A Comparison of Design and Model-based Survey Indices for the Northern Rockfish Stock in the Gulf of Alaska

Curry J. Cunningham, Peter-John F. Hulson, Chris R. Lunsford, Dana H. Hanselman

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Introduction

This document describes an exploration of alternative methods for incorporating fishery-independent survey data within the stock assessment of the northern rockfish (*Sebastes polyspinis*) stock in the Gulf of Alaska (GOA). We compare stock assessment model estimates when fit to the design-based biomass index currently in use, with estimates using a model-based biomass index estimated with a vector-autoregressive spatio-temporal (VAST) model (Thorson and Barnett 2017). VAST models for survey index standardization provide several benefits over design-based methods: (1) VAST models estimate and leverage the spatial correlation structure within the survey data to maximize information and reduce uncertainty in the estimated index, and (2) VAST models partition variance among the encounter probability and positive catch rate components of the sampling process which may be useful for patchily-distributed species like northern rockfish.

Models

Three alternative models were compared. Model 15.4 is the accepted 2015 model that was used as the basis for setting harvest limits in 2016-2018 which fits to the design-based index from the bottom trawl survey. Model 15.5 fits to a VAST biomass index in place of the previous design-based index, but maintains the same likelihood weighting. Model 15.6 fits the model-based VAST index but scales the likelihood weight placed on fitting the survey index proportional to the ratio of coefficient of variation (CVs) between the design and model based indices as was done when the VAST model was adopted for dusky rockfish (Lunsford et al. 2015). The accepted 2015 model (15.5) specified a weight of 1.0 for the survey index data. When accounting for the ratio of index CVs, the weight in 15.6 was 0.5. Our purpose for scaling the survey index data weight is to present and compare outcomes from a model that results in a relatively similar likelihood contribution to the base model yet fits to the model-based index.

The model-based index was calculated by fitting a VAST model to bottom trawl survey data (1984-2017), assuming 500 knots. It should be noted that only the indices through 2015 was provided to the assessment models. This level of spatial resolution was selected based on previous analyses presented at the September 2017 Joint Groundfish Plan Team suggesting that changes in the scale of model-based indices with increasing spatial complexity are diminishing, and 500 knots provides a good balance between precision and computational efficiency. The estimated biomass index was corrected for small but persistent bias associated with the estimation and transformation of spatial and spatio-temporal random effects (Thorson and Kristensen 2016).

Results

Comparison of indices

Relative to the design-based index, the VAST index for GOA northern rockfish is both lower in magnitude across the time series and exhibits less interannual variation (Figure 1). In addition to differences in the trend and scale of the two indices, estimated uncertainty in the model-based biomass index is substantially lower (mean CV: 19.5%) than of the design-based index (mean CV: 41.0%). While both design-based and model-based indices are fairly similar through 1996, the large design-based biomass estimates in 2003, 2005, and 2013 are not reflected in the model-based index. These three high design-based biomass estimates are associated with highest uncertainty of any estimates in the time series (Figure 1, SE).

The high uncertainty in these estimates and the longevity of northern rockfish make such interannual changes in biomass biologically implausible, together suggest the model-based index may be more reasonable. From a statistical perspective the non-uniform distribution of northern rockfish across space may inherently lend itself better to separate estimation of the encounter probability and positive catch rate components of the sampling process. This partitioning of the two components drives part of the observed reduction in uncertainty.

Model fits to survey indices

Figure 2 shows the assessment model fit to survey biomass indices. The 2015 base model (15.4) did not fit the design-based survey index particularly well, failing to track the high survey indices in 1999, 2001, 2005, and 2013 but were still well within the large confidence intervals. When fit to the model-based index (15.5), the assessment model predicted survey biomass was closer to annual point estimates and better captured the average trend in model-based indices. However, 15.5 predictions still fail to capture the high model-based indices in 2005 and 2013, but the magnitude of error was less than that observed with the design-based index under 15.4.

When the likelihood weighting on the survey index was reduced from 1.0 to 0.5 under 15.6, the a priori expectation is for a poorer fit to these survey data. However, the model fit appears very similar. This indicates that the assessment model's ability to fit the index is rather insensitive to the likelihood weight suggesting the model-based index does not provide information that is in conflict with another data source.

Estimated biomass

The estimated trends in both spawning stock biomass and total biomass are similar across alternative models, with a period of low biomass in the late 1960's through the early 1970's followed by a general increase through the mid 1990's (Figure 3). However, the magnitude of estimated biomass begins to diverge among the models after 1980. Models fitting to the VAST survey index (15.5 and 15.6) predict higher biomass in the recent period, relative to the model fitting the design-based index (15.4). The reduction in weighting on the survey index under 15.6 results in biomass estimates closer to those predicted by the model fit to 15.4.

