**Analysis of past BSAI and GOA Groundfish Plan Team recommendations to set ABC below the maximum permissible level**

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## Introduction

The minutes of the February 2018 SSC meeting state, "The SSC recommends *identification of clear and transparent rules* for defining the specific criteria to be used when adjusting the recommended ABC" (emphasis added). This paper describes an attempt to develop a starting point for satisfying the SSC's request by reverse-engineering a set of rules from previous ABC recommendations.

## Methods

During the 15 years spanning the period 2003-2017, the BSAI and GOA Groundfish Plan Teams ("Teams") recommended setting ABC below the maximum permissible level ("maxABC") in a total of 76 instances, for an average of 5.07 instances per year (Figure 1). In all but 4 instances the Teams listed at least one reason for their recommendations, with an average of 2.68 reasons per instance. After omitting some non-essential verbiage, a total of 122 unique reasons were listed over the course of the 15 years (some reasons were listed more than once).

To make the analysis more tractable, the 122 unique reasons were condensed into a set of 66 initial paraphrased reasons ("Round 1" variables, Table 1). This resulted in a 76 × 66 (instance × reason) matrix **X**, where each element is either 0 or 1 depending on whether the given reason (column) was listed by the Teams for the given ABC reduction (row). The product **X′X** turned out to be singular, due in part to confounding of several of the Round 1 variables. Specifically, the members of 8 subsets of Round 1 variables never occurred in the matrix apart from the other members of the respective subset. This was considered problematic insofar as it rendered ordinary least-squares regression impossible.

Each of the 8 confounded subsets of Round 1 variables was therefore consolidated into a single "Round 2" variable (Table 2; note that all Round 1 variables not listed in this table were retained for Round 2). This resulted in a new **X** matrix of dimension 76 × 52 (22 Round 1 variables were included in the 8 confounded subsets, resulting in 66–(22–8) = 52 variables in Round 2). However, the product **X′X** was still singular, with 10 of the 52 eigenvalues being zero. The zero eigenvalues were associated with 20 of the Round 2 variables.

Each of the 20 Round 2 variables associated with the zero eigenvalues was therefore combined with one Round 2 variable that was *not* associated with the zero eigenvalues, giving the list of "Round 3" variables shown in Table 3 (note that all Round 2 variables not listed in this table were retained for Round 3). The choices regarding which variables to combine were subjective, with a goal of minimizing the degree of controversy resulting from those choices. This resulted in another new **X** matrix of dimension 76 × 32 (52 Round 1 variables – 20 Round 1 variables associated with the zero eigenvalues = 32 variables in Round 3). The product **X′X** was now non-singular.

The set of reductions in ABC, expressed as proportions of maxABC ("**y**"), were logit-transformed for $i$=1,2,...,76 as follows:

$$logit\_y_i = ln\left(\frac{1+y_i}{1-y_i}\right).$$

Least-squares parameter estimates were then calculated as follows:

$$\boldsymbol{\beta 1} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{logit\_y}\,.$$

Some of the resulting $\boldsymbol{\beta 1}$ values were negative, implying that, if any subset of the corresponding variables were the only ones that were to apply in a particular situation, the ABC would have to be adjusted upward, rather than downward, from maxABC. Therefore, the $\boldsymbol{\beta 1}$ estimates were used as initial values for $\boldsymbol{\beta 2}$ in the following constrained optimization problem, which ensures that adjustments relative to maxABC are always in the downward direction (note that the least-squares reduction estimates have undergone a logistic back-transformation):

$$\text{minimize} \sum_{i=1}^{76}\left(y_i - \left(2\big(1+\exp(-(\mathbf{X}\boldsymbol{\beta 2})_i)\big)^{-1} - 1\right)\right)^2 \text{ subject to } \beta 2_i \geq 0 \text{ for all } i = 1,2,\ldots,76\,.$$

**Results**

Figure 2 compares the $\boldsymbol{\beta 1}$ and $\boldsymbol{\beta 2}$ estimates for the 32 Round 3 variables, sorted in increasing order of $\boldsymbol{\beta 2}$. Note that 8 of the $\boldsymbol{\beta 1}$ estimates are less than zero. The corresponding $\boldsymbol{\beta 2}$ estimates for the first 7 of these are zero, and the eighth (variable 9 in Figure 2) is positive. Back-transforming the least-squares model ($\boldsymbol{\beta 1}$**)** to the natural scale gives an $R^2$ of 0.826, while the constrained model ($\boldsymbol{\beta 2}$, which has already been back-transformed**)** gives an $R^2$ of 0.824. The $\boldsymbol{\beta 2}$ values, sorted in increasing order, are shown in Table 4 along with the implied univariate ABC reduction for each (i.e., the ABC reduction that would result if no other variable was applicable).

