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Maritimes Region

An application of DLMtool to 4X5Y Cod

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The outputs of several population models proposed for 4X5Y cod are used to condition Operating Models in a simulation framework (DLMtool), to help visualize uncertainty related to in stock, fishery, and observation dynamics not currently accounted for in the population models. With guidance from Resource Managers, three Management Procedures were tested within each Operating Model, although over-estimation in the terminal years of the Operating Models undermined the usefulness of this exercise, given the timing constraints of the 4X5Y Cod Framework. Although the application of DLMtool did not contribute to the 2018 4X5Y Cod Framework, the tool does have broader application potential for other groundfish stocks in the Maritimes Region.

INTRODUCTION

Fisheries Management relies on stock assessment models to accurately characterize the population dynamics of a given fish stock and provide accurate advice on catch levels required to achieve pre-determined Management Objectives. In the Maritimes Region, many groundfish stocks are on a multi-year assessment schedule, which begins with a framework review, followed by several years of assessments or updates utilizing the framework set in the first year. During the framework review, such as the one for 4X5Y Cod on November 6–7, 2018, several population models are generally presented, the strengths and weaknesses discussed, and a single ‘best’ model is put forward to generate advice during the interim years. In many cases, the weaknesses of each model are presented as a generic description of unaccounted-for uncertainties, applicable to both past stock dynamics and future projections, leaving the participants to visualize the magnitude of uncertainty involved when considering each model. The 4X5Y Cod stock framework is a good example of this, with several factors identified that are thought to influence stock dynamics but that are difficult for the presented models to discern.

To expand on the generic description of unaccounted-for uncertainties associated with each presented model, we apply a simulation framework conditioned on the outputs of each model, and introduce uncertainty in aspects of stock, fishery, and observation dynamics best thought to represent the unaccounted-for factors.

METHODS

DLMtool (Carruthers and Hordyk 2018) is a modeling framework designed to evaluate the robustness of a variety of Management Procedures (MPs) to uncertainties in a given Operating Model (OM). DLMtool is not a population assessment tool; it is a framework that can be used to simulate a stock and evaluate the performance of various harvest strategies within that simulation framework. Although DLMtool is not a population assessment tool in itself, it can absorb the outputs of most conventional stock assessment models and emulate the population dynamics prescribed by those models in its simulation.

In the current application of DLMtool, we initially planned to generate four Operating Models, each matching a formulation presented during the 4X5Y Cod modeling framework (see Wang 2022 for detailed model formulations). However, at the time of the assessment, only data for the 3M_VPA_Ffirst model (three natural mortality blocks, ages 1–2, 3–4 and 5+; Ffirst method) were available.

In addition to stock assessment outputs, the DLMtool framework requires Management Procedures whose robustness can be evaluated against the uncertainties involved. The 4X5Y Cod stock is in the Critical Zone, so Science advice has been to keep removals of Atlantic Cod at the lowest possible level (DFO 2015, 2017). In keeping with the Precautionary Approach (DFO 2009), Fisheries and Oceans Canada (DFO) Science is not able to advise Resource Management on a Total Allowable Catch (TAC) level while the stock is in the Critical Zone.

However, Management has requested that Science evaluate the robustness of the following Management procedures to the major uncertainties in the stock assessments:

1. current catch (1650 mt over two years)
2. half of the current catch (825 mt over two years)
3. no catch (0 mt)

The data-limited nature of these MPs is one reason why the DLMtool framework was chosen over data-rich harvest strategy evaluation packages (e.g., MSEtool). Additional OMs or MPs can be tested based on the outcomes of the 4X5Y Cod modeling framework (November 6–7, 2018).

OPERATING MODELS (OMS)

At the time of document preparation, only the 3M_VPA_Ffirst assessment model outputs were available to create the OM, so this document will be limited to the one model. The remaining OMs will be generated as the assessment outputs become available.

DLMtool simulates the population by relying on user-specified parameters belonging to four broad categories: Stock, Fleet, Observation, and Implementation. The Stock parameters reflect dynamics of the stock, the Fleet parameters attempt to describe the fishery, the Observation parameters are intended to capture the observation process, and the Implementation parameters deal with how well the MPs are implemented (Carruthers and Hordyk 2018). In the current application, population model-dependent parameters (i.e., stock-recruit relationship, depletion, natural mortality [M] and fishing mortality [F]) were modified to correspond with each model tested, while model-independent parameters (e.g., growth, observation error) remained consistent across operating models. The full DLMtool parameterization of the 3M_VPA_Ffirst OM is provided in the Appendix.

The Stock component of the 4X5Y Cod OM was parameterized based on the outputs of the 3M_VPA_Ffirst model (Wang 2018) and the information provided in the data inputs meeting (Andrushchenko 2022). Spawning Stock Biomass (SSB) and Recruitment were used to derive a Beverton-Holt stock recruit relationship, which consequently provided the estimate of unfished recruitment (R_0), steepness (h) and depletion (D) values. The DFO Research Vessel (RV) survey data provided age and length at maturity information (L_{50}, L_{50_95}), as detailed in Andrushchenko et al. (2018). Growth parameters (L_{inf}, K, t_0) were based on data from the port sampling program, but unlike Andrushchenko et al. (2018), these were provided for the whole management unit instead of east and west stock components. The formulation of 3M_VPA_Ffirst described here assumes no directional change in any of these stock parameters throughout the time series (e.g., Kgrad=0, Linfgrad=0).