Figure 4 (page 9) shows the percent difference in biomass estimates between the two alternative models fitting the model-based (VAST) index (15.5 and 15.6) and the base 2015 model (15.4) fitting the design-based index. The percent difference in both spawning stock biomass and total biomass estimates between the alternative models has increased over time. Spawning stock biomass 1961-1980 was estimated to be 10.3% higher on average by 15.5 and 7.7% higher by 15.6, relative to the model fit to the design-based index (15.4). The difference between spawning stock biomass estimates increased substantially after 1980, with 2015 estimates from 15.5 that were 48.9% higher than the base model (15.4) and 29.2% higher from 15.6 compared with the base model. This pattern of increasing differences between biomass estimates over time, among models fitting to model-based and design-based indices, was also reflected in the estimates of total biomass (Figure 4).

Estimated uncertainty in biomass

Uncertainty in GOA northern rockfish biomass estimates exhibited similar trends over time, independent of model alternative (Figure 5). All models estimated high uncertainty in spawning stock biomass through 1970 and a characteristic increase in uncertainty in both spawning stock biomass and total biomass toward the end of the time series (1990+). After 2000 however, greater differences among models in biomass uncertainty are evident. The base model (15.4) estimates ~5% lower CV in both spawning stock biomass and total biomass between 1970 and 1990, after which the CV for biomass from the 15.5 and 15.6 models fitting the model-based index exhibit lower CVs (Figure 6). The progressive reduction in uncertainty for 15.5 and 15.6, relative to the base model, continues through the end of the time series. The CV for the spawning stock biomass estimate in 2015 from 15.5 was 19.5% lower than the base model, while the estimate from 15.6 with the lower likelihood weight on fitting the model-based index only 9.2% lower than the base model (Figure 6). Differences in the CV of estimated total biomass among alternative models over time, was similar to that observed for spawning stock biomass.

Comparison of assessment model parameters

Select assessment model parameters were compared among the three models to identify the influence of fitting to the alternative indices and adjusting data weighting, and also to understand what drove differences in assessed spawning stock biomass and total biomass (Figure 3). Figures 7 and 8 illustrate differences in estimated and derived assessment model parameters among alternative models, and their associated uncertainty. Fitting to the model-based (VAST) index (15.5) in place of the design-based index (15.4) resulted in a reduction in estimated survey catchability from 0.714 to 0.619 (Figure 7), while reducing weight on the survey data results in an intermediate estimate of survey catchability of 0.657. Both natural mortality and the log mean fishing mortality rate are estimated lower when the model-based index is fit (15.5) in place of the design-based index (15.4). Conversely, both log mean recruitment and the two parameters of the logistic survey selectivity function (age at 50% maturity and slope) are higher when the GOA northern rockfish assessment model is fit to the model-based index. However, it should be noted that differences in estimates among models are quite small relative to approximated parameter uncertainty (Figure 7). Together this suggests that in order to fit the new lower model-based index alongside catch and composition data: (1) catchability must be lower, (2) the survey must be selecting fish at a slightly older age, (3) average recruitment must be slightly higher but (4) this is balanced by slightly lower average natural and fishing mortality.

Differences among alternative models were also observed in derived parameter estimates (Figure 8). A higher spawning stock biomass in 2015 was estimated by fitting the model-based index (15.5) of 52,750 t, as compared to 35,426 t from the base model (15.4), with an intermediate 2015 SSB estimate of 45,753 from the model with reduced weight on the survey data (15.6). The differences in the biomass reference point ($B_{40\%}$) estimated at 27,983 t by the base model (15.4), 35,105 t from the model fitting the model-based index (15.5), and $B_{40\%}$=32,163 t from 15.6 were a result of the increase in recruitment estimates from the inclusion of the VAST model. Taken together these differences in derived parameter estimates suggest that although fitting to the model-based index increases estimates of spawning stock size at the end of the time series, commensurate changes in reference points imply that the overall stock status is not appreciably different. However, the acceptable biological catch estimated for 2016 increases from 4008 t to 6012 t when the design-based index is replaced by the model-based index in the assessment model (Figure 8). Not unexpectedly, values for $F_{35\%}$ and $F_{40\%}$ do not differ appreciably among alternative models.

References

Thorson, J.T., and Barnett, L.A.K. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. Ices Journal of Marine Science **75**(4): 1311-1321.

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. Fisheries Research **175**: 66-74.

Table 1. Log-likelihood comparison among model components.