The ABC reductions estimated by the two models are compared against the observed ABC reductions in Figure 3. The errors (absolute value) from both models were less than 0.2 in all but six instances. The following five instances of errors greater than 0.2 were common to both models:

| Stock | Year |
|---|---|
| EBS pollock | 2011 |
| EBS pollock | 2014 |
| AI pollock | 2008 |
| BSAI Greenland turbot | 2004 |
| BSAI Greenland turbot | 2005 |

The sixth instance of an error greater than 0.2 occurred with respect to 2014 EBS Pacific cod for the unconstrained model ($\boldsymbol{\beta 1}$) and 2003 BSAI Greenland turbot for the constrained model ($\boldsymbol{\beta 2}$).

**Discussion**

First, some caveats/clarifications:

- Some of the steps involved in this analysis were necessarily subjective, and it is likely that other analysts would have arrived at a somewhat different final model (just like in a stock assessment).
- The analysis is necessarily one-sided in that the Teams did not check consistently to determine which, if any, of the variables listed in Table 1 were applicable to each stock/complex in each year; rather, the reasons for reducing ABC were typically articulated after the assessment author or the Team became concerned that a reduction for a particular stock/complex in a particular year might be warranted, without consistent regard for whether those same reasons, or reasons articulated for the same stock or other stocks in previous years, might apply elsewhere.
- A zero coefficient (**β2**) does not necessarily imply that the corresponding variable, considered in isolation, is unimportant; only that it does not provide any explanatory power over and above those of the other variables with which it has been paired in previous applications.

The multivariate logistic nature of the final model developed here (**β2**) is appealing in that the functional form is fairly simple, all coefficients are positive (meaning that if only a single variable applies in a particular situation, the resulting reduction is guaranteed to be positive), and the resulting reductions will always be between 0 and 1 (this would not necessarily be the case if a linear, rather than logistic, form were used).

However, this analysis is intended as a starting point only. If the basic approach is adopted, it is expected that the Teams will want to both add to, and subtract from, the list of variables in Table 4. For example:

- "None" is not a particularly compelling reason to reduce ABC below maxABC.
- Variables such as "SSC's rule for Bogoslof pollock ABC" are likely of historical interest only.
- To satisfy the SSC's request for "identification of clear and transparent rules," it may be necessary to frame each of the variables in objectively quantifiable terms (e.g., "most recent survey CV is in excess of 50%," may be preferable to "large survey CV").
- Potential candidate variables suggested by the SSC (February 2018) include:
  - Stock assessment uncertainty relative to levels upon which the Tier system was constructed.
  - Atypical data availability or usage (e.g., reliance on only catch-per-unit-effort vs. a survey index).
  - Ecosystem considerations.

Not only is the list of variables subject to modification, but it is expected that the Teams will want to modify the corresponding coefficients as well. When setting a coefficient value, it may be desirable to reverse-engineer it from a specified univariate reduction through the logit transform described above. For example, to achieve a 10% univariate reduction for some particular variable, the corresponding coefficient would be set equal to ln((1+0.1)/(1-0.1)) = ln(1.1/0.9) ≈ 0.201.

Once the set of variables to be included and the values of the corresponding coefficients **β** have been determined, the proportional reduction in any particular situation (i.e., combination of stock/complex and year) can be computed as

$$reduction = 2\left(1+\exp\left(-\sum_{var=1}^{nvar} x_{var}\beta_{var}\right)\right)^{-1} - 1\,,$$

where *nvar* represents the number of variables included in the decision process, and **x** is a vector with elements equal to 0 or 1 depending on whether the variable applies in the particular situation.

