PROPOSED BOOTSTRAP SIMULATION METHOD FOR ANALYZING ROCKFISH BYCATCH IN THE AT SEA WHITING SECTORS

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Introduction

Bycatch of darkblotched rockfish has become constraining to the at-sea whiting sectors, both mothership (MS) and catcher-processor (CP). In 2014, the MS sector was temporary closed in part due to inseason attainment of their darkblotched rockfish allocation (Agenda Item J.8, Inseason Situation Summary, November 2014). And in 2015, bycatch of darkblotched is once again constraining for the MS sector (38 percent whiting attainment, 35 percent darkblotched attainment) as well as for CPs (55 percent whiting attainment, 54 percent darkblotched attainment). Accordingly, the Groundfish Management Team (GMT) seeks to develop a more robust model to analyze certain management measures and annual catch limits (ACL) alternatives related to the CP and MS sectors in the 2017-2018 biennial harvest specifications and management measures cycle.

The current model used by the GMT to project constraining species impacts in the at-sea whiting sectors simply applies average historical bycatch rates (e.g., total darkblotched landings/ total whiting landings) to total whiting allocations (or residuals for inseason management). Accordingly, no measures of uncertainty are generated (e.g., probability of exceeding an allocation), and the use of average bycatch rates is not well suited for the rare-event encounters that can characterize bycatch in the at-sea whiting sectors.

The proposed bootstrap model (random resampling of historic tows) generates thousands of simulations of total year catches for target and bycatch species based on summation of random draws of historic tows (each with an equal probability of being drawn). As such, the bootstrap model provides measures of uncertainty: (1) percent of simulations that exceed allocation(s) (similar to a probability analysis) and (2) provides upper magnitudes of potential bycatches (more informative than past ranges). Both of these measures of uncertainty could be useful for decision makers to structure allocations to better accommodate the needs of the fishery without having to resort to inseason closures.

The Scientific and Statistical Committee (SSC) endorsed a bootstrap simulation as an appropriate methodology for the recent analysis of bycatch caps in the swordfish drift gillnet (DGN) fishery.[1] The GMT is seeking SSC endorsement to apply the method here, and if endorsed, guidance on

[1] PFMC Briefing Book March 2015, Agenda Item H.4.b, Supplemental SSC Report.

applying it to this problem and appropriately interpreting the results. While this analysis will be led by the GMT, Corey Niles (Washington Department of Fish and Wildlife) proposed the use of method to the GMT, developed the code, and is the primary author of this report.

If the SSC endorses the method for these fishery sectors, the bootstrap would be employed to analyze certain management measures and ACL alternatives related to the CP and MS sectors in the 2017-2018 biennial harvest specifications and management measures cycle. These analyses would be available for potential SSC review later in the process. The current analysis focuses on darkblotched rockfish; however, we see the method as being potentially useful for other bycatch of other constraining species in these sectors like Pacific Ocean perch, canary rockfish, and salmon. Applying the method to other species would require consideration of species specific trends as shown below for darkblotched rockfish. This method may also prove useful as an inseason bycatch projection model as it was initially developed as an attempt to evaluate the relative chances that the MS sector would be able to successfully complete the 2015 fishing season after experiencing high catch rates over the first months of the season.

There are two main proposed uses for the simulation outputs:

1. Percent of simulations exceeding a pre-specified allocation (e.g., 60 percent for 10 mt and 40 percent for 15 mt) or
2. Setting an allocation based on a desired percentage of simulations not to exceed that threshold (e.g., the tonnage needed not to exceed five percent of the simulations exceeding the allocation.

The Data

The bootstrap simulation uses haul level estimates of catch from PacFIN’s Comprehensive NPAC table. This table blends “real-time” and processed data from the National Marine Fisheries Service (NMFS) At-sea Hake Observer Program (i.e. data from the “current” and “debriefed” tables in the NMFS NORPAC database).

The NPAC4900 table includes catch and location data from 68,397 total hauls back to 1990. In addition to the MS and CP sectors, the dataset covers deliveries from tribal catcher vessels to MS processing vessels. We did not consider those deliveries here because the tribal fishery is managed under separate allocations and authorities and also experiences different bycatch patterns related to the fishery being restricted to the Usual and Accustomed fishing areas off northern Washington and other factors.

We have done initial data exploration of the darkblotched catch patterns back to 1991, the first full year of the U.S. fishery. For the reasons described below, the current analysis focuses on data from 2001 through October 20, 2015. This includes 33,386 hauls with 33,163 (99.3 percent) having been directly sampled by an observer (only sampled hauls are used in the bootstrap estimates for non-sampled hauls are imputed using data from similar hauls). We may consider additional time periods for the final analysis.

Catches in the data are expanded estimates based on subsampling of the hauls. The Comprehensive NPAC4900 dataset does not currently include a field reporting the sampling coverage by haul. We have made a request for this information. The target sampling intensity has been 50 percent of each haul since 2005. We discuss the history of sampling coverage below in the discussion on which time periods to include in the resampling. Here we note that we while expect sampling error to affect certain aspects of the analyses, such as the estimate of the non-zero bycatch rate over a small number of hauls, the noise it adds to the annual bycatch estimates is likely to be minor compared to other sources of variability.

Motivations for the Approach

Darkblotched rockfish bycatch shows a high degree of randomness, with total impacts driven by sporadic low bycatch events (i.e., < 1 mt) and relatively infrequent "lightning strikes" of large quantity tows (Figure 1 and Figure 2). Considering patterns within and among seasons, whiting catches have accumulated at a remarkably steady rate (Figure 3) whereas darkblotched catches have shown high variability (Figure 4). Within seasons, darkblotched catch has accumulated very rapidly over the course of a few hauls (e.g. CP catch in 2011 and 2015, MS sector in 2010 and 2014); at a steady, relatively high rate (e.g. CPs in 2001, MS and CP in 2007); and also at relatively low rates (e.g. 2009 and 2012 for both sectors). The rate of positive hauls can vary widely within a season as well and exceed 50 percent at times (Figure 5). Relative to the large volumes of whiting caught, the rate of darkblotched bycatch is very low and has averaged 0.007 percent over 2000-2014. The annual ratios are shown in (Figure 6).

