Gulf of Alaska Pacific cod model updates

Steven J. Barbeaux

Model additions for review during the September Plan Team

The following issues were addressed in preparing the 2017 assessment:

1) Stratifying fishery observer length data to total catch by year, area, gear, and trimester
2) Including ADF&G port sampled length composition data to compensate for loss of observer data in the Pot fishery (2017 expected coverage to be between 2% and 4% potentially inadequate to evaluate seasonal and spatial differences).
3) Evaluate using VAST modeling for the NMFS trawl survey data
4) Evaluate the effect of using a water temperature index on bottom-trawl survey catchability.

1.0 Stratifying length composition data

For the 2016 assessment models, fishery length composition data were proportioned based on the extrapolated number of fish in each haul for all hauls in a gear type for each year.

2016 Method: $p_{ygl} = \frac{\sum_h \frac{n_{yghl}}{\sum_l n_{yahl}} N_{ygh}}{\sum_h N_{yg}}$

Where *p* is the proportion of fish at length *l* for gear type *g* in year *y*, *n* is the number of fish measured in haul *h* at length *l* from gear type *g*, and year *y* and *N* is the total extrapolated number of fish in haul h for gear type *g*, and year *y*.

For 2017 for post-1991 length composition we propose proportioning the length additionally by the total Catch Accounting System (CAS) derived total catch weight for each gear type, NMFS management area, trimester, and year (Fig. 1). Data prior to 1991 were unavailable at this resolution so those size composition estimates are unchanged.

2017 method (post-1991): $p_{ygl} = \sum_{t,a}\left(\left(\frac{\sum_h \frac{n_{ytaghl}}{\sum_l n_{ytaghl}} N_{ytagh}}{\sum_h N_{ytag}}\right)\left(\frac{W_{ytag}}{\sum_{tag} W_{ytag}}\right)\right)$

Where *p* is the proportion of fish at length *l* for gear type *g* in year *y*, *n* is the number of fish measured in haul *h* at length *l* from gear type *g*, NMFS area *a*, trimester *t*, and year *y* and *N* is the total extrapolated number of fish in haul h for gear type *g*, NMFS area *a*, trimester *t*, and year *y*. The *W* terms come from the CAS database and represent total (extrapolated) weight for gear type *g*, NMFS area *a*, trimester *t,* and year *y*.

1.1 Results

Comparing the methods, the length composition are similar between the two approaches (Fig. 2a - c). There tends to be some smoothing of the distributions using the catch-weighted method. In the trawl fishery in particular there were some peaks (e.g. 1993, 1995, and 1996) that were caused by small samples in areas with little catch that were smoothed out when the proportions were weighted by the trimester and area. For a few years and fisheries (e.g. 1998 in the longline fishery, 2013 and 2014 in the trawl fishery) the 2017 method resulted in a less smooth distribution as there were few samples in the areas and times with the greatest catch .

Comparing these new length composition estimates within the model resulted in slightly higher *M* and lower Q estimates compared to last year's method (Fig. 3). Recruitment and spawning biomass also increased slightly but were within the confidence intervals of the 2016 model.

1.2 Recommendation

There is no quantitative means of determining the better method. In theory the 2017 proposed method for weighting the length composition provides a better representation of the GOA Pacific cod catch, but may not be truly representative in some years due to low sample sizes in some areas and times. Despite these drawbacks, the authors suggest moving forward for the 2017 stock assessment with the new method.

Figure 1: Proportion of catch in biomass by gear, area, trimester, and year. Area includes all areas from 0-9 (e.g. area 640 includes areas 640 and 649 and 650 includes 650 and 659). Color indicates trimester and size indicates proportion by area of the circle. The area of the circles for each year sum to 1.00.

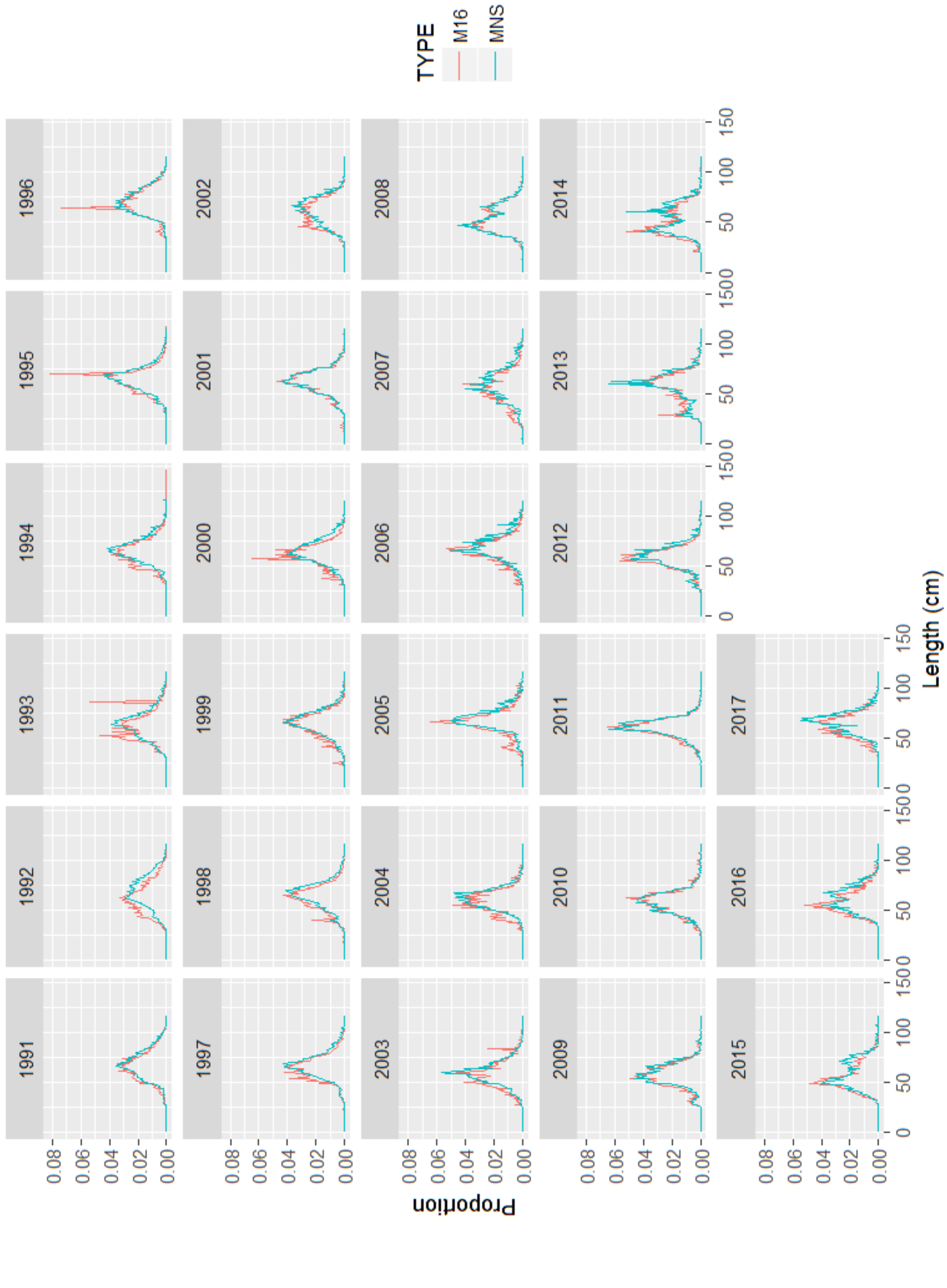


Figure 2a. GOA Pacific cod Length composition proportions for the trawl fishery by year for 2016 (M16) and 2017 (MNS) methods of weighting data.

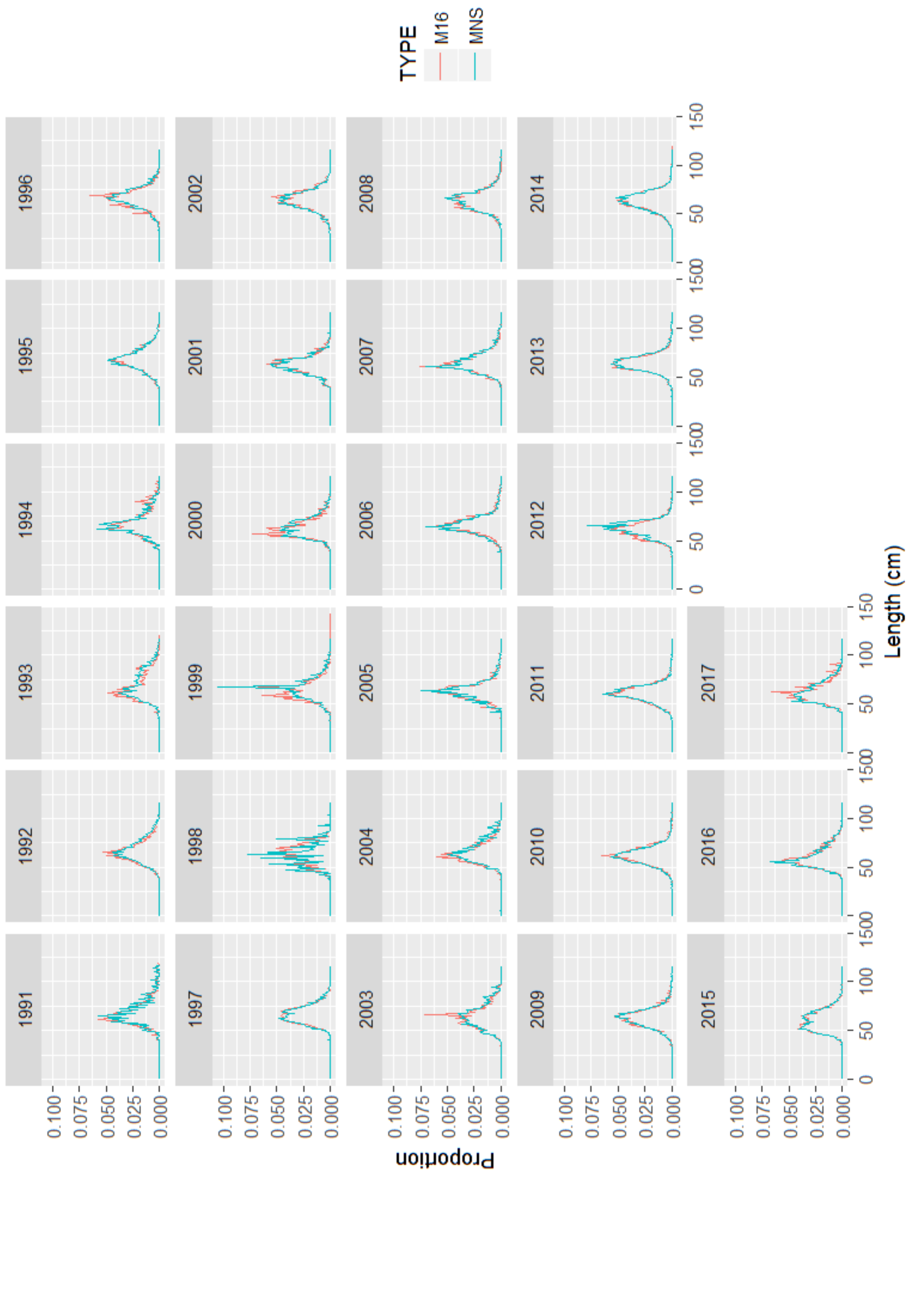


Figure 2b. GOA Pacific cod Length composition proportions for the longline fishery by year for 2016 (M16) and 2017 (MNS) methods of weighting data.