## Tables

*Table 1 (page 1 of 2). Round 1 paraphrased reasons (variables) for setting ABC<maxABC.*

| Round 1 variables | N | Assessments, in alphabetical order |
|---|---|---|
| Catching maxABC would require large increase in effort | 1 | 2017 EBS pollock |
| Change in biomass estimates between assessments | 1 | 2008 BSAI Greenland turbot |
| Dome-shaped selectivity may overestimate abundance | 1 | 2003 BSAI Pacific cod |
| Dominance of single year class | 7 | 2010-2014 EBS pollock, 2003-2004 GOA Atka mackerel |
| Dorn's buffer | 13 | 2003-2015 GOA pollock |
| Estimated selectivity may not capture year class targeting | 1 | 2011 EBS pollock |
| Few older fish | 4 | 2017 BSAI sablefish, 2016-2017 EBS pollock, 2017 GOA sablefish |
| Habitat-specific residency | 12 | 2003-2013 and 2015 GOA demersal shelf rockfish |
| Hedge against future regime shift | 1 | 2010 EBS pollock |
| Important role in ecosystem as prey | 2 | 2016-2017 EBS pollock |
| Increased patchiness of distribution | 1 | 2016 EBS pollock |
| Increasing catch on a declining stock | 2 | 2003 BSAI sablefish, 2014 BSAI skates |
| Increasing predation pressure | 1 | 2006 EBS pollock |
| Keep spawning exploitation rate below all-time high | 1 | 2007 EBS pollock |
| Large survey CV | 2 | 2016-2017 Bogoslof pollock |
| Late maturation | 12 | 2003-2013 and 2015 GOA demersal shelf rockfish |
| Late-breaking analysis (not included in assessment) | 1 | 2014 GOA Pacific cod |
| Longevity | 12 | 2003-2013 and 2015 GOA demersal shelf rockfish |
| Long-term biomass decline | 2 | 2003 and 2005 BSAI Greenland turbot |
| Long-term poor recruitment | 3 | 2008 AI pollock, 2003 BSAI Greenland turbot, 2004 GOA pollock |
| Low biomass | 5 | 2008 AI pollock, 2017 BSAI sablefish, 2011 and 2013 EBS pollock, 2017 GOA sablefish |
| Low roe recovery rates | 2 | 2013 and 2016 EBS pollock |
| Maintain fishery CPUE | 3 | 2011, 2014, and 2015 EBS pollock |
| maxABC would be a dramatic increase over historic catch | 4 | 2008 AI pollock, 2004 and 2006 BSAI Greenland turbot, 2008 BSAI Pacific cod |
| Multispecies model estimates higher biomass reference points | 2 | 2016-2017 EBS pollock |
| No history of rebuilding from current level when catch=maxABC | 1 | 2007 EBS pollock |
| No new survey | 1 | 2006 BSAI Greenland turbot |
| No reliable biomass estimate | 2 | 2003-2004 GOA Atka mackerel |
| None | 4 | 2014 and GOA demersal shelf rockfish, 2003-2004 GOA other slope rockfish |
| Possibility of localized depletion | 2 | 2003-2004 GOA Atka mackerel |
| Potential overharvest in distant past | 2 | 2003-2004 GOA Atka mackerel |
| Precedent | 3 | 2017 GOA demersal shelf rockfish, 2003-2004 GOA shortraker/rougheye rockfish |
| Preferred model does not account for structural uncertainty | 1 | 2016 EBS pollock |