Both M and the Process Error (Perr) parameters were over-written using the custom parameters (cpars) functionality. The M matrix specified for the historic time-series was based on the outputs of the Virtual Population Analysis (VPA), with no deviations introduced between simulations (Table 1). Given the increase in M throughout the historic time series, the projected M was set as the mean M-at-age during the terminal five years, again with no deviations permitted in the simulations. Process error on recruitment deviations was specified based on the fit of the stock-recruit relationship and carried over into the projected years with the same level of deviation. The Perr parameter was also used to circumvent the base DLMtool assumption that the time series starts from an unfished state by forcing a $Perr_{1983}$ of 0.9, which corresponds to the ratio of R_{1983}/R_0.

Similar to the Stock object, the Fleet parameters were specified based on the fishing mortality (F) outputs from each model (Table 1) and the Observation parameters were specified based on a precise, unbiased fishery structure (Carruthers and Hordyk 2018).

MANAGEMENT PROCEDURES (MPS)

With guidance from Resource Management, three harvest strategies were incorporated into this exercise: current catch (MP1; 1650 mt over two years), half of current catch (MP2; 825 mt over two years) and no catch (MP3; 0 mt). The two year quota structure of MP1 and MP2 was specified by setting an annual TAC equivalent to half of the two-year value (825 mt for MP1, 412.5 mt for MP2), accompanied by the TACFrac parameter in the Implementation component, which allowed the fraction of annual TAC taken to vary from 85% to 100% (Appendix). This range was chosen based on the lowest fraction of annual quota taken since the inception of the two-year quota management structure (Wang 2022). The R code used for formulating the three MPs is documented in the Appendix.

RESULTS AND DISCUSSION

The conditioning of the OM was examined by comparing the simulated stock to the outputs of the 3M_VPA_Ffirst model. In general, the 3M_VPA_Ffirst OM tended to under-estimate biomass during the early part of the time series and over-estimate it in the recent years, as compared to the VPA (Figure 1). The same trend is evident in the age-specific abundances, and the under-estimation of abundance at age in the OM gets progressively worse with age; the effect on the 7+ group is particularly bad (Figure 2). The progressive worsening of the trend with age can be caused by a variety of factors, including growth or length-weight differences, and additional work is needed to understand the divergence. The differences in treatment of older age groups by the VPA (plus group) versus the OM (ages 11+ do not exist) is likely contributing to the severity of the problem for the 7+ group.

The SSB comparison shows a strong over-estimation during the initial years on the part of the OM, implying that the $Perr_{1983}$ adjustment of R_0 was not effective (Figure 1). However, the indices at age show that the disagreement in overall SSB is driven by ages 6 and older, while ages 1 and 2 are much more consistent (Figure 2). Consequently, the Perr adjustment was effective, but additional modifications will be necessary to further distance year 1 (Y1) abundance of older fish from the unfished state.

Future versions of DLMtool are expected to account for a user-specified level of depletion at the beginning of the time series, circumventing the need to adjust Y1 abundance manually.

For the model examined, the differences between simulated and VPA population estimates carry over to the simulated fishery catch, leading to an over-estimation in the most recent time period, as compared to the VPA (Figure 3). These persistent issues need to be resolved before the OM can be considered fully operational, though it was noted that the ‘true state’ values of the VPA already fall within the current range of uncertainty encompassed by the simulations for all models (Figures 1–3).

The current formulations of the OM are relatively restrictive, limiting uncertainty to a modest amount of process and observation error, as well as some deviations in growth parameters and stock depletion (Appendix). The current level of uncertainty encompassed in the OM is arguably the minimum that should be included given the state of knowledge for this stock and, once optimally conditioned, should be increased further and include any expected directional changes in stock productivity (e.g., temperature-driven effects). Finally, the current version of DLMtool cannot emulate the two stock component structure of 4X5Y Cod, nor can it handle multiple fishing fleets. Once both functionalities become available in future versions of DLMtool or MSEtool, they should be used to explore additional parameterization of different growth and mixing rates for the two stock components, as well as simulation of other fleets to account for unreported catches of Cod.

The three identified MPs can be tested on the current formulation of the OMs, with the assumptions on the productivity of the stock moving forward already specified in the Appendix. However, as the MPs are inherently tied to the most recent level of catches, the current level of over-estimation in the terminal years of the time series is problematic and needs to be resolved before the MPs can be effectively tested. Sample outputs from the projected portion of the OM are given in Figures 4 and 5, but their use is not recommended.

CONCLUSION

DLMtool is a closed-loop simulation framework, which can test the robustness of different data-limited MPs to inherent uncertainty in population models. In addition, it can be used to expand on the generic weaknesses associated with population assessment models and help DFO Science convey the effect of those weaknesses to Resource Management. Assuming Resource Management is supportive of this application and finds value in it, we will continue developing its application to 4X5Y Cod and other Maritimes groundfish stocks.

ACKNOWLEDGEMENTS

This application of DLMtool was made possible due to the availability and willingness of its co-creators, Adrian Hordyk and Tom Carruthers, to answer many questions and explain the technical details.

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TABLES

Table 1. Fishing (F) and Natural (M) mortality outputs from the 3M_VPA_Ffirst model.