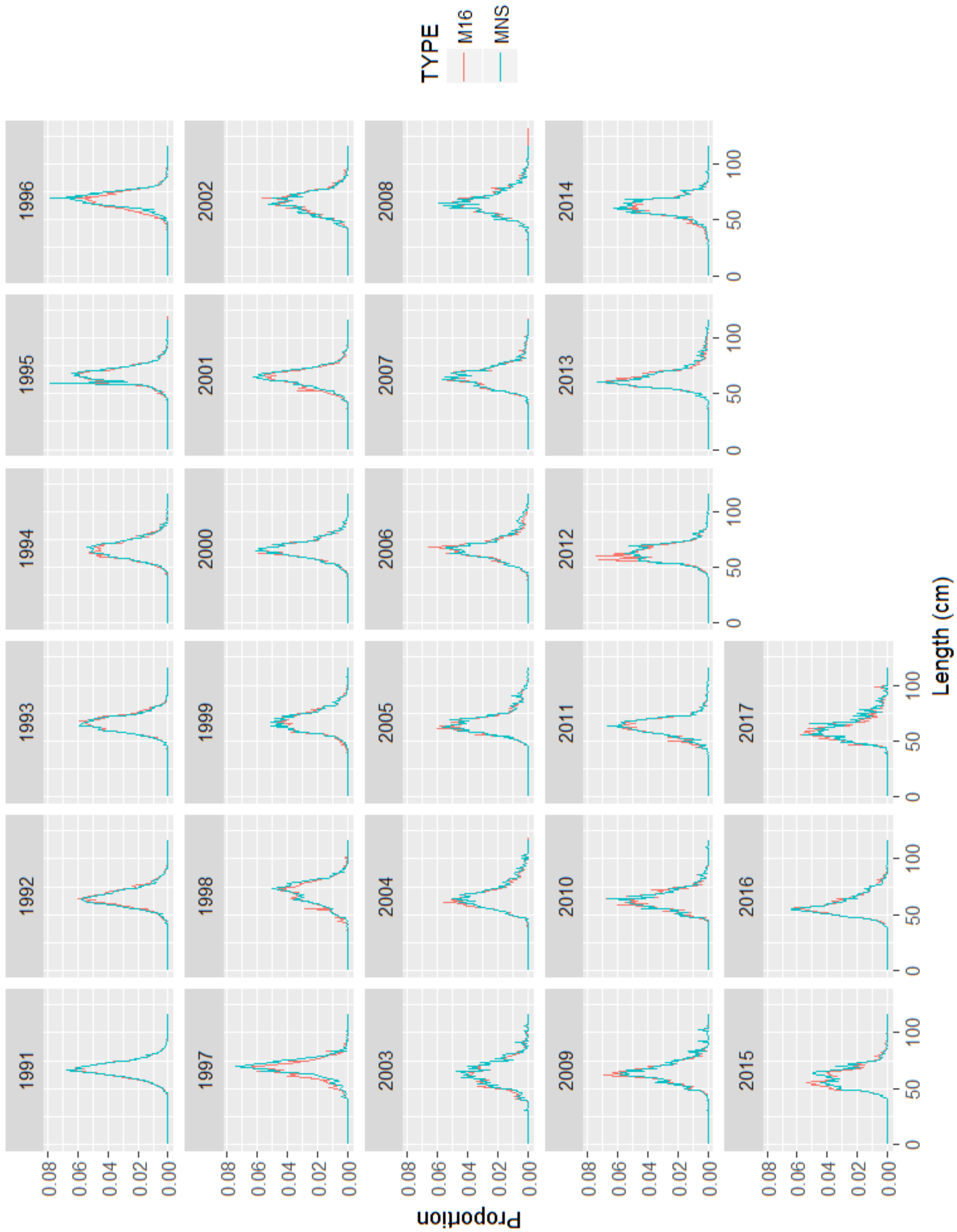

TYPE
M16
MNS
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Proportion
Length (cm)

Figure 2c. GOA Pacific cod Length composition proportions for the pot fishery by year for 2016 (M16) and 2017 (MNS) methods of weighting data.

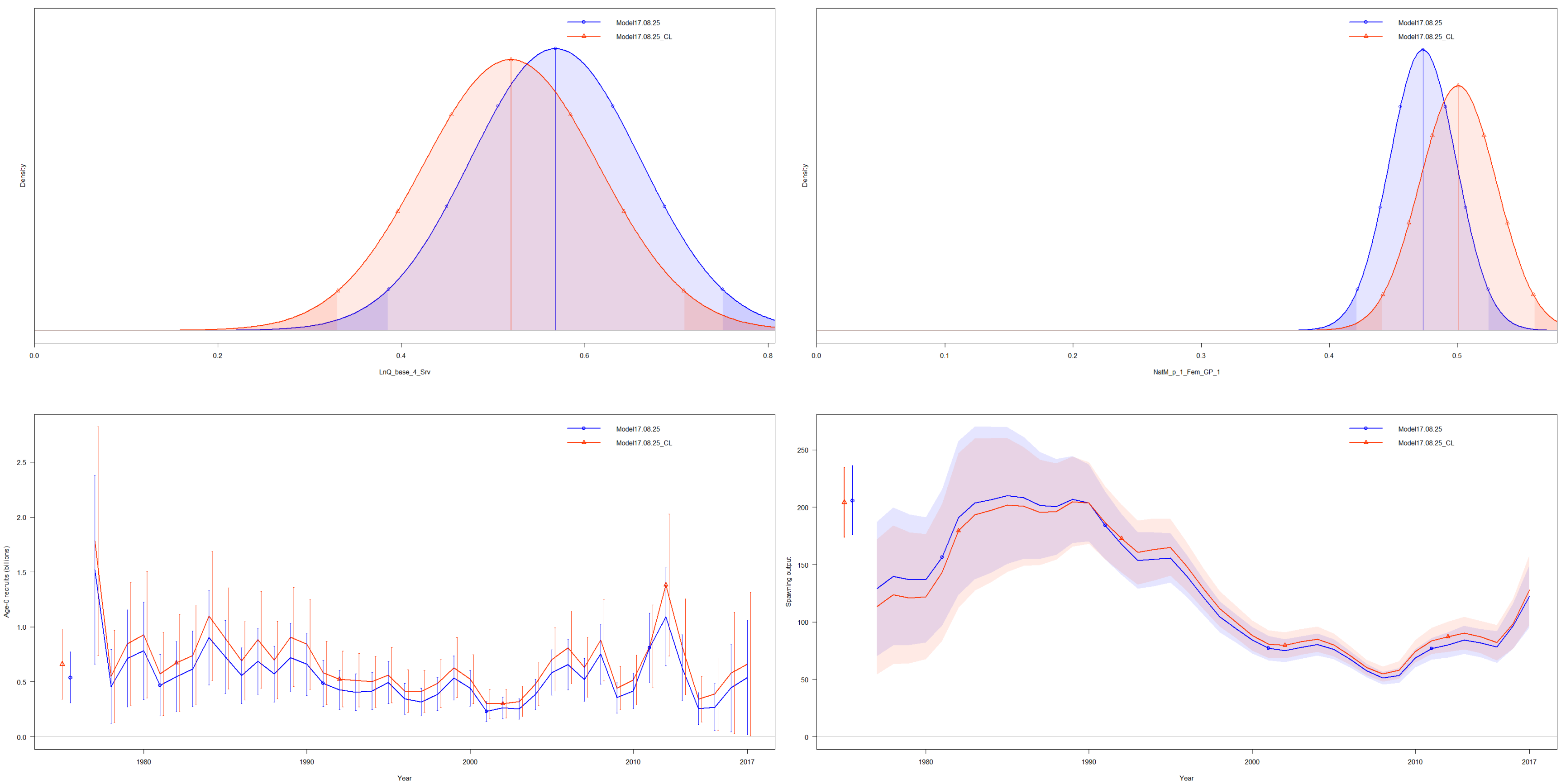


Figure 3. Comparison of effects on model results for Model 17.08.25, the reference model configuration in 2016.

2.0 Addition of ADF&G port landings length composition data

In 2017 observer coverage changed as managers established electronic monitoring (EM) as a substitute for observer coverage. This is likely to affect coverage of the GOA Pacific cod pot fishery (estimates of around 4%, (Craig Faunce, personal comm. 25 July 2017) compared to 14.7% coverage in 2016). The EM program is currently unable to measure fish for length composition (and obviously is unable to include age structure sampling). In 2016 the pot fishery caught 59% of the total allocation of GOA Pacific cod with 75% of this caught in state waters (Fig. 4). This leaves a large proportion of the catch without observer collected length composition data. To mitigate this loss of data, other sources of pot fishery length composition data are being considered. The ADF&G has routinely collected length data from Pacific cod landings since 1997 (Fig. 5a and Fig. 5b). As such, evaluating these data as a way to augment the pot fishery length composition data for the stock assessment is important.

The ADF&G port sampling and NMFS at-sea observer methods are follow different sampling frames so combining them poses some challenges. We propose two methods; method

1) use ADF&G data from the pot fishery for all trimester/areas in which there were more fish measured than by observers,
2) use ADF&G data from the pot fishery for trimester/areas in which observer data were missing. The resolution of the ADF&G data required the assumption that all of the samples collected in an area/trimester were representative of the overall catch for that trimester/area.

Method for ADF&G data: $p_{ytagl} = \frac{n_{ygl}}{\sum_l n_{yal}} \left(\frac{W_{ytag}}{\sum_{tag} W_{ytag}} \right)$

Where *p* is the proportion of fish at length *l* for gear type *g* in NMFS area *a* in trimester *t* for year *y*, *n* is the number of fish measured at length *l* from gear type *g* in trimester *t* of year *y.* W is the catch accounting total weight for gear type *g*, NMFS area *a*, trimester *t,* and year *y*.

2.1 Results

For method 1 from 1997 to 2017 there were 59 trimester/area combinations of the total 136 that had more measured fish in the ADF&G port sampling data than in the federal observer data. For method 2 there were 17 trimester/area combinations without federal observer length data that had ADF&G port sampler length data. Under both method 1 and method 2, 13 trimester/area combinations with catch lacked length data. However the catch from these missed times/areas only comprised 2% of the total GOA pot Pacific cod catch for the period (Fig.6 and Fig.7). Differences in length distribution for the pot fishery for 1997-2017 for the three methods are relatively minor (Figure 8) and stock assessment results were very similar (Fig. 9).

2.2 Recommendations

There was little difference in the results from the two methods which employ ADF&G port sampling data. Since the 2017 sampling year is incomplete and anticipated to be lower coverage, further evaluations of these two approaches will be carried forward for the assessment.

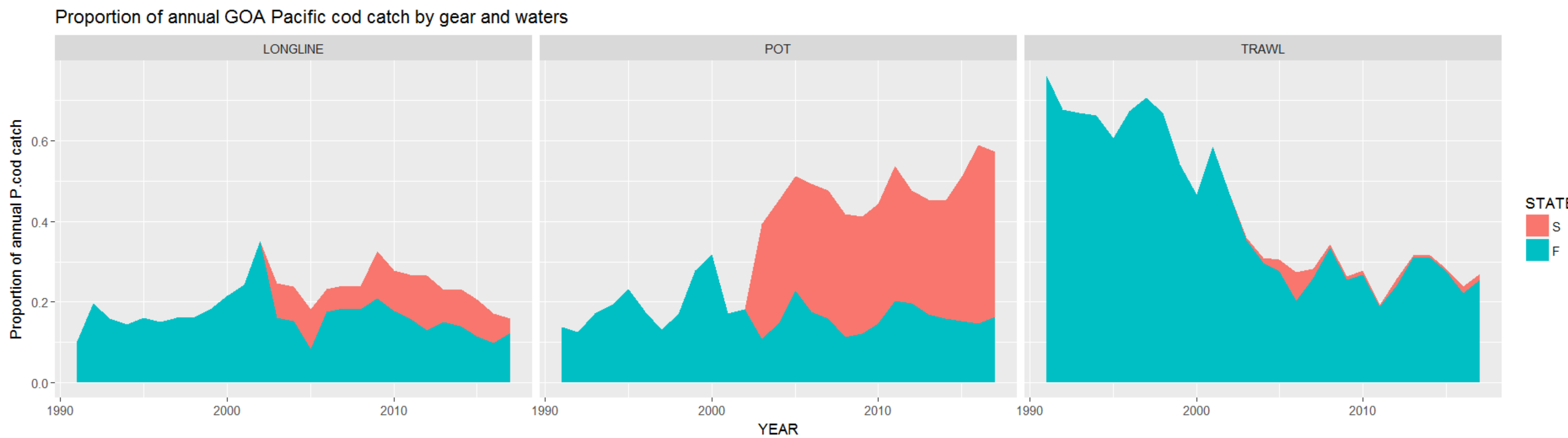


Figure 4. Proportion of GOA Pacific cod catch by gear inside (S) and outside (F) Alaska state waters for 1991-2017. The 2017 value is through 8 August 2017. Note that prior to 2003 Pacific cod catch was not differentiated between state and federal waters in the catch accounting tables.