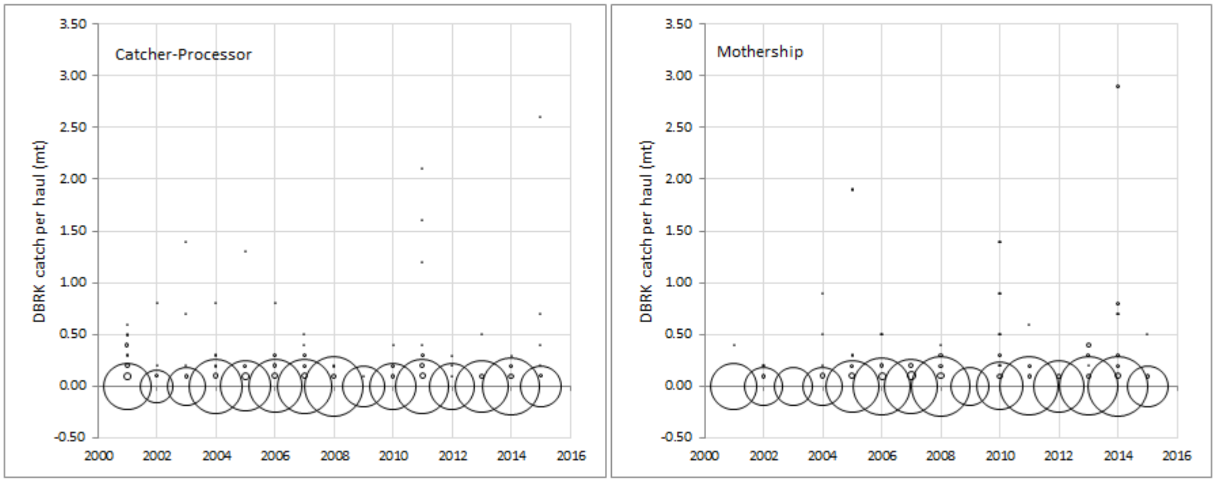

Figure 1: Catch frequencies of darkblotched rockfish per tow for the at-sea whiting sectors.

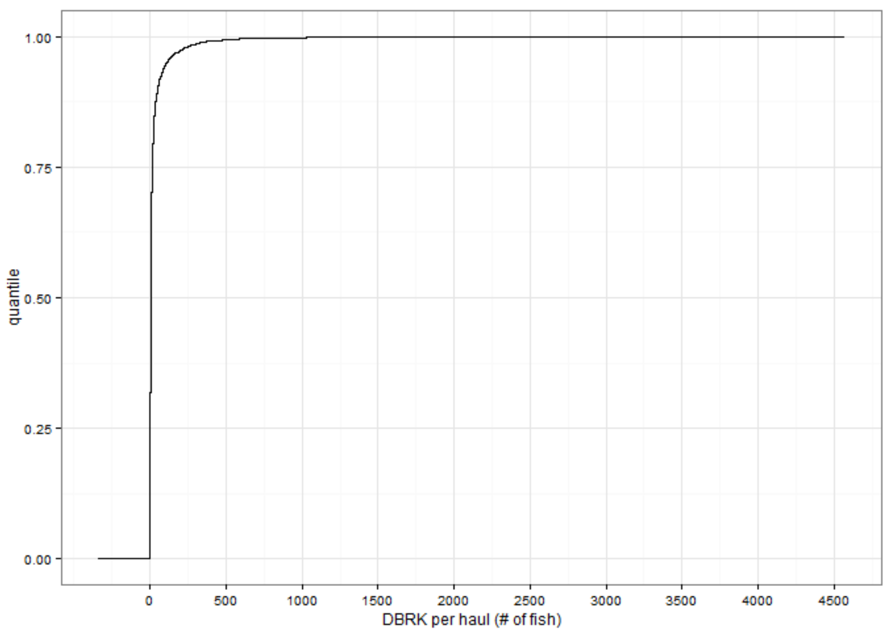

Figure 2. Empirical cumulative distribution of the estimated number of darkblotched per haul (non-zero hauls only) in the CP and MS sectors, 2000-October 4, 2015.

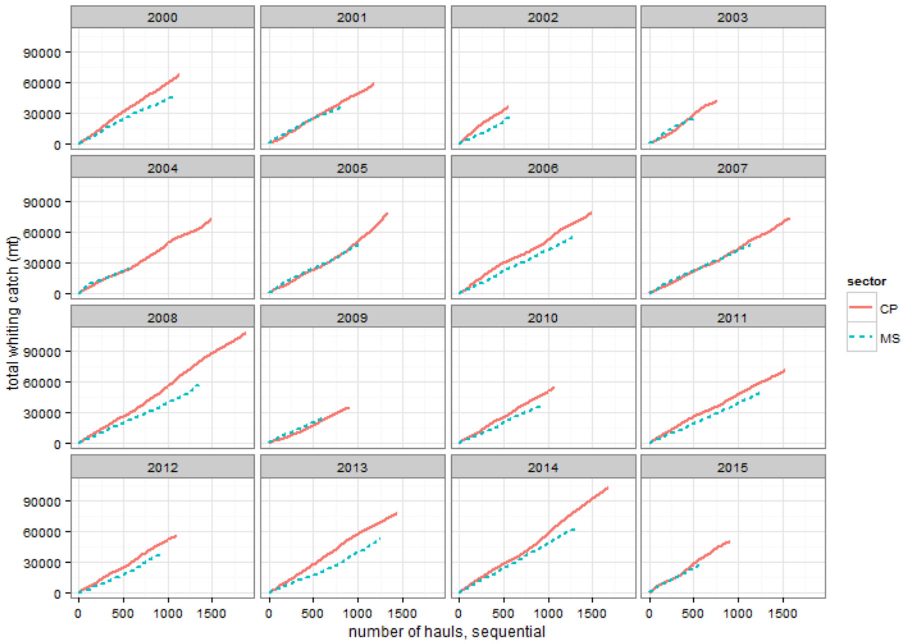

Figure 3: Accumulation of whiting catch by season and sector (i.e. the y-axis shows cumulative catch over the sequence of hauls).

Figure 4: Accumulation of darkblotched rockfish catch by sector and season (i.e. the y-axis shows cumulative catch over the sequence of hauls). The horizontal dashed lines mark the current darkblotched allocations of 6.5 mt for the MS sector and 9.2 mt for the CP sector.

Figure 5: Moving 30 haul average of positive darkblotched hauls by sector and year shown with dotted lines and solid lines created by ggplot2's geom_smooth (method = "loess" and span = .1)

Figure 6: Darkblotched rockfish to Pacific whiting ratio plotted by year and sector.