	Fishing Mortality (F)								Natural Mortality (M)		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Ages 7+	F4–7	Ages 1–2	Ages 3–4	Ages 5+
1983	0.00	0.07	0.21	0.21	0.41	0.28	0.32	0.28	0.202	0.215	0.365
1984	0.00	0.06	0.24	0.27	0.29	0.27	0.27	0.28	0.202	0.216	0.387
1985	0.00	0.04	0.15	0.25	0.39	0.26	0.32	0.31	0.202	0.216	0.409
1986	0.00	0.02	0.21	0.26	0.28	0.25	0.26	0.27	0.202	0.217	0.430
1987	0.00	0.03	0.10	0.24	0.27	0.20	0.36	0.26	0.202	0.216	0.451
1988	0.00	0.02	0.14	0.26	0.34	0.25	0.25	0.28	0.203	0.216	0.473
1989	0.00	0.02	0.15	0.22	0.18	0.18	0.16	0.20	0.203	0.217	0.496
1990	0.00	0.01	0.13	0.26	0.26	0.22	0.22	0.25	0.203	0.217	0.521
1991	0.00	0.03	0.21	0.37	0.31	0.30	0.26	0.33	0.203	0.217	0.554
1992	0.00	0.04	0.35	0.45	0.54	0.45	0.26	0.46	0.203	0.218	0.592
1993	0.00	0.06	0.26	0.38	0.35	0.33	0.15	0.32	0.203	0.218	0.631
1994	0.00	0.01	0.22	0.27	0.36	0.28	0.14	0.27	0.204	0.219	0.674
1995	0.00	0.01	0.09	0.16	0.14	0.13	0.08	0.14	0.204	0.220	0.734
1996	0.00	0.00	0.09	0.15	0.12	0.12	0.07	0.14	0.205	0.222	0.808
1997	0.00	0.01	0.14	0.24	0.13	0.17	0.11	0.17	0.206	0.224	0.899
1998	0.00	0.02	0.19	0.19	0.21	0.20	0.11	0.19	0.206	0.227	1.003
1999	0.00	0.01	0.09	0.18	0.14	0.16	0.13	0.15	0.207	0.229	1.108
2000	0.00	0.01	0.09	0.14	0.18	0.16	0.19	0.15	0.208	0.232	1.212
2001	0.00	0.01	0.09	0.13	0.13	0.13	0.25	0.13	0.209	0.235	1.287
2002	0.00	0.00	0.05	0.12	0.11	0.12	0.52	0.13	0.210	0.239	1.334
2003	0.00	0.01	0.04	0.11	0.14	0.12	0.86	0.14	0.211	0.242	1.368
2004	0.00	0.01	0.10	0.08	0.13	0.11	0.41	0.11	0.212	0.245	1.370
2005	0.00	0.01	0.05	0.11	0.09	0.10	0.29	0.11	0.213	0.249	1.336
2006	0.00	0.01	0.08	0.10	0.15	0.13	0.23	0.14	0.214	0.252	1.314
2007	0.00	0.04	0.10	0.14	0.13	0.14	0.20	0.14	0.216	0.257	1.298
2008	0.00	0.06	0.13	0.18	0.22	0.20	0.40	0.21	0.217	0.262	1.288
2009	0.00	0.06	0.17	0.11	0.10	0.11	0.20	0.11	0.218	0.267	1.317
2010	0.00	0.08	0.23	0.17	0.11	0.14	0.28	0.15	0.219	0.272	1.383
2011	0.00	0.01	0.11	0.15	0.13	0.14	0.20	0.14	0.220	0.276	1.474
2012	0.00	0.01	0.12	0.15	0.13	0.14	0.47	0.15	0.220	0.278	1.582
2013	0.00	0.01	0.04	0.12	0.07	0.09	0.10	0.10	0.221	0.279	1.652
2014	0.00	0.02	0.07	0.04	0.07	0.06	0.03	0.05	0.221	0.279	1.644
2015	0.00	0.01	0.05	0.06	0.03	0.05	0.02	0.04	0.221	0.281	1.559
2016	0.00	0.00	0.03	0.05	0.05	0.05	0.24	0.05	0.221	0.282	1.496
2017	0.00	0.00	0.02	0.04	0.23	0.14	0.22	0.09	0.221	0.282	1.481

FIGURES

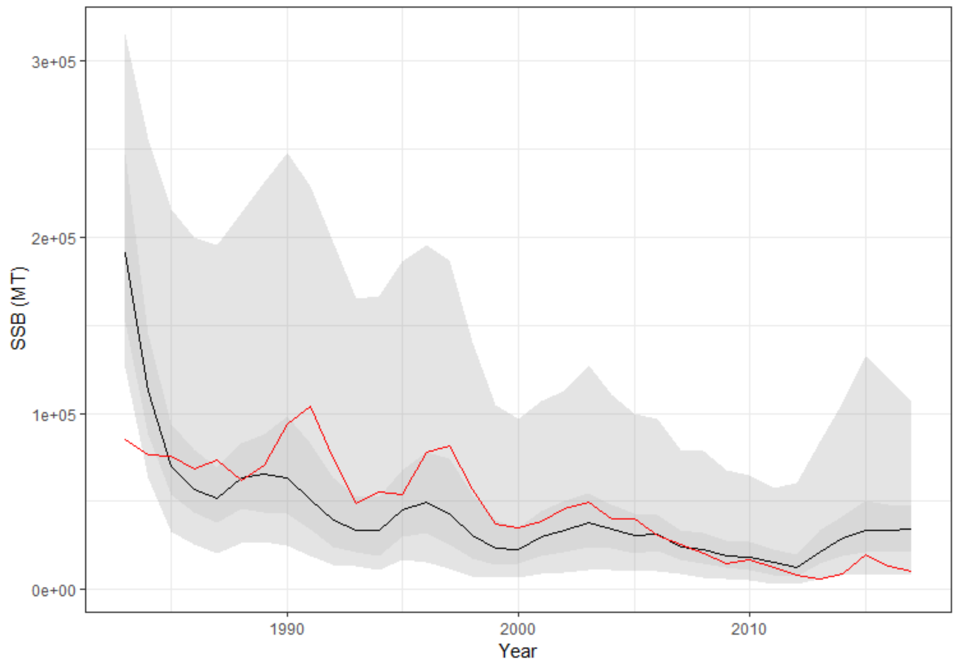

Figure 1. Spawning Stock Biomass (SSB) estimated by the 3M_VPA_Ffirst model (red) and the DLMtool OM simulation (black, median). Grey lines identify 2.5%, 25%, 75%, and 97.5% quantiles for the simulations.

