tanner crab is not included in this figure due to three large outliers when survey data were removed from the assessment model (Figure A9). CV estimates were not available for EBS snow crab when this report was written.

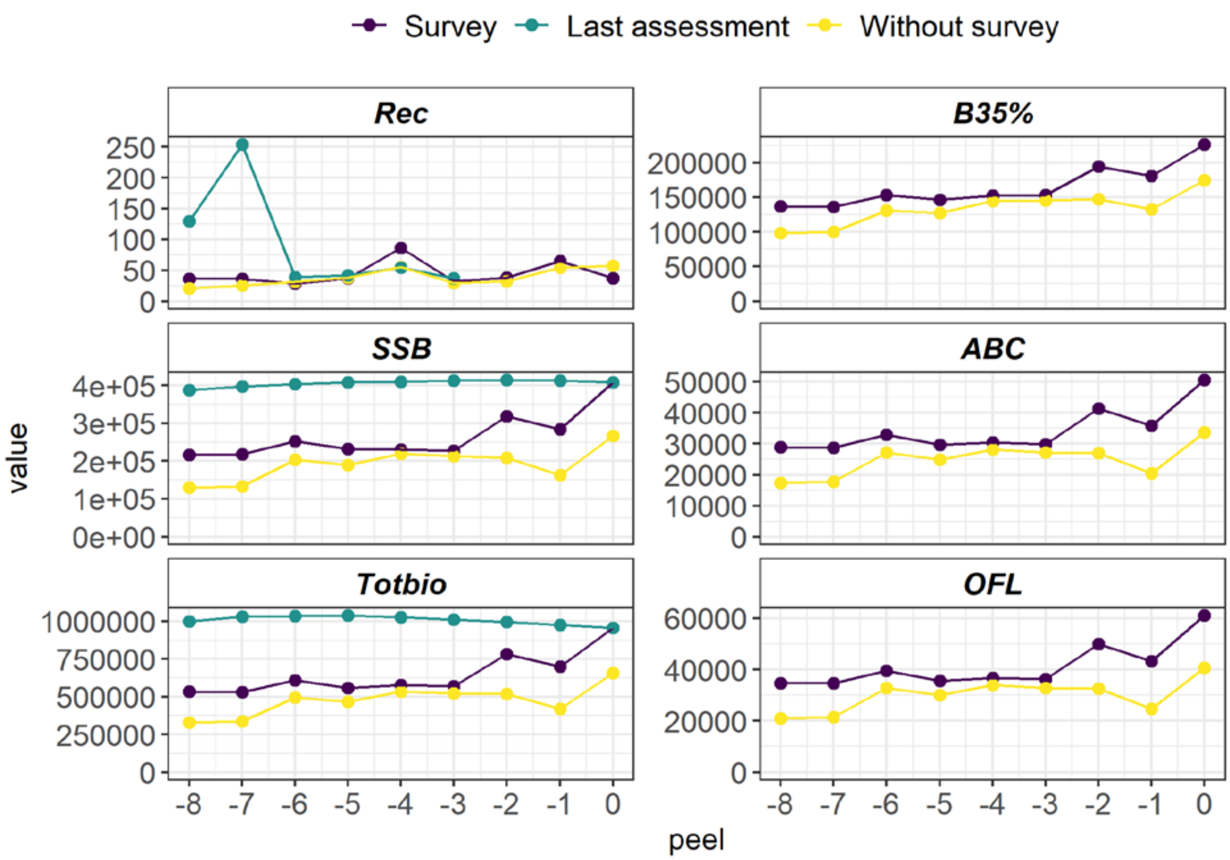

Figure 3. BSAI Pacific ocean perch terminal estimates of recruitment, SSB, and total biomass and management quantities.

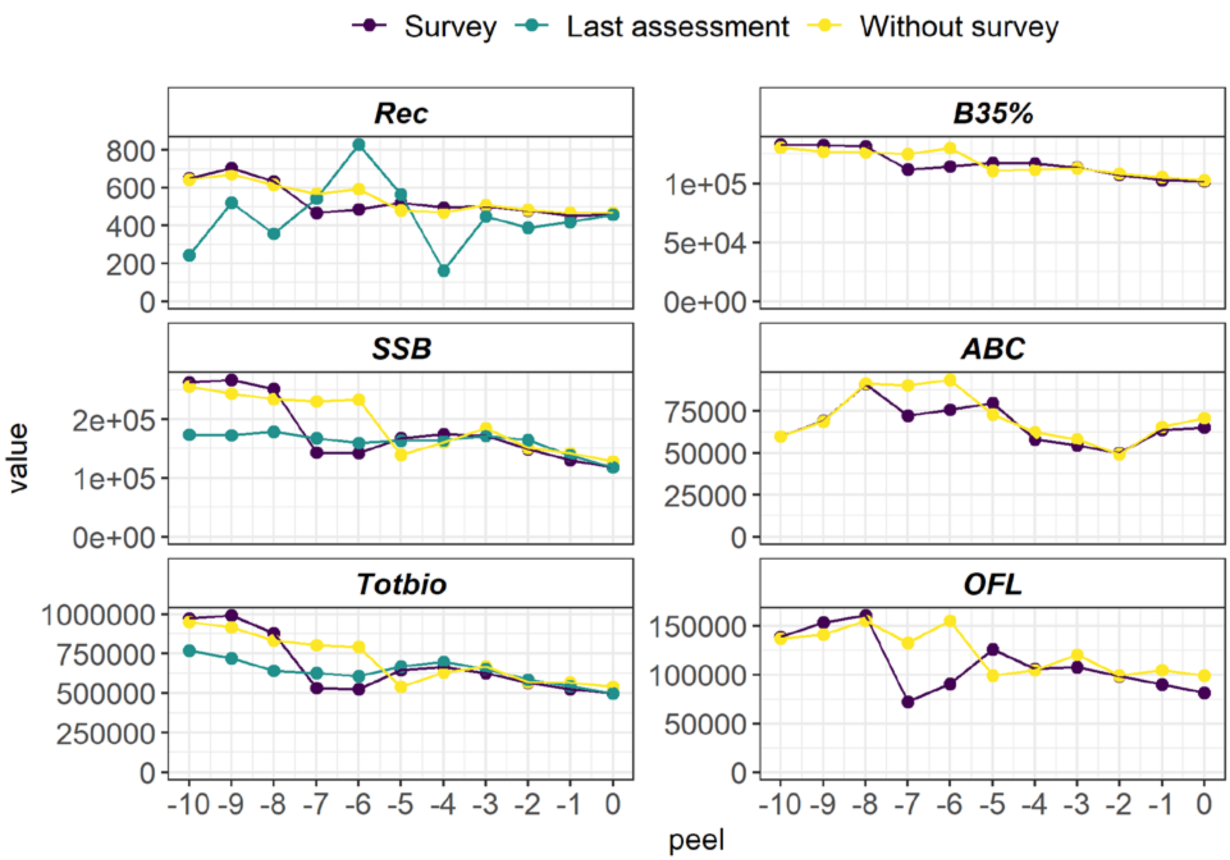

Figure 4. BSAI Atka mackerel terminal estimates of recruitment, SSB, and total biomass and management quantities.

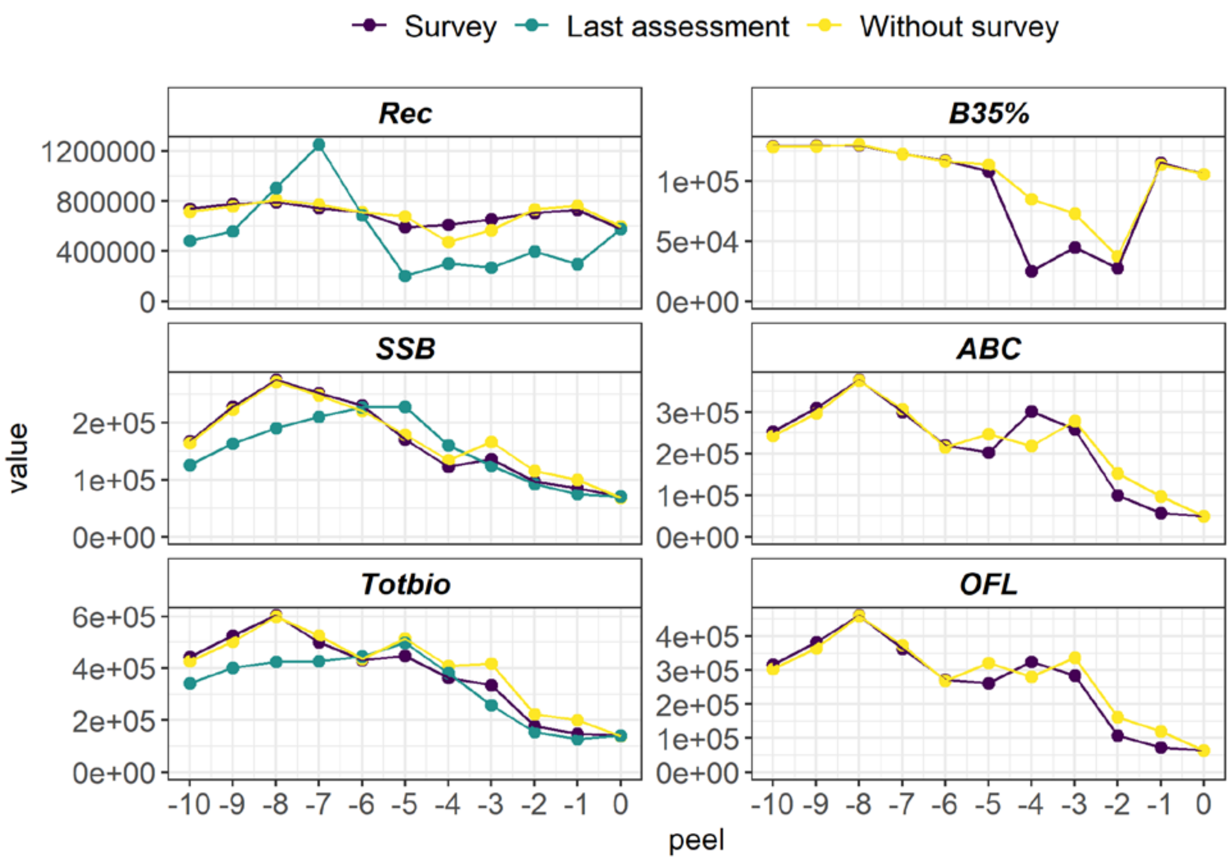

Figure 5. GOA Pacific cod terminal estimates of recruitment, SSB, and total biomass and management quantities.

