Revised Bootstrap Methodology to Compare the Operation of the West Coast Large Mesh Drift Gillnet Fishery under Alternatives for Individual and Variable Length Hard Caps

Dr. Stephen M. Stohs
Southwest Fisheries Science Center
February 3, 2023

I. Background

In September 2015, the Pacific Fishery Management Council (Council) adopted a Range of Alternatives (ROA) to implement hard caps for the West Coast large mesh drift gillnet (DGN) fishery. A bootstrap simulation analysis was developed to analyze the ROA (Stohs 2015). Following Scientific and Statistical Committee (SSC) review at their March 2015 meeting (SSC 2015), the methodology was revised to address SSC recommendations, and the Council considered the results in choosing a Final Preferred Alternative in September 2015. The ensuing regulations were ultimately vacated by court order.

At its November 2021 meeting, Council revisited this action by adopting a new ROA to establish hard caps for high priority protected species (HPPS), including marine mammal species of special concern and endangered sea turtles (PFMC May 2022). In addition to the "No Action" alternative (Alternative 1) and rolling two-year fishery closures the Council adopted in September 2015 (Alternative 2), the November 2021 ROA offered a number of options and sub-options to use individual and fleet-wide caps and closures of shorter duration (Alternative 3). Given that Alternatives 1 and 2 from the 2015 ROA were included again in the current ROA, the Council's Highly Migratory Species Management Team (HMSMT) adopted a proposal to extend the bootstrap methodology used previously to support analysis of the new options and sub-options for individual and varying length caps in Alternative 3.

Based on discussion at its November 2022 meeting, the Council narrowed its ROA to include No Action plus three alternatives for hard caps, and requested for the analysis to be updated using the additional methods for reporting bootstrap simulation results recommended by the SSC (PFMC November 2022, SSC November 2022).

The bootstrap approach to simulating outcomes in an empirical context subject to uncertainty is described in a number of sources (Davison and Hinkley 1994, Efron and Tibshirani 1997, Efron and Hastie 2016). The bootstrap model of the Council's ROA for hard caps was initially coded in the R programming language (R Core Team) to analyze the Council's 2015 hard caps ROA, and updated for the 2022 ROA. This report documents the bootstrap methodology, including revisions to address SSC recommendations, and presents the results.

II. Model of DGN Fishery Operation under Hard Caps

A stylized model of fishery profits subject to regulatory constraints is provided to describe policy objectives in a framework that is amenable to analysis by bootstrap simulation. For the fishery to achieve economic viability, participants must prosecute a level of effort that generates sufficient revenues to cover variable costs of operation, including debt financing and the economic cost of participation[1] in a season of DGN fishing relative to alternative occupations. Letting *i* denote an individual vessel participating in the fishery, for $i = 1, 2, \ldots, L$, vessel-level variable financial profit for a season is

$$\Pi_i(N_i) = \sum_{j=1}^{N_i} \left(R_{ij} - C_{ij}\right),$$

and total fleet variable profits are given by

$$\sum_{i=1}^{L} \Pi_i(N_i) = \sum_{i=1}^{L} \sum_{j=1}^{N_i} \left(R_{ij} - C_{ij}\right),$$

where N_i is the number of sets fished in the season by vessel *i*, *L* is the total number of active vessels, R_{ij} is the revenue generated when the operator of vessel *i* sold retained market species catch on set *j* of his fishing season, and C_{ij} is the variable cost of vessel *i*'s effort on set *j*[2].

Suppose there are *M* species which are subject to management under the Endangered Species Act (ESA), Marine Mammal Protection Act or Magnuson-Stevens Fishery Conservation and Management Act, and hard caps are used to limit expected number of interactions with high-priority protected species (HPPS), measured as counts for each HPPS of individual mortality or injury events per season, below levels d_1, d_2, ..., d_M, where d_m is the limit on expected interaction counts[3] for species *m*. Let b_1, b_2, ..., b_M, denote corresponding regulatory limits on the numbers of annual observed drift gillnet interaction counts, and X_{ijm} represent the interactions count for species *m* by fishery vessel *i* on set *j*.

Using the above formulation and assuming a fixed (or maximum) fleet size *L*, an optimization problem may either be stated in terms of the proposed objectives of maximizing either expected total fleet profits or expected average fleet profits, subject to regulatory constraints. The first objective reflects a societal goal of maximizing aggregate profits due to fishery operation, while the second objective focuses on maximizing the incentive for individual participation.

Proposed Objective 1: Choose the alternative A to maximize expected total fleet variable profits subject to regulatory limits:

$$\max_{A} E\left\{\sum_{i=1}^{L} \Pi_i(N_i)\right\} \text{ subject to}$$

$$E\left\{\sum_{i=1}^{L} \sum_{j=1}^{N_i} X_{ijm}\right\} \leq b_m, \quad m = 1, 2, \ldots, M.$$

---

[1] Economic cost includes accounting costs plus the opportunity cost, where the latter refers to the foregone potential gain from not pursuing the next best alternative.

[2] Due to a lack of cost data representative of individual fishing days, an average cost per set was estimated for purposes of simulating daily fishing profits ($C_{ij} = C$, for all *i, j).*

[33] With less than 100% observer coverage, the exact interaction count is not observed; hence the objective is stated in terms of expected interactions, d_i, and managed by regulatory limits on observed interaction counts, b_i.

Proposed Objective 2: Choose the alternative A to maximize expected average variable profits subject to regulatory limits:

$$\max_A E\left\{\sum_{i=1}^{L} \Pi_i(N_i)\right\}/L \text{ subject to}$$

$$E\left\{\sum_{i=1}^{L}\sum_{j=1}^{N_i} X_{ijm}\right\} \leq b_m, \;\; m = 1, 2, \ldots, M.$$

Bootstrap analysis, as described in the following sections, was used to simulate the operation of the fishery to explore the effects on profitability and interactions under the range of alternatives under consideration. The alternatives are simulated for a range of potential fleet sizes, to reflect potential future levels of participation in the fishery. To reduce confounding extraneous variation between simulations of alternatives, each simulated season of potential fishing effort was subjected to all management alternatives under comparison. The results are thus representative of a comparison of the relative effects of the alternatives on profits and protected species interactions, while controlling for other potential sources of variation between outcomes.