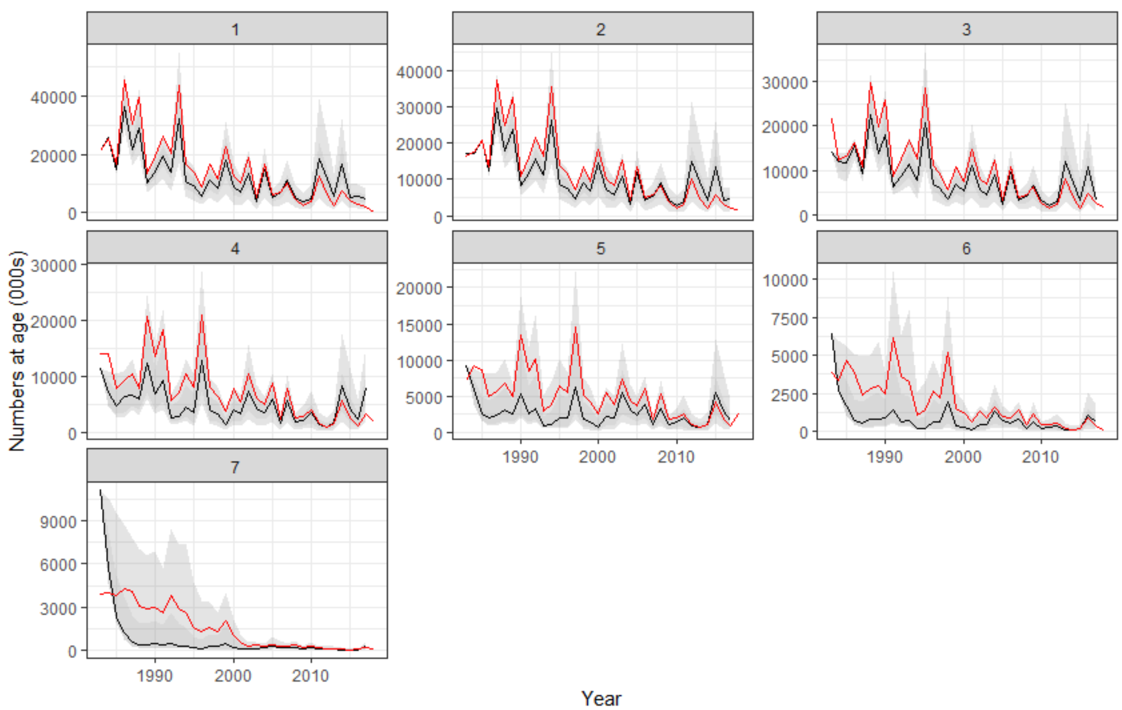

Figure 2. Population numbers at age for the 3M_VPA_Ffirst model (red) and DLMtool OM simulation (black, median). Grey lines identify 2.5%, 25%, 75%, and 97.5% quantiles for the simulations. Each panel represents an age group, and the age 7 panel includes all older ages (7+).

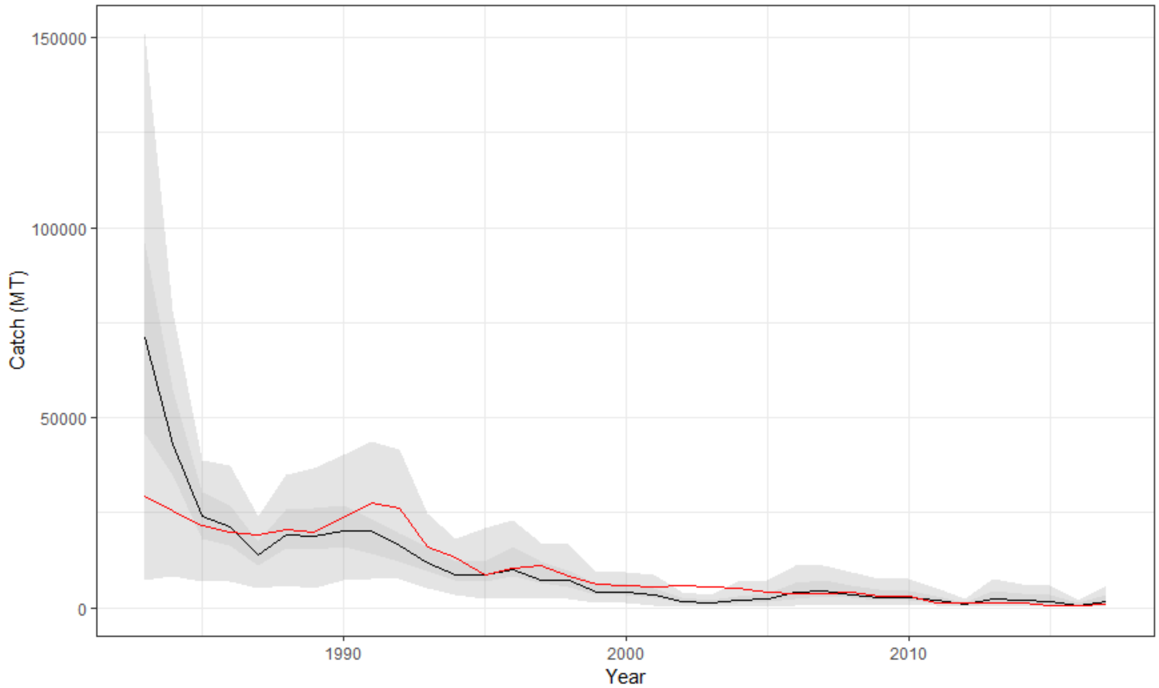

Figure 3. Simulated (black, median) historic catches from the 3M_VPA_Ffirst OM and actual (red) historic catches from the 4X5Y Cod fishery. Grey lines identify 2.5%, 25%, 75%, and 97.5% quantiles for the simulations.