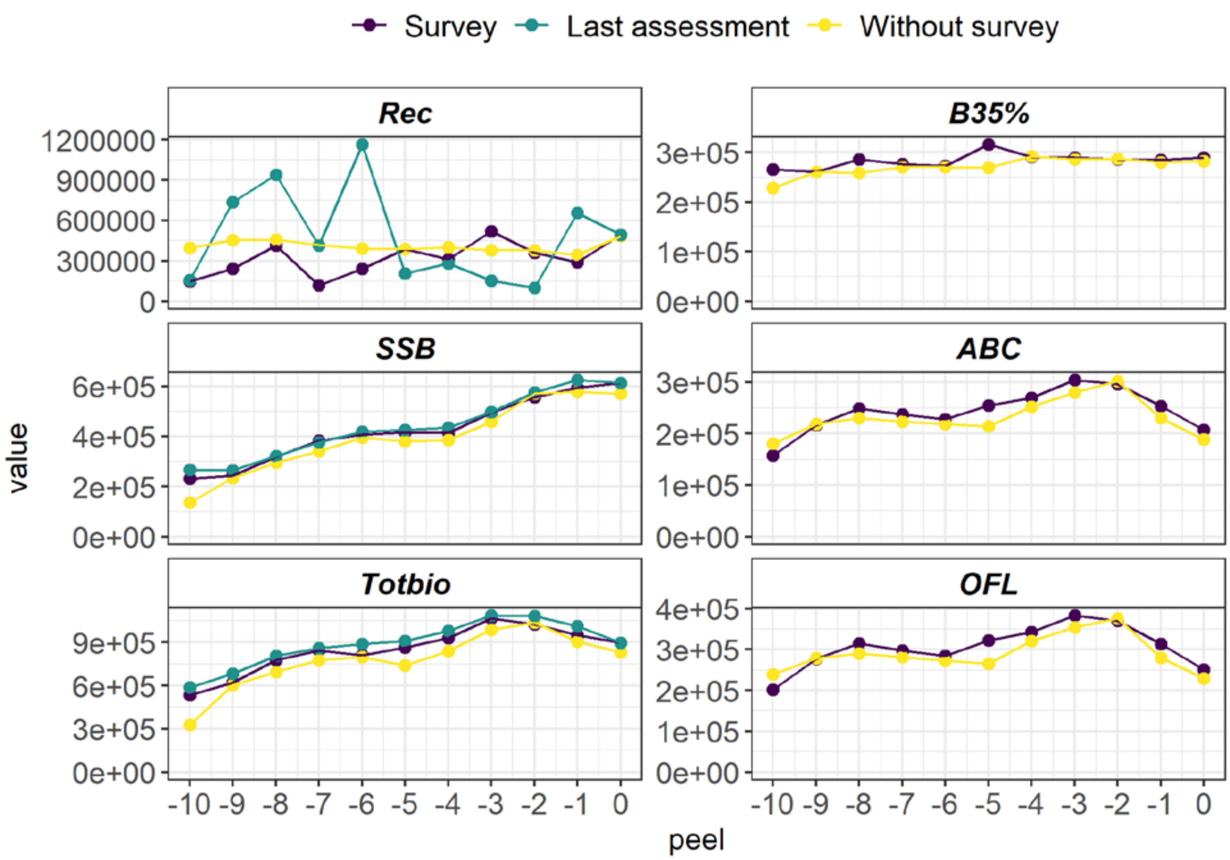

Figure 6. EBS Pacific cod: terminal estimates of recruitment, SSB, and total biomass and management quantities.

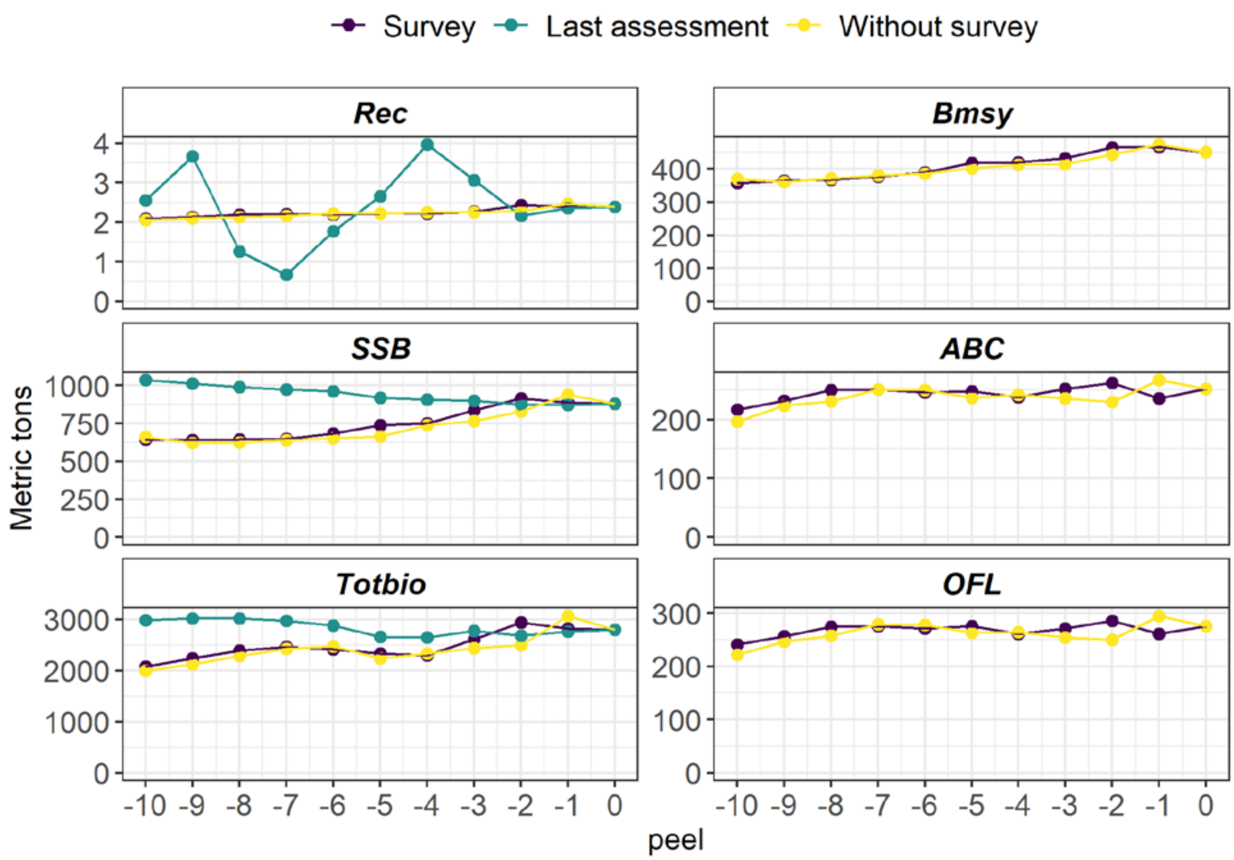

Figure 7. EBS yellowfin sole: terminal estimates of recruitment, SSB, and total biomass and management quantities.