III. Methods to Analyze Alternatives 1 and 2

Alternatives 1 and 2 in the Council's 2022 ROA reintroduce two of the alternatives that were included in the 2015 ROA. The essential features of the bootstrap methodology used to analyze them in 2015 were retained for conducting the present analysis, as described below:

1. The observed (empirical) distribution of recorded landings per season for each active DGN vessel is compiled from PacFIN records for purposes of simulating the number of planned trips fished in a season for a given number of active DGN vessels[4]. With L vessels fishing, the number of trips in a simulated season of effort is $\widehat{N} = \sum_{i=1}^{L} \widehat{N}_i$ where $\widehat{N}_i$ is a random draw for vessel $i = 1, 2, \ldots, L$ from the pooled empirical distribution of effort across all active vessels.

2. A random sample of $\widehat{N}$ draws is selected from the empirical distribution of DGN observer trips for time-area combinations which remained open after the Pacific Leatherback Conservation Area (PLCA) closure in 2001. The sets corresponding to these trips are formatted into a matrix $\hat{S}$ of $\widehat{N}$ rows where columns represent landings, revenues and numbers of protected species takes. Each row of $\hat{S}$ represents landed catch and interactions for a simulated set of effort, with potential sets for the season listed in chronological order from top to bottom. Bootstrap replicates for economic variables (landings and revenues) $\hat{Y}_i$ and protected species interactions $\hat{X}_i$ are randomly sampled from the empirical distribution of post-2001 observed sets for each of the $\widehat{N}$ potential sets of effort in a simulated season. The entries in row *i* are $\hat{S}_i = [\hat{Y}_i \; \hat{X}_i]$, where $\hat{Y}_i$ and $\hat{X}_i$ are respective row vectors for bootstrap replicates of economic metrics and protected species interactions.

[4] This approach may result in a slight overestimate of trips per season, due to rare occurrences of more than one landing from a single trip.

3. A side-by-side comparison of management alternatives is made on each bootstrap iteration by determining the number of potential sets of effort that could be fished for the simulated season under each policy:

   i. The full matrix $\hat{S}$ is interpreted as a simulated season of effort for the L active vessels under status quo (No Hard Caps) management.

   ii. To determine the number of sets that would occur under hard caps, the cumulative sum of simulated protected species interactions is calculated down each column of the matrix $\hat{S}$ for each species or species group subject to caps under one of the alternatives. The first row for which the cumulative count equals or exceeds the corresponding hard cap represents the last allowable set of fishing effort under hard cap management. The sub-matrix of $\hat{S}$ including only the rows for sets before reaching an annual hard cap is denoted $\hat{S}_H$.

   iii. To simulate the operation of the fishery under partial observer coverage, the sample of DGN effort to represent a full simulated season for all vessels in the fleet is resampled at the specified observer coverage level to represent a simulated observer sample to which caps were applied. The row index in $\hat{S}$ of the observed set which triggers the cap is treated as the last set in the (full) season for purposes of compiling total retained catch and interactions for a simulated season.

   iv. To model two-year caps under the Council's 2015 final preferred alternative (current Alternative 2), the previous year's record of observer sets is retained in order to compute two-year cumulative totals of interactions as of each (potential) observed day of fishing in the current season. These are added to observed interactions in the current season to determine whether and when a two-year cap is triggered in the current simulated season. An additional field representing the number of days since January 1 for each set in the current season (*DayInYr*) is calculated and appended to each row of $\hat{S}$ to enable computation of two-year interaction totals at each point in a simulated season. The previous season's interaction count is updated at the end of each successive simulated season by replacing it with the current season's count.

   i. A side-by-side comparison of management alternatives is made for each bootstrap iteration by summarizing the simulated number of sets, total fleet and average fleet landings, variable profits and interactions under each alternative. For each simulated season, after the simulation loop finishes executing for the chosen number of simulated seasons, summary statistics are compiled to describe the bootstrap distributions of economic and bycatch metrics computed across the simulated seasons.

IV. Extension of Bootstrap Methodology to Analyze Alternative 3 Options and Sub-options

The range of options and sub-options under Alternative 3 in the Council's November 2021 ROA include features that were not part of the 2015 ROA, such as individual vessel and fleet closures of varying lengths which allow for the reopening of the fishery before the end of the season (PFMC May 2022). Table 1 shows the options and sub-options under Alternative 3 for individual and fleet closures of varying lengths, and Table 2 shows hard cap levels under Alternative 3. Additionally, Alternative 3 provides for separate treatment of unobservable vessels in case of individual closures. A richer methodology than used previously is needed to capture the nuance of detail included under Alternative 3.

Table 1: Summary of Alternative 3 options and sub-options

<table>
<tr><th></th><th>Alternative 3 Options</th><th></th><th></th><th></th><th></th></tr>
<tr><th>Cap level</th><th>A.1</th><th>A.2</th><th>B</th><th>C.1</th><th>C.2</th></tr>
<tr><td>Vessel cap reached</td><td>Vessel closed 30 days if 5/1-10/31, 14 days if 11/1-1/31</td><td>Vessel closed for remainder of fishing year</td><td>Vessel closed 30 days if 5/1-10/31, 14 days if 11/1-1/31</td><td colspan="2">Vessel closed 30 days if 5/1-10/31, 14 days if 11/1-1/31</td></tr>
<tr><td>Vessel cap exceeded</td><td colspan="2"></td><td>Vessel closed for remainder of fishing year</td><td colspan="2">Vessel closed for remainder of fishing year
Fleet closed for 30 days if 5/1-10/31, 14 days if 11/1-1/31</td></tr>
<tr><td>Fleetwide cap reached</td><td colspan="2">Fleet closed for remainder of fishing year</td><td></td><td colspan="2">Fleet closed for 30 days if 5/1-10/31, 14 days if 11/1-1/31*</td></tr>
<tr><td>Fleetwide cap exceeded</td><td colspan="2"></td><td>Fleet closed for remainder of fishing year</td><td>Fleet closed until beginning of following fishing year</td><td>Fleet closed to following 10/31, with cap counts beginning 11/1 each year</td></tr>
</table>

Source: PFMC.

Table 2: Hard Cap Levels under Alternative 3 (Counts of HPPS Interactions)

Species	Individual Cap Reached	Individual Cap Exceeded and Fleetwide Cap Reached	Fleetwide Cap Exceeded
Fin whale	1	2	3
Humpback whale	1	2	3
Sperm whale	1	2	3
Leatherback sea turtle	1	2	3
Loggerhead sea turtle	1	2	3
Olive-Ridley sea turtle	1	2	3
Green sea turtle	1	2	3
Short-fin pilot whale C/O/W	3	4	5
Common bottlenose dolphin C/O/W Offshore stock	3	4	5

Source: PFMC.