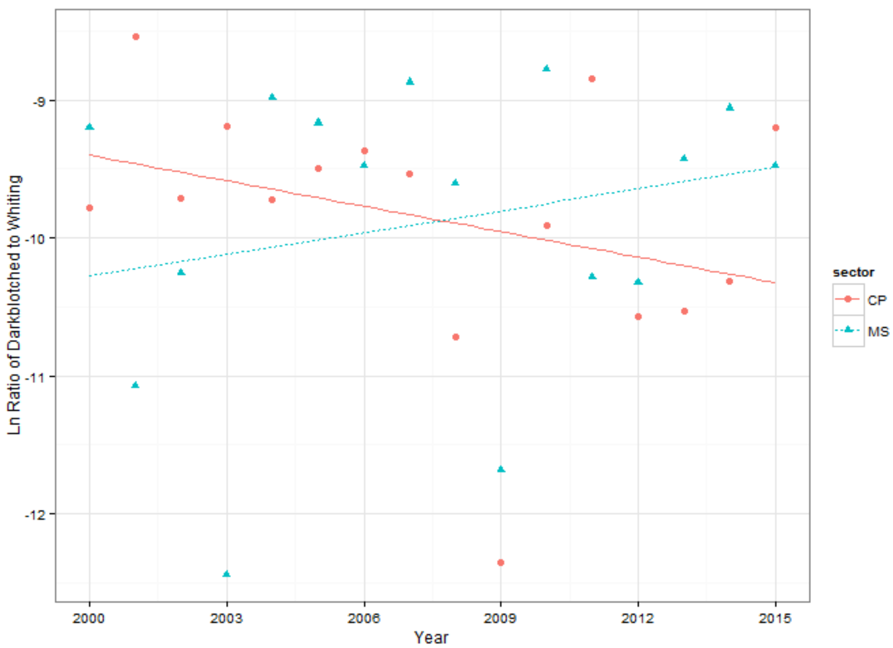

Figure 7: Annual ratios of darkblotched to whiting (log scale) over 2000-2015 (2015 is through October 4) with trend lines from ggplot2's stat_smooth function (method = "lm"). Neither trend line is statistically significant (the log-linear model *Ratio* ~ *Year* + *Sector* produces a p-value = 0.992 and Adjusted R-squared = -0.06835).

The bootstrap method used by Dr. Steve Stohs and the Highly Migratory Species Management Team (HMSMT) to analyze hard caps in the Swordfish DGN fishery is a relatively simple to apply and superior analytical technique to the GMT's current method. As with the DGN analysis, this bootstrap simulation would allow the Council fuller consideration of the range of outcomes that would be possible under different management scenarios (e.g. various allocation levels).

The high degree of annual variation has made the point estimate approach that the GMT typically uses largely uninformative for projecting bycatch impacts and the lack of statistical relationships between whiting and darkblotched catches has hindered attempts to develop better bycatch projection models (Figures 6 and 7).

With no reliable projection method, the Council and the GMT currently sets the projected impacts in the overfished species scorecard equal to the allocations to each sector. This is based at least partly on a performance standard approach that relies on the commitment of the MS and CP co-ops to stay under their allocations. To do so, the co-ops have taken extraordinary measures that go beyond what is possible by regulation. These measures include closed areas, constant monitoring of and protocols for reacting to bycatch events, and a penalty system for noncompliance and unacceptable performance. Despite theories on what leads to high rates of bycatch of darkblotched, the co-ops still face a high degree of unpredictability.

Reasons for using the bootstrap methods instead of a model

As with the review of the DGN bootstrap method, we anticipate that the SSC may suggest the use of a model fitting approach. We made some attempts to do so, yet our initial data exploration suggests that a more sophisticated modeling technique would require more time and/or expertise than is available for the 2017-2018 analysis. Such methods could be pursued for future analyses, but for the reasons we note here, we suspect that the bootstrap method may prove to be the superior method.

Dr. Stohs proposed the bootstrap simulation for the DGN fishery because bycatch many of species at focus there are very rare events. In the CP and MS sectors, bycatch of darkblotched rockfish is not a rare event in itself yet large catches—a.k.a. “disaster tows” or “lightning strikes”—do show rare event type characteristics or at least a pattern that is difficult to fit with statistical models. The problem of “disaster tows” or “lightning strikes” has been known for years yet analysts have not so far attempted to quantitatively gauge the level of risk they pose in terms of fishery closures.

To explore the use of a mixture distribution approach, we broke down the bycatch events into: (1) the pattern of positive or non-zero hauls and (2) the cumulative distribution of catches on non-zero hauls. Much of the difficulty in finding an appropriate modeling approach comes from the latter. None of the standard, long-tailed distributions (e.g. gamma, lognormal, Lévy) appear to fit the data. Figure 8 illustrates a pattern that occurs across several lognormal based linear models. The rate of non-zero tows may also be difficult to model as they have shown a high degree of variability within a season.

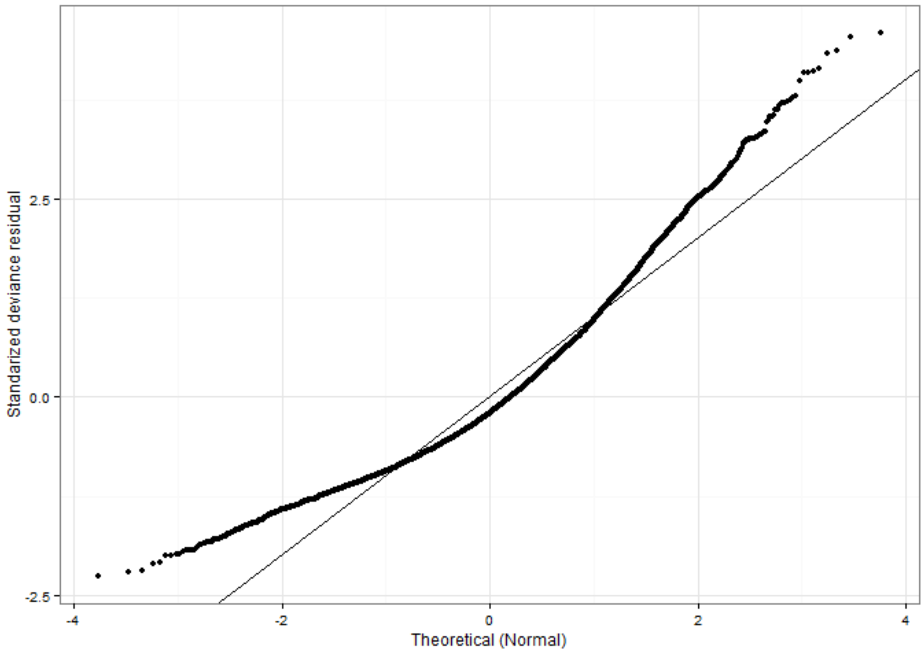

Figure 8: Normal QQ-Plot of the standardized residuals from the log-linear model for positive Darkblotched hauls illustrating the difficulty in fitting the pattern. The model used to produce this example is: Log(Catch) ~ Sector + Year + poly(FishingDepth, 2) + poly(HaulDuration, 2) + poly(StartLatitude, 4).