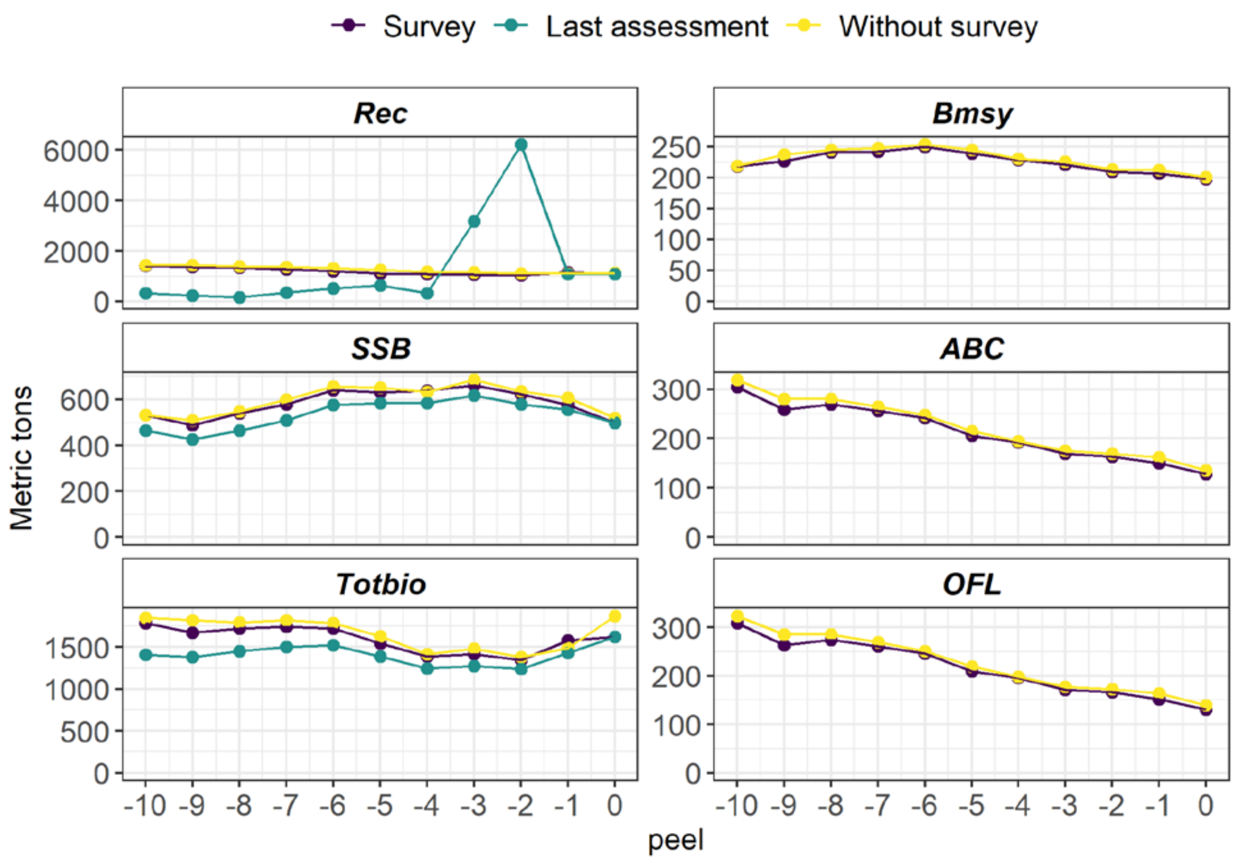

Figure 8. BSAI northern rock sole: terminal estimates of recruitment, SSB, and total biomass and management quantities.

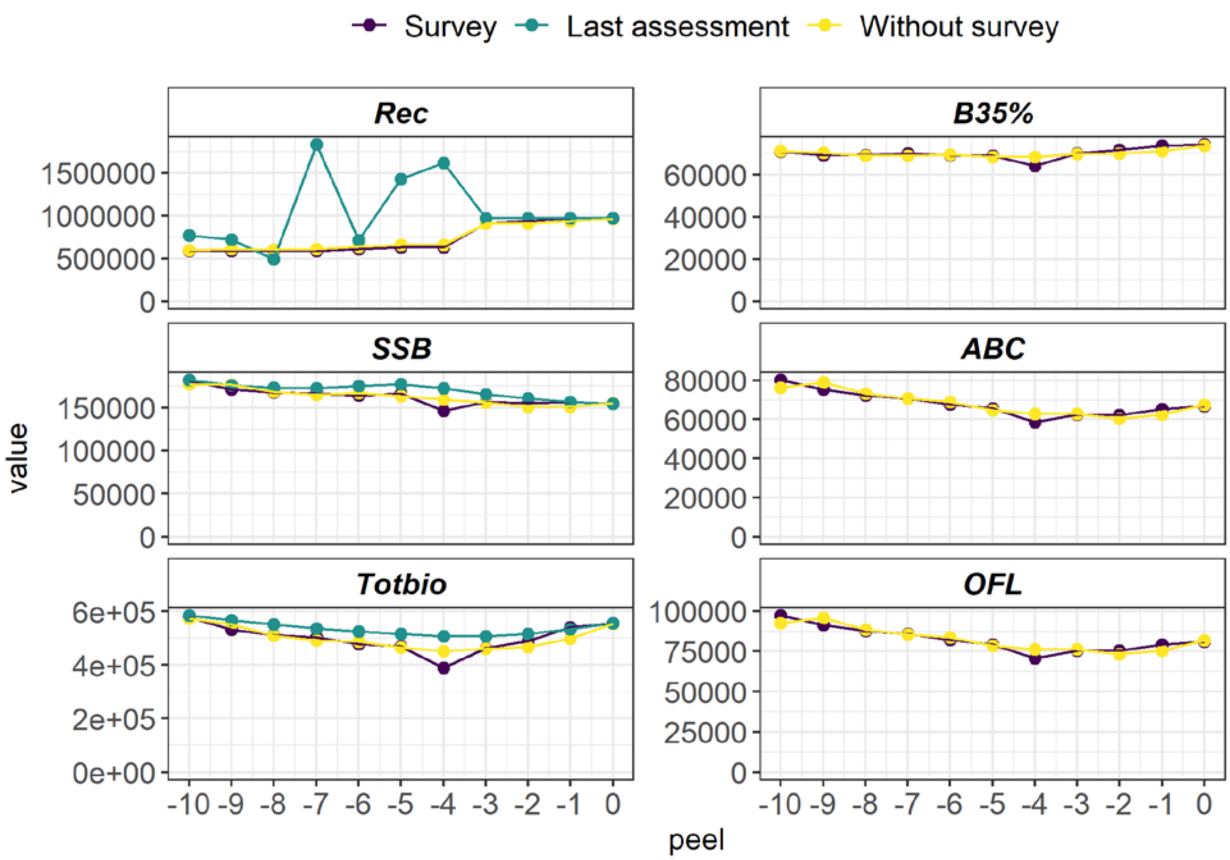

Figure 9. BSAI flathead sole: terminal estimates of recruitment, SSB, and total biomass and management quantities.

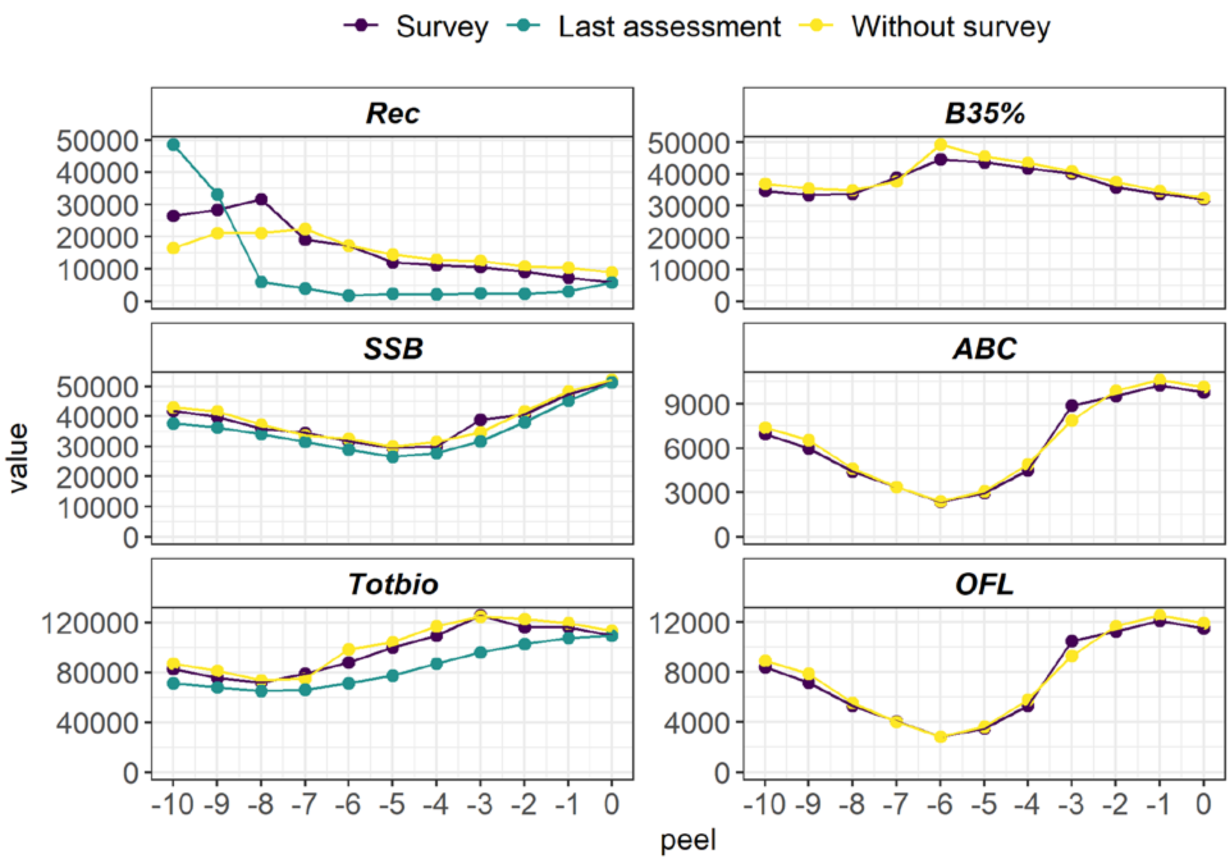

Figure 10. BSAI Greenland turbot: terminal estimates of recruitment, SSB, and total biomass and management quantities.