The following approach was developed to extend the bootstrap methodology for the 2015 ROA to analyze Alternative 3 in the updated ROA:

1) To model individual vessel closures and separate treatment of observable and unobservable vessels, the data for a simulated season builds in the following features that were not included in the 2015 ROA analysis:
   a. A vessel number field (*VesNum*) to associate sets of effort with individual vessels
   b. An observable vessel indicator is used to indicate which vessels are feasible to observe (*Observable* = TRUE if a vessel is observable, FALSE if unobservable)
   c. An observed indicator (*Observed* = TRUE if a vessel is observed, FALSE if not) is used to indicate which observable vessels are actually observed in the current simulated season.
   d. Comparison of the date a set was fished (*DayInYr*) to the dates determining closure length (e.g., November 1 through January 31), to determine at what point in the season a cap is reached for closures of varying lengths.
   e. For each of the alternatives, options, and suboptions (besides Alternative 1), a fishing indicator variable which reflects whether a set is fished under the closure policy for a given alternative (e.g., *Alternative2* = TRUE if the fishery is open on a given day of a simulated season, FALSE if not).

2) A bootstrap sample of historical effort is used to model the operation of the fishery for a simulated season of DGN fishing without hard caps (Alternative 1).

3) Alternatives 2 and 3 assume a percentage of fleetwide effort is observed. A subsample of fleetwide effort is randomly chosen from the observable part of the fleet at a rate to match the assumed level of observer coverage.

4) The strategy for modeling closures under Alternatives 2 and 3 uses the same simulated season as for Alternative 1, subject to the closure provisions of the policy being analyzed. Observed days of a simulated season are ordered chronologically, and cumulative numbers of hard cap species interactions are tallied at each observed day of a simulated season. Based on days when a cap is reached or exceeded, the indicator variable for whether a given set is allowed is set to FALSE for any subsequent sets that are subject to the closure. For example, under Alternative 2, if the condition for a fleet closure is reached, an 'Alternative 2' indicator variable is set to 'FALSE' for the remaining days of the current simulated season and any additional closed days of the subsequent season. Using the same approach as taken for the 2015 ROA analysis, a simulated season is then summarized under each alternative using only those sets for which the fishing indicator variable is equal to TRUE for that alternative. This produces a *ceteris paribus* comparison across alternatives: using the same simulated season as a baseline, the only differences in economic and conservation impacts across the ROA will be from differences in the closure policy.

5) The Alternative 3 options and sub-options are complicated by interactions between different cap conditions. For example, if an individual closure would be reached on the 10th observed day of a simulated season, but a fleet cap is reached on the 5th day resulting in a closure that remains in effect on the 10th observed day, the individual cap condition on day 10 would not be reached. The following recursive updating approach was developed to address this issue:

a) For each Alternative 3 option or sub-option, the long matrix of sets in the current simulated season is converted to a wide format. The resulting wide matrix, *WBycatch*, contains a column for individual action counts for each combination of vessel and hard cap species plus fleetwide interaction counts of hard cap species on each observed day of the simulated season. Taking the cumulative sum of takes down each column results in a matrix of cumulative takes for each combination of species and individual vessel or fleet.

b) The wide matrix of cumulative takes of hard cap species compared to individual and fleet caps determines the first day in the season when a cap is reached or exceeded.

c) Depending on the first applicable cap to be reached or exceeded, the subsequent rows of the wide matrix of hard cap species interactions are revised to disallow interactions on days when a closure would have applied.

d) The revised wide matrix of hard cap species interactions is cumulatively summed to determine if additional cap conditions would be reached or exceeded before the last observed day of the simulated season. In addition, the fishing indicator vector is updated to FALSE for any days in the full simulated season that would be prohibited by the cap.

e) A recursive process of searching for later dates in the season when additional caps would apply and updating later rows of the wide matrix to reflect any caps that are reached or exceeded continues until the full season is processed.

f) Upon completion of the recursive updating process, the fishing indicator vector for the current simulated season contains a record of which days the fishery was closed under the caps policy for the current Alternative 3 option or sub-option being analyzed, indicated by FALSE values. The outcome for the simulated season is summarized for the option or sub-option in question by only including values when the fishery would have been open (fishing indicator equals TRUE).

V. Revised Resampling Protocol

Modeling hard cap closures that apply to individual vessels complicated the sampling protocol used to construct bootstrap replicates. With individual vessels included in the model, resampling at the trip level, as done previously, created problems when the same day in the year was selected multiple times for a given vessel, as an individual vessel fishing multiple sets on the same day is not consistent with actual fishery operations, and thus seems like an unreasonable condition to allow. This also led to problems in converting the long format matrix of sets in a simulated season into the wide format matrix (‘WBycatch’) used to analyze individual and fleet caps.

To address this concern, the sampling protocol was revised to the following approach:

1) For each vessel included in the analysis, a simulated season is created by randomly sampling the number of trips in the season based on resampling from the empirical distribution of trips per season, proxied by PacFIN landings per vessel.

2) For each of the vessel's simulated trips, a number of sets is simulated from the empirical distribution of observed sets per trip.

3) A simulated sequence of fishing days on different days of the year is drawn without replacement from the empirical distribution of fishing days ('*DayInYr*' variable in the data).

4) The sample of sets fished for the vessel is randomly drawn from the historically observed effort that matches the sample of *DayInYr* values.

This procedure results in a sample which represents the empirical distribution of *DayInYr* value in a manner which avoids multiple sets on the same day.

VI. Scenarios and Assumptions

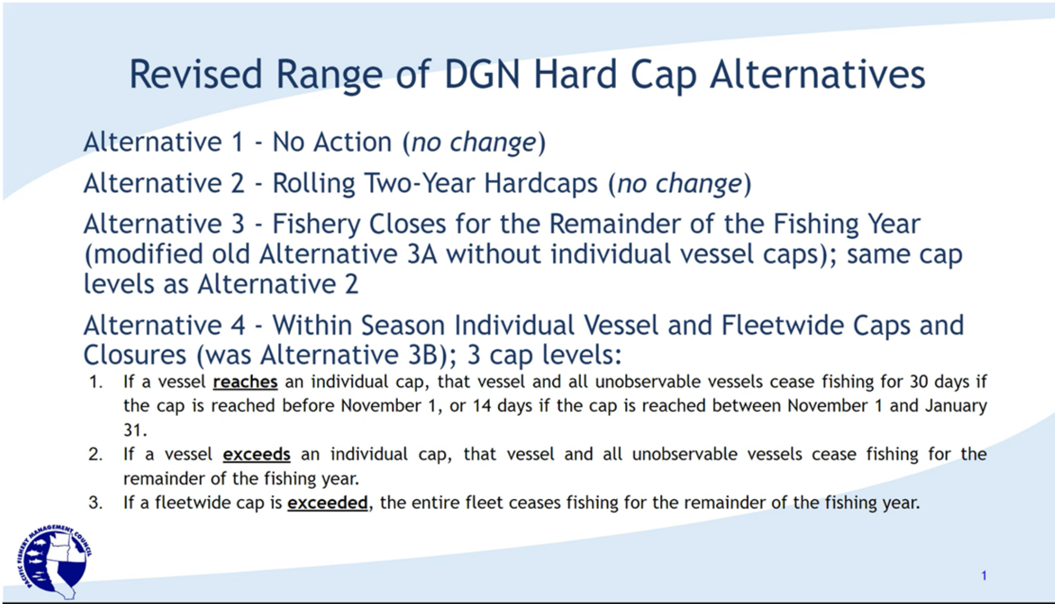
Based on past work by the HMSMT and the Council's November 2022 request, Scenarios and assumptions reflected in the present analysis include:

- The period from 2001-02 through 2020-01 seasons is used in the analysis to represent recent operation of the fishery.
- The fleet size scenario for the analysis assumes 7 observable and 4 unobservable vessels.
- A 25% observer coverage level was used to represent current fishery operations, based on input from NMFS West Coast Regional Office observer program staff.
- Given the absence of relevant data to document the effects of individual and fleet level hard caps on fishing behavior and resulting DGN interaction rates with hard cap species, the analysis assumes no incentive effect of individual caps on fishing behavior and bycatch rates.
- The analysis is applied to the Council's November 2022 ROA (Table 3). The revised bootstrap methodology described above remains applicable.

Additional assumptions underlying the model include the following:

- The observed sets and associated landings data used to construct the data for bootstrap simulation provide a suitable representation of present-day resource stocks; oceanographic, environmental, and market conditions; and the state of technology to characterize current fishery operations.
- Individual hard caps are non-transferable across vessels.

Table 3: Summary of November 2022 ROA



Source: PFMC.

VII. Data Update

Data for the 2015 analysis ended with the 2013-2014 fishing season. The data were updated to include the 2014-2015 through the 2020-2021 seasons for the current analysis.

The data used to simulate DGN fishery operation under hard caps include set-level observer counts of retained target species catch and protected species interactions from the NMFS California Gillnet Observer Database. The observer data used in the analysis are limited to times and locations which remained open after the implementation of ESA regulations which closed the PLCA during the August 15-November 15 period each year since 2001, which substantially altered the operation of the fishery, including protected and market species interaction (catch) rates.

Additional data included the PacFIN landings database (fish tickets) for the years subsequent to the 2001-2002 season, which were matched to observed trips using permit number (PacFIN *VESSEL_NUM* against observer data *PermitNum*) and last set date for an observer trip versus PacFIN *LANDING_DATE*. This approach was used to add trip-level records of market species landed weights and revenues to the analysis. The results of a 2008-2010 DGN fishery cost-and-earnings study were used to estimate the trip-level average variable cost of DGN fishing.

The data were updated through the following steps:

1) Observer data and PacFIN landings were obtained for the 2014-2015 through 2020-2021 DGN season.

2) The Gross Domestic Product Implicit Price Deflator was used to adjust dollar values in the PacFIN data and the estimated cost of a set of DGN fishing used in the 2015 ROA analysis to real 2021 dollars.

3) Observer trips from 2014-2015 through 2020-2021 were matched to corresponding PacFIN landings records. Trip-level landings (dressed pounds) and revenues from PacFIN were appended to matched observed DGN trips; landings and revenues were then equally apportioned over the sets on matched trips. (Note that set-level landings and revenue data are not available.)

4) The additional data for years past the 2013-2014 season were appended to create a history of set-level data from which bootstrap samples could be generated.

VIII. Further Methods to Analyze Bootstrap Simulation Outputs

Further methods used for the current ROA analysis include the following:

1. Standardized Metric for the Opportunity Cost of Bycatch Reduction

Assume there are a total of T bootstrap replicates are used to simulate DGN fishery operation under the Council's ROA. Let x_t^a denote the value of simulation outcome *x* for alternative *a* in the *t^th^* bootstrap replicate, and $dx_t^a = x_t^a - x_t^1$ denote the difference between the outcome under alternative a less the outcome under the Alternative 1 ("No Action"). A summary statistic to facilitate comparison of results between alternative *a* and Alternative 1 was developed based on comparing the bootstrap estimate of the mean change in revenues per season from Alternative 1 to Alternative *a*, $\bar{d}_R^a = \sum_{t=1}^{T} dR_t^a/T,$ to the bootstrap estimate of the sum total of the mean change in HPPS mortalities and injuries, $\bar{d}_{MI}^a = \sum_{i=1}^{9} \overline{dMI}_i^a$, where $\overline{dMI}_i^a = \sum_{t=1}^{T} dMI_{it}^a/T$ is the bootstrap estimator of the mean change in mortalities and injuries for species *i.* A ratio comparison between $\bar{d}_R^a$ and $\bar{d}_{MI}^a$ provides a metric for the opportunity cost of revenues per unit of mortalities and injuries for all HPPS:

$$OCR^a = \frac{\bar{d}_R^a}{\bar{d}_{MI}^a}.$$

Because the quantities in the numerator and denominator both represent rates per season, the time dimension cancels out and the OCR^a measures the opportunity cost of revenues reduction per unit decrease in HPPS mortalities and injuries in moving from Alternative 1 to Alternative *a*.

2. Dead Discard Estimate

A metric for finfish discards per season under alternative *a* is

$$\overline{FF}^a = DDR_{FF} \times \bar{S}^a,$$

where DDR_{FF} is the estimated dead finfish discard rate per set and $\bar{S}^a = \sum_{t=1}^{T} S_t^a/T$ is the bootstrap estimate of the mean sets fished per season under alternative *a*.

IX. SSC Review

The SSC reviewed the bootstrap methodology at their November 2022 meeting and offered a number of recommendations for improving the presentation of results (G.3.a, Supplemental SSC Report 1). These include the following:

1. The estimated effects of the hard-cap options are primarily reported as averages; however, with HPPS interactions being relatively rare, the average is not an appropriate metric since the distribution of impacts can be highly skewed, and the average does not capture the risk (economic- or conservation-wise) associated with the different hard-cap options. The analysts should also report measures of risk that focus on the magnitude of the economic and conservation impacts associated with extremely bad events—for example, the expected effects conditional on being in the 5 percent worst-case outcomes.

2. Rather than comparing the distributions of the simulated outcomes under the different hard-cap options, the analysts could report the distributions of the effects for each hard-cap option as differences from the status quo.