Model	Total	Data	Catch	Survey Biomass	Fish Age	Survey Age	Fish Size
15.4 (2015 Base Model)	228.8	144.6	0.1	10.1	28.5	55.3	50.6
15.5 (2015 Base Model + VAST index)	231.9	146.9	0.2	11.4	28.6	57.3	49.5
15.6 (VAST index + Scaled survey weight)	225.9	141.4	0.1	6.5	28.5	56.0	50.2

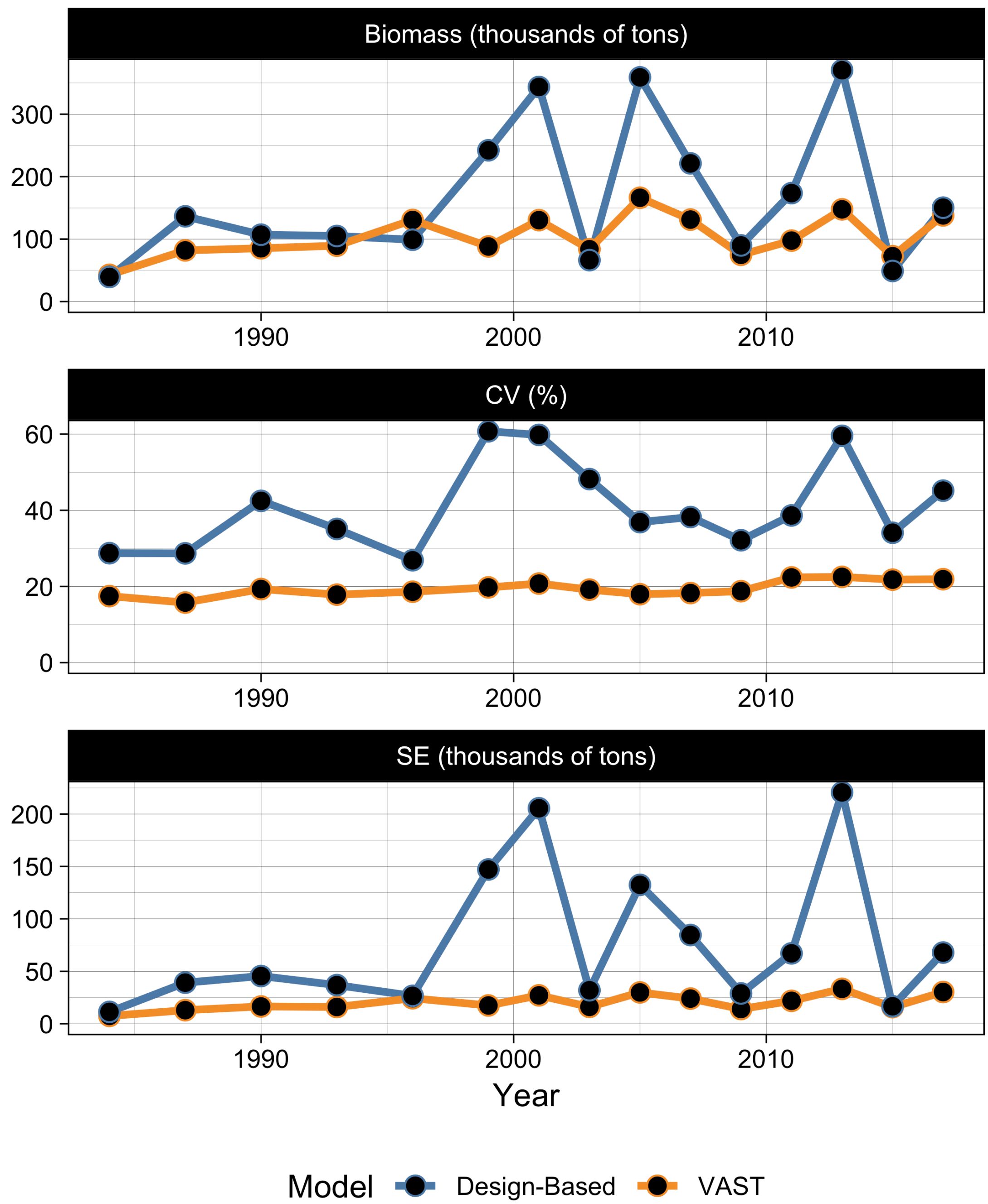

Figure 1. Comparison of design-based and model-based (VAST) biomass indices. Successive panels show the total biomass index in kilotons (thousands of tons) the coefficient of variation, and the standard error in for each index.