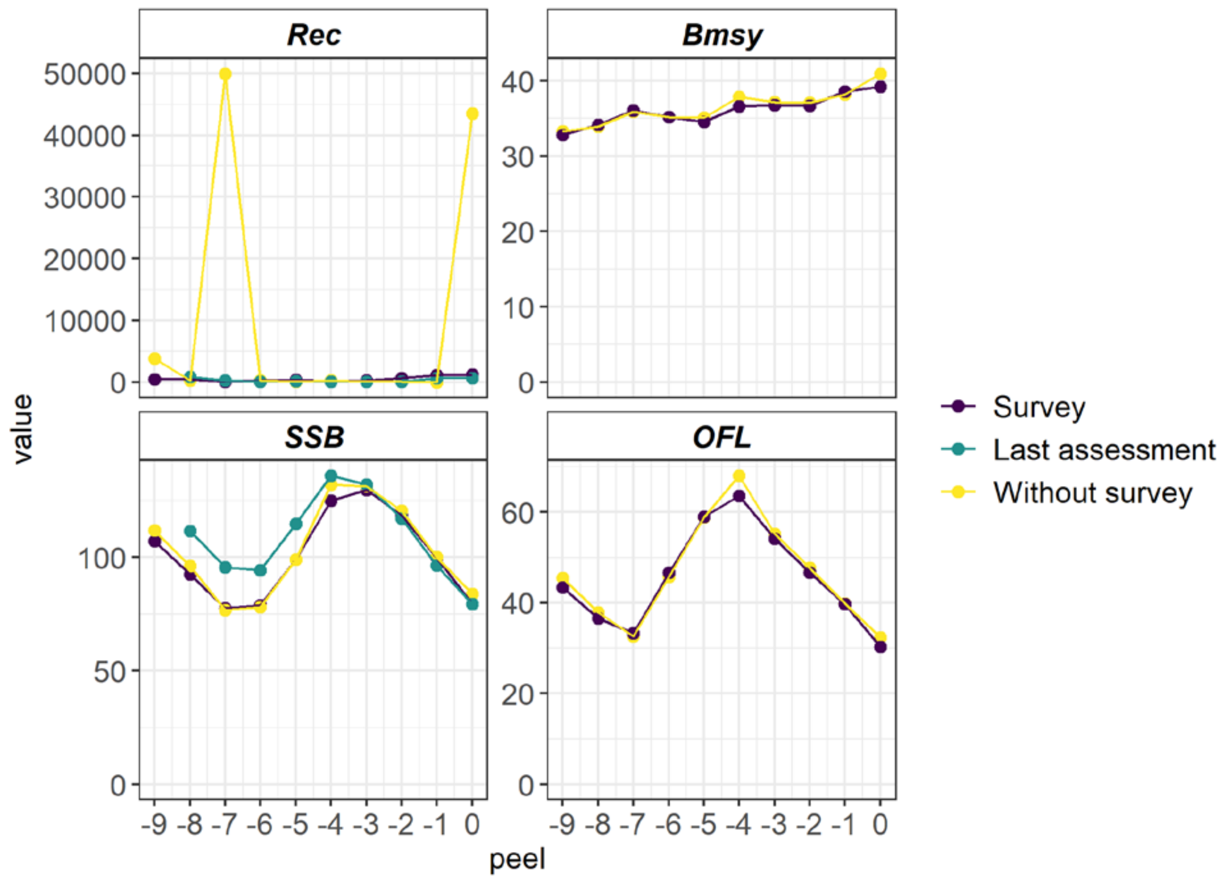

Figure 11. EBS Tanner crab: terminal estimates of recruitment (millions), MMB (1000s t) and management quantities.

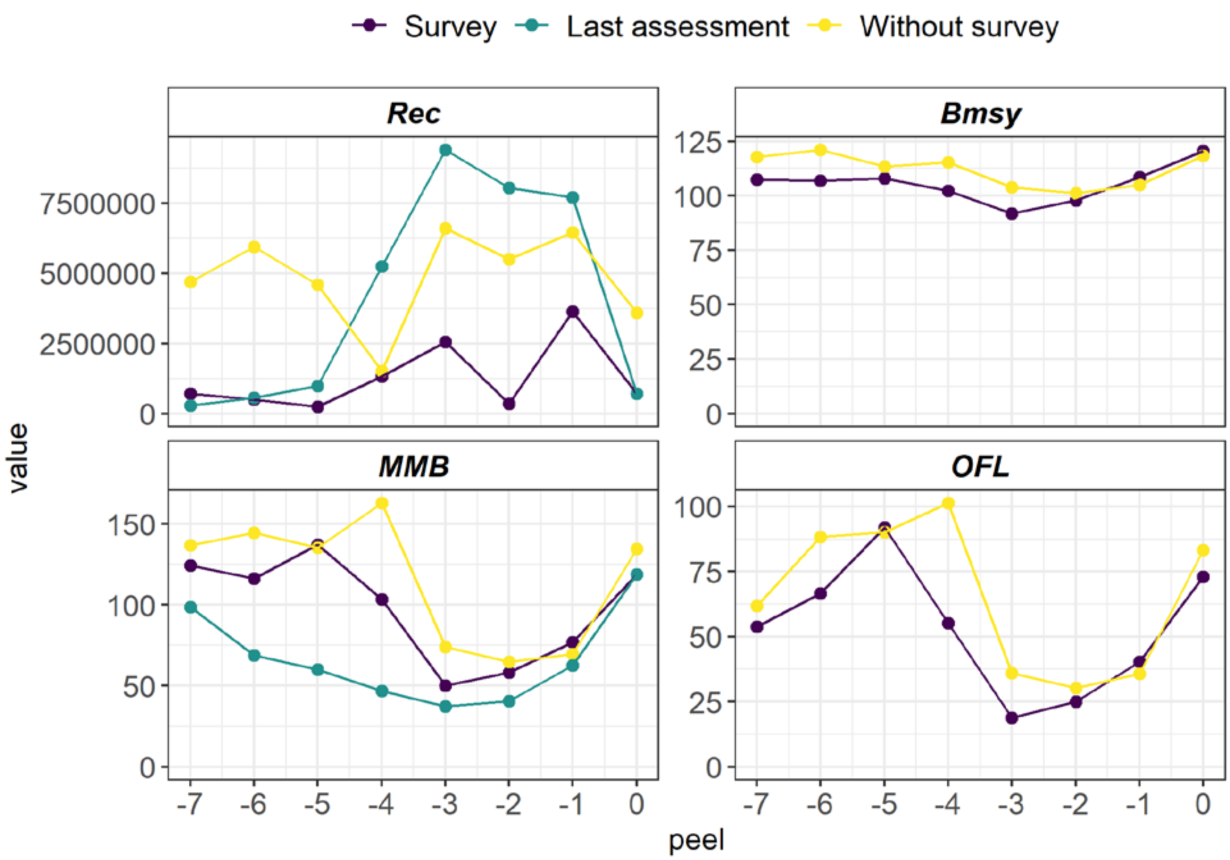

Figure 12. EBS snow crab: terminal estimates of recruitment (millions), MMB (1000s t) and management quantities.