Our initial conclusion is that fitting a model would requires something comparable to the extraordinary catch event (ECE) mixture distribution approach of Thorson et al.[2] Most non-zero hauls of darkblotched consist of a few fish with a small proportion encountering large shoals that number in the few thousands of fish. At the same time, large darkblotched catches have shown the tendency to cluster over the course of a few hauls. The likely cause of this is vessels trawling through the same area in relatively short succession (i.e. the trailing vessels have already caught the fish by the time feedback on the lead vessels' catch is available). We understand that this clustering pattern would create even more complexity for modeling. Dr. Stohs and members of the SSC pointed to such clustering in the DGN bycatch patterns as one reason for using the bootstrap simulation instead of a Bayesian modeling methods.

The final reason for forgoing a modeling approach relates the potential factors contributing to bycatch variability, such as area (i.e. preferred darkblotched habitat). Even if key covariates were identified, it is unlikely that they would offer much predictive power because they too would be difficult to forecast. Forecasting prospects aside, further modeling efforts could prove useful in identifying such factors that could aid the Council in considering additional regulatory measures and the co-ops with their bycatch protocols. A successful model would also be helpful for

[2] Thorson, J. T., Stewart, I. J., and Punt, A. E. (2011). Accounting for fish shoals in single- and multi-species survey data using mixture distribution models. Can. J. Fish. Aquat. Sci., 68(9):1681-1693.

determining whether there truly has been and whether we should continue to expect an increasing trend in darkblotched encounter rates.

Structuring the bootstrap simulation method

There are many variations possible in terms of the resampling is structured varied around what years to include in the resampling, whether to treat the sectors differently, and on the choice of resampling positive hauls differently from the size of positive hauls.

For this review, we took the following approach:

1. Use sector specific random draw to determine positive/zero darkblotched hauls and the size of the whiting catch.
2. Use second random draw that pools the CP and MS data to determine size of the positive hauls.

For now, the bootstrap simulation resamples all haul level data from the year 2000 through October 20, 2015 focusing for now just on whiting and darkblotched catches. This period has been reasonable stable in terms of the observer coverage levels and patterns of darkblotched catches (Figure 9 and Figure 10). It may be reasonable to use earlier data, especially for the CP sector.

Lastly, the U.S. Pacific whiting total allowable catch (TAC) and the resulting allocations to the MS and CP sectors set the target for a successful season. The 2015 TAC is used in this analysis, as the 2016 allocations will not be set until April 2016.

The pattern of darkblotched catches and consideration of trends

As just noted, we recognize that it is important to consider which time period to include in the resampling because the core assumption underlying bootstrapping methods is that the factors affecting catches "will be the same in the future as in the re-sampled period."[3]

Increasing or decreasing trends in the magnitude or frequency over the time series would therefore undermine this assumption as there might changes in regulatory and economic incentives, sampling protocols, or abundance of whiting and darkblotched in the future. Despite known or suspected changes in several of these factors (e.g. increased abundance of darkblotched from rebuilding or variations in whiting TACs), the noise in the bycatch pattern makes it difficult to see any strong trends over the 2000-2015 time period in either the positive catch rates or the distribution of non-zero catches. In addition to trends over the time series, we have been considering differences between sectors and as checking for seasonality in the pattern.

[3] PFMC Briefing Book March 2015, Agenda Item G.2.a, Supplemental SSC Report

Starting with the distribution of non-zero darkblotched catches, we detect no major trends over time or differences between the two sectors. Pooling all years combined, the tow-by-tow distributions and cumulative distributions are visually indistinguishable between the two sectors (Figure 11). And while not having exhaustively tested for it, they are likely statistically indistinguishable as well. None of the generalized linear or quantile regression models explored have shown sector as a statistically significant coefficient. The CP vessels typically have higher catch capacity yet the distribution of non-zero darkblotched catches does not appear to be related to effort metrics such as haul duration or the whiting catch on the haul.

Considering differences between seasons, the distribution of non-zero catches does show some annual variation yet only in upper 25th percentile and mainly above the 97.5th percentile (Figure 12 and 13). Much of this variation appears to be driven by the length of the upper limb, i.e. by the size of the disaster tows seen in a year. This could be more related to the rarity of such events than any sort of trend or systematic differences in the fishery.

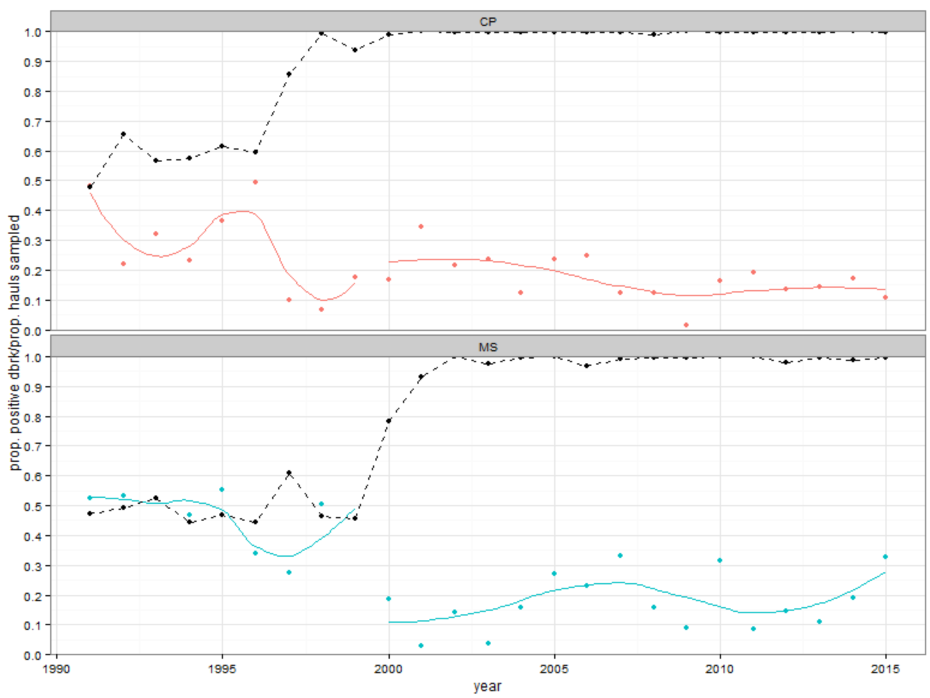

Figure 9. Proportion of non-zero hauls of Darkblotched by year and sector with loess curves fit to two time periods: (i) 1991-1999 and (ii) 2000-2015. The dashed, black lines show the proportion of hauls sampled each year for each sector.