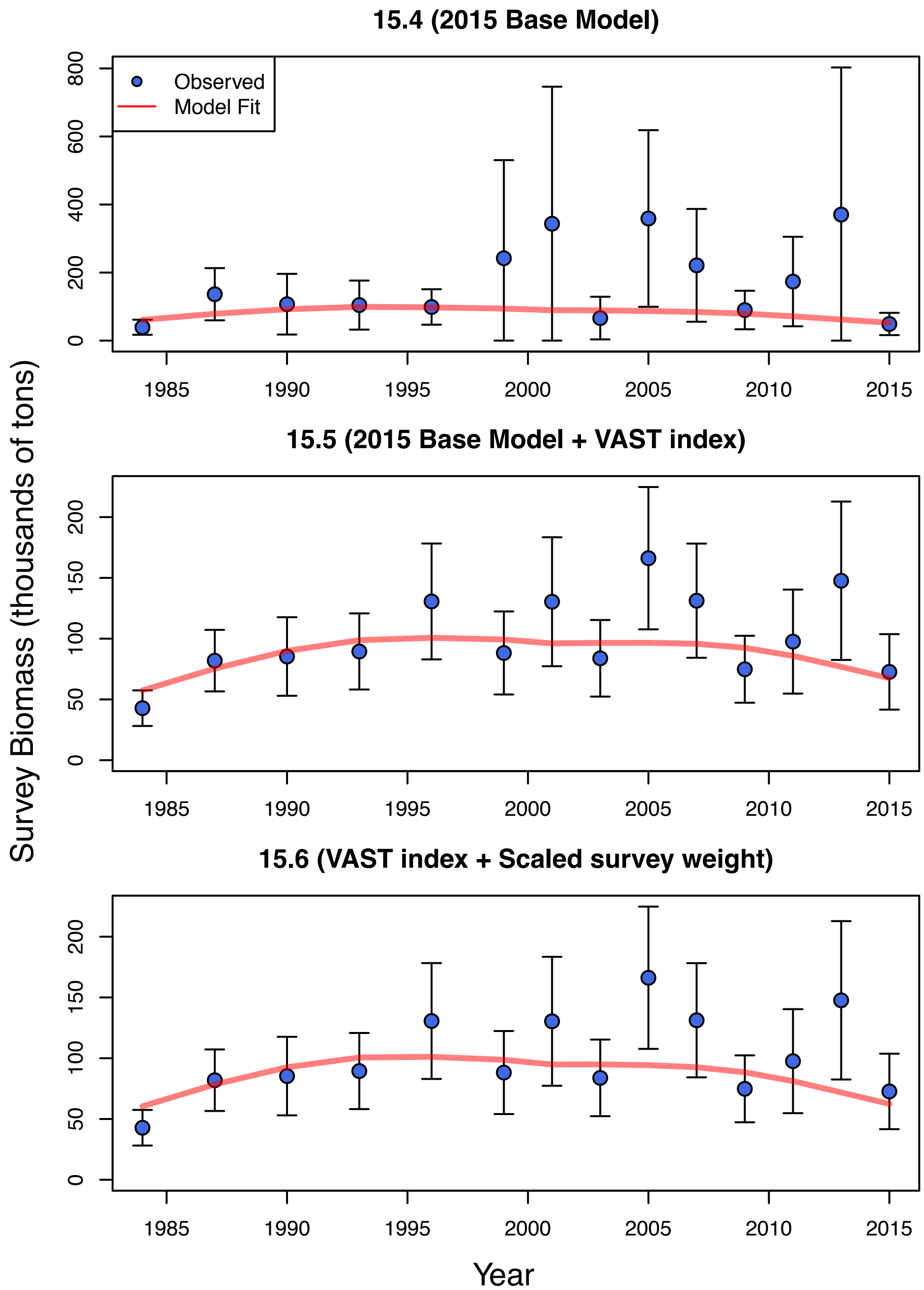

Figure 2. Stock assessment model fit to annual survey biomass indices specified under each alternative. The top panel (Model 15.4) shows the fit to the design-based index, while the lower two panels (Models 15.5 and 15.6) show fits to the model-based index.