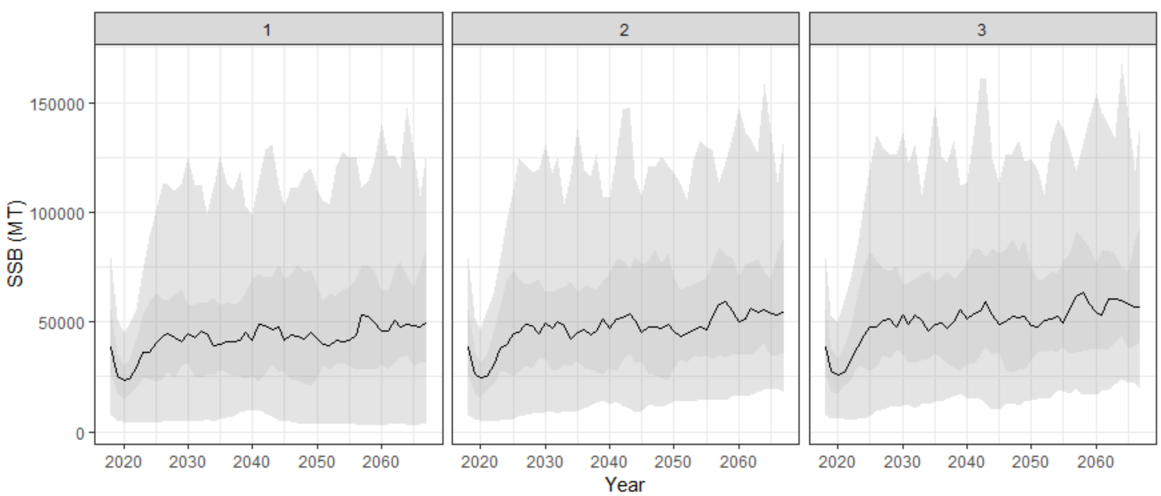

Figure 4. Projected 3M_VPA_Ffirst OM Spawning Stock Biomass (SSB) under Management Procedure 1 (MP1) 1 (left panel), MP2 (middle panel), and MP3 (right panel).

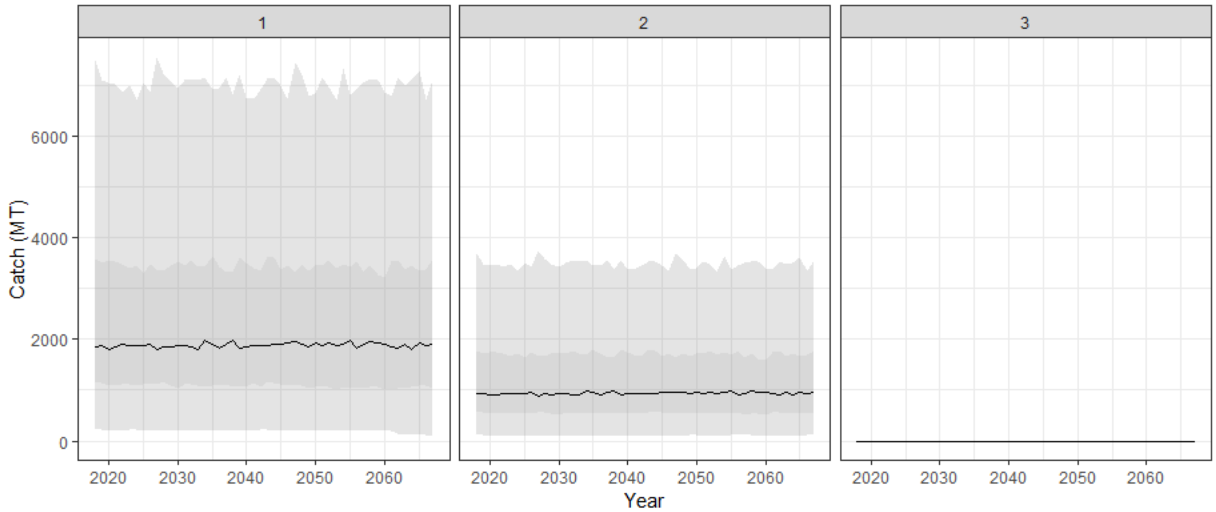

Figure 5. Projected catch from the 3M_VPA_Ffirst OM under Management Procedure (MP) 1 (left panel), MP2 (middle panel) and MP3 (right panel).

APPENDIX

This is a DLMtool-generated document describing the specifications of the current 3MFfirst OM.

SPECIES INFORMATION

Species: *Gadus morhua*

Common Name: Atlantic Cod

Management Agency: Canadian DFO

Region: Atlantic Canada

Latitude: -65

Longitude: 42

OM PARAMETERS

OM Name: Name of the operating model: Cod_4X5Y_DFO_VPA_3M_Ffirst

nsim: The number of simulations: 50

proyears: The number of projected years: 50

interval: The assessment interval—how often would you like to update the management system? 1

pstar: The percentile of the sample of the management recommendation for each method: 0.5

maxF: Maximum instantaneous fishing mortality rate that may be simulated for any given age class: 2

reps: Number of samples of the management recommendation for each method. Note that when this is set to 1, the mean value of the data inputs is used. 1

Source: 2018 4X5Y Atlantic Cod Framework Data Inputs. CSAS 2019/nnn.