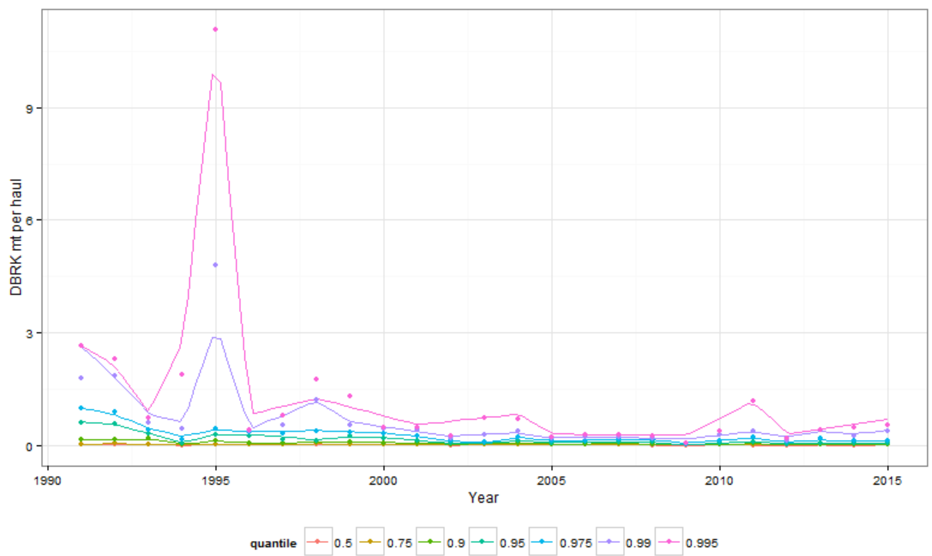

Figure 10. Empirical quantiles of non-zero darkblotched hauls plotted as points for the CP and MS sectors with trend lines fit using ggplot2's stat_quantile to the haul level data (method = "rqss", lambda = 0.5). The specific quantile levels displayed are: 0.50, 0.75, 0.90, 0.95, 0.975, 0.99, and 0.995.

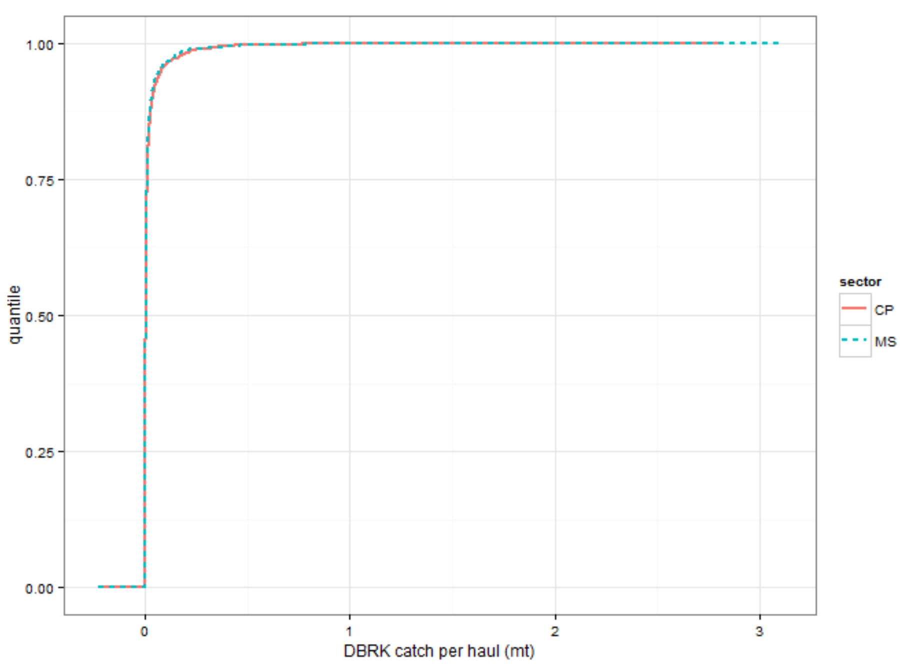

Figure 11: Empirical cumulative distributions of non-zero darkblotched rockfish catches over 2000-2015 (thru October 4) by sector.

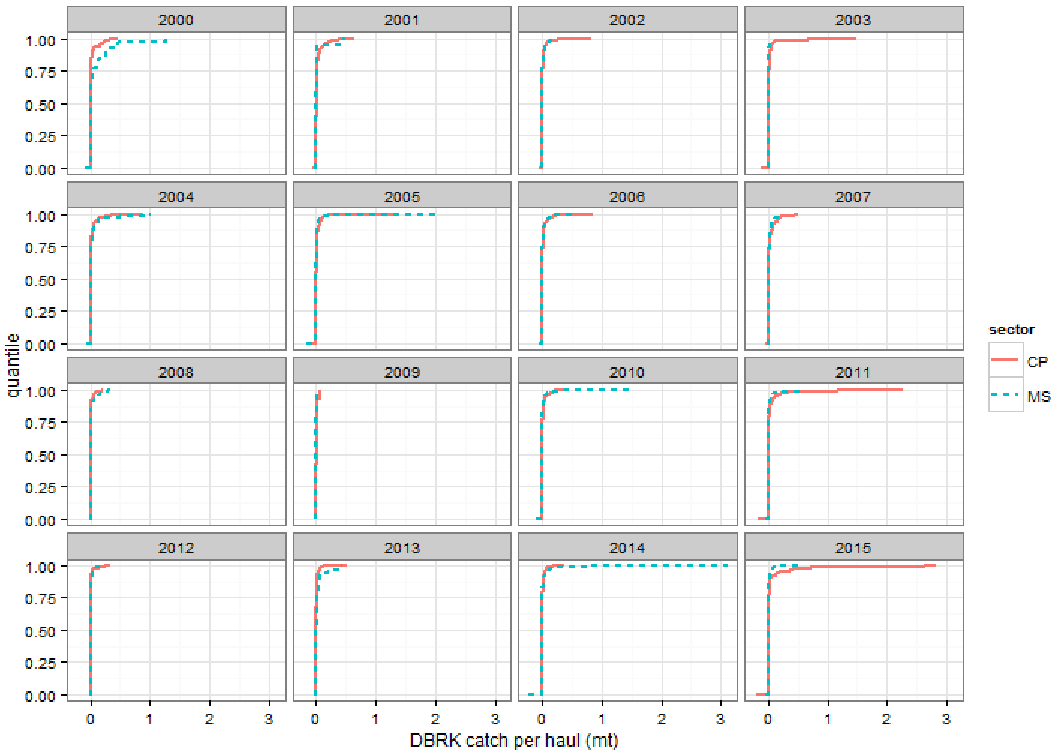

Figure 12: Empirical cumulative distribution of non-zero Darkblotched by sector and faceted by year.