*Table 1 (page 2 of 2). Round 1 paraphrased reasons for setting ABC<maxABC.*

| Round 1 variables | N | Assessments, in alphabetical order |
|---|---|---|
| Prevent B<B20% | 1 | 2017 GOA Pacific cod |
| Projected biomass decline | 4 | 2017 EBS pollock, 2006 GOA Pacific cod, 2004 GOA pollock, 2003 GOA sablefish |
| Projected poor recruitment | 2 | 2016-2017 EBS pollock |
| Protect against disproportionate harvest within complex | 1 | 2004 GOA shortraker/rougheye rockfish |
| Recent bird die-offs | 3 | 2017 EBS Pacific cod, 2016-2017 EBS pollock |
| Recent poor recruitment | 3 | 2017 EBS Pacific cod, 2007 EBS pollock, 2006 GOA Pacific cod |
| Recent year class estimated to be extremely large | 2 | 2017 BSAI sablefish, 2017 GOA sablefish |
| Reduce ABC to account for State GHL | 11 | 2003-2013 GOA pollock |
| Reduce bycatch | 2 | 2014-2015 EBS pollock |
| Reduced condition factor | 2 | 2017 EBS Pacific cod, 2013 EBS pollock |
| Reduced prey availability | 2 | 2006 and 2016 EBS pollock |
| Reliable minimum biomass estimate available for Tier 6 stock | 1 | 2010 GOA sharks |
| Retrospective bias | 6 | 2014-2015 EBS Pacific cod, 2007 and 2011-2012 EBS pollock, 2014 GOA Pacific cod |
| Sedentary life history | 12 | 2003-2013 and 2015 GOA demersal shelf rockfish |
| Short-term biomass decline | 3 | 2003 BSAI Pacific cod, 2017 EBS Pacific cod, 2011 EBS pollock |
| Significant probability of exceeding FMSY | 1 | 2012 EBS pollock |
| SSC's rule for Bogoslof pollock ABC | 4 | 2007-2010 Bogoslof pollock |
| Survey index lower than expected | 2 | 2006 EBS pollock, 2004 GOA pollock |
| Trend of increasing F on oldest ages | 1 | 2013 EBS pollock |
| Uncertain biomass estimates | 2 | 2013 and 2015 GOA demersal shelf rockfish |
| Uncertain recruitment estimates | 4 | 2004 BSAI Greenland turbot, 2017 BSAI sablefish, 2011 EBS pollock, 2017 GOA sablefish |
| Uncertain stock structure | 2 | 2011 and 2017 EBS pollock |
| Uncertain stock trend | 1 | 2008 BSAI Greenland turbot |
| Uncertainty surrounding M and Q | 2 | 2004 AI pollock, 2003 GOA Pacific cod |
| Uncertainty surrounding Q | 1 | 2015 EBS Pacific cod |
| Vessels are needing to travel farther | 1 | 2006 EBS pollock |
| Whale depredation | 4 | 2016-2017 BSAI sablefish, 2016-2017 GOA sablefish |
| Yield variability | 2 | 2004 BSAI Pacific cod, 2004 GOA Pacific cod |

*Table 2. Mapping confounded Round 1 variables into Round 2 variables. (Round 1 variables not shown here were retained in Round 2).*

| **Round 1 variables** | **Round 2 variables** |
|---|---|
| Habitat-specific residency | Some concerns unique to most GOA demersal shelf rockfish assessments |
| Late maturation | Some concerns unique to most GOA demersal shelf rockfish assessments |
| Longevity | Some concerns unique to most GOA demersal shelf rockfish assessments |
| Sedentary life history | Some concerns unique to most GOA demersal shelf rockfish assessments |
| No reliable biomass estimate | Some concerns unique to the 2003 and 2004 GOA Atka mackerel assessments |
| Possibility of localized depletion | Some concerns unique to the 2003 and 2004 GOA Atka mackerel assessments |
| Potential overharvest in distant past | Some concerns unique to the 2003 and 2004 GOA Atka mackerel assessments |
| Increasing predation pressure | Some concerns unique to the 2006 EBS pollock assessment |
| Vessels are needing to travel farther | Some concerns unique to the 2006 EBS pollock assessment |
| Keep spawning exploitation rate below all-time high | Some concerns unique to the 2007 EBS pollock assessment |
| No history of rebuilding from current level when catch=maxABC | Some concerns unique to the 2007 EBS pollock assessment |
| No history of strong year classes emerging from current stock level | Some concerns unique to the 2007 EBS pollock assessment |
| Change in biomass estimates between assessments | Some concerns unique to the 2008 BSAI Greenland turbot assessment |
| Uncertain stock trend | Some concerns unique to the 2008 BSAI Greenland turbot assessment |
| Important role in ecosystem as prey | Some concerns unique to the 2016 and 2017 EBS pollock assessments |
| Multispecies model estimates higher biomass reference points | Some concerns unique to the 2016 and 2017 EBS pollock assessments |
| Projected poor recruitment | Some concerns unique to the 2016 and 2017 EBS pollock assessments |
| Increased patchiness of distribution | Some concerns unique to the 2016 EBS pollock assessment |
| Preferred model does not account for structural uncertainty | Some concerns unique to the 2016 EBS pollock assessment |
| Recent bird die-offs | Some concerns unique to the 2017 EBS Pacific cod assessment |
| Recent high age 1 mortality from multispecies model | Some concerns unique to the 2017 EBS Pacific cod assessment |
| Recent low crab abundance | Some concerns unique to the 2017 EBS Pacific cod assessment |