3. While there is little quantitative difference between some of the Alternative 3 options, there are qualitative differences between the options that should be discussed in the analysis. For example, vessel-level caps are relatively riskier for individual vessels than fleet-wide caps and may not provide additional conservation benefit if vessels do not have much control over the likelihood of HPPS interactions. On the other hand, individual caps would provide additional incentives to the extent that vessels can influence the likelihood of HPPS interactions.

The Council requested that the analysis be revised to reflect SSC recommendations. These revisions are described in the following section.

X. Revisions to Address SSC Recommendations

Tail-conditional expectations (TCEs) are a potentially more appropriate metric than the mean to characterize the risk of extreme outcomes, particularly in the case of highly skewed distributions such as those which result from using hard caps to manage rare event bycatch (Holland 2010, Holland and Jannot 2012, Landsman and Valdez 2005). To apply the TCE concept to discrete distributions of simulation outcomes, the following calculations were used:

$$\text{Lower } p\% \text{ TCE} = \frac{\sum_{i=1}^{n_p} x_{(i)}}{n_p}$$

$$\text{Upper } p\% \text{ TCE} = \frac{\sum_{i=N-n_p+1}^{N} x_{(i)}}{n_p}$$

where N is the number of values in the discrete distribution (e.g., bootstrap replicates), $x_{(i)}$ denotes the i^{th} order statistic[5], and n_p is the number of values in the lower or upper $p\%$ tail. Intuitively, the lower $p\%$

[5] Order statistics are obtained by ranking the values in a data distribution from smallest to largest, where $x_{(1)}$ is the minimum value and $x_{(i)}$ denotes the i^{th} value in order from the minimum.

TCE is the average of the lowest *p*% of the values in the distribution, while the upper *p*% TCE is the average of the highest *p*% of the values.

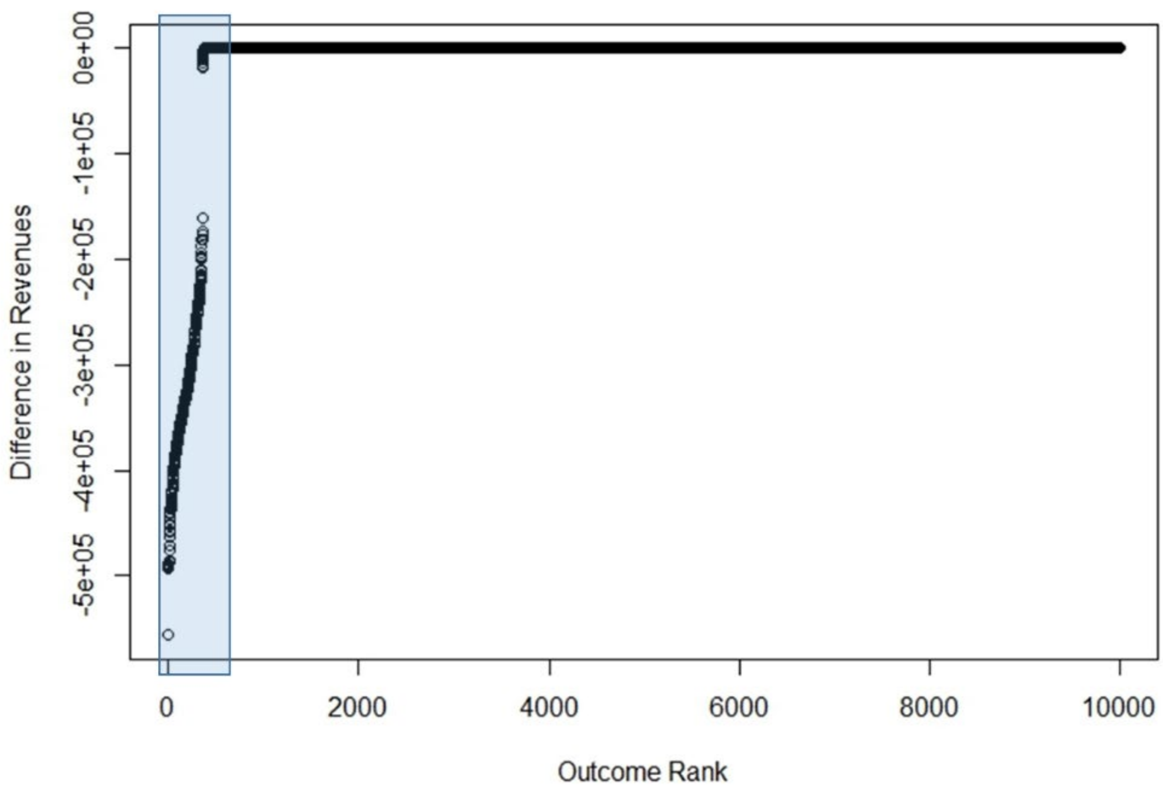
Two approaches to computing TCEs for comparing alternatives in the ROA are included in the analysis:

1. 5% TCEs are computed for absolute levels of simulation outcomes, x_i^a, under each of the alternatives. Each alternative can then be compared to the baseline ("No Action") using either subtractive or percentage differences between absolute TCEs.

2. 5% TCEs are computed for the distribution of differences, d_i^a, between the outcome for a given action alternative and the corresponding baseline ("No Action") outcome for each bootstrap replicate. The advantage of this approach is to focus on simulated seasons where an action alternative would have produced different results than the baseline.

Figure 1 illustrates the lower 5% TCE calculation applied for simulated differences in revenues under Alternative 3A and Alternative 1 ("No Action"). Going from left to right in the figure, the simulated differences are first ranked from smallest (most negative) to largest (0, in this case). For over 95% of simulated seasons, there was no difference in revenues between these two alternatives. The blue rectangle includes cases where Alternative 3A resulted in lower revenues than Alternative 1, due to a cap condition leading to a reduction in fishing effort and revenues production. Averaging differences in revenues in this lower 5% tail produces the TCE for differences in revenues between Alternative 3A and Alternative 1.

Figure 1: TCE for Difference in Revenues between Alternative 3A and Alternative 1 ("No Action")



To explore the correlation across simulated seasons between the level of HPPS bycatch reduction and the loss of revenues ("correlation analysis"), an additional approach is a bivariate analysis of HPPS bycatch reduction and loss of revenues compared to the baseline ("No Action") alternative across simulated seasons. Given highly skewed distributions and a limited range of (nonzero) HPPS bycatch reduction outcomes across simulated seasons, the methodology enumerates the frequency distribution of HPPS bycatch reduction in simulation results paired with conditional mean levels of revenues reduction. Further details are provided in the following section along with results.