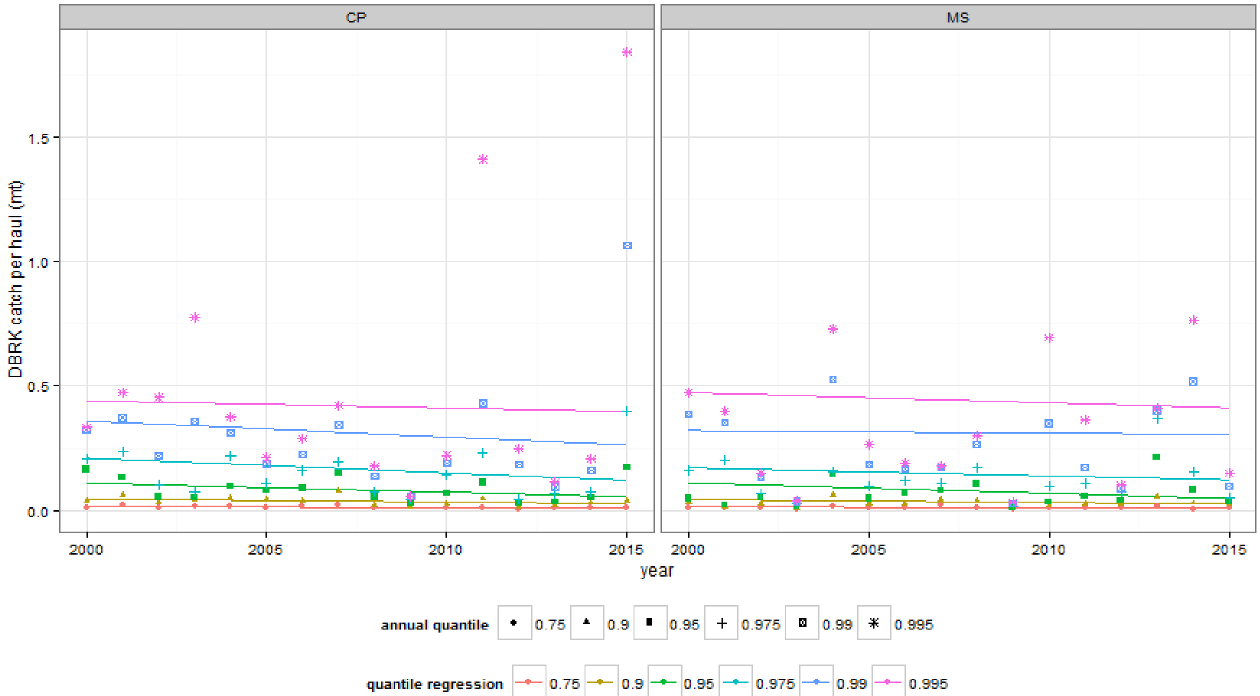

Figure 13: Annual quantiles of non-zero darkblotched hauls plotted as points for the CP and MS sectors with trend lines plotted by ggplot2's stat_quantile (i.e. quantile regression method = "rq" fitted to the haul level data). The specific quantile levels are displayed in the legends. These specific trend lines were not tested for statistical significance.

Preliminary outputs

We present preliminary results from a set of simulations to demonstrate the type of analysis we anticipate informing with this method. We considered four darkblotched allocation scenarios based on status quo levels, the approximate allocations the sectors would receive under the Council's darkblotched ACL alternatives, and an effective "no cap" scenario (Table 1). The whiting allocations are set to the 2015 levels of 90,673 mt for the CPs and 64,004 for the MS sector. The simulated seasons are set up to "close" upon reaching or exceeding either the whiting or darkblotched allocations.

For this report, we only show results using cumulative distribution plots and intend just to show the type of outputs we are contemplating. If the method is endorsed for this application, we would present the results in more detailed form. Figure 14 displays the main output of simulated darkblotched catches. These results do show the risk of early closure to the sectors under status quo whiting allocations, especially to the MS sector. These preliminary results suggest that the risk of closure is appreciably reduced under the other alternatives with little differentiation among them in terms of the number of hauls conducted by simulated season (Figure 15). The potential cost of early closures in terms of forgone whiting can be gauged by the output displayed in Figure 16. However, one interpretation of these results is that this simulation method may not be able to detect any differences between the action alternatives.

Table 1. Preliminary scenarios run in the bootstrap.

Preliminary Alternatives	Mothership	Catcher Processor
Status Quo	6.5	9.2
Alt 1	12.7	18.0
Alt 2	10.4	14.7
"No Cap" Scenario	1,000	1,000