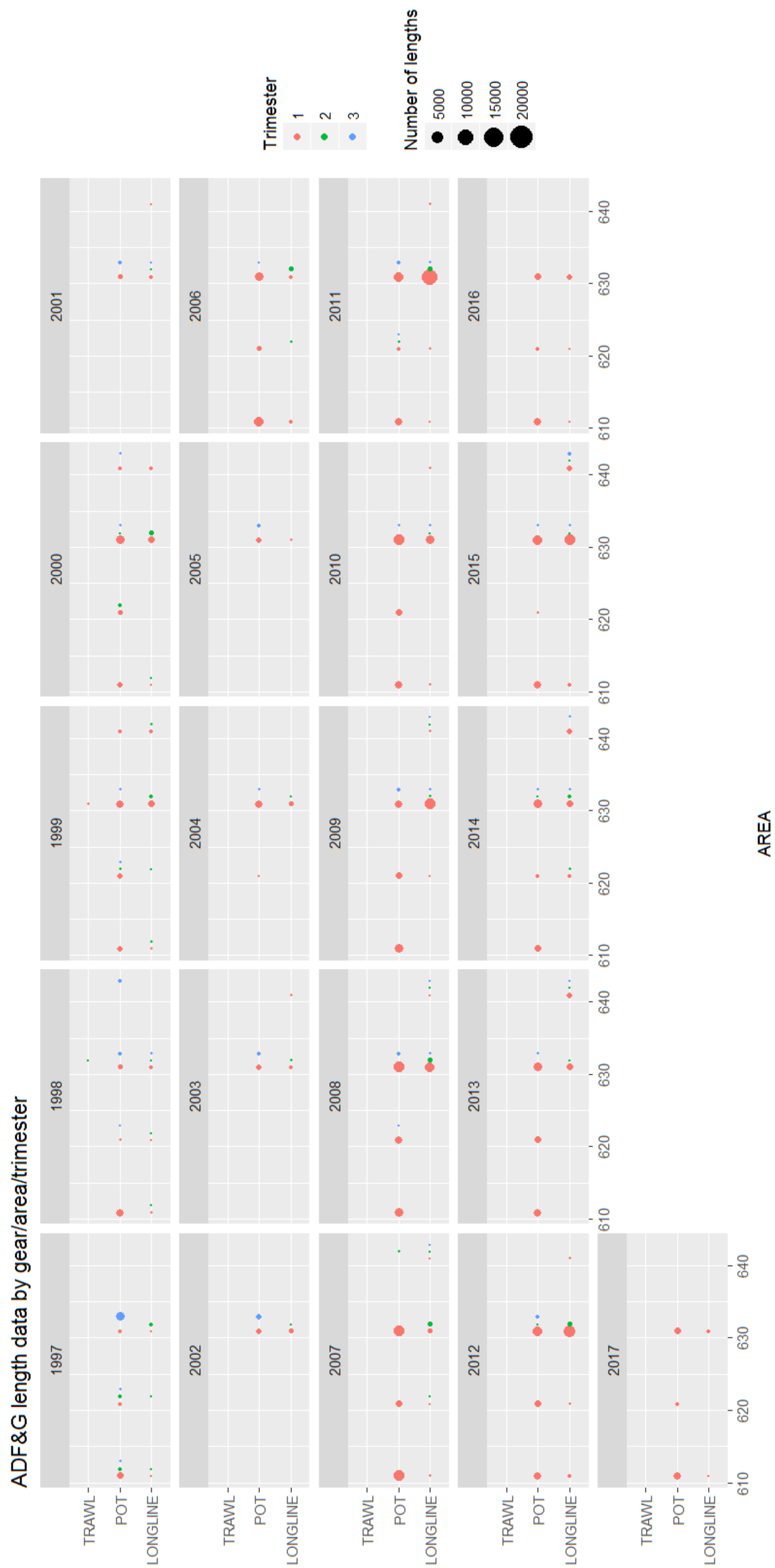


Figure 5a. Number of Pacific cod length measurments recorded by ADF&G port sampling. Area of the circle represents number of fish measured, color is the trimester. See Figure 1 above for overall catch by area, year, and trimester.

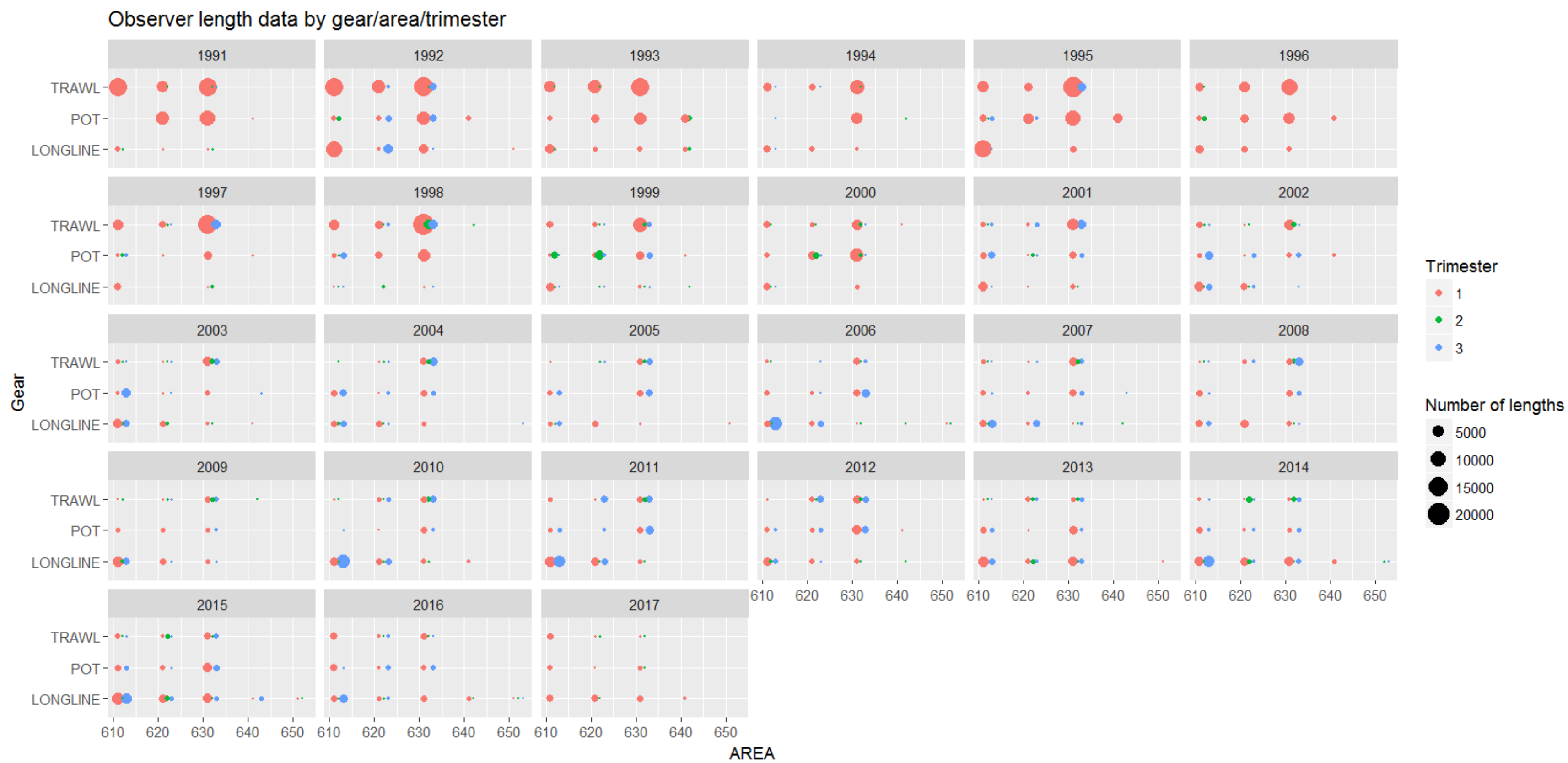


Figure 5b. Number of Pacific cod length measurments recorded by at sea observers. Area of the circle represents number of fish measured, color is the trimester. See Figure 1 above for overall catch by area, year, and trimester.

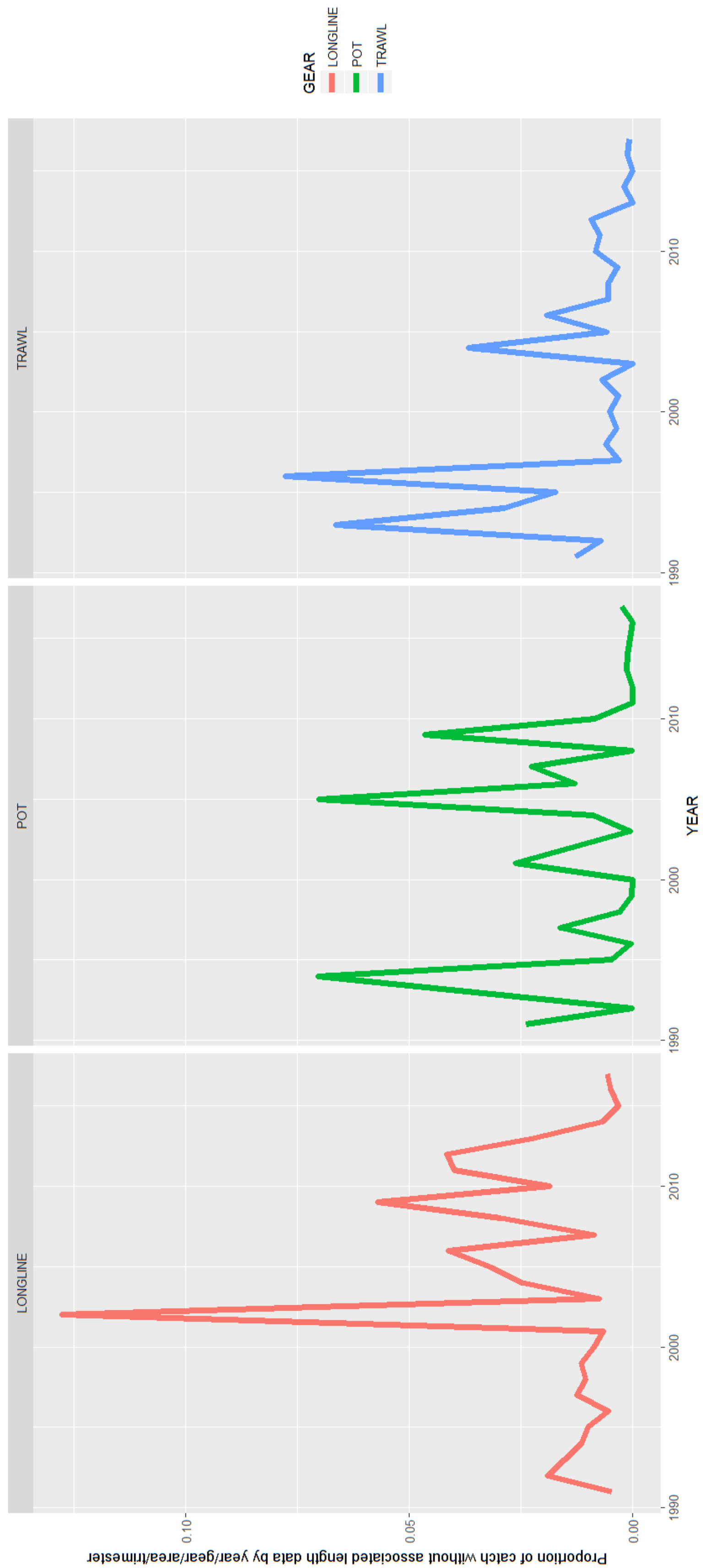


Figure 6. Proportion of total annual GOA Pacific cod catch with no associated length composition data by gear/year/area/trimester under both methods 1 and 2.