XI. Results Summary

Absolute TCEs

Absolute TCEs were computed for economic metrics and HPPS M/I for each of the alternatives, using 5% as the tail area (Tables 4-11). For action alternatives (2, 3A and 3B), differences in TCEs from Alternative 1 ("No Action") are reported in levels and percentage changes. Upper 5% TCEs for sets and related finfish mortality under each of the alternatives, including comparisons to Alternative 1 for the action alternatives, are reported in Table 12.

Opportunity Cost Metric

The results from computing the opportunity cost metric for HPPS M/I reduction based on TCEs of differences between action alternatives and No Action are provided in Table 13 and Figures 2 and 3. Figure 3 measures the TCE for reduction in HPPS M/I on the horizontal scale and the TCE for reduction in revenues on the vertical scale; values for the three alternatives from Table 13 are indicated by three markers in the figure. The slope of the line in Figure 3 from the origin through the point corresponding to Alternative 2 equals the opportunity cost metric for Alternative 2 ($694,273), which is highest among the three alternatives. Table 2 shows the opportunity cost metric values in a bar plot.

Correlation analysis

A classical statistics framework typically employs a linear regression approach or calculation of correlation coefficients under the assumption that the data follow a bivariate normal distribution to examine the correlation between a pair of random variables. Given the highly skewed and non-normal distributions of bootstrap simulation results for the hard caps ROA analysis, a heuristic approach is used instead to describe the bivariate distribution of HPPS M/I reductions between action alternatives and No Action to the related reductions in revenues.

Table 14 shows the correlation analysis results to compare the distribution of differences in HPPS M/I from Alternative 1 under each alternative (dMI) to differences in revenues from Alternative 1 (dR). The Frequency column provides the frequency distribution of dMI in simulation results, with the frequencies for dMI = 0 split between cases where dR = 0 and dR < 0. Simulation outcomes where dMI = 0 and dR < 0 correspond to simulated seasons where fishing effort is reduced due to a cap condition applying, but no further HPPS M/I would have occurred had the fishery remained open.

For rows of the table with dR < 0, the conditional mean of the reduction in revenues, E(dR | dMI) is calculated, to illustrate any trends in lost revenues with the level of HPPS M/I reduction. Generally, within the three alternatives, there is a weak trend towards higher levels of revenue loss with larger levels of HPPS M/I reduction, with the smallest revenue loss seen in cases with dMI = 0.

Across the three alternatives, the values of E(dR | dMI) are by far the largest for Alternative 2. While Alternative 3B has smaller values of E(dR | dMI) than Alternative 3A has, the results also indicate smaller reductions in HPPS M/I, consistent with the opportunity cost results (Table 13, Figures 2 and 3).

Table 4: Absolute TCEs and mean simulation outcomes for economic metrics under Alternative 1 (No Action)

Alternative 1	Lower TCE	Mean
Sets	357	586
Total Revenue	$554,568	$910,216
Total Profits	$116,401	$230,671
Avg. Profits	$10,582	$20,970
Landings (mt)	79	130

Table 5: Absolute TCEs and mean simulation outcomes for HPPS M/I under Alternative 1 (No Action)

Alternative 1	Mean	Upper TCE
Fin Whale	0.00	0.00
Humpback	0.23	1.41
Sperm Whale	0.30	2.37
Leatherback	0.00	0.00
Loggerhead	0.00	0.00
Olive Ridley	0.00	0.00
Green Turtle	0.00	0.00
SF Pilot Whale	0.60	2.49
Bottlenose	0.15	1.19
All HPPS	1.28	4.58

Table 6: Absolute TCEs and mean simulation outcomes for economic metrics under Alternative 2

Alternative 2	Lower TCE	Mean
Sets	91	565
Total Revenue	$141,561	$877,863
Total Profits	$27,704	$222,308
Avg. Profits	$2,519	$20,210
Landings (mt)	20	126
Net change (absolute)		
Sets	-265	-21
Total Revenue	-$413,006	-$32,353
Total Profits	-$88,698	-$8,363
Avg. Profits	-$8,063	-$760
Landings (mt)	-59	-5
Net change (percentage)		
Sets	-74.4%	-3.5%
Total Revenue	-74.5%	-3.6%
Total Profits	-76.2%	-3.6%
Avg. Profits	-76.2%	-3.6%
Landings (mt)	-74.5%	-3.6%

Table 7: Absolute TCEs and mean simulation outcomes for HPPS M/I under Alternative 2

Alternative 2	Mean	Upper TCE
Fin Whale	0.00	0.00
Humpback	0.22	1.40
Sperm Whale	0.29	2.36
Leatherback	0.00	0.00
Loggerhead	0.00	0.00
Olive Ridley	0.00	0.00
Green Turtle	0.00	0.00
SF Pilot Whale	0.58	2.48
Bottlenose	0.15	1.18
All HPPS	1.23	4.55
Net change (absolute)		
Fin Whale	0.00	0.00
Humpback	-0.01	-0.01
Sperm Whale	-0.01	-0.01
Leatherback	0.00	0.00
Loggerhead	0.00	0.00
Olive Ridley	0.00	0.00
Green Turtle	0.00	0.00
SF Pilot Whale	-0.02	-0.01
Bottlenose	-0.01	-0.01
All HPPS	-0.05	-0.02
Net change (percentage)		
Fin Whale	NA	NA
Humpback	-4.0%	-0.8%
Sperm Whale	-3.7%	-0.5%
Leatherback	NA	NA
Loggerhead	NA	NA
Olive Ridley	NA	NA
Green Turtle	NA	NA
SF Pilot Whale	-3.5%	-0.6%
Bottlenose	-3.6%	-0.7%
All HPPS	-3.6%	-0.5%

Table 8: Absolute TCEs and mean simulation outcomes for economic metrics under Alternative 3A

Alternative 3A	Lower TCE	Mean
Sets	342	579
Total Revenue	$526,892.12	$898,448.94
Total Profits	$107,074.81	$227,026.72
Avg. Profits	$9,734.07	$20,638.79
Landings (mt)	76	129
Net change (absolute)		
Sets	-15	-7
Total Revenue	-$27,675	-$11,767
Total Profits	-$9,327	-$3,644
Avg. Profits	-$848	-$331
Landings (mt)	-4	-2
Net change (percentage)		
Sets	-4.2%	-1.2%
Total Revenue	-5.0%	-1.3%
Total Profits	-8.0%	-1.6%
Avg. Profits	-8.0%	-1.6%
Landings (mt)	-4.4%	-1.2%