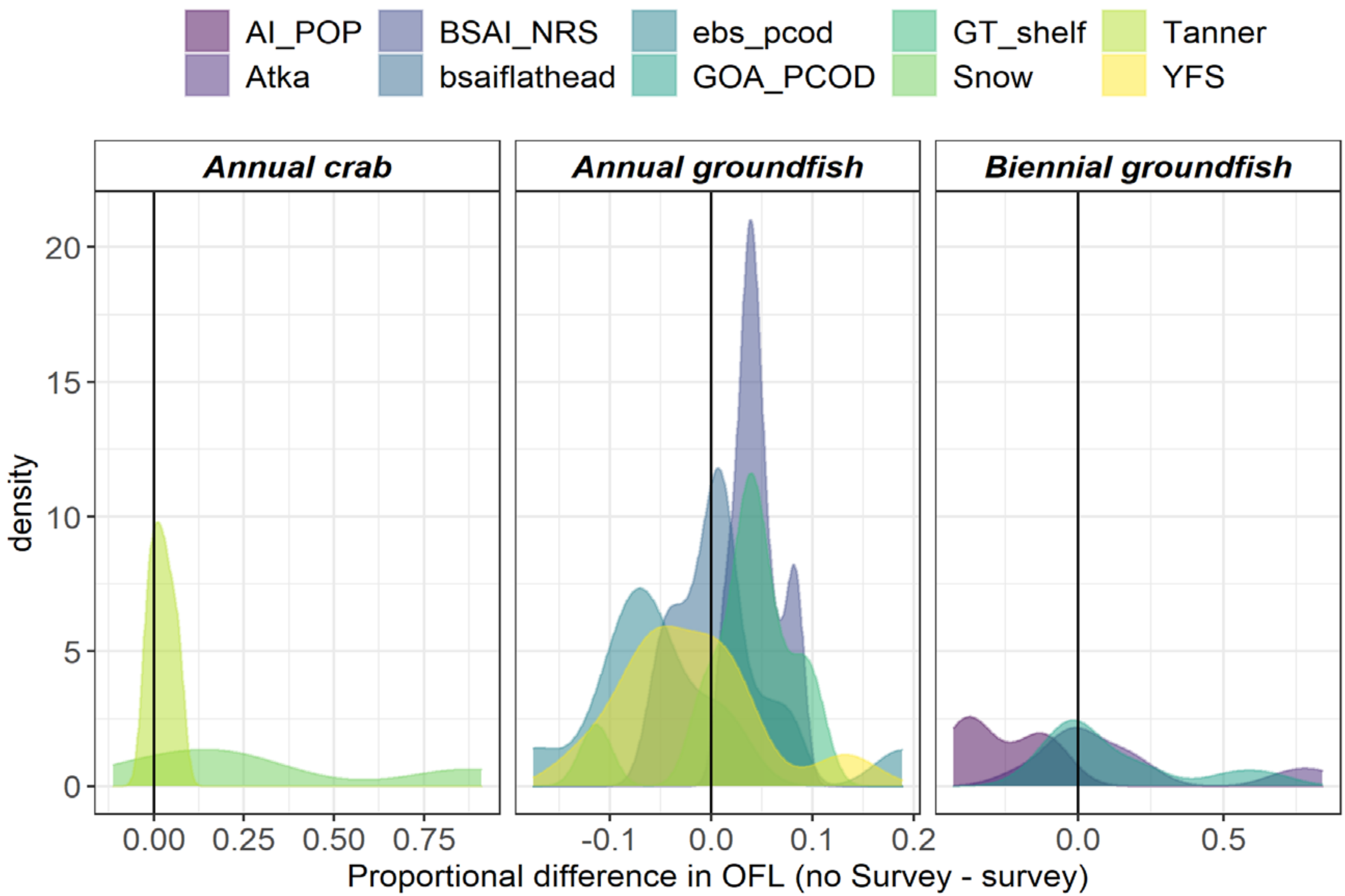

Figure 13. Density plot of the proportional difference in OFL between the retrospective missing the most recent survey data and the standard survey. Differences less than one indicate the OFL from retrospective missing the survey data is less than the standard retrospective.

Appendix

Figure A1. BSAI Pacific Ocean perch retrospective plots, Aleutian Island bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

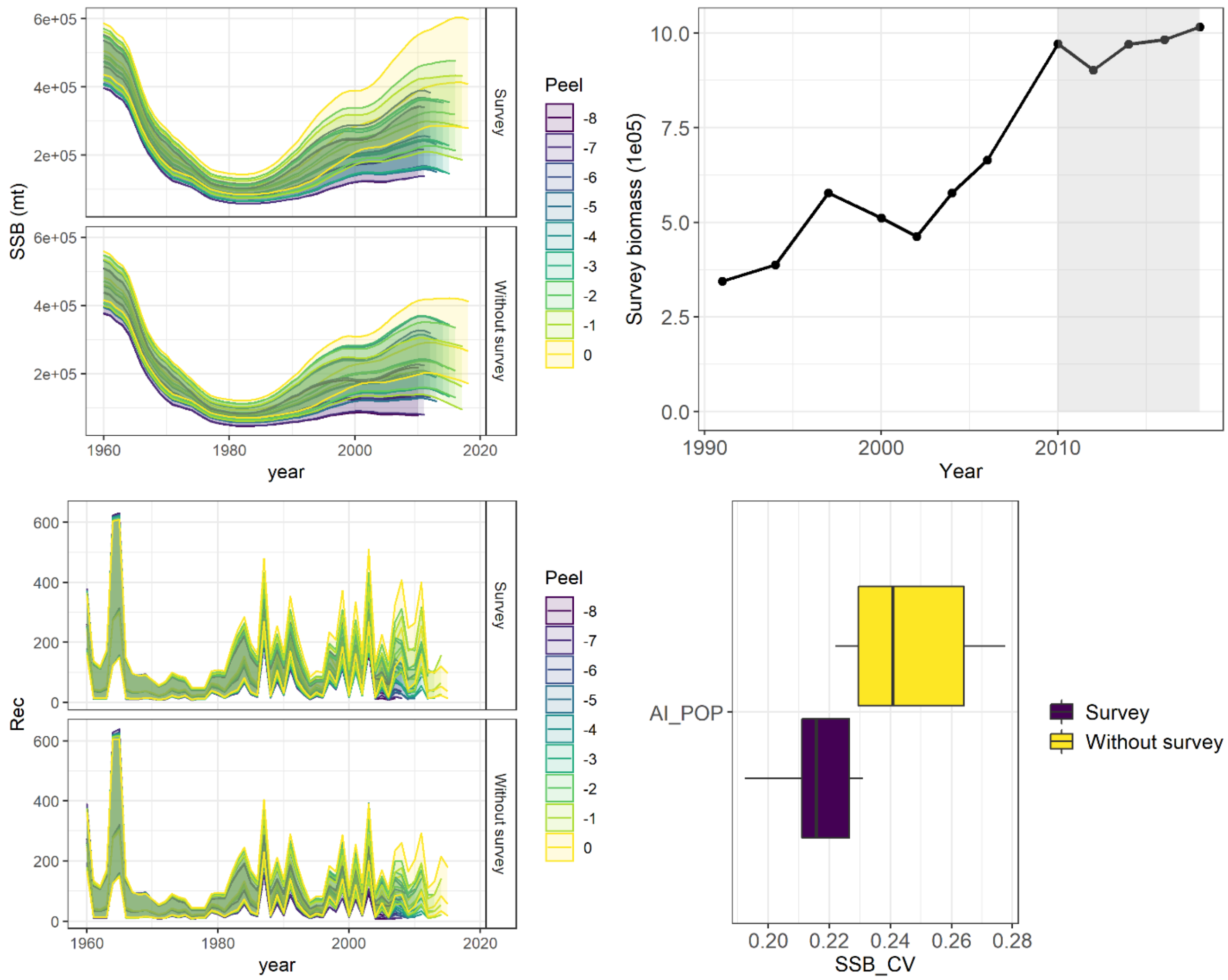

Figure A2. BSAI Atka mackerel retrospective plots, Aleutian Island bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

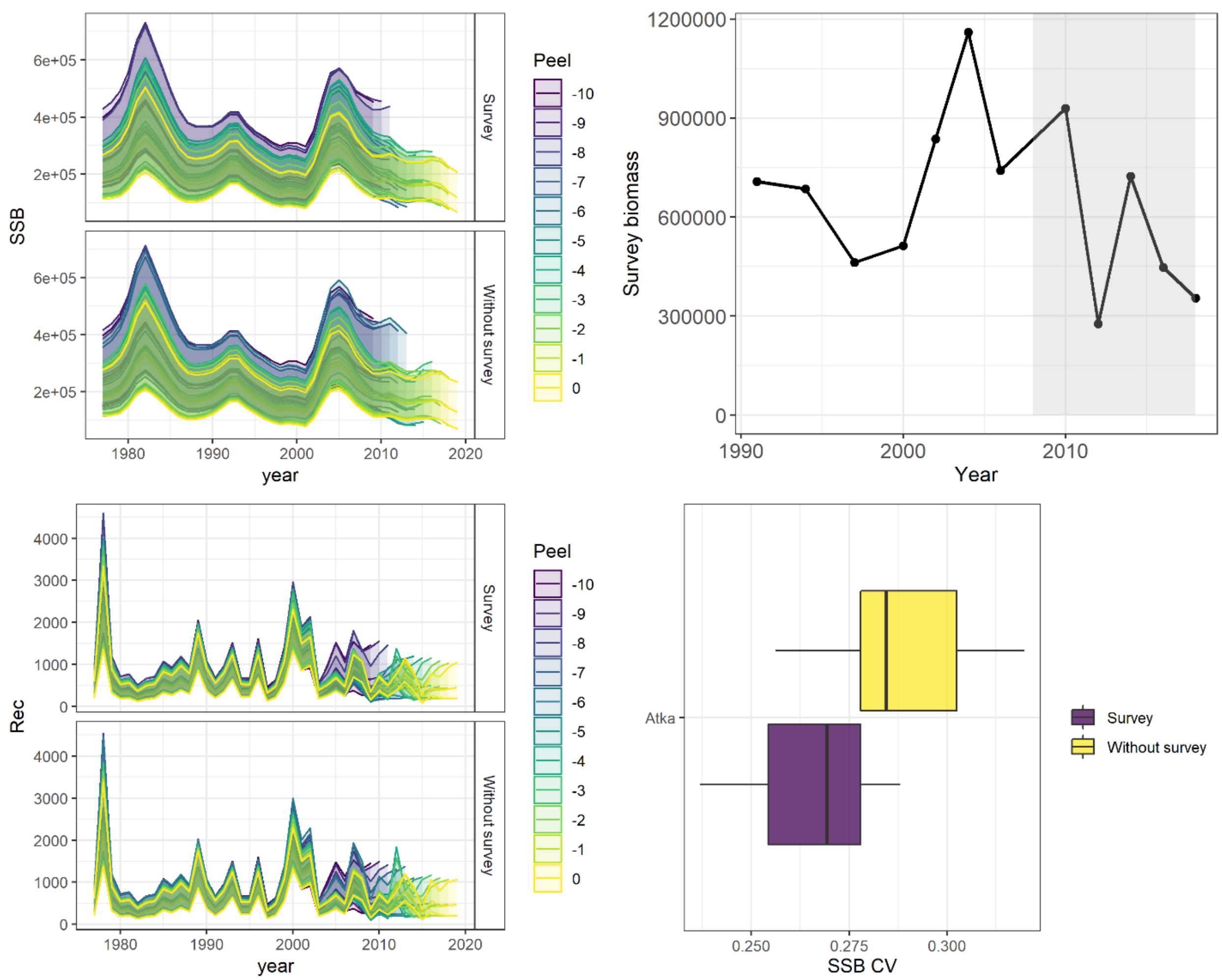

Figure A3. Gulf of Alaska Pacific cod retrospective plots, Gulf of Alaska bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