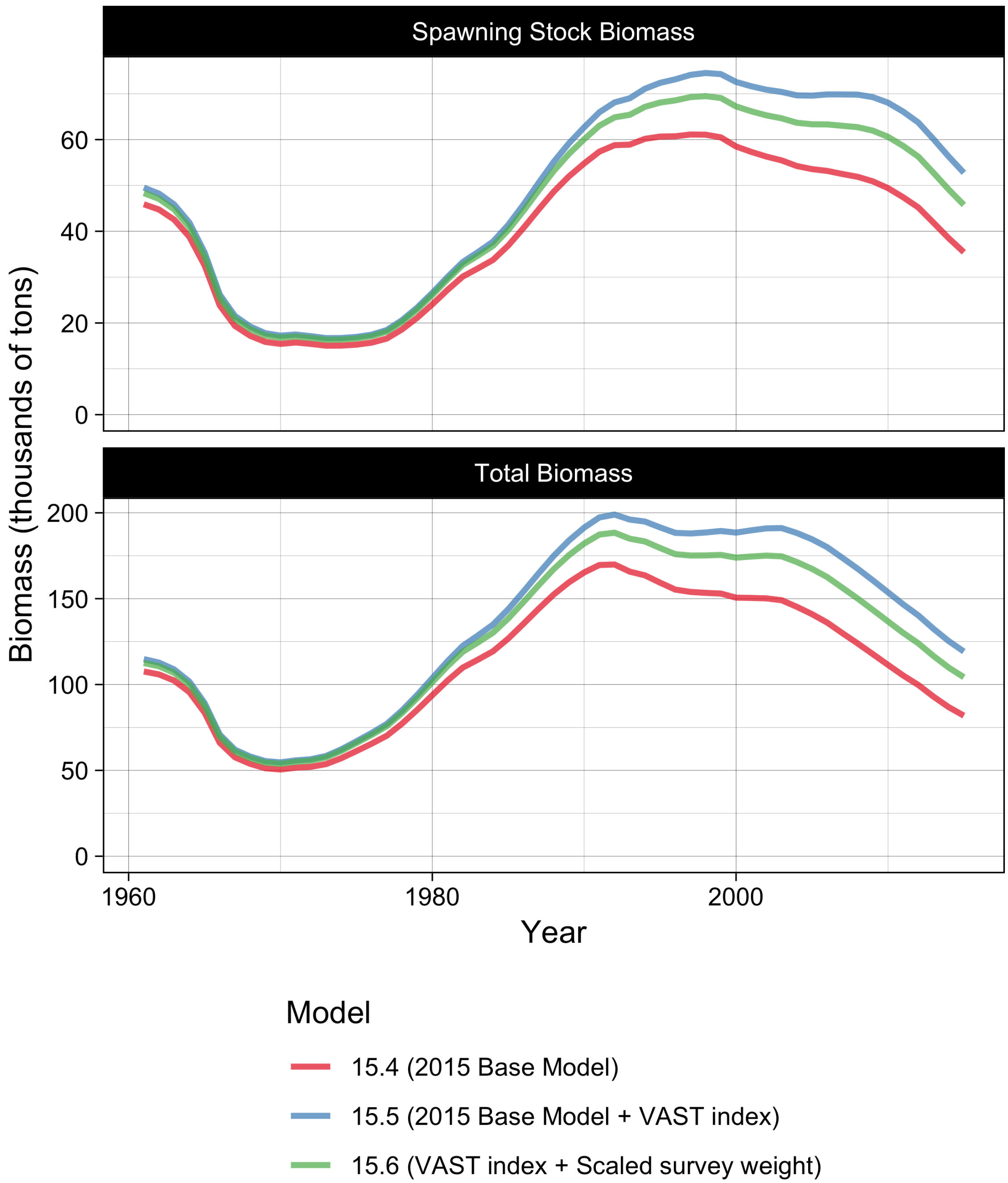

Figure 3. Estimated biomass. Comparison of predicted northern rockfish spawning stock biomass and total biomass over time, across the three alternative models.