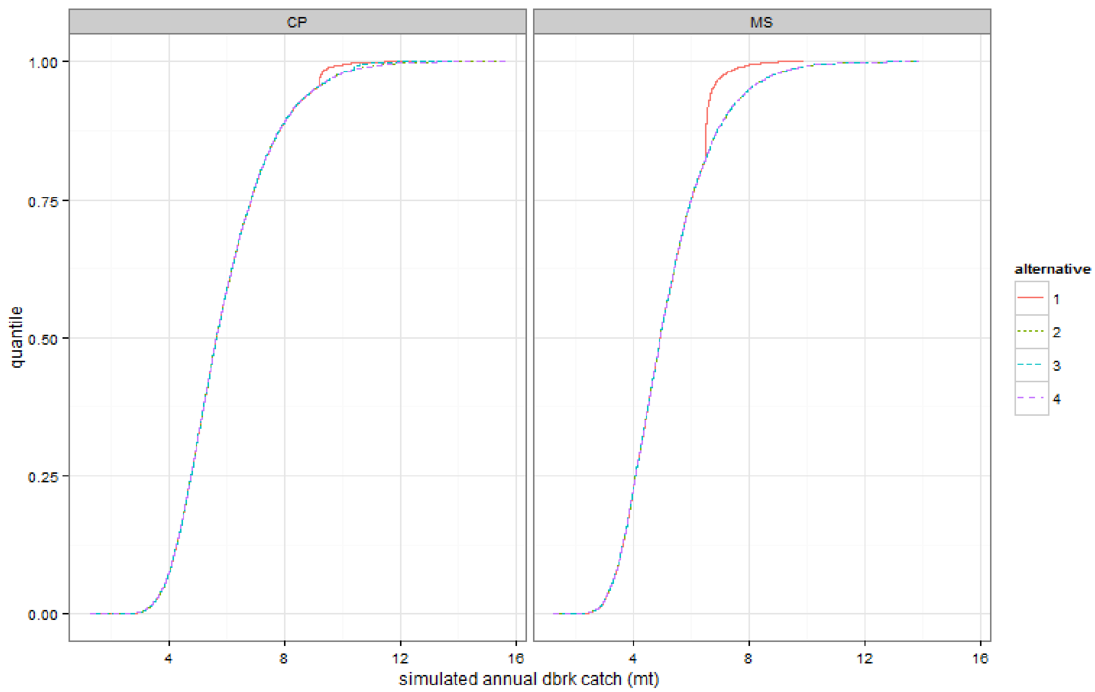

Figure 14. Cumulative distribution of simulated annual darkblotched catches by sector.

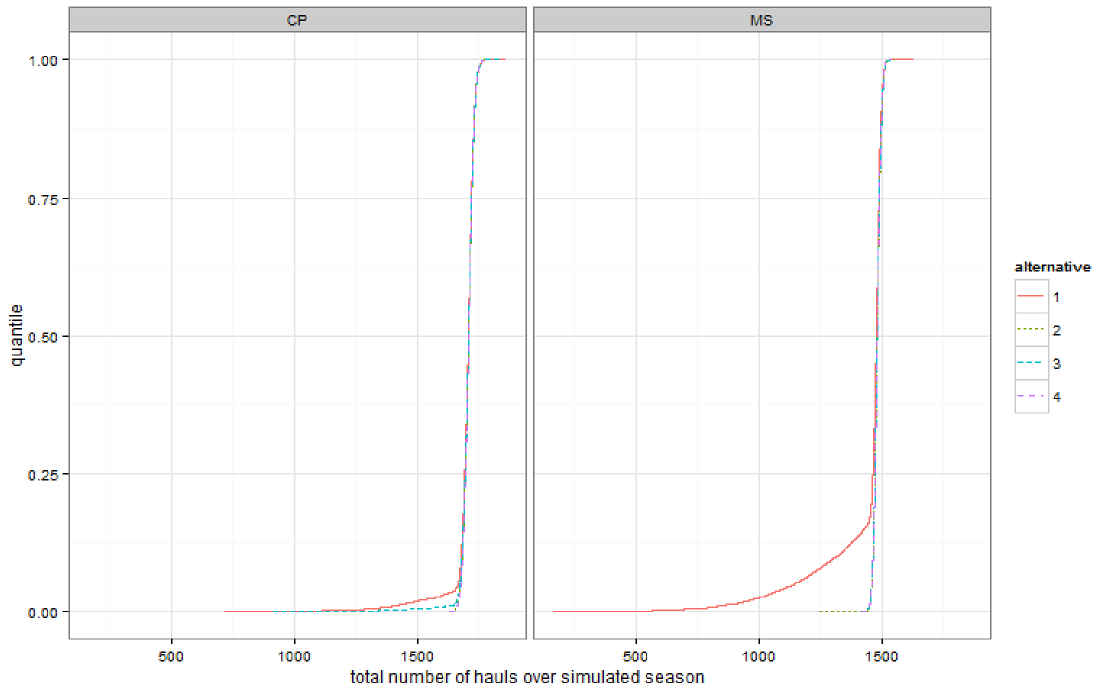

Figure 15. Cumulative distribution of simulated number of hauls by sector.

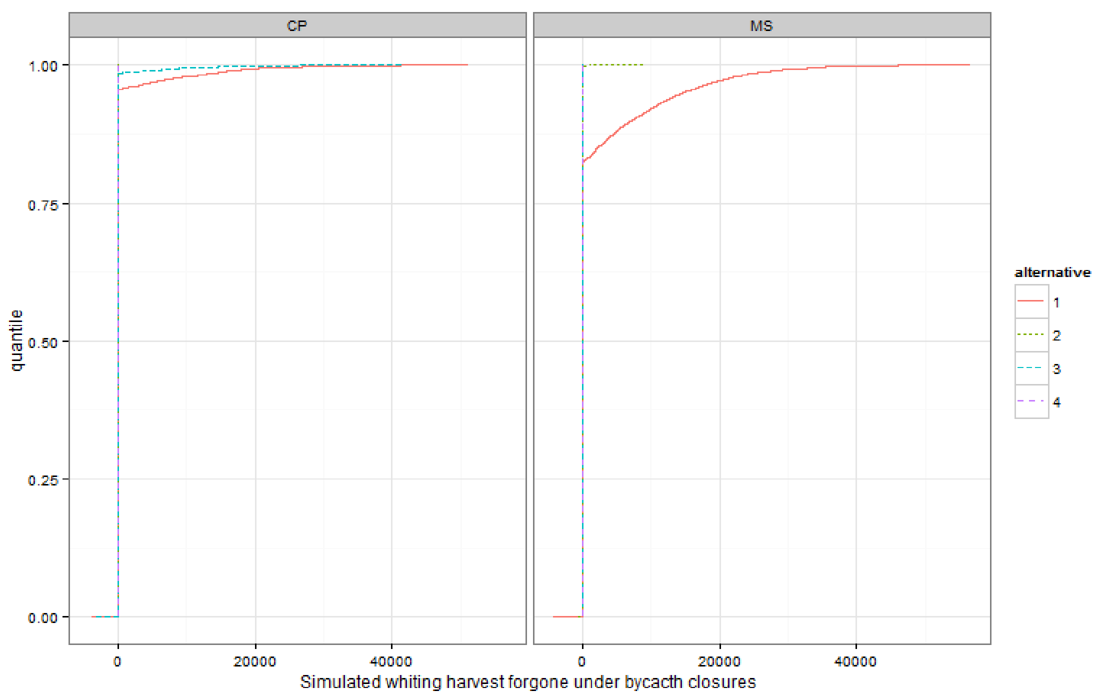

Figure 16. Cumulative distribution of simulated forgone whiting harvest (i.e. whiting left unharvested after a bycatch closure).