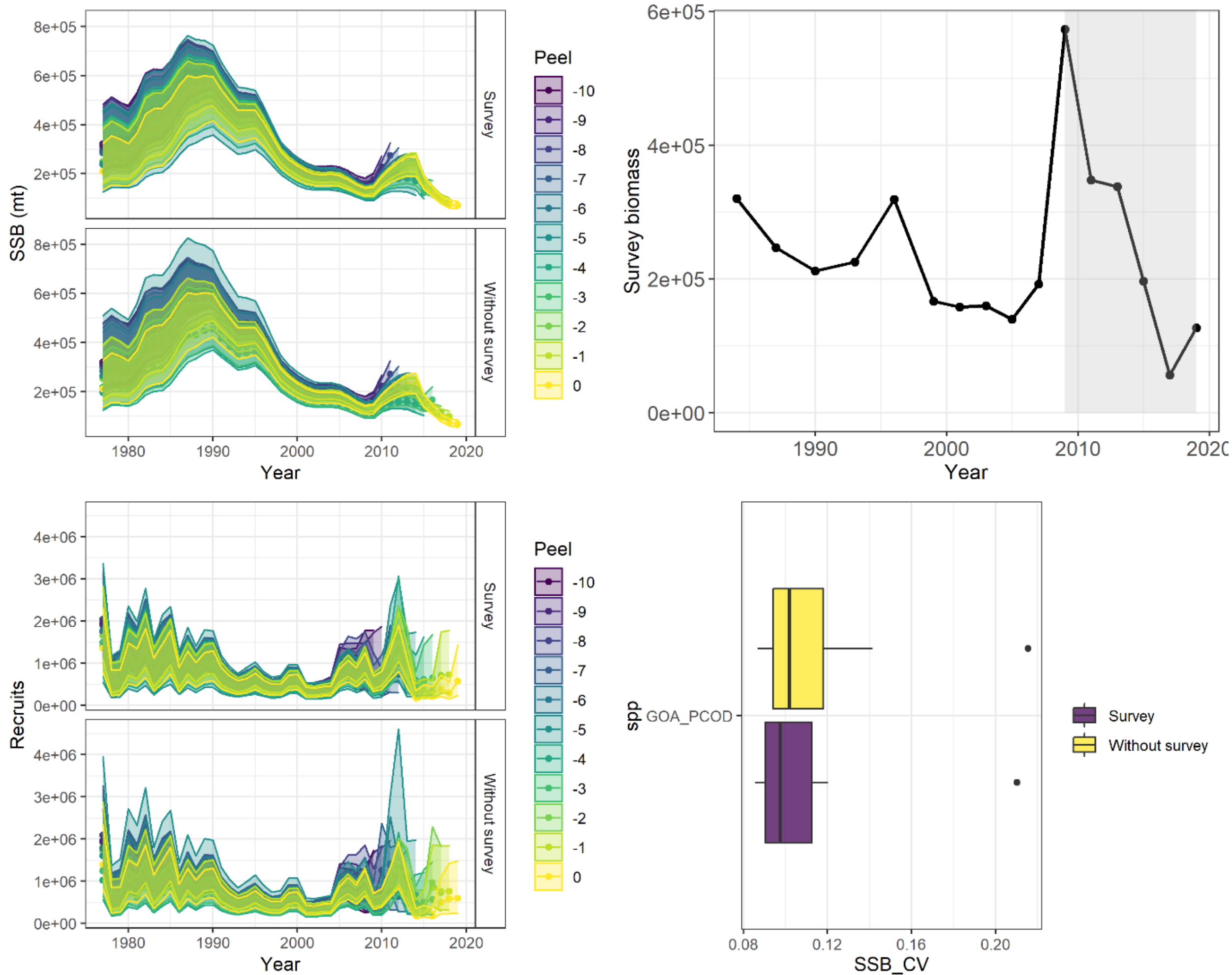

Figure A4. Eastern Bering Sea Pacific cod retrospective plots, EBS shelf bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

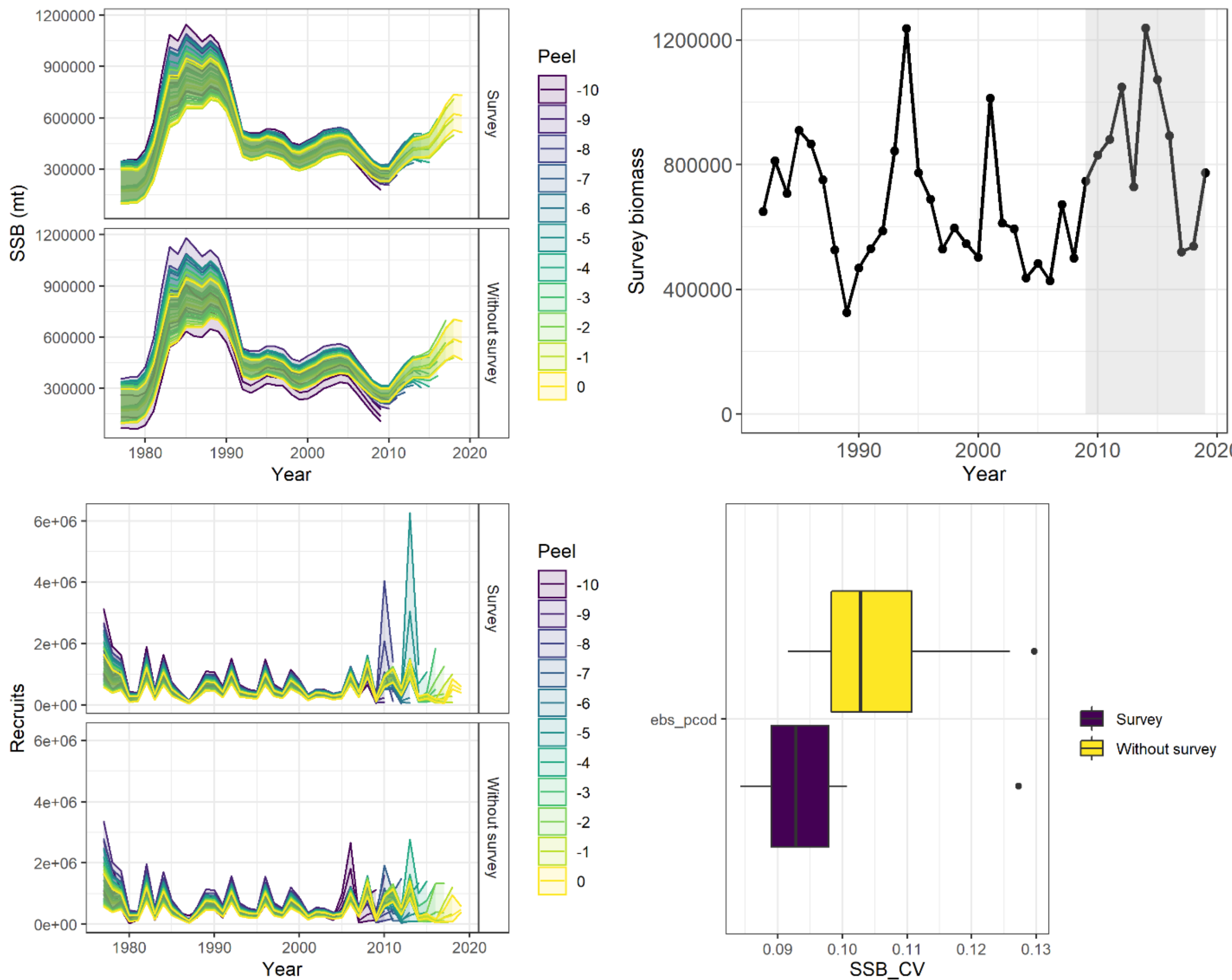

Figure A5. BSAI yellowfin sole retrospective plots, EBS shelf bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