Table 9: Absolute TCEs and mean simulation outcomes for HPPS M/I under Alternative 3A

Alternative 3A	Mean	Upper TCE
Fin Whale	0.00	0.00
Humpback	0.22	1.39
Sperm Whale	0.30	2.37
Leatherback	0.00	0.00
Loggerhead	0.00	0.00
Olive Ridley	0.00	0.00
Green Turtle	0.00	0.00
SF Pilot Whale	0.58	2.47
Bottlenose	0.15	1.19
All HPPS	1.26	4.45
Net change (absolute)		
Fin Whale	0.00	0.00
Humpback	-0.01	-0.02
Sperm Whale	0.00	0.00
Leatherback	0.00	0.00
Loggerhead	0.00	0.00
Olive Ridley	0.00	0.00
Green Turtle	0.00	0.00
SF Pilot Whale	-0.01	-0.02
Bottlenose	0.00	0.00
All HPPS	-0.02	-0.12
Net change (percentage)		
Fin Whale	NA	NA
Humpback	-3.8%	-1.4%
Sperm Whale	0.0%	0.0%
Leatherback	NA	NA
Loggerhead	NA	NA
Olive Ridley	NA	NA
Green Turtle	NA	NA
SF Pilot Whale	-2.4%	-0.9%
Bottlenose	0.0%	0.0%
All HPPS	-1.8%	-2.7%

Table 10: Absolute TCEs and mean simulation outcomes for economic metrics under Alternative 3B

Alternative 3B	Lower TCE	Mean
Sets	353	582
Total Revenue	$548,462	$904,318
Total Profits	$114,717	$228,883
Avg. Profits	$10,429	$20,808
Landings (mt)	79	130
Net change (absolute)		
Sets	-4	-4
Total Revenue	-$6,106	-$5,898
Total Profits	-$1,684	-$1,788
Avg. Profits	-$153	-$163
Landings (mt)	-1	-1
Net change (percentage)		
Sets	-1.0%	-0.6%
Total Revenue	-1.1%	-0.6%
Total Profits	-1.4%	-0.8%
Avg. Profits	-1.4%	-0.8%
Landings (mt)	-1.0%	-0.6%

Table 11: Absolute TCEs and mean simulation outcomes for HPPS M/I under Alternative 3B

Alternative 3B	Mean	Upper TCE
Fin Whale	0.00	0.00
Humpback	0.23	1.40
Sperm Whale	0.30	2.37
Leatherback	0.00	0.00
Loggerhead	0.00	0.00
Olive Ridley	0.00	0.00
Green Turtle	0.00	0.00
SF Pilot Whale	0.59	2.48
Bottlenose	0.15	1.19
All HPPS	1.27	4.51
Net change (absolute)		
Fin Whale	0.00	0.00
Humpback	0.00	-0.01
Sperm Whale	0.00	0.00
Leatherback	0.00	0.00
Loggerhead	0.00	0.00
Olive Ridley	0.00	0.00
Green Turtle	0.00	0.00
SF Pilot Whale	-0.01	-0.01
Bottlenose	0.00	0.00
All HPPS	-0.01	-0.06
Net change (percentage)		
Fin Whale	NA	NA
Humpback	-1.9%	-1.0%
Sperm Whale	0.0%	0.0%
Leatherback	NA	NA
Loggerhead	NA	NA
Olive Ridley	NA	NA
Green Turtle	NA	NA
SF Pilot Whale	-1.0%	-0.5%
Bottlenose	0.0%	0.0%
All HPPS	-0.8%	-1.4%

Table 12: Absolute Upper TCEs for Sets and Finfish Mortality

	Upper TCE for Sets	TCE for Finfish Mortality	Net Change (Absolute)	Net Change (Level)
Alternative 1	859.2	2405.6	NA	NA
Alternative 2	857.4	2400.6	-5.0	-0.2%
Alternative 3A	856.5	2398.2	-7.4	-0.3%
Alternative 3B	856.2	2397.4	-8.3	-0.3%

Table 13: Opportunity Cost of Revenues for HPPS M/I Reduction

	Alt 2	Alt 3-A	Alt 3-B
TCE for Reduction in Revenues	-$647,062	-$235,340	-$116,953
TCE for Reduction in HPPS M/I	-0.932	-0.466	-0.210
TCE Ratios (Opportunity Cost)	$694,273	$505,021	$556,919

Figure 2: Ratio of TCE for Reduction in Revenues to TCE for Reduction in HPPS M/I