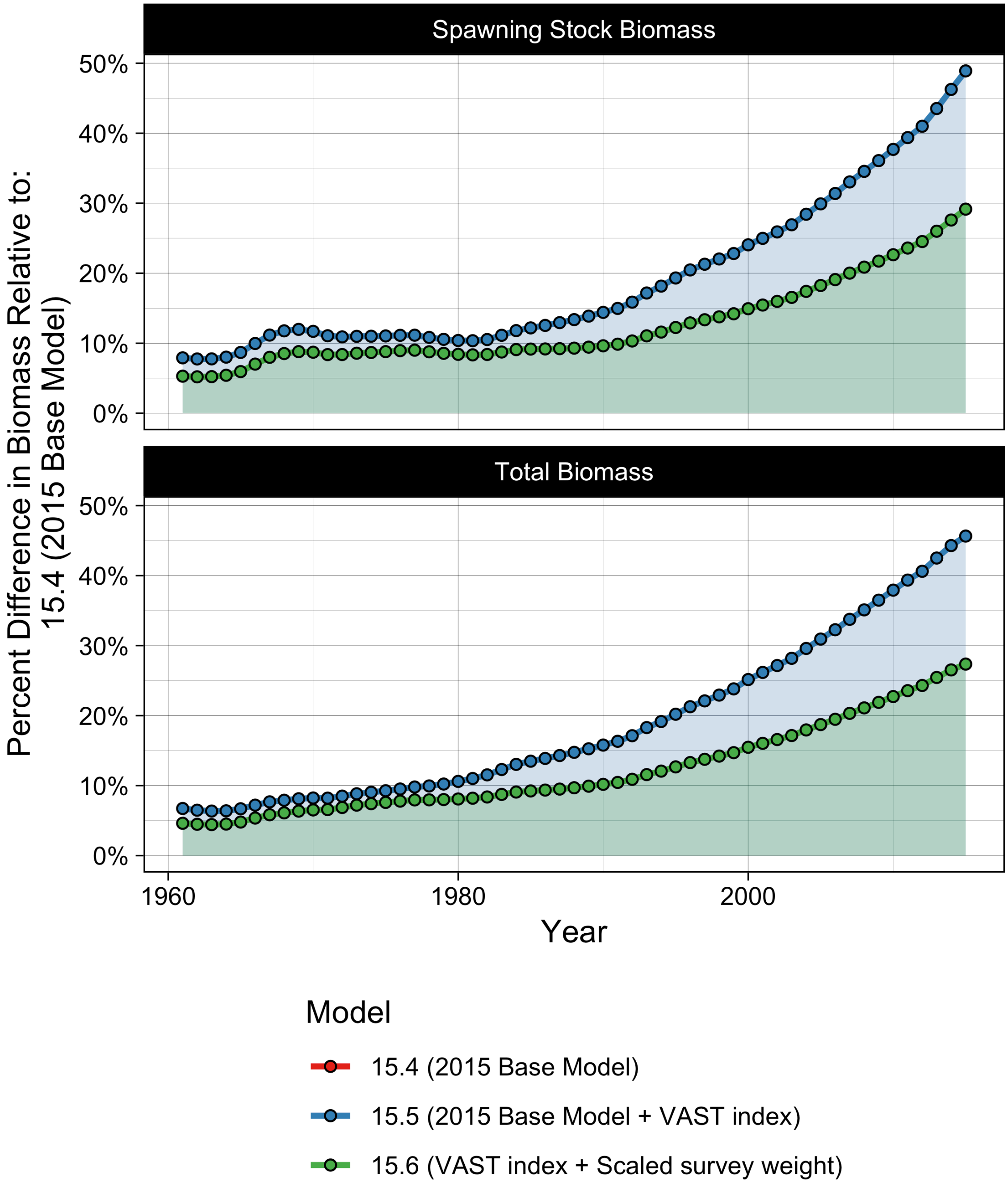

Figure 4. Percent difference in annual spawning and total biomass estimates, between model-based alternatives (15.5 and 15.6) and the 2015 base model (15.5).

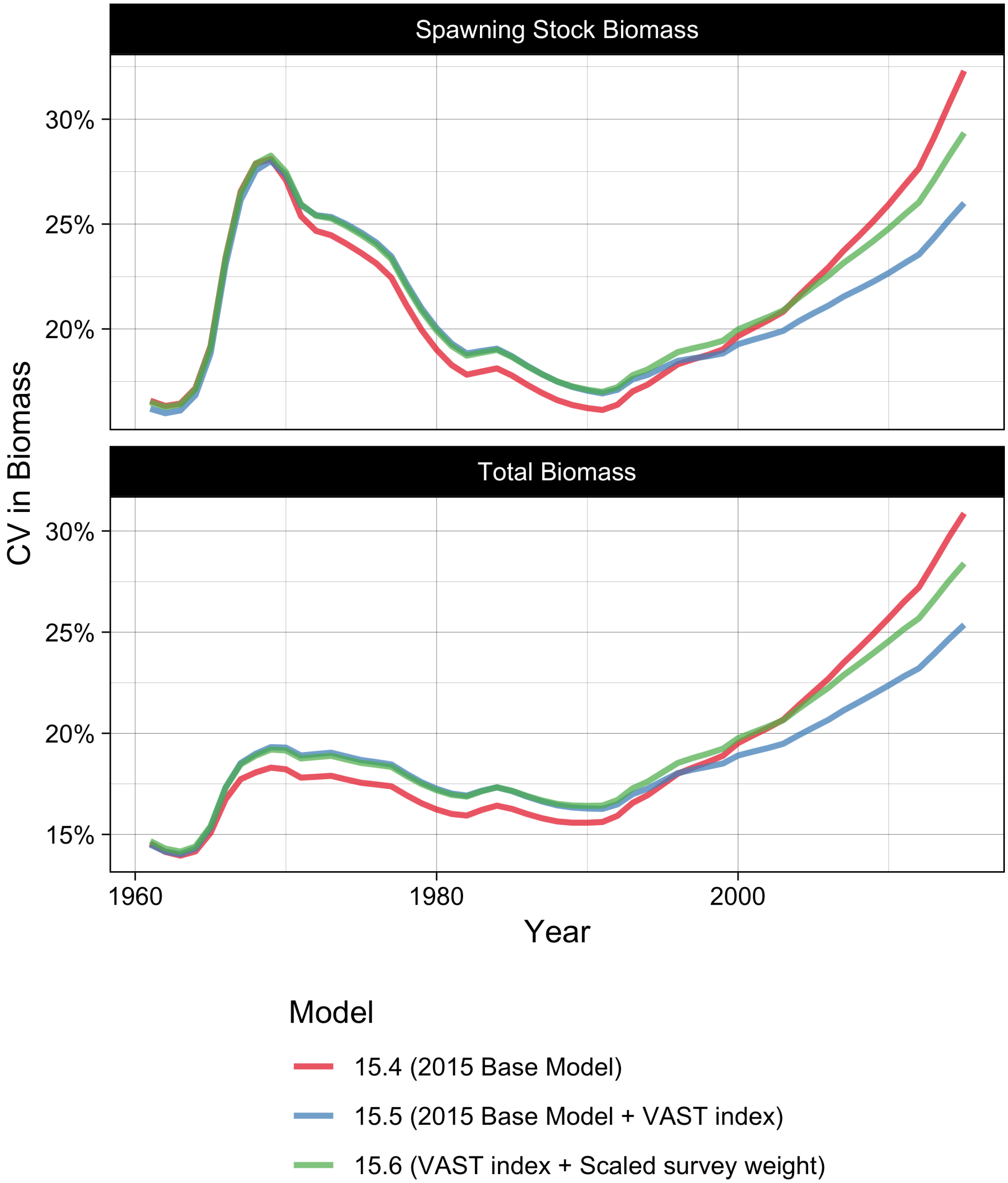

Figure 5. Uncertainty in biomass estimates. Comparison of the estimated CV (Hessian approximation) in predicted northern rockfish in spawning stock biomass and total biomass over time, across the three alternative models.