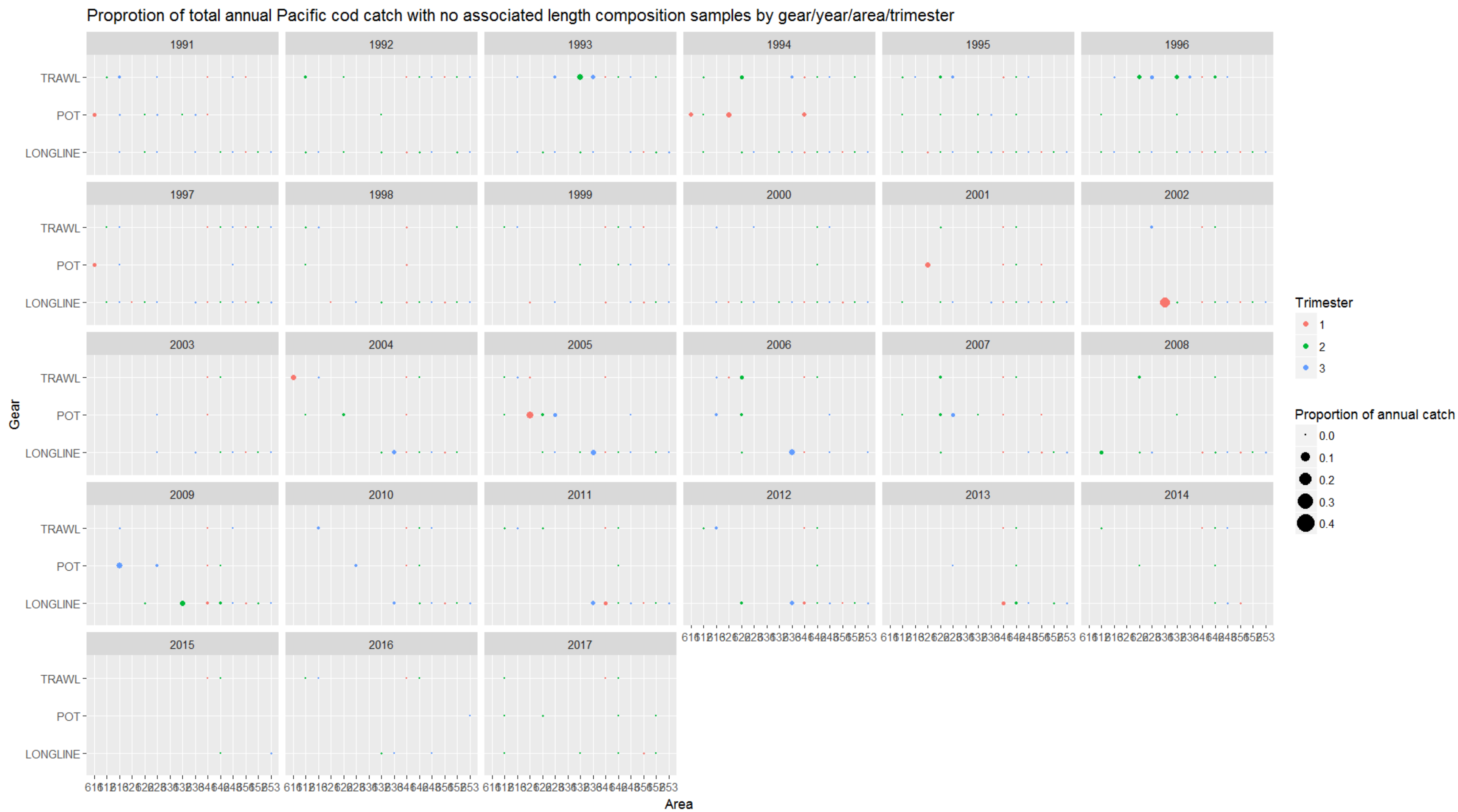


Figure 7. Proportion of total annual GOA Pacific cod catch with no associated length composition data by gear/year/area/trimester under both methods 1 and 2.

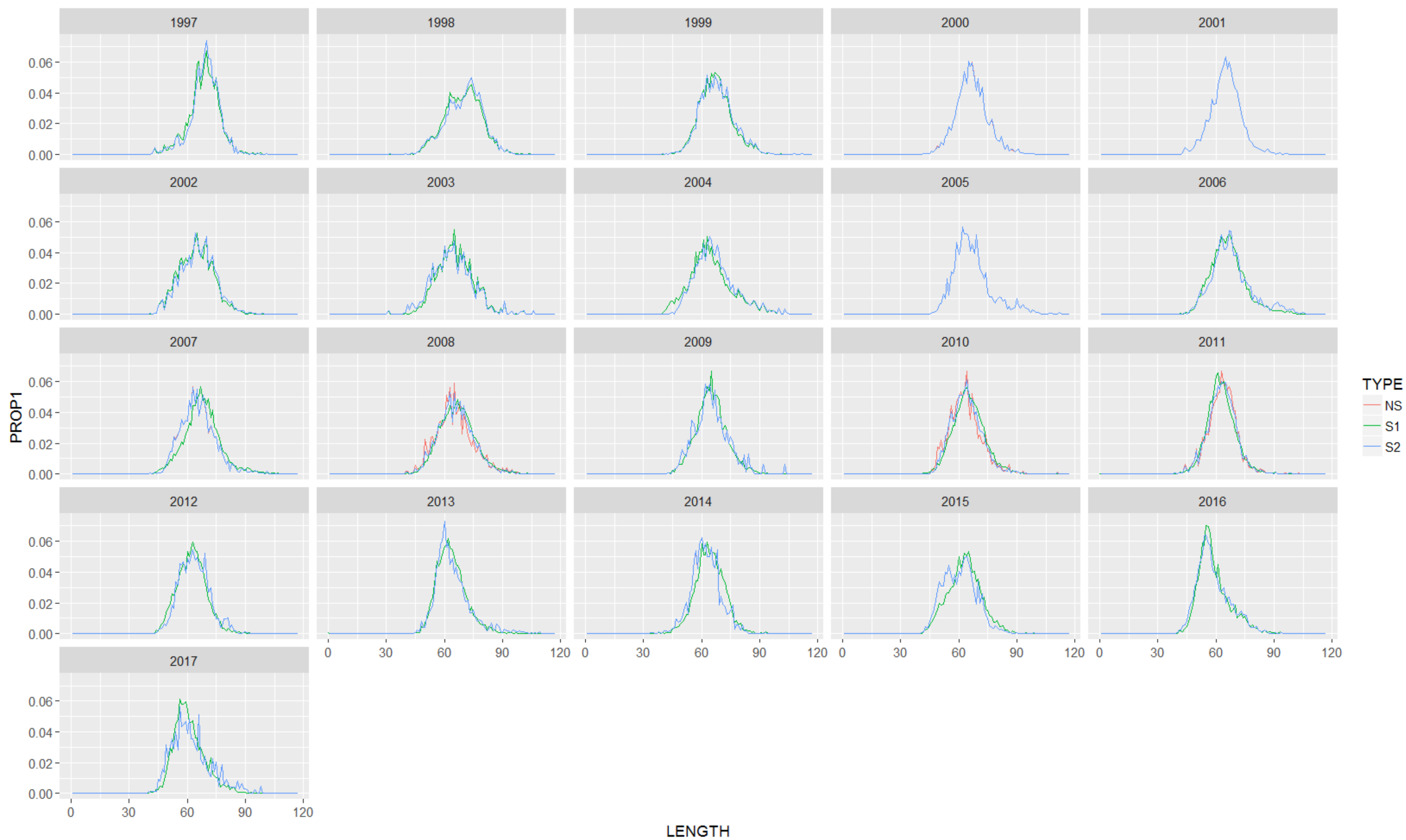


Figure 8. Length composition for the GOA pot Pacific cod fishery for 1997-2017 comparing distributions derived from just the observer data (NS), using method 1 for the ADF&G port sampling data (S1) and using method 2 for the ADF&G port sampling data.

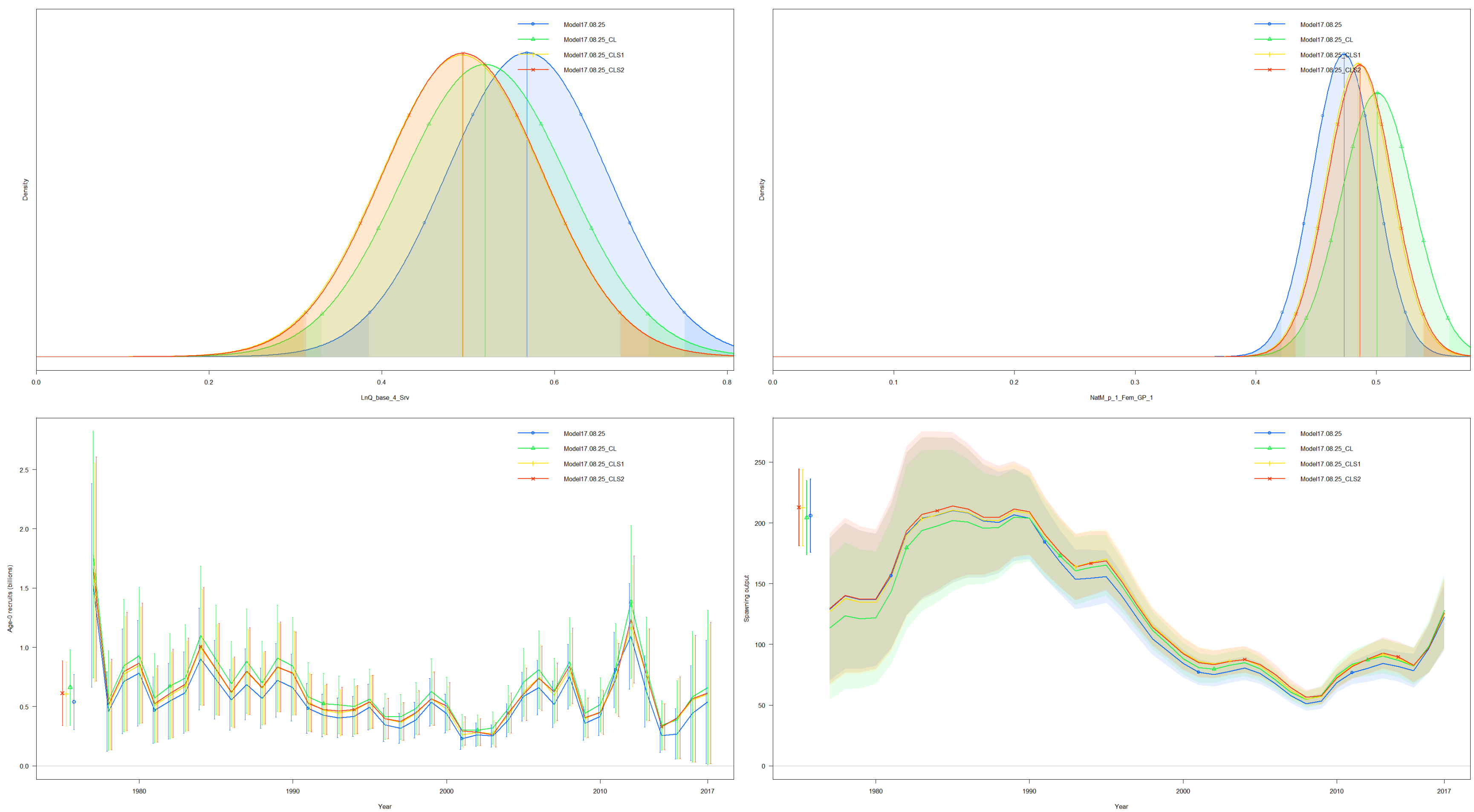


Figure 9. Comparison of effects of adding ADF&G port sampling length data in method 1 (Model17.08.25_CLS1) and method 2 (Model17.08.25_CLS2) with the reference model from 2016 (Model17.08.25) and the new 2017 method of weighting lengths (Model17.08.25_CL).

3.0 Vector Autoregressive Spatio-Temporal model (VAST) for the GOA bottom trawl survey

The GOA bottom trawl survey follows a stratified random sampling design. This provides estimates using conventional statistics for biomass estimates for a variety of species. However the sampled strata has varied over time and this affects region-wide estimates over time. Thorson *et al.* (2015) applied a geostatistical delta-generalized linear mixed model approach that has been shown to improve the precision of survey estimates:

> "VAST is an R package for conducting spatio-temporal analysis of data from multiple categories (species, sizes, etc.), and includes both spatial and spatio-temporal variation in density for each category, with either factor-analysis or autoregressive correlations among categories, with derived calculation of abundance indices, center-of-gravity, and area-occupied." (Thorson 2016)

Simulations have shown that this approach provides unbiased estimates with well-calibrated confidence intervals and on average 20% lower estimate errors in comparison with a stratified approach, such as historically applied to the GOA bottom trawl survey data (Thorson *et al.* 2015).