*Table 3. Mapping zero-eigenvalue Round 2 variables (red) into Round 3 variables. (Round 2 variables not shown here were retained in Round 3).*

| Round 2 variables | Round 3 variables |
|---|---|
| Dominance of single year class | Age structure concerns |
| Few older fish | Age structure concerns |
| Increasing catch on a declining stock | Dramatic increase in catch or increasing catch on a declining stock |
| maxABC would be a dramatic increase over historic catch | Dramatic increase in catch or increasing catch on a declining stock |
| Long-term biomass decline | Low or long-term declining biomass |
| Low biomass | Low or long-term declining biomass |
| Some concerns unique to the 2007 EBS pollock assessment | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Catching maxABC would require large increase in effort | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Dome-shaped selectivity may overestimate abundance | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Estimated selectivity may not capture year class targeting | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Low roe recovery rates | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Maintain fishery CPUE | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Recent ocean warming | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Reduce bycatch | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Reduced condition factor | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Reduced prey availability | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Short-term biomass decline | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Some concerns unique to the 2006 EBS pollock assessment | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Some concerns unique to the 2016 and 2017 EBS pollock assessments | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Some concerns unique to the 2016 EBS pollock assessment | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Some concerns unique to the 2017 EBS Pacific cod assessment | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Trend of increasing F on oldest ages | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Uncertain stock structure | Some concerns unique to various EBS pollock and Pacific cod assessments |
| Uncertain recruitment estimates | Uncertain recruitment estimates, including recent large estimates |
| Recent year class estimated to be extremely large | Uncertain recruitment estimates, including recent large estimates |

*Table 4. Constrained regression coefficients (beta) with corresponding univariate ABC reductions.*

| **Round 3 variables** | **beta** | **univariate reduction** |
|---|---|---|
| Age structure concerns | 0.00 | 0.00 |
| Protect against disproportionate harvest within complex | 0.00 | 0.00 |
| Recent poor recruitment | 0.00 | 0.00 |
| Retrospective bias | 0.00 | 0.00 |
| Survey index lower than expected | 0.00 | 0.00 |
| Uncertain biomass estimates | 0.00 | 0.00 |
| Whale depredation | 0.00 | 0.00 |
| Reduce ABC to account for State GHL | 0.08 | 0.04 |
| Dramatic increase in catch or increasing catch on a declining stock | 0.11 | 0.06 |
| Prevent B<B20% | 0.14 | 0.07 |
| Projected biomass decline | 0.21 | 0.10 |
| Long-term poor recruitment | 0.22 | 0.11 |
| Dorn's buffer | 0.23 | 0.11 |
| None | 0.24 | 0.12 |
| Late-breaking analysis (not included in assessment) | 0.25 | 0.12 |
| Yield variability | 0.31 | 0.15 |
| Precedent | 0.33 | 0.16 |
| Some concerns unique to various EBS pollock and Pacific cod assessments | 0.37 | 0.18 |
| Uncertain recruitment estimates, including recent large estimates | 0.40 | 0.20 |
| Model uncertainty | 0.43 | 0.21 |
| Some concerns unique to most GOA demersal shelf rockfish assessments | 0.47 | 0.23 |
| Uncertainty surrounding Q | 0.47 | 0.23 |
| Uncertainty surrounding M and Q | 0.60 | 0.29 |
| Some concerns unique to the 2008 BSAI Greenland turbot assessment | 0.80 | 0.38 |
| Low or long-term declining biomass | 0.82 | 0.39 |
| Significant probability of exceeding FMSY | 0.86 | 0.40 |
| Hedge against future regime shift | 0.87 | 0.41 |
| Reliable minimum biomass estimate available for Tier 6 stock | 0.89 | 0.42 |
| Large survey CV | 0.91 | 0.43 |
| No new survey | 1.81 | 0.72 |
| Some concerns unique to the 2003 and 2004 GOA Atka mackerel assessments | 2.69 | 0.87 |
| SSC's rule for Bogoslof pollock ABC | 2.99 | 0.90 |