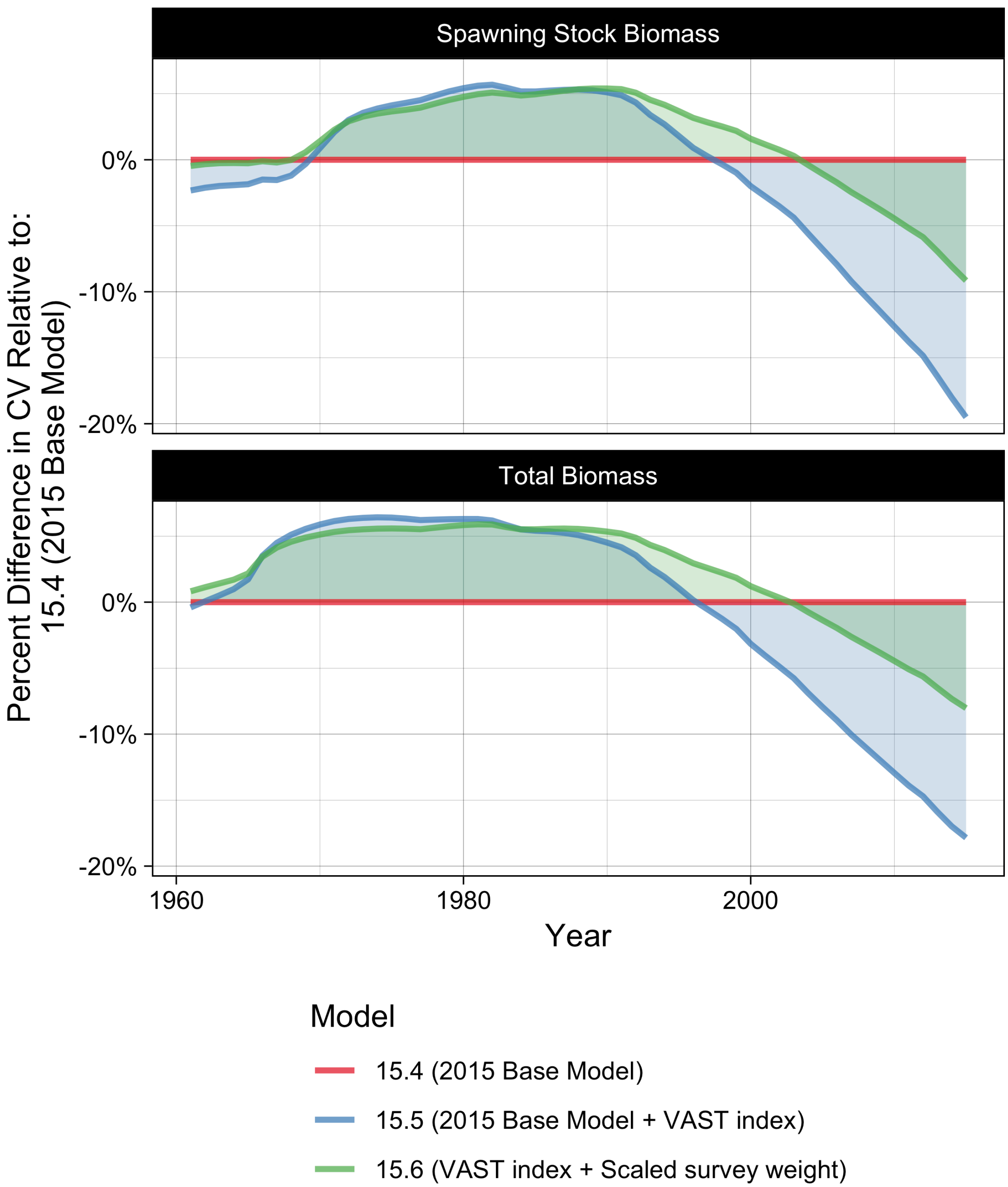

Figure 6. Percent difference in the estimated uncertainty (CV) for annual spawning and total biomass estimates, between model-based alternatives (15.5 and 15.6) and the 2015 base model (15.5).