For 2017 we selected several model configurations. Two broad categories include a set where Pacific cod catch rates are in terms of numbers, and the other in terms of biomass. Haul locations vary from year to year (Figure 10). A 25 km grid size. We examined the effect of changing the number of knots from 100, 250, and 500. For the 100 knot models. In other model sets we examined the inclusion of a bias correction (Thorson and Kristensen 2016) and the inclusion of a vessel effect (Thorson and Ward 2014). Both of these model runs were conducted using 100 knots.

3.1 Results

For all the models explored diagnostics showed convergence and low final gradients. In assessing the impacts of the number of knots in the spatial mesh we see very similar distributions (Fig. 11a and Fig. 11b) and an insignificant decrease in the coefficient of variation across all years with the increase in the number of knots (Fig. 12). All of the VAST model values were lower for both biomass and abundance than the stratified survey estimates, with the 2009 estimate being substantially lower for all three knot series. There was little difference in VAST results among the three differing knot models run for biomass (~-3.8% on average 100 vs 500 knots) except for the 2009 and 2011 biomass levels which were lower by -11% and -7% in the 100 vs. 500 knot models (Fig. 13). The differences were substantially higher in the abundance models with an average of +21% between the 100 vs. 500 knot models. The largest disparity between the abundance models were in 2009 and 2011 with +29% and +31% from the 100 vs. 500 knot models. In general, the greater number the knots the lower the biomass and abundance estimates. We suspect this is due to the assumptions on the geostatistical distribution and skewness of the data. The larger number of knots reduces the impact of extreme hauls because the data are modeled on more and smaller areas and the geostatistical model smooths the extreme values towards the mean.

Although adding bias correction increased the AIC in both abundance and biomass estimates, comparison of models in this manner is not applicable. Including the bias correction decreases the variability for both the abundance and biomass estimates (Fig. 14). The use of bias correction in the VAST model increased estimates of abundance and biomass for all years (Fig. 15). The biomass estimates for the 1984-1993 and 2011-2015 surveys exceeded the design based estimates, 1996-2009 were lower than the designed based estimates. The abundance estimates were nearly identical to the design based estimates for all years except 1996 and 2009. These two years had higher than average uncertainty with large numbers of small fish encountered in only a few hauls.

Adding a vessel effect increased the number of coefficients by 46 (2 fixed and 44 random), but reduced AIC by 86.8 and 77.2 in the biomass and abundance models. As would be expected including the vessel effect increased the variance of the model estimates for both abundance and biomass (Fig. 14). For the abundance estimates including a vessel effect made little difference from a model with just bias correction included (Fig. 16), except for the 2009 survey estimate which was somewhat higher in the model with vessel effects. For biomass estimation including vessel effects resulted in higher biomass estimates than with the bias correction alone for all but three years, 1984, 2013, and 2015.

The addition of these indices to the stock assessment model in place of the design based estimates makes a substantial change to the results with a much lower recruitment estimate for the 2009-2012 year classes, this results in a lower estimate spawning biomass in the most recent period. Using biomass instead of abundance resulted in lower estimates of spawning biomass, when the vessel effect was included results become much more similar. The change in model results are within the bounds of the suite of models presented last year.

3.2 Recommendations

If the VAST approach is to be implemented we recommend using the 100 knot alternative as there was little improvement in variance with the addition of knots, while the larger number of knots required more computation time. The literature on the subject (Thorson and Kristensen 2016) suggests that application of the bias correction is an improvement to the model. This addition drives the model results to more closely resemble the design based estimates. Addition of the vessel effect does improve model fit, but increases variance, we suggest further exploration of this model configuration for implementation in the 2017 assessment.

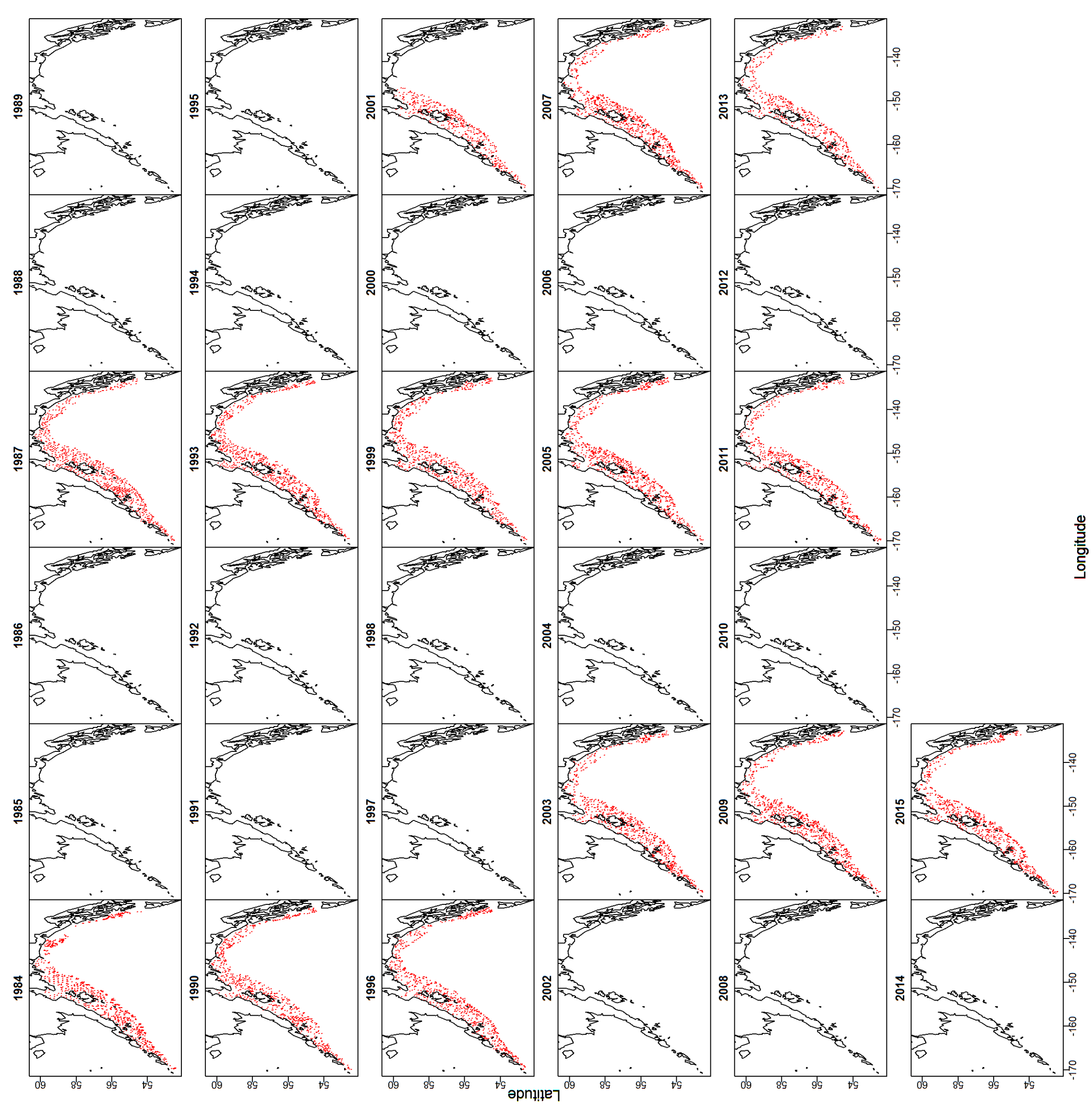
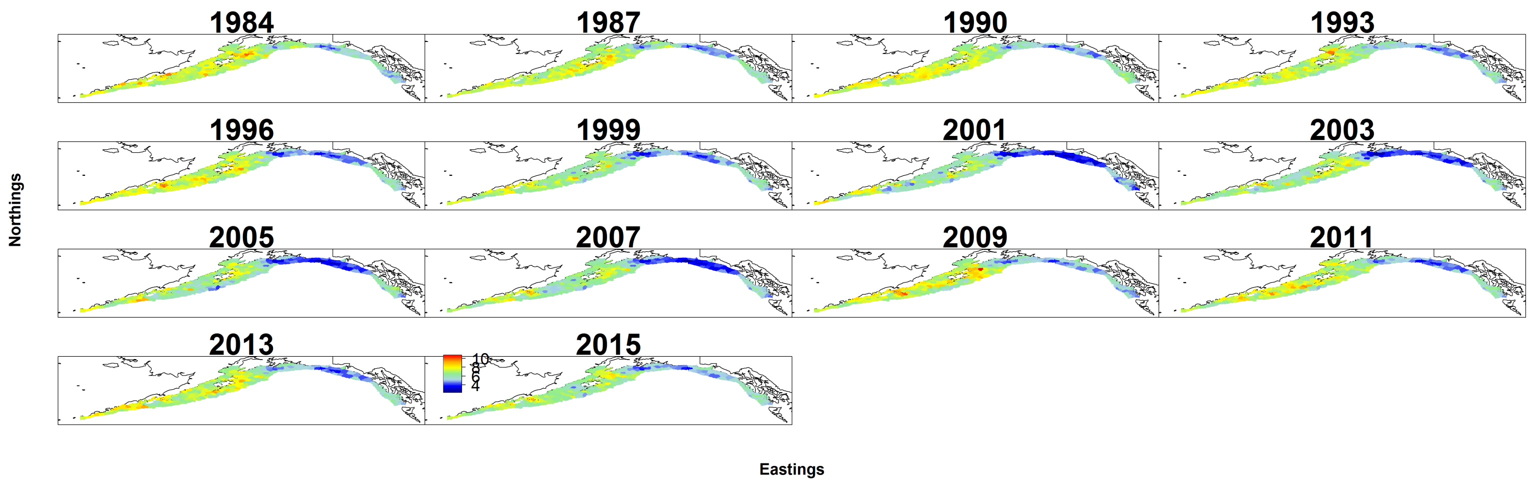


Figure 10. GOA bottom trawl haul locations for VAST modeling.

100
Knots



250
Knots

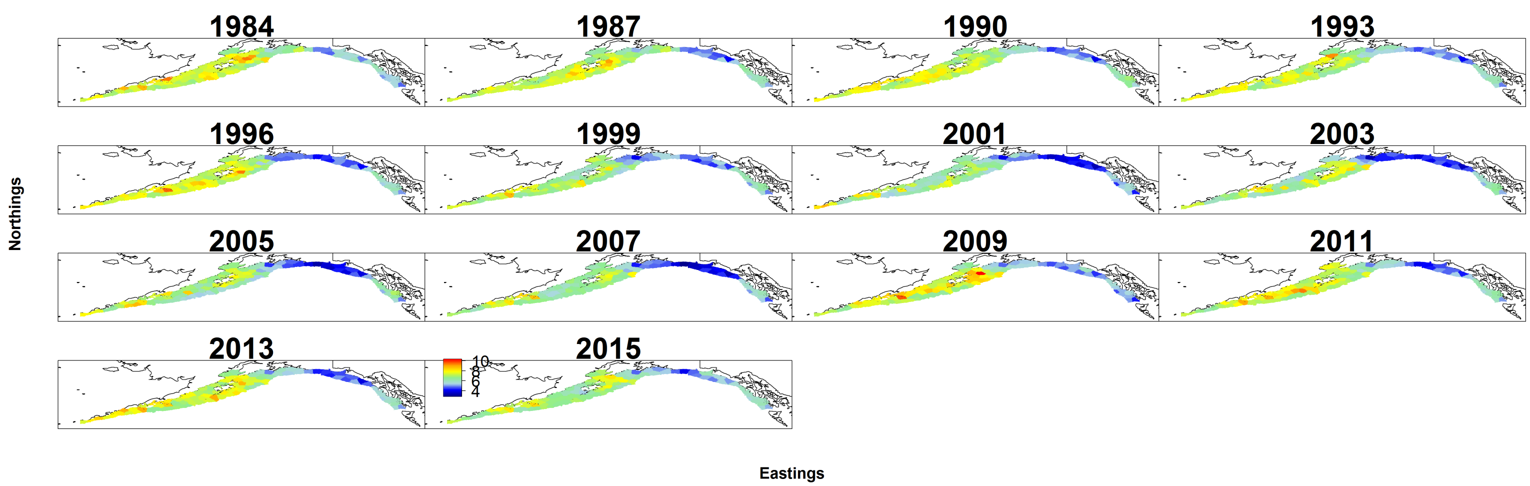


Figure 11a. VAST model biomass log density differences for the GOA bottom trawl survey based on number of knots for 100 knots (top) and 250 knots (bottom).