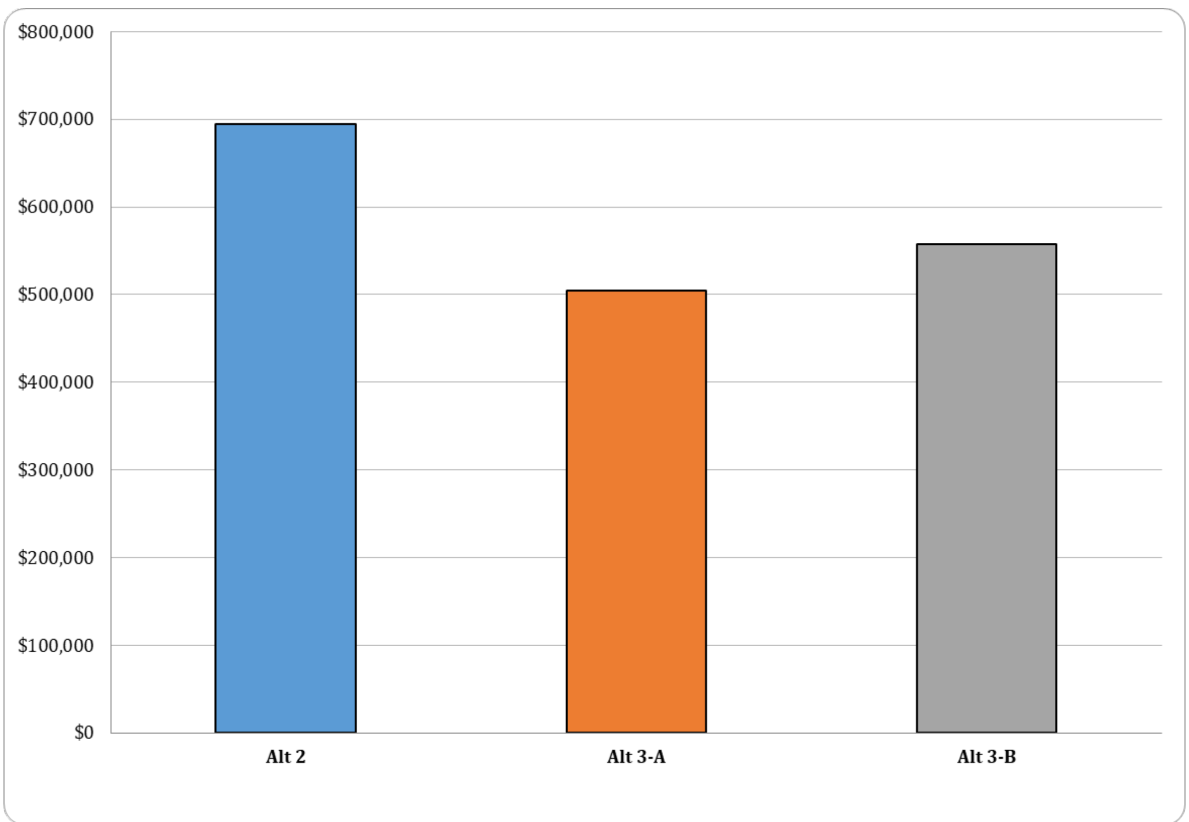


Figure 3: TCE for Reduction in Revenues & Reduction in HPPS M/I

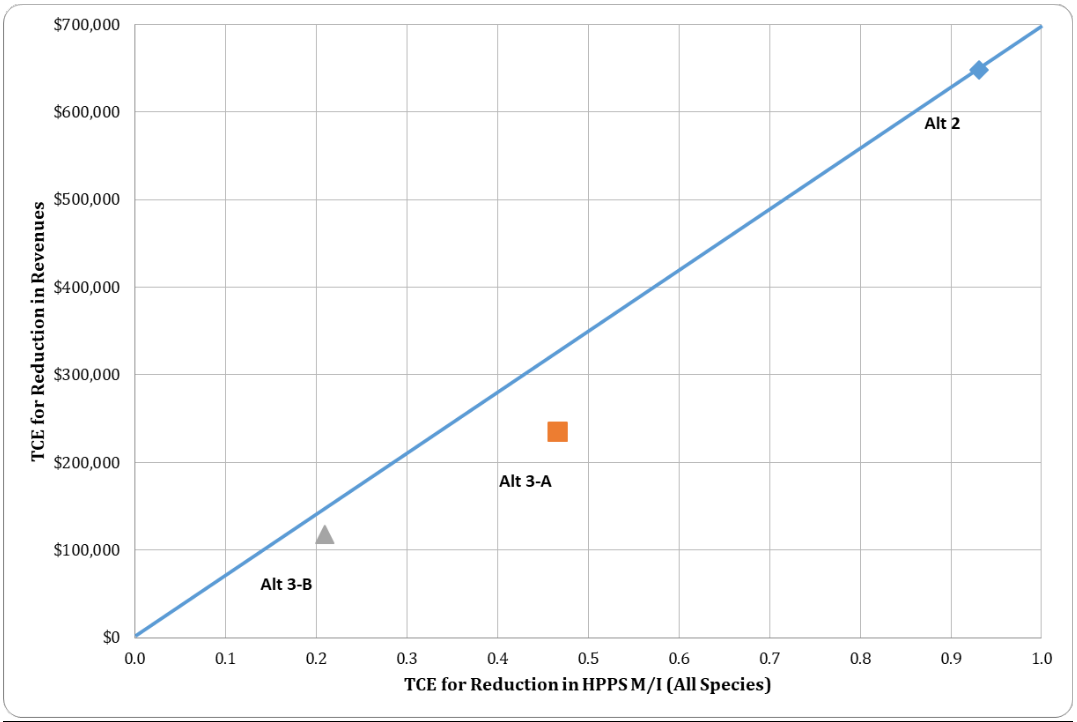


Table 14: Correlation Analysis

Alternative 2			
Frequency	dMI	dR	E(dR| dMI)
96.45%	0	= 0	$0
1.13%	0	< 0	-$868,073
1.06%	-1	< 0	-$919,027
0.85%	-2	< 0	-$931,382
0.26%	-3	< 0	-$939,402
0.17%	-4	< 0	-$992,449
0.04%	-5	< 0	-$933,098
0.04%	-6	< 0	-$956,489
Alternative 3A			
96.31%	0	= 0	$0
1.97%	0	< 0	-$297,875
1.23%	-1	< 0	-$341,317
0.40%	-2	< 0	-$347,216
0.08%	-3	< 0	-$337,580
0.01%	-6	< 0	-$417,300
Alternative 3B			
92.11%	0	= 0	$0
6.92%	0	< 0	-$61,044
0.89%	-1	< 0	-$172,332
0.08%	-2	< 0	-$175,101

Acknowledgments

The author thanks Jennifer Couture for her assistance with developing the original version of the bootstrap model of DGN hard caps management and organizing the data to analyze the Council's 2015 ROA, and Naresh Pradhan, Sean Matson, and SSC members for providing helpful reviews. Karter Harmon helped extend the R code to analyze the 2022 ROA and produced some of the figures in this report. Thanks also to Dale Squires, Kit Dahl, Karter Harmon, the Southwest Fisheries Science Center Fisheries Resources Division, and members of the Council's HMSMT and SSC for their reviews, and to members of the HMSMT for their help with developing scenarios for analysis.

References

Davison, A. C., and D. V. Hinkley. "Bootstrap methods and their application Cambridge University Press." Cambridge, UK 193 (1997).

Efron, B., and Hastie, T., 2016. Computer Age Statistical Inference. Institute of Mathematical Statistics Monographs.

Efron, B., and Robert J. Tibshirani. An introduction to the bootstrap. Vol. 57. CRC press, 1994.

Holland, D.S., 2010. Markets, pooling and insurance for managing bycatch in fisheries. Ecological Economics, 70(1), pp.121-133.

Holland, D.S. and Jannot, J.E., 2012. Bycatch risk pools for the US West Coast groundfish fishery. Ecological Economics, 78, pp.132-147.

Landsman, Z. and Valdez, E.A., 2005. Tail conditional expectations for exponential dispersion models. ASTIN Bulletin: The Journal of the IAA, 35(1), pp.189-209.

Pacific Fishery Management Council. Agenda Item G.3, Attachment 1. November 2022.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Scientific and Statistical Committee. Agenda Item H.4.b, Supplemental SSC Report. March 2015.

Scientific and Statistical Committee. Agenda Item G.3.a Supplemental SSC Report 1. November 2022.

Stohs, S. “Bootstrap Analysis to Compare the Operation of the Drift Gillnet Fishery under Hard Caps Alternatives.” Supplemental NMFS Report 5, September 2015 Pacific Fishery Management Council Briefing Book.