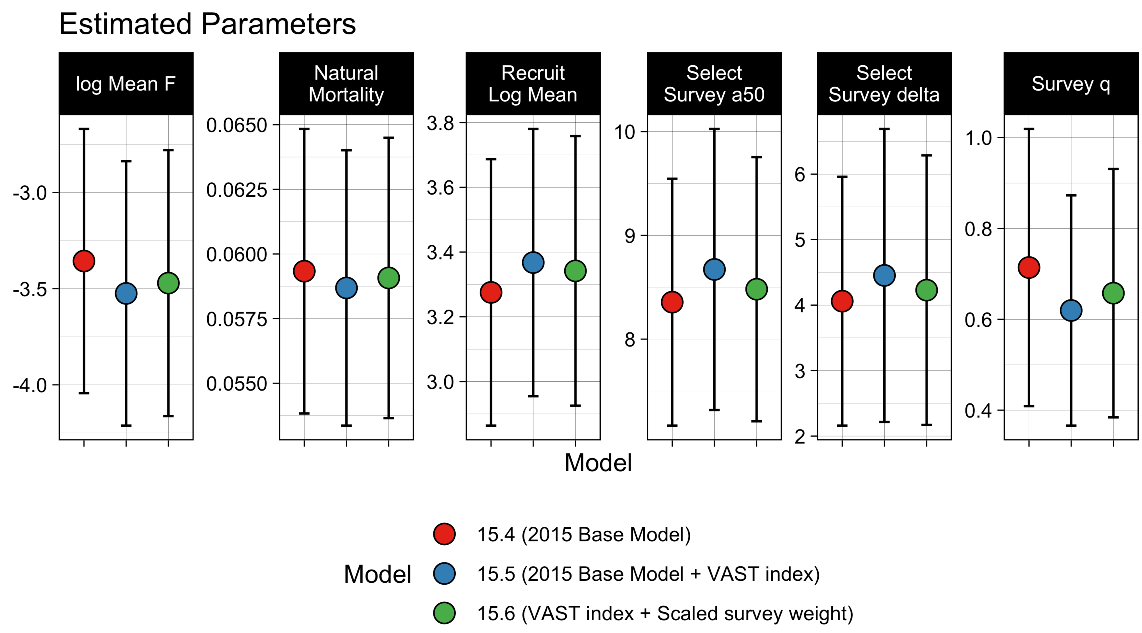

Figure 7. Comparison of estimated stock assessment model parameters for GOA northern rockfish across alternative models. Parameters include natural mortality, log mean recruitment, the A50 and Delta parameters for survey selectivity, and survey catchability (q). Error bars describe the bounds of the 95% confidence intervals, estimated by the delta method in ADMB.

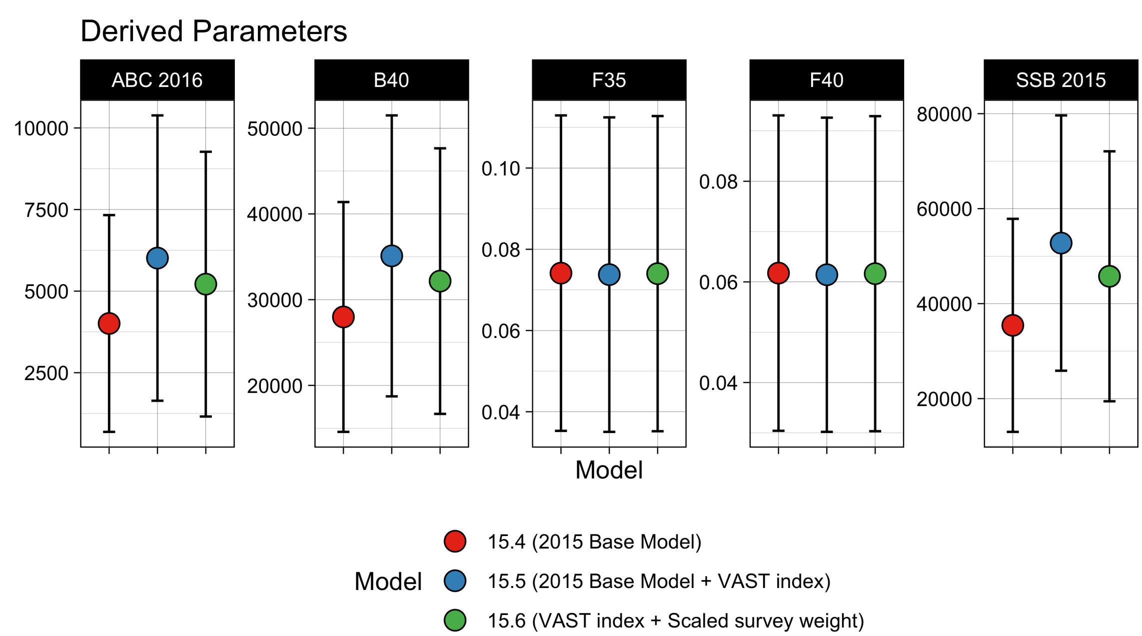

Figure 8. Comparison of derived stock assessment model parameters for GOA northern rockfish across alternative models. Parameters include the 2016 ABC, B40, $F_{35\%}$, $F_{40\%}$, and estimated spawning stock biomass in 2015. Error bars describe the bounds of the 95% confidence intervals, estimated by the delta method in ADMB.