500
Knots

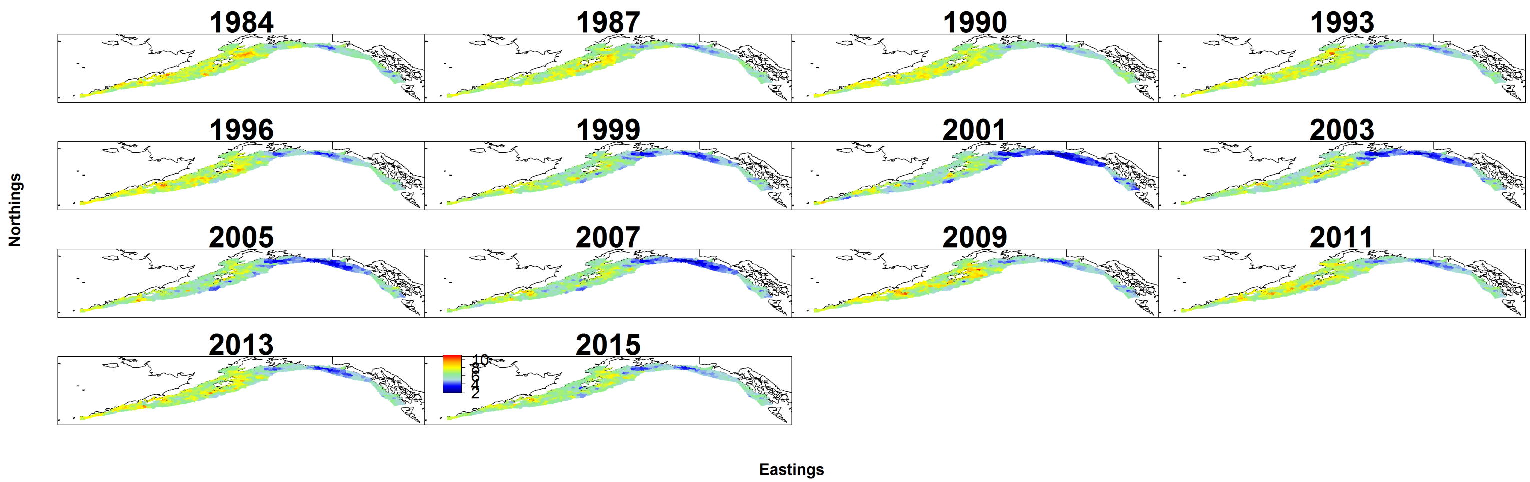


Figure 11b. VAST model biomass log density differences for the GOA bottom trawl survey based on number of knots for 500 knots

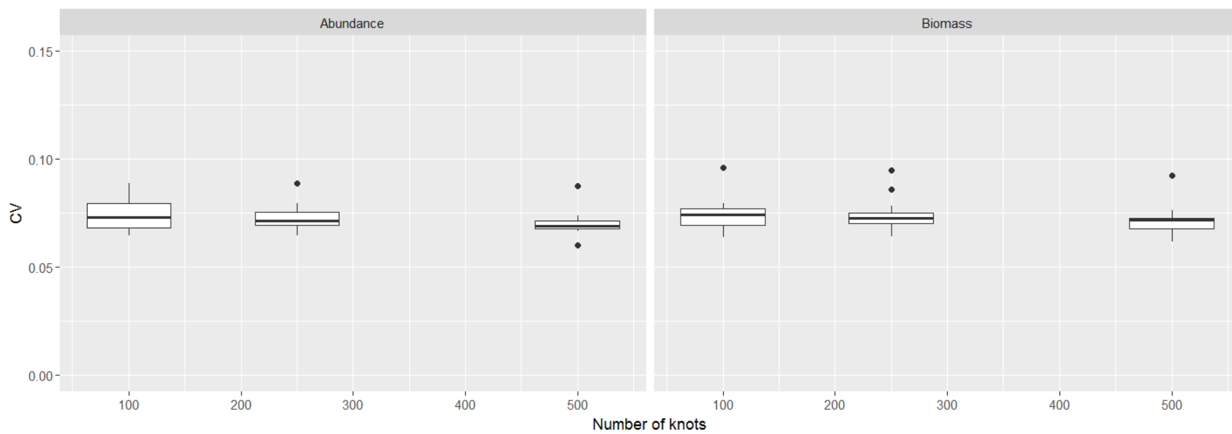


Figure 12. Boxplots of Pacific cod VAST model coefficient of variations (CV) for GOA bottom trawl survey over the number of knots for all years for abundance and biomass estimates.

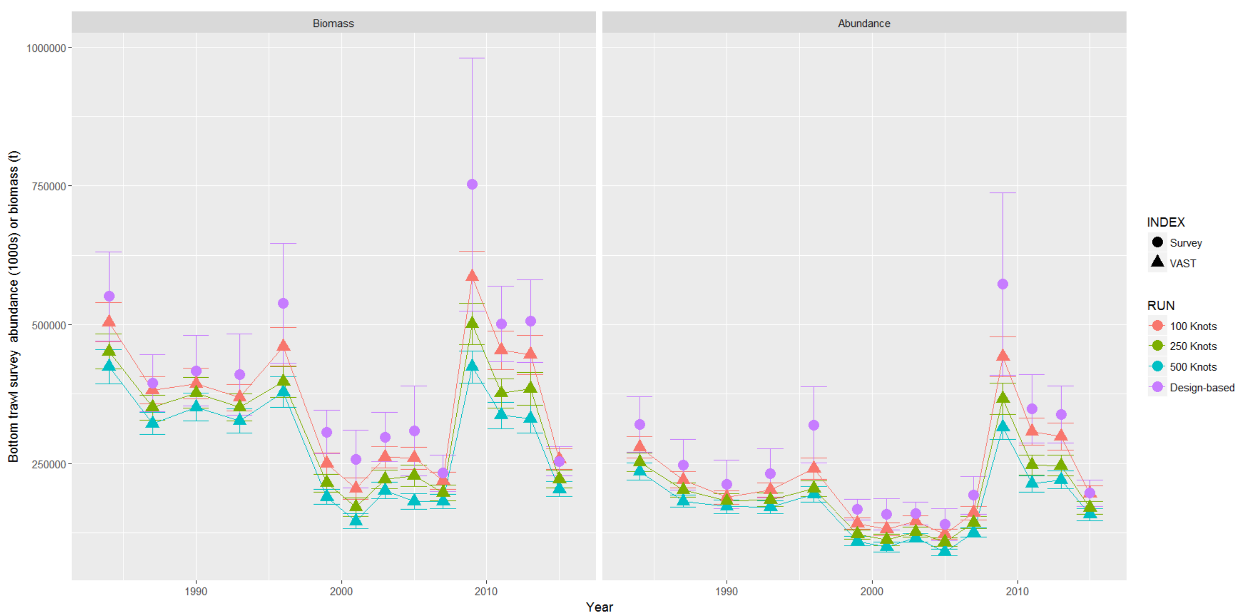


Figure 13. VAST model differences for Pacific cod biomass (left) and abundance (right) indices for the GOA bottom trawl survey based on number of knots. The design-based stratified survey estimates are purple circles.

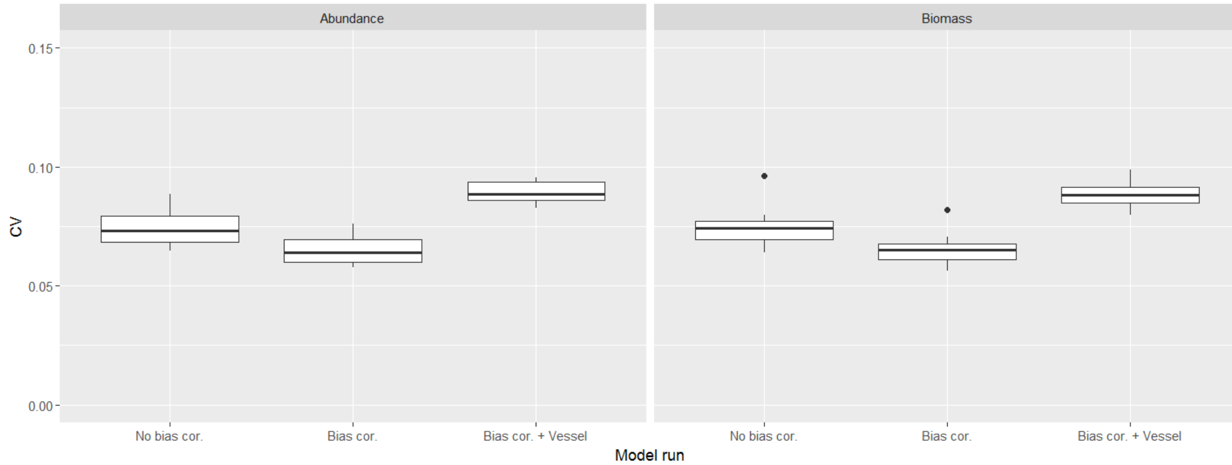


Figure 14. Boxplots of Pacific cod VAST model coefficient of variations (CV) for GOA bottom trawl survey with the addition of bias correction and vessel effect for all years for abundance and biomass estimates.

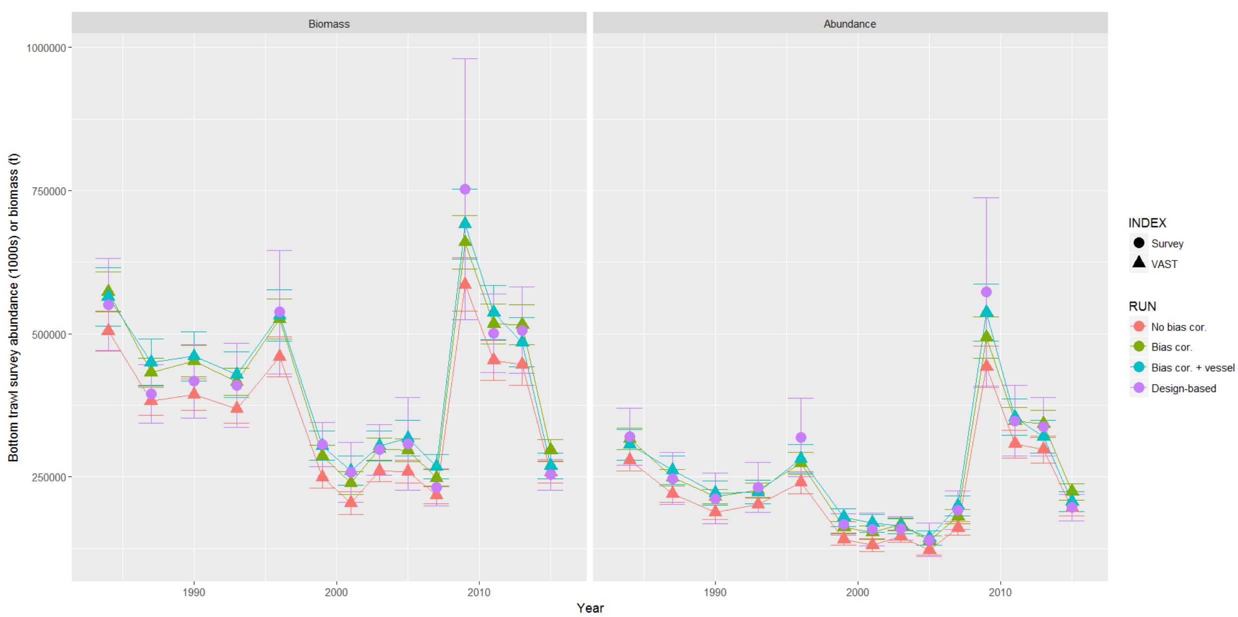


Figure 15. VAST model differences for Pacific cod biomass (left) and abundance (right) indices for the GOA bottom trawl survey including bias correction and vessel effect in the model. Note all models are based on a 100 knot mesh.