Initial examination of predictive ability

Validation of models results by comparing a subset of years to the actual or estimated catch from a known year is important to test predicative capability of the model. We have completed some preliminary validation runs based on the varied time periods:

1. 2000 – 2015
2. 2005 – 2015
3. 2001 – 2015
4. 2005 – 2014
5. 2000-2015 drop 2009
6. 2009-2015

We ran the simulation to for each year 2000-2015 keyed to the actual number of hauls recorded for the year. The results are summarized visually in Figure 17. At least for these six scenarios, it appears that the years included in the resampling do not substantially alter the results in terms of the general magnitude and variability of possible annual darkblotched bycatch.

At the same time, the bootstrap seems to have relative low predictive power in that it is not able to match the years in which darkblotched catch was low. There is only one instance where actual catch was higher than the two-sided 95th and 99th intervals (i.e. 2001 for the CPs) yet there are several instances across both sectors where the actual catch was below these intervals or just on the edge. It would be very unlikely for so many low probability events across a 16 year period. We will investigate the possible reasons for this behavior. Initial examinations suggest that the annual non-zero encounter rate does drop below ~12 percent in the simulations whereas actual rates have been below 2 and 3 percent in some years. For this and other reasons, we plan on simulating the non-zero encounter rate via other means (e.g. random binomial draws with randomly or systematically varying probabilities of success) to explore the effect on simulated results.

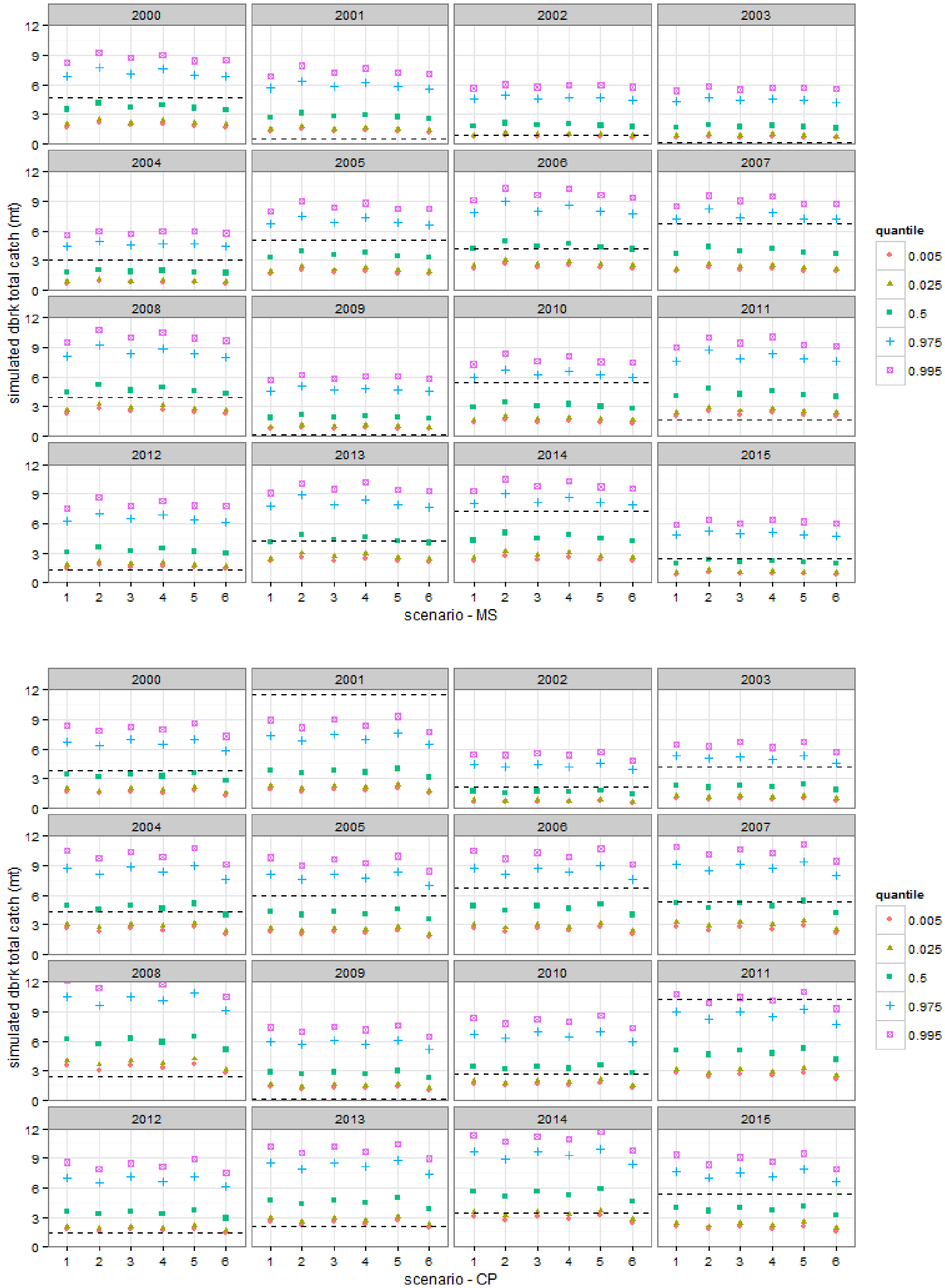

Figure 17. Quantiles of simulated annual darkblotched catches for six scenarios by year and sector. The horizontal dashed line marks the actual catch for the year. See text for description of the scenarios.

Discussion and Interpretation

In sum, we propose using this bootstrap simulation as a substantial improvement over current analytical methods and see it as providing the Council and public with a fuller, more direct picture of the bycatch risk. Instead of the current method that only produces point estimates based on average bycatch rates, the bootstrap method will provide measures of uncertainty and variability that could be useful for setting allocations.

We understand that the SSC cautioned again using the DGN bootstrap results as "absolute projections", as the randomness of bycatch patterns may change over time due to a variety of factors (whereas a main assumption to the bootstrap approach assumes that the future will remain similar to the past).[4] This is a limitation of most all statistical techniques. As such, the GMT would specify that the bootstrap approach does not provide true probabilities or forecasts. Nonetheless, as with the DGN analysis the simulation would be valuable for weighing the relative risks of closures under different bycatch allocations.

[4] PFMC Briefing Book March 2015, Agenda Item G.2.a, Supplemental SSC Report