STOCK PARAMETERS

Mortality and age: maxage, R0, M, M2, Mexp, Msd, Mgrad

maxage: The maximum age of individuals that is simulated (there is no plus group). Specified Value(s): 10

Important assumption, as DLMtool cannot handle a plus group. Anything above maxage is assumed to be dead. Although fish exist out to age 15 in the 1980s survey, they tend to be preceded by blanks and currently there aren't many past age 6. This parameter has to jive with the VPA plus group (7+), as setting it too high creates paper fish, but setting it too low can kill fish off too quickly.

R0: The magnitude of unfished recruitment. Specified Value(s): 23541000

Max value of predict SR relationship, using SSB and Recruitment from VPA model.

M: Natural mortality rate. Specified Value(s): 0.2, 1

Overwritten using cpars matrix.

M2: (Optional) Natural mortality rate at age. Vector of length maxage. Positive real number

Slot not used.

Mexp: Exponent of the Lorenzen function assuming an inverse relationship between M and weight. Uniform distribution lower and upper bounds. Real numbers <= 0. Specified Value(s): 0, 0

Not specified. Optional.

Msd: Inter-annual variability in natural mortality rate expressed as a coefficient of variation. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0.2, 0.4

Variability over-written by specifying an array in cpars.

Mgrad: Mean temporal trend in natural mortality rate, expressed as a percentage change in M per year. Uniform distribution lower and upper bounds. Real numbers. Specified Value(s): 0, 0

Not needed. M dynamics specified using array in cpars.

Recruitment: h, SRrel, Perr, AC

h: Steepness of the stock recruit relationship. Uniform distribution lower and upper bounds. Values from 1/5 to 1. Specified Value(s): 0.45, 0.8

Estimated as 0.63 from the SR, but fed in bounds of 0.45–0.8. Can be more limiting.

SRrel: Type of stock-recruit relationship. Single value, switch (1) Beverton-Holt (2) Ricker. Integer. Specified Value(s): 1

Specified as Beverton Holt (1).

Perr: Process error, the CV of lognormal recruitment deviations. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified value: 0.13, 5.53

Specified in cpars. derived from observed recruitment (VPA) and modeled SR relationship. Initial value (Year1) adjusted to account for starting depletion.

AC: Autocorrelation in recruitment deviations rec(t)=AC*rec(t-1)+(1-AC)*sigma(t). Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s) in cpars: 0.13, 0.13

Non-stationarity in stock productivity: Period, Amplitude

Period: (Optional) Period for cyclical recruitment pattern in years. Lower and upper bounds.

Slot not used.

Amplitude: (Optional) Amplitude in deviation from long-term average recruitment during recruitment cycle (e.g., a range from 0 to 1 means recruitment decreases or increases by up to 100% each cycle). Uniform distribution lower and upper bounds. 0 < Amplitude < 1

Slot not used.

Growth: Linf, K, t0, LenCV, Ksd, Kgrad, Linfsd, Linfgrad

Linf: Maximum length. Lower and upper bounds. Positive real numbers. Specified Value(s): 110.45, 141.2

Combined BoF and SS, got the 90% interval around the data and used it as bounds on all three of the growth parameters. Bounds on Linf are 110–141. Can be made more restrictive, but cannot currently handle a two stock structure.

Also have the option of over-ridding vonB preset with array in cpars.

K: von Bertalanffy growth parameter k. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.13, 0.18

See Linf explanation. Bounds are 0.13–0.18.

t0: von Bertalanffy theoretical age at length zero. Uniform distribution lower and upper bounds. Non-positive real numbers. Specified Value(s): -0.2, -0.4

See Linf explanation.

LenCV: Coefficient of variation of length-at-age (assumed constant for all age classes). Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.23, 0.23

Based on the LAA distribution.

Ksd: Inter-annual variability in growth parameter k. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0, 0

Set at 0, but could be given a range to be more flexible.

Kgrad: Mean temporal trend in growth parameter k, expressed as a percentage change in k per year. Uniform distribution lower and upper bounds. Real numbers. Specified Value(s): 0, 0

Not used.

Linfsd: Inter-annual variability in maximum length. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0, 0

Set at zero for now. See comment on Ksd.

Linfgrad: Mean temporal trend in maximum length, expressed as a percentage change in Linf per year. Uniform distribution lower and upper bounds. Real numbers. Specified Value(s): 0, 0

Not used.

Maturity: L50, L50_95

L50: Length at 50 percent maturity. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 37, 43

Bounds set at 37cm and 43cm to encompass differences in maturity throughout history and between the two stock components involved (See Fig 34 in Data Inputs).

L50_95: Length increment from 50 percent to 95 percent maturity. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 6, 8.5

Bounds set at 6–8.5cm, also based on Figure 34 in Data Inputs.

Stock depletion: D

D: Current level of stock depletion SSB(current)/SSB(unfished). Uniform distribution lower and upper bounds. Fraction. Specified Value(s): 0.01, 0.5

Bounds set (0.01–0.5) broadly because of the funny definition of SSB(unfished) that had to be made for this exercise. This awkward definition also has implications on SSB-based reference points.

Length-weight conversion parameters: a, b

a: Length-weight parameter alpha. Single value. Positive real number. Specified Value(s): 0

Length-weight parameter alpha, from port sampling. 0.000007875

b: Length-weight parameter beta. Single value. Positive real number. Specified Value(s): 3.06

Length-weight parameter beta, from port sampling. 3.05745

Spatial distribution and movement: Size_area_1, Frac_area_1, Prob_staying

Size_area_1: The size of area 1 relative to area 2. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.5, 0.5

Not really used. Normally applicable to stocks where fish spend first portion of their life in one area, then move to a second area (e.g., inshore juvenile habitat, offshore adult).