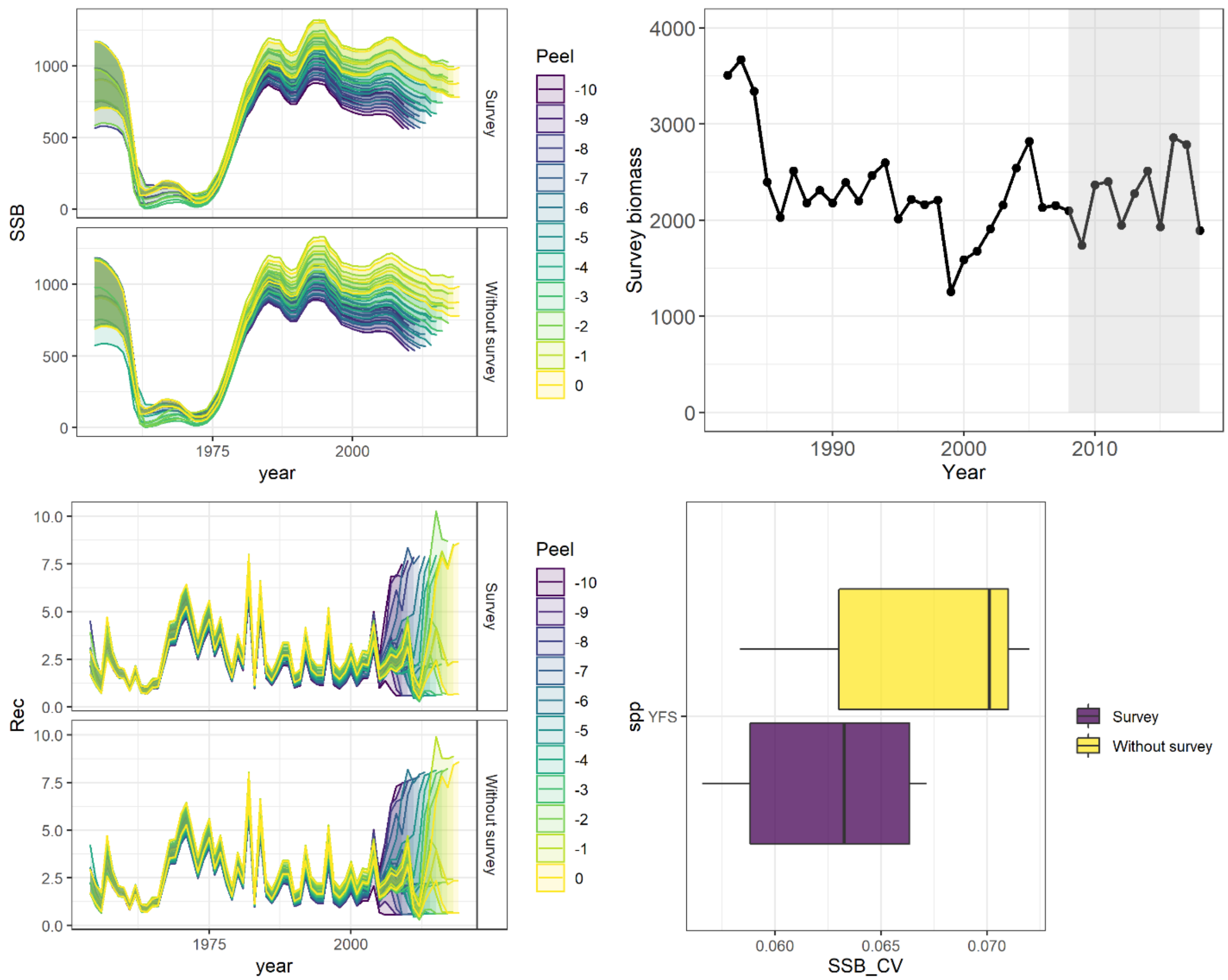

Figure A6. BSAI northern sole retrospective plots, EBS shelf bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

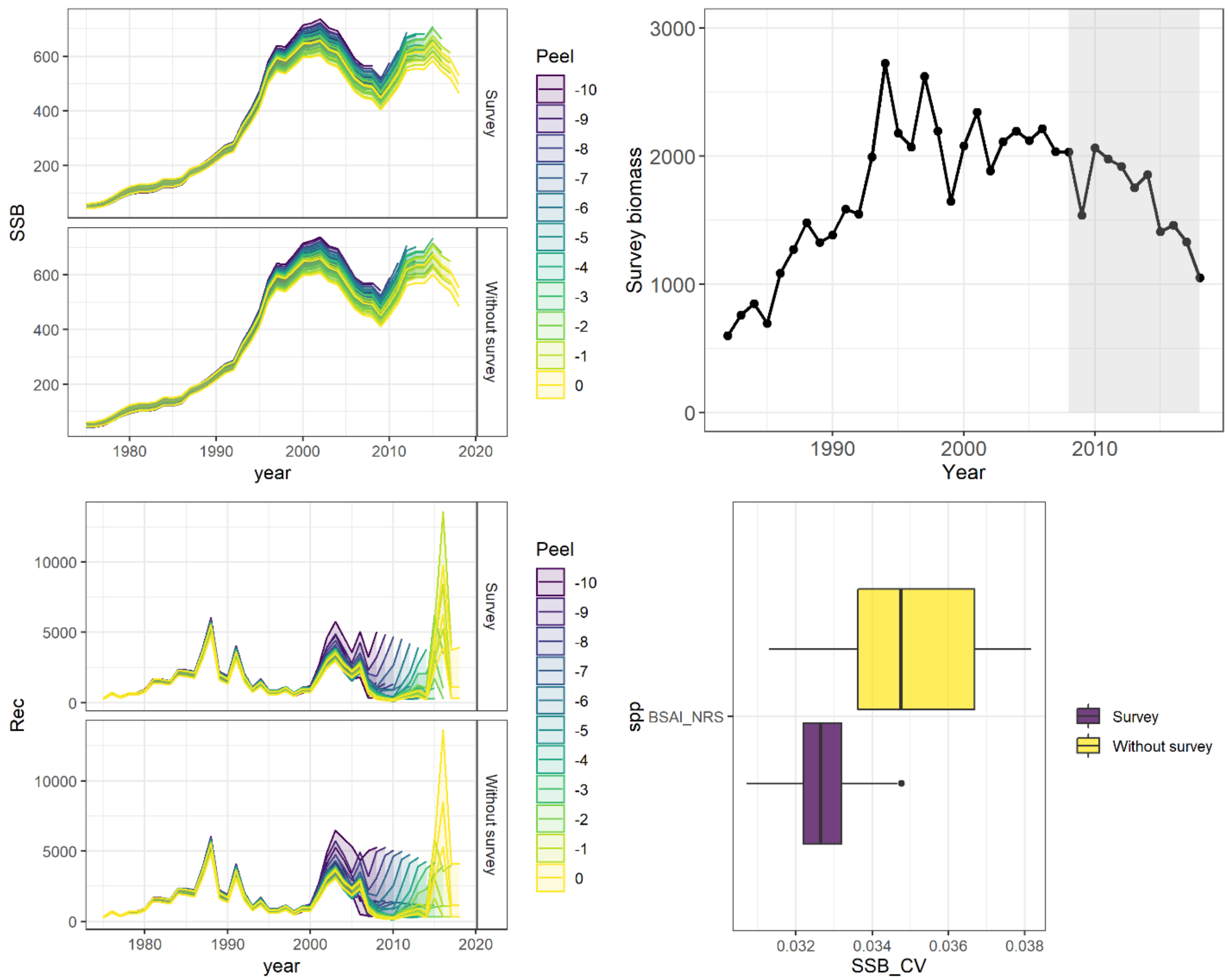

Figure A7. BSAI flathead sole retrospective plots, EBS shelf bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

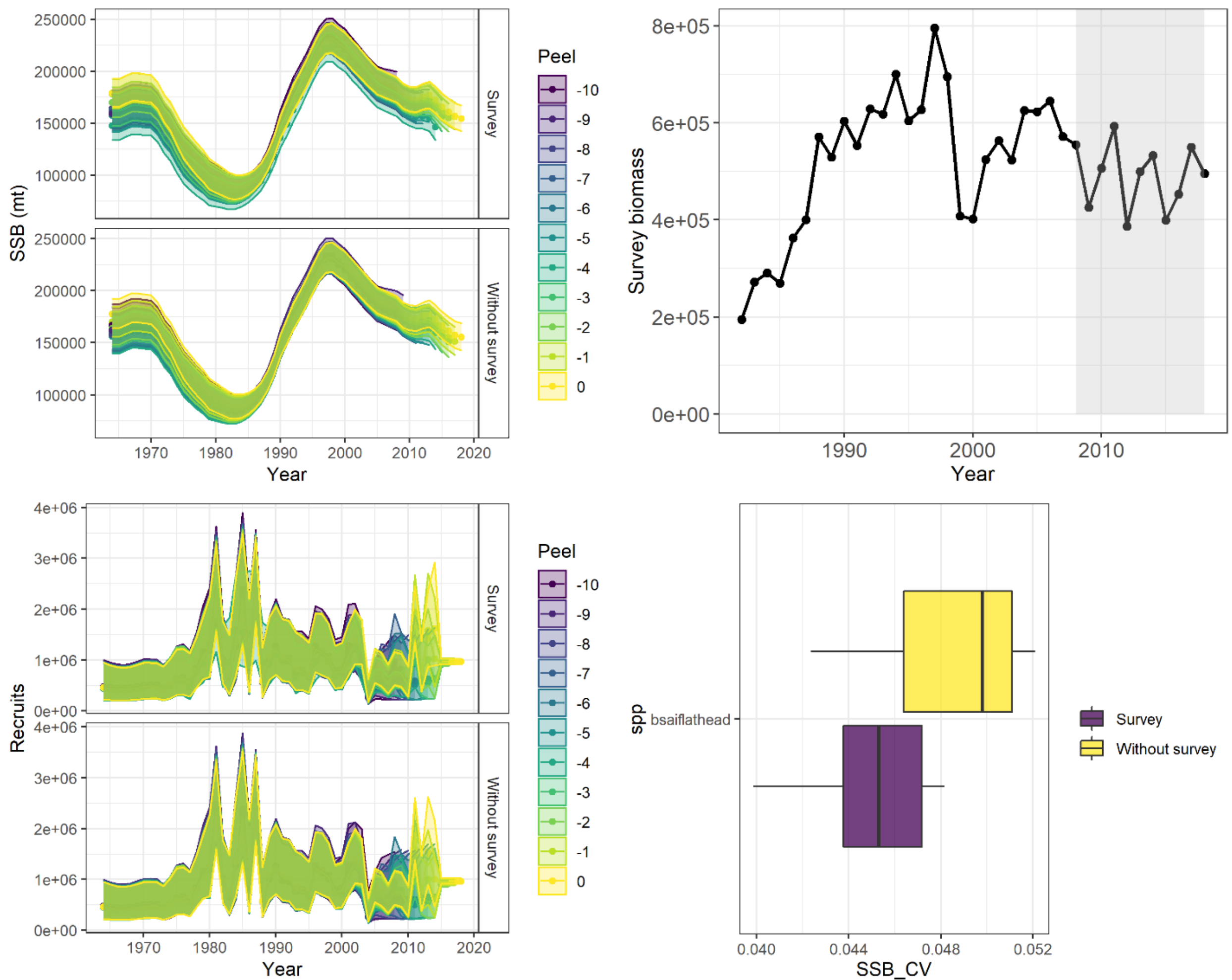

Figure A8. BSAI Greenland turbot retrospective plots, EBS shelf bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year spawning stock biomass CV.