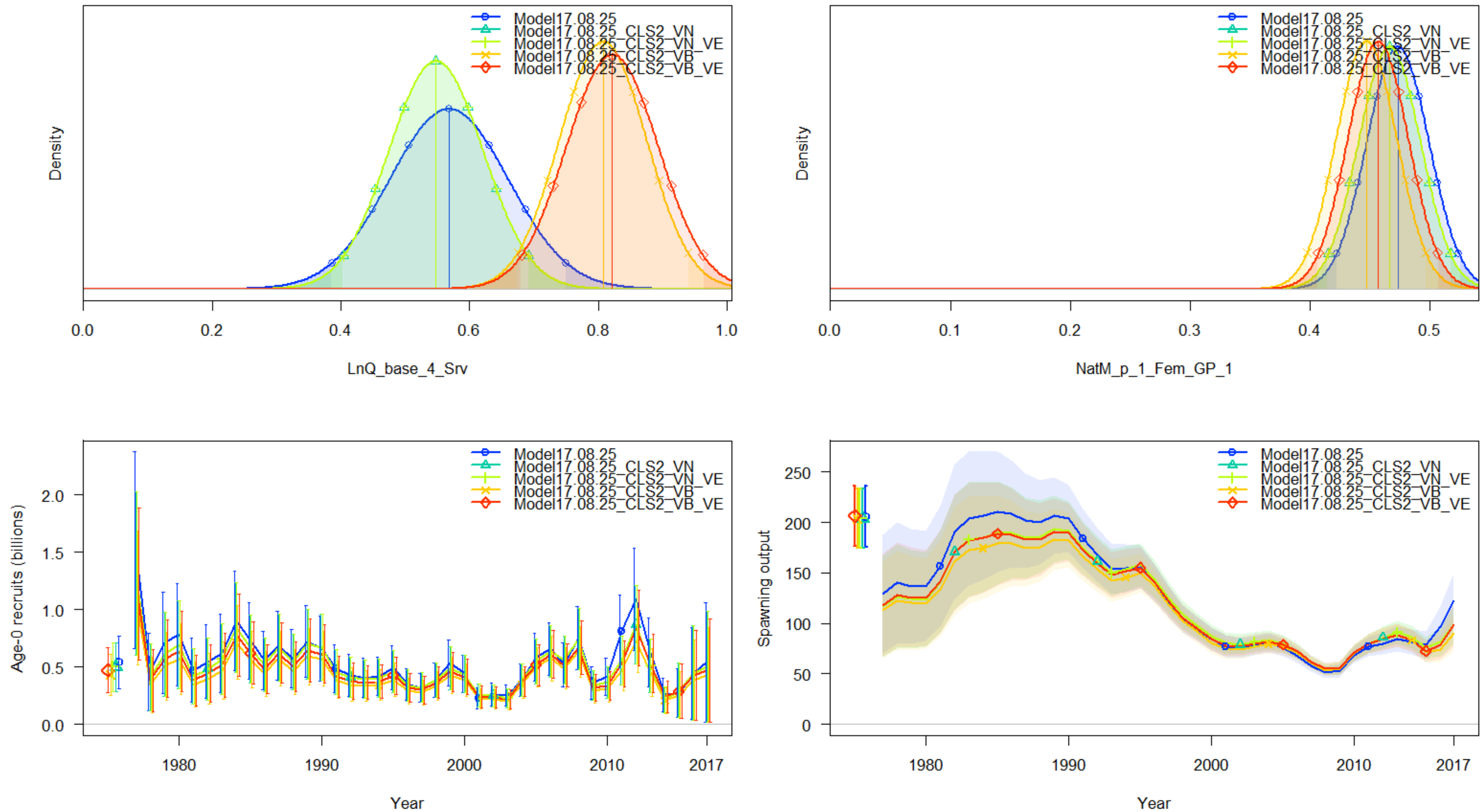


Figure 16. Comparison of effects of using VAST abundance (Model17.08.25_CLS2_VN) and biomass (Model17.08.25_CLS2_VB) indices with 100 knots and bias adjusted with the reference model from 2016 (Model17.08.25) and the new 2017 method of weighting lengths with the addition of ADF&G port sampling data (Model17.08.25_CLS2).

4.0 Water temperature index impacts on fitting catchability in the bottom trawl survey

The GOA bottom trawl survey data show Pacific cod moving to deeper water to the southwest in years with warmer bottom temperatures (Fig. 17). The movement of fish could potentially lead to differences in survey catchability. This year we explored that connection in the stock assessment model. In the process of assessing temperature impacts on fish distribution Qiong Yang, an oceanographer post-doc working with Ned Cokelet, develop indices of fish temperature for work in NPRB project 1509. These temperature indices are specific for each size category of Pacific cod at 10 cm intervals based on the mean depth of fish of the size category and temperatures at this depth from the Climate Forecast System Reanalysis (CFSR; Sahana *et al.* 2010) for the central GOA from 1979-2017 (Fig. 18).

For the first analysis catchability of the bottom trawl survey was allowed to be fit with an extra parameter that scaled it to the CFSR-based bottom temperature index for 0-10 cm Pacific cod. We used Model 17.08.25 with Method 2 using state length data and both the abundance and biomass VAST GOA survey index. The best model fit was observed using the temperature of the 0-10cm fish, this was also the index with the shallowest depth and highest bottom temperature variability. We then resampled the temperature index without replacement 1000 times and rerun the model. We hypothesize that if the model improvement was because of the addition of a parameter and allowing the model more flexibility in fitting Q then the proportion of resampled model runs with a likelihood lower than the initial index fit should be greater than 5%.

4.1 Results

The biomass and abundance indexed models' likelihoods were improved by 26.5 and 18.6 points when catchability was fit to the CFSR index for 0-10cm Pacific cod. For both the biomass and abundance index models the negative log-likelihood for the resampled temperature indices were only lower than the actual index in 1.9% of the runs (Fig. 18) suggesting the improvement to the model fit was due primarily to fitting the index and not solely a result of added flexibility in the model.

In the best fit models catchability for both the biomass and abundance indexed models were higher in years with colder than average bottom temperatures (Fig. 19) with an environmental link of -0.365 for biomass indexed model and -0.308 for the abundance indexed model.

When the CFSR index is used to fit catchability, recruitment is estimated to be higher in recent years (particularly 2012) than in the 2016 reference model resulting in higher estimate of current total and spawning biomass. The final model estimates closely resemble those obtained from the 2016 reference model (Model17.08.25; Fig. 19).

4.2 Recommendations

We would recommend inclusion of a single model in the suite of models for November with catchability fit with an environmental link to the 0-10 cm Pacific cod CFRS bottom temperature index.

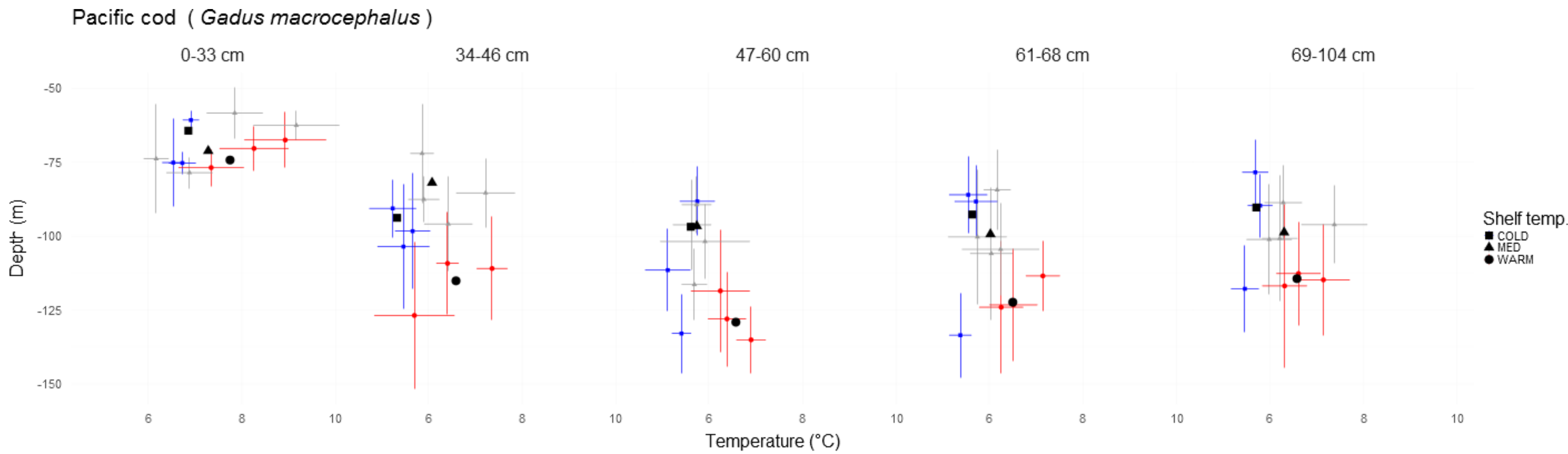


Figure 17. Annual centroids of bottom depth and bottom temperature for central GOA Pacific cod coded by mean shelf-wide temperature with colder than 0.66 stanadard deviations from the mean (blue), warmer than 0.66 stanadard deviations from the mean (red) and intermediate (grey).

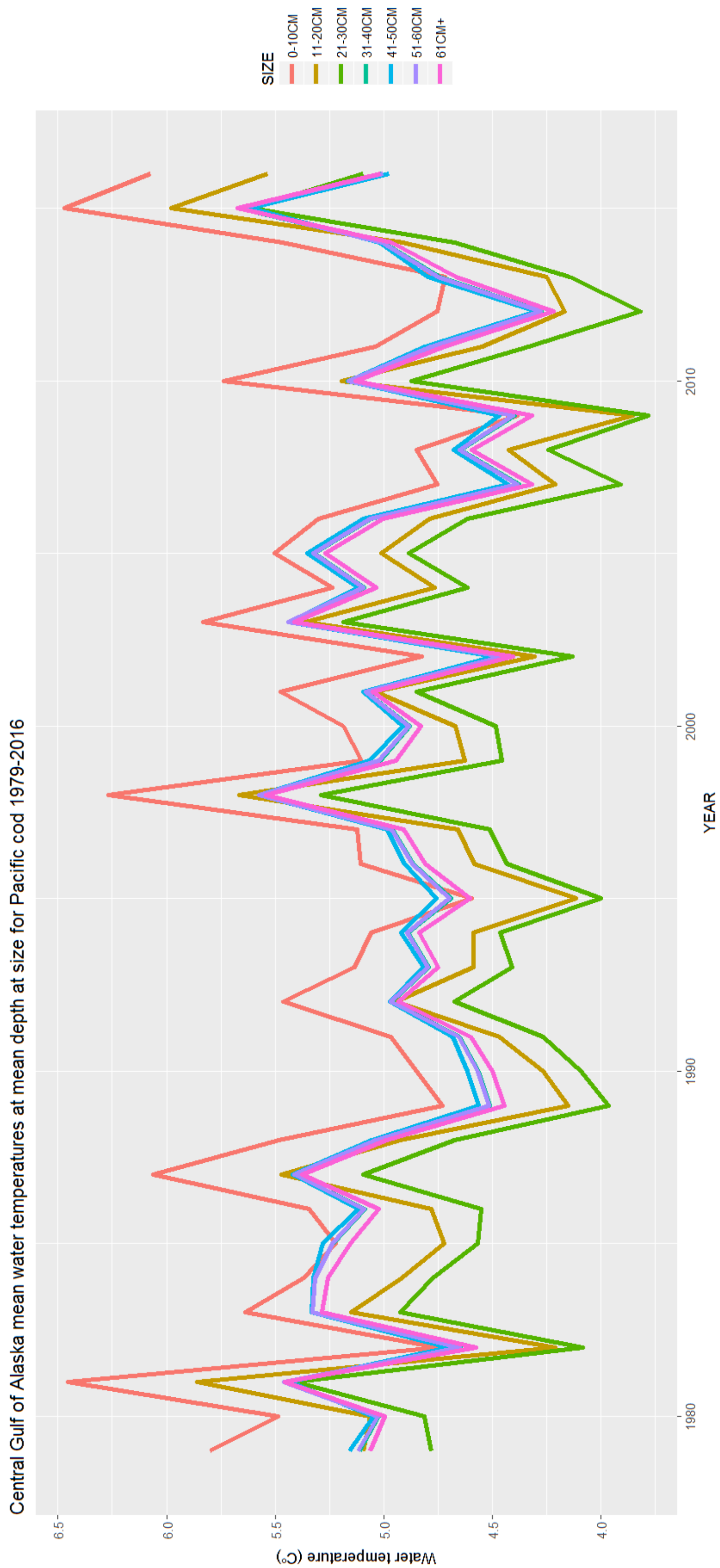


Figure 18. Mean bottom temperature at the mean depth for Pacific cod in the central GOA from the Climate Forecast System Reanalysis (CFSR) data.