**Figures**

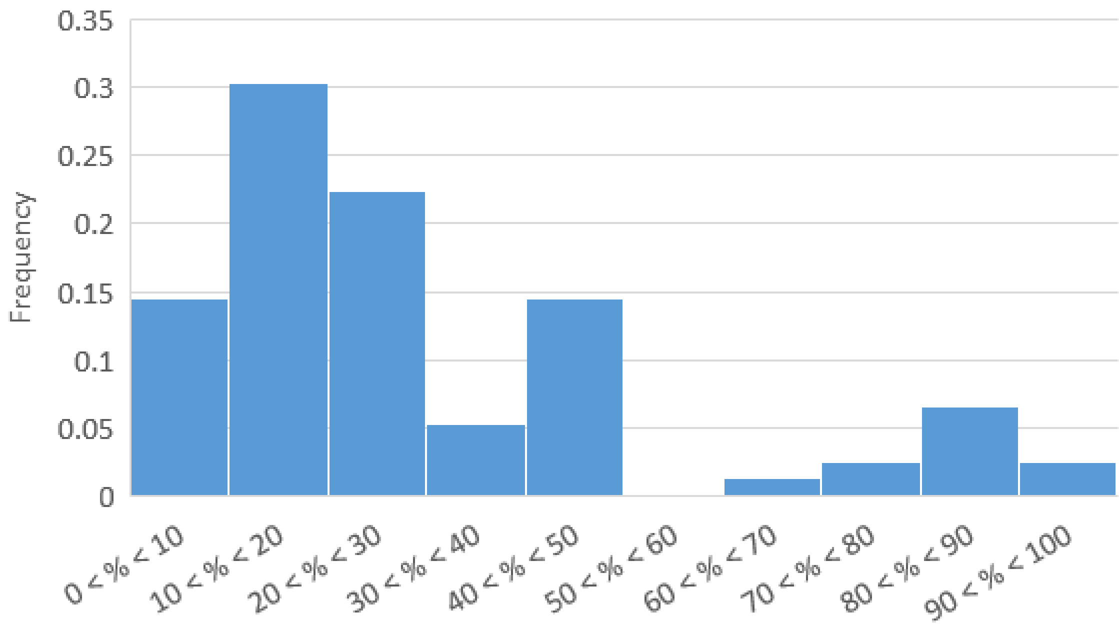


*Figure 1. Frequency of reductions, binned in 10% increments.*

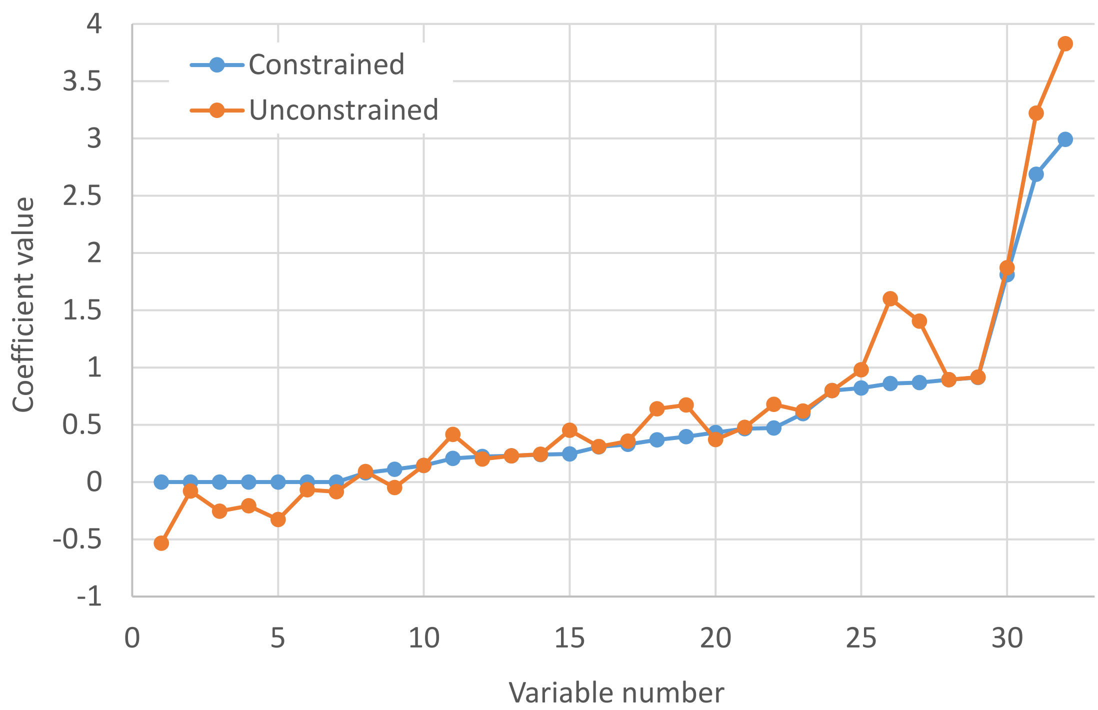


*Figure 2. Comparison of constrained