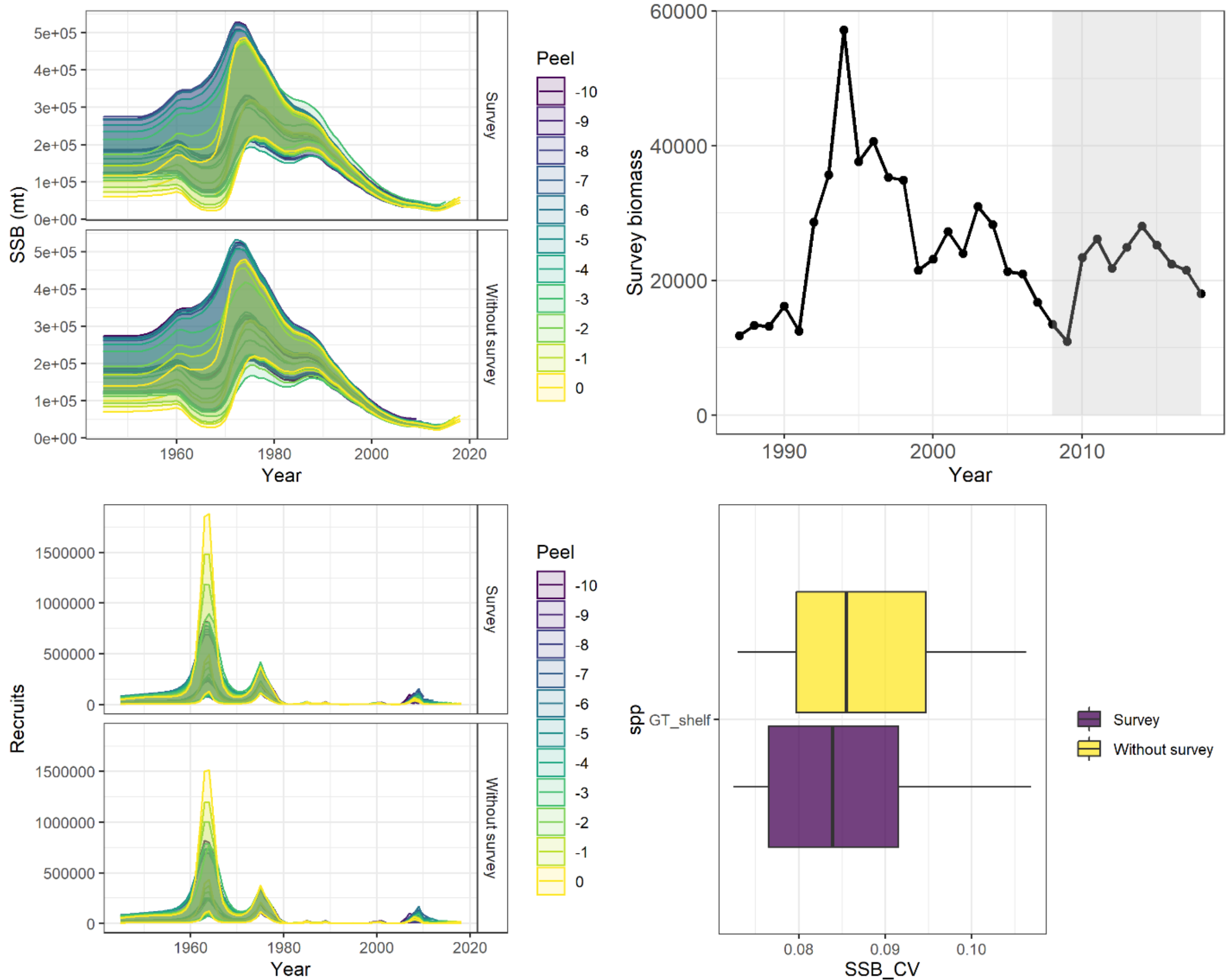

Figure A9. EBS Tanner crab retrospective plots, EBS shelf bottom trawl survey biomass estimates (shaded region highlights the years included in retrospective analysis), and boxplots of the terminal year male mature biomass CV (labeled SSB_CV in plot).

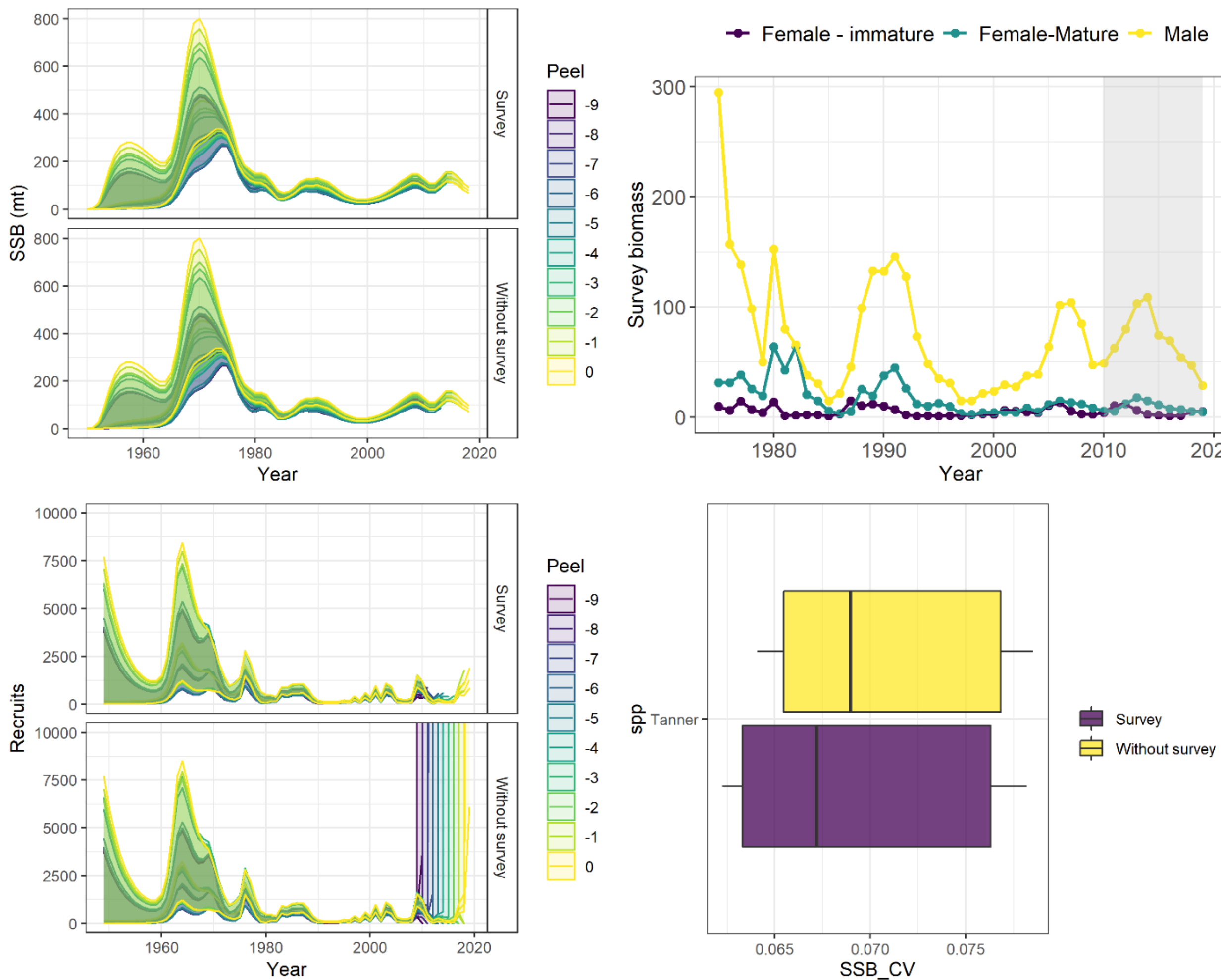

Figure A10. EBS snow crab retrospective plots and EBS shelf bottom trawl survey biomass estimates (shaded region highlights the retrospective years).