Frac_area_1: The fraction of the unfished biomass in stock 1. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.5, 0.5

Initially thought to be area proportions of two stock components; turns out it is not. I left it as 1 because I do not actually think it makes a difference right now, but it will when they incorporate multiple stocks.

Prob_staying: The probability of individuals in area 1 remaining in area 1 over the course of one year. Uniform distribution lower and upper bounds. Positive fraction. Specified Value(s): 1, 1

Again, currently left as uninformed (1) but this would be a useful field when there is a multi-stock option.

Discard Mortality: Fdisc

Fdisc: Fraction of discarded fish that die. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 1, 1

Not used.

FLEET PARAMETERS

Historical years of fishing, spatial targeting: nyears, Spat_targ

nyears: The number of years for the historical spool-up simulation. Single value. Positive integer. Specified Value(s): 35

Used 1983–2018, so 35 years.

Spat_targ: Distribution of fishing in relation to spatial biomass: fishing distribution is proportional to B^Spat_targ. Uniform distribution lower and upper bounds. Real numbers. Specified Value(s): 1, 1.

Set to 1 because consider fishing proportional to density.

Trend in historical fishing effort (exploitation rate), interannual variability in fishing effort: EffYears, EffLower, EffUpper, Esd

EffYears: Years representing join-points (vertices) of time-varying effort. Vector. Non-negative real numbers.

Sequence of 1:35.

EffLower: Lower bound on relative effort corresponding to EffYears. Vector. Non-negative real numbers

Just set as 1 for all years and bounds. Overridden with F matrix from VPA in cpars.

EffUpper: Upper bound on relative effort corresponding to EffYears. Vector. Non-negative real numbers

Just set as 1 for all years and bounds. Overridden with F matrix from VPA in cpars.

Esd: Additional inter-annual variability in fishing mortality rate. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0, 0

Set as 0, but can increase the variability.

Annual increase in catchability, interannual variability in catchability: qinc, qcv

qinc: Average percentage change in fishing efficiency (applicable only to forward projection and input controls). Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): -0.1, 0.1

Set low to -0.1 and 0.1 because there’s no reason to believe that gear will become substantially more efficient in the near future.

qcv: Inter-annual variability in fishing efficiency (applicable only to forward projection and input controls). Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0.1, 0.1

Set at moderate levels (0.1); could be adjusted when multi-fleet version is available.

Fishery gear length selectivity: L5, LFS, Vmaxlen, isRel

L5: Shortest length corresponding to 5 percent vulnerability. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 1, 1

Feeds into selectivity, which is overridden using cpars.

LFS: Shortest length that is fully vulnerable to fishing. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 1, 1

Feeds into selectivity, which is overridden using cpars.

Vmaxlen: The vulnerability of fish at Stock@Linf. Uniform distribution lower and upper bounds. Fraction. Specified Value(s): 1, 1

Feeds into selectivity, which is overridden using cpars.

isRel: Selectivity parameters in units of size-of-maturity (or absolute eg cm). Single value. Boolean. Specified Value(s): FALSE

Set as False (absolute values for selectivity parameters, rather than at maturity).

Fishery length retention: LR5, LFR, Rmaxlen, DR

LR5: Shortest length corresponding to 5 percent retention. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0, 0

Overridden using cpars.

LFR: Shortest length that is fully retained. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0, 0

Overridden using cpars.

Rmaxlen: The retention of fish at Stock@Linf. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 1, 1

Overridden using cpars.

DR: Discard rate - the fraction of caught fish that are discarded. Uniform distribution lower and upper bounds. Fraction. Specified Value(s): 0, 0

Set at 0.

Time-varying selectivity: SelYears, AbsSelYears, L5Lower, L5Upper, LFSLower, LFSUpper, VmaxLower, VmaxUpper

SelYears: (Optional) Years representing join-points (vertices) at which historical selectivity pattern changes. Vector. Positive real numbers.

Slot not used.

AbsSelYears: (Optional) Calendar years corresponding with SelYears (eg 1951, rather than 1), used for plotting only. Vector (of same length as SelYears). Positive real numbers.

Slot not used.

L5Lower: (Optional) Lower bound of L5 (use ChooseSelect function to set these). Vector. Non-negative real numbers.

Slot not used.

L5Upper: (Optional) Upper bound of L5 (use ChooseSelect function to set these). Vector. Non-negative real numbers.

Slot not used.

LFSLower: (Optional) Lower bound of LFS (use ChooseSelect function to set these). Vector. Non-negative real numbers.

Slot not used.

LFSUpper: (Optional) Upper bound of LFS (use ChooseSelect function to set these). Vector. Non-negative real numbers.

Slot not used.

VmaxLower: (Optional) Lower bound of Vmaxlen (use ChooseSelect function to set these). Vector. Fraction.

Slot not used.

VmaxUpper: (Optional) Upper bound of Vmaxlen (use ChooseSelect function to set these). Vector. Fraction.

Slot not used.

Current Year: CurrentYr

CurrentYr: The current calendar year (final year) of the historical simulations (e.g., 2011). Single value. Positive integer. Specified Value(s): 2017

Existing Spatial Closures: MPA

MPA: (Optional) Matrix specifying spatial closures for historical years.

Slot not used.

OBS PARAMETERS

Catch statistics: Cobs, Cbiascv, CAA_nsamp, CAA_ESS, CAL_nsamp, CAL_ESS

Cobs: Log-normal catch observation error expressed as a coefficient of variation. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0.05, 0.1

Relatively low CV (0.05–0.10) as catches are observed fairly precisely for the groundfish fleet.