and unconstrained coefficients (sorted in order of the former).*

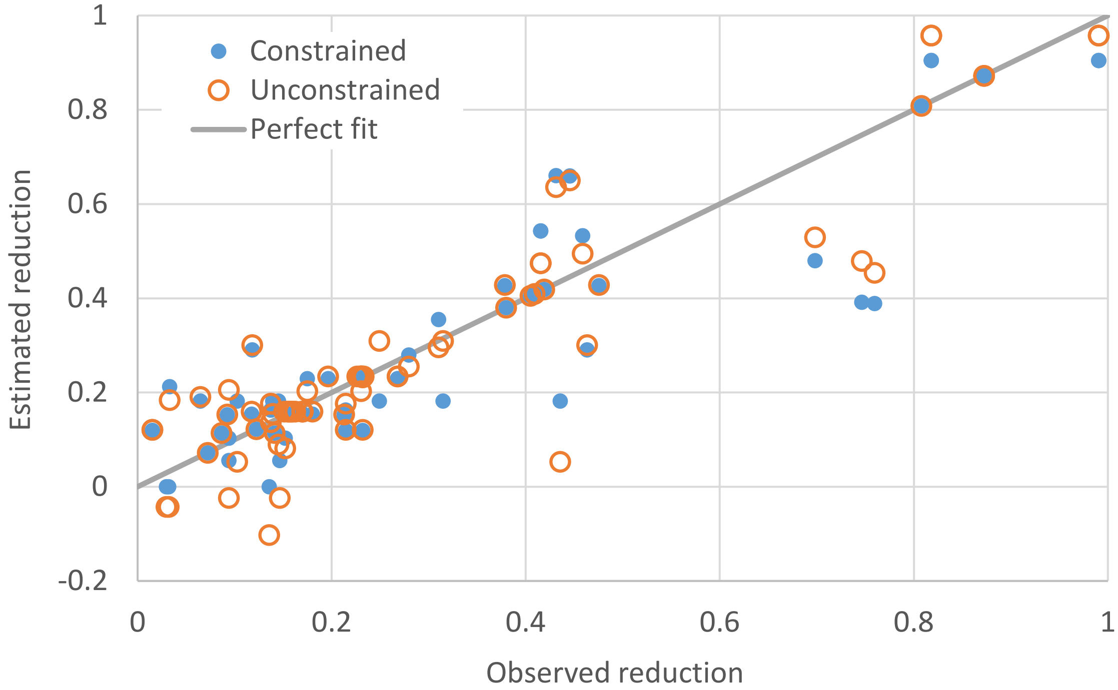


*Figure 3. Estimated (constrained and unconstrained) versus observed ABC reductions.*