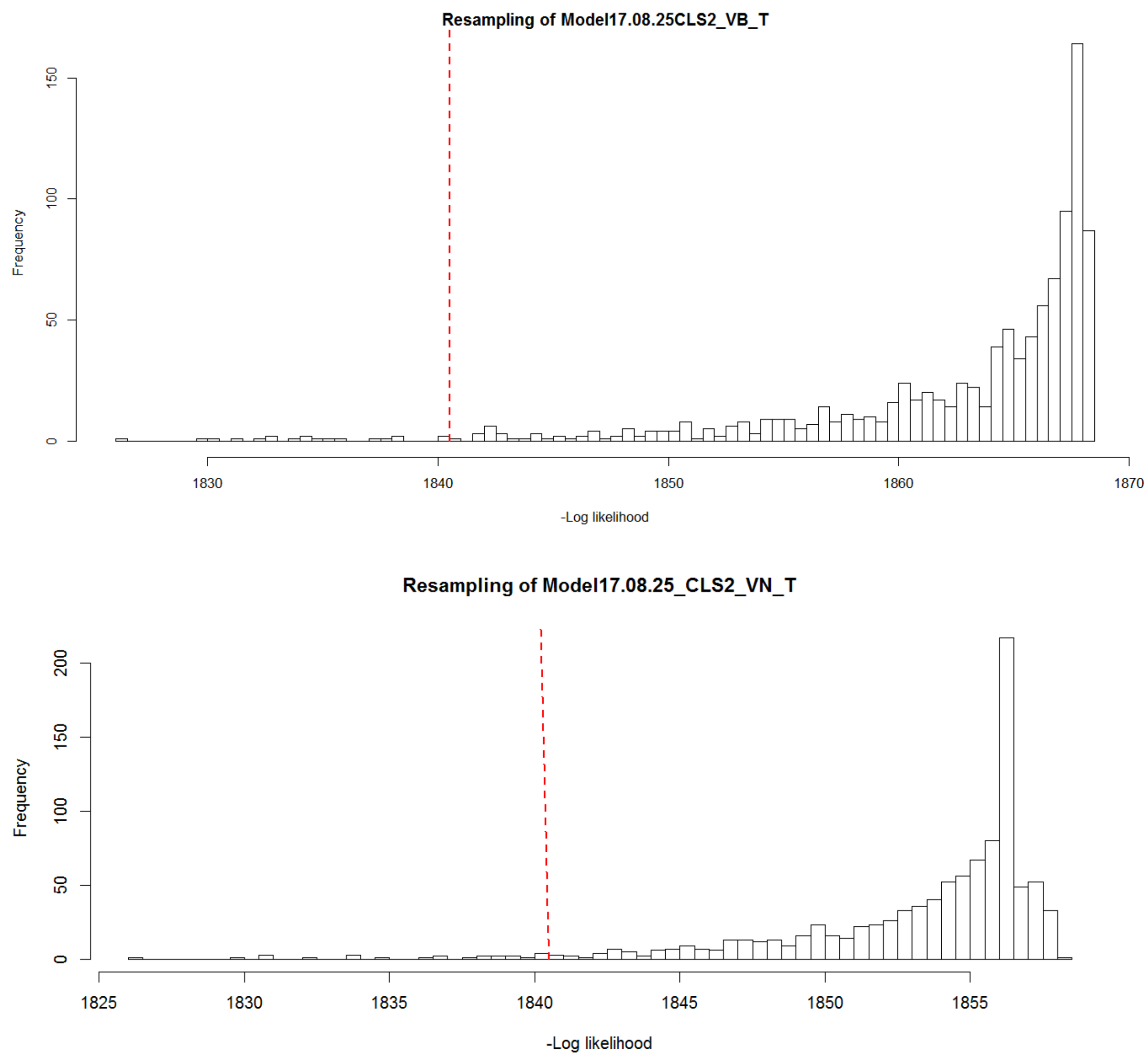


Figure 19. Distribution of negative log-likihoods from resampling the mean bottom temperature index for Pacific cod in the central GOA from the Climate Forecast System Reanalysis (CFSR) data for the Biomass model (left) and abundance model (right) using method 2 for ADF&G

port sampling data and VAST developed GOA bottom trawl survey indices. The red dashed lines are the negative log-likelihood from the initial models.

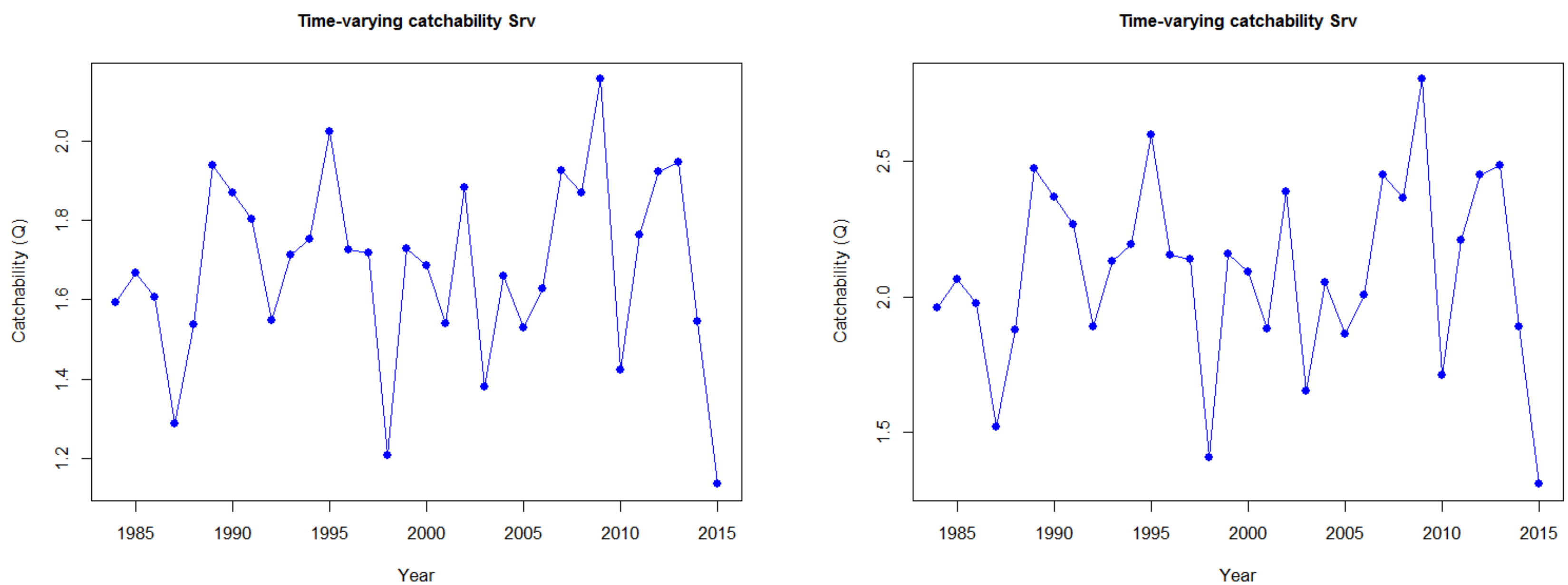


Figure 20.Time varying catchability for the GOA bottom trawl survey with VAST index of abundance (left) and index of biomass (right) having catchability with with the CFSR index of bottom temperature for 0-10 cm Pacific cod.

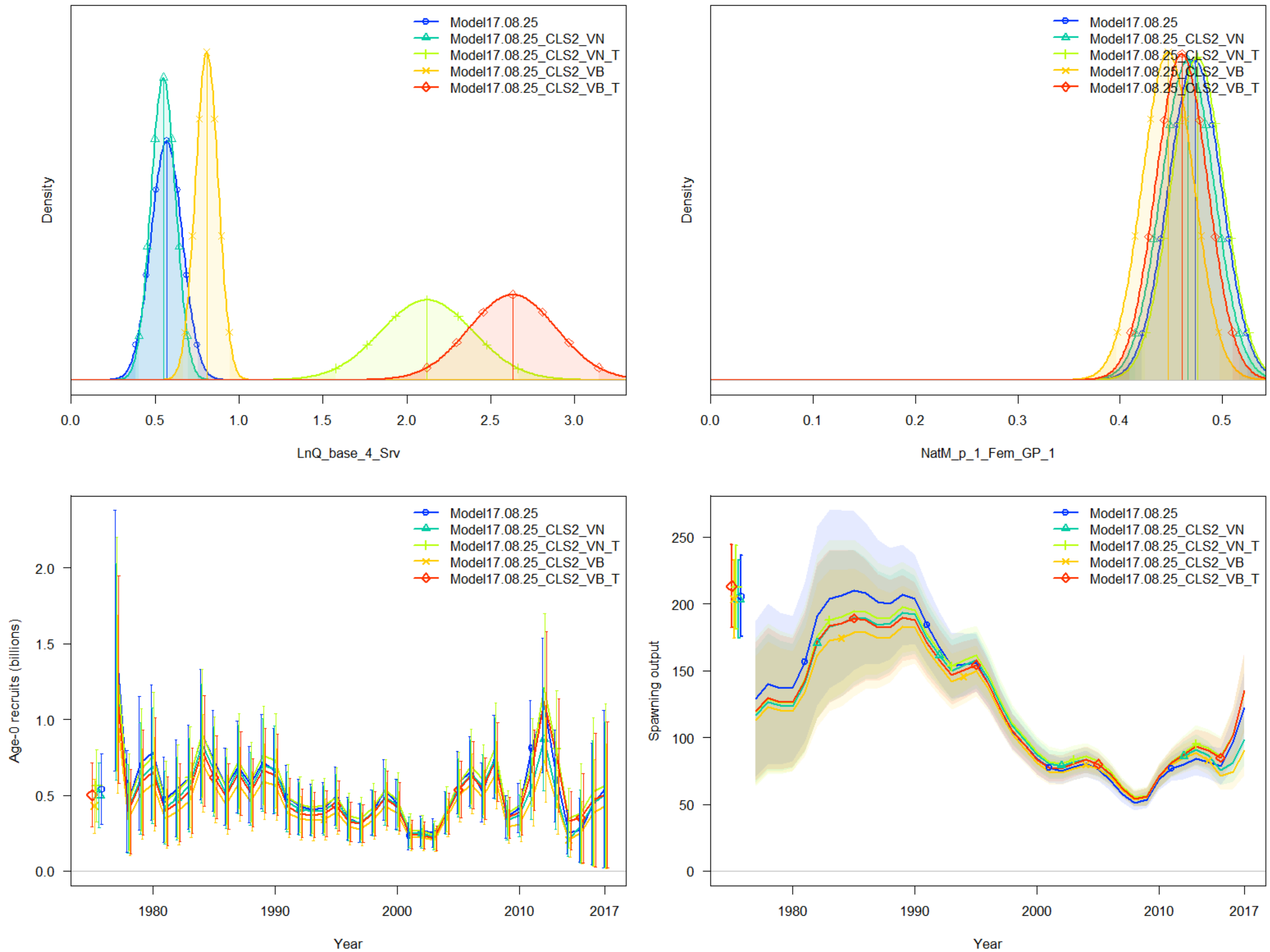


Figure 21. Comparison of effects of using CFSR index for bottom temperatures for 0-10cm Pacific cod in the stock assess models using GOA bottom trawl abundance (Model17.08.25_CLS2_VN_T) and biomass (Model17.08.25_CLS2_VB_T) indices with the reference model from 2016 (Model17.08.25) and the new 2017 method of weighting lengths with the addition of ADF&G port sampling data and VAST abundance and biomass indices (Model17.08.25_CLS2_VN and Model17.08.25_CLS2_VB).

5.0 References

Saha, S. *et al.* 2010: The NCEP Climate Forecast System Reanalysis. Bull. Amer. Meteor. Soc., 91, 1015–1057. DOI: 10.1175/2010BAMS3001.1

Thorson, J.T. 2016. VAST user manual. Available: https://github.com/James-Thorson/VAST/blob/master/examples/VAST_user_manual.pdf

Thorson, J.T., and Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fish. Res. 175: 66–74. doi:10.1016/j.fishres.2015.11.016.

Thorson, J.T., Shelton, A.O., Ward, E.J. and Skaug, H.J., 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES Journal of Marine Science, 72(5), pp.1297-1310.

Thorson, J.T., Ward, E.J., 2014. Accounting for vessel effects when standardizing catch rates from cooperative surveys. Fish. Res. 155, 168–176. doi:10.1016/j.fishres.2014.02.036