Cbiascv: Log-normal coefficient of variation controlling the sampling of bias in catch observations for each simulation. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0.02

Specified as mean bias CV of 0.025 (non-directional) instead of bounds, so 95% of simulations are between 95% and 105% of true simulated catches.

CAA_nsamp: Number of catch-at-age observation per time step. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 800, 1200

Ages per year counts. Set actual bounds of 800–1200 otoliths per year.

CAA_ESS: Effective sample size (independent age draws) of the multinomial catch-at-age observation error model. Uniform distribution lower and upper bounds. Positive integers. Specified Value(s):800, 1200.

For now set as independent (so 800–1200). Can be adjusted otherwise.

CAL_nsamp: Number of catch-at-length observation per time step. Uniform distribution lower and upper bounds. Positive integers. Specified Value(s): 8000, 12000

Lengths per year counts. Set actual bounds of 8000–12000 lengths per year.

CAL_ESS: Effective sample size (independent length draws) of the multinomial catch-at-length observation error model. Uniform distribution lower and upper bounds. Positive integers. Specified Value(s): 8000, 12000.

For now set as independent (so 8000–12000), as I'm still trying to really understand how the ESS is used in the simulation.

Index imprecision, bias and hyperstability: Iobs, Ibiascv, Btobs, Btbiascv, beta

Iobs: Observation error in the relative abundance indices expressed as a coefficient of variation. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.1, 0.15

Set as 0.1–0.15 for now. Expected that survey index is observed fairly precisely (CV of 10 to 15%).

Ibiascv: Log-normal coefficient of variation controlling error in observations of relative abundance index. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.2

Log-normal coefficient of variation controlling error in observations of relative abundance index. Uniform distribution lower and upper bounds. Not used (although default specified to run).

Btobs: Log-normal coefficient of variation controlling error in observations of current stock biomass among years. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.2, 0.5

Set default bounds for a precise, unbiased example (0.2–0.5).

Btbiascv: Uniform-log bounds for sampling persistent bias in current stock biomass. Uniform-log distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.5, 2

The value specified in the Stock object is assumed to be the 'true' value, and this parameter affects how the 'current' stock biomass is generated in the application of the Management Procedure. Can be argued in a variety of directions; for now, assumed to range from 0.5–2, so no bias and somewhat imprecise. Although I can see argument for a bias existing, it may not be defensible to identify the direction.

beta: A parameter controlling hyperstability/hyperdepletion where values below 1 lead to hyperstability (an index that decreases slower than true abundance) and values above 1 lead to hyperdepletion (an index that decreases more rapidly than true abundance). Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.66, 1.5

This can be discussed forever, and is a question of whether the survey is subject to hyperstability, hyperdepletion, or both. For the sake of brevity, the base model just assumes survey varies proportionally to actual abundance, so set to range from 0.66–1.5.

Bias in maturity, natural mortality rate and growth parameters: LenMbiascv, Mbiascv, Kbiascv,t0biascv, Linfbiascv

LenMbiascv: Log-normal coefficient of variation for sampling persistent bias in length at 50 percent maturity. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.1

Assumes length of maturity generated in the OM (and used in projection and application of MP) is not the 'true' value specified in the Stock object, but a value sampled with a 10% CV. For the base run, left it as default for a precise, unbiased structure (0.1) because we have a fair amount of confidence in the length-maturity data (although not split by stock).

Mbiascv: Log-normal coefficient of variation for sampling persistent bias in observed natural mortality rate. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.2

This can be a great sensitivity run for this model. For the base run, left it as 0.2 value, but can give it a bias and an increase in CV to test.

Kbiascv: Log-normal coefficient of variation for sampling persistent bias in observed growth parameter K. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.05

Don't think there's much argument here, so left it at 0.05.

t0biascv: Log-normal coefficient of variation for sampling persistent bias in observed t0. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0

Left at 0 to avoid fish being length=0 at time t>0.

Linfbiascv: Log-normal coefficient of variation for sampling persistent bias in observed maximum length. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.05

Again, fairly confident in this value so set at 0.05.

Bias in length at first capture, length at full selection: LFCbiascv, LFSbiascv

LFCbiascv: Log-normal coefficient of variation for sampling persistent bias in observed length at first capture. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.05

Set at 0.05 because I don't think this is actually used.

LFSbiascv: Log-normal coefficient of variation for sampling persistent bias in length-at-full selection. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.05

Set at 0.05 because I don't think this is actually used.

Bias in fishery reference points, unfished biomass, FMSY, FMSY/M ratio, biomass at MSY relative to unfished: FMSYbiascv, FMSY_Mbiascv, BMSY_B0biascv

FMSYbiascv: Log-normal coefficient of variation for sampling persistent bias in FMSY. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.2

Currently set at 0.2, but can be increased with uncertainty in future M. This parameter does not need to deviate independently of Mbiascv.

FMSY_Mbiascv: Log-normal coefficient of variation for sampling persistent bias in FMSY/M. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.05

Set at 0.05 because the Fmsy and M should vary concurrently, so Fmsy/M should be more stable.

BMSY_B0biascv: Log-normal coefficient of variation for sampling persistent bias in BMSY relative to unfished. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.2

Currently set at 0.2, but can be increased with uncertainty in future M.

Management targets in terms of the index (i.e., model free), the total annual catches and absolute biomass levels: Irefbiascv, Crefbiascv, Brefbiascv

Irefbiascv: Log-normal coefficient of variation for sampling persistent bias in relative abundance index at BMSY. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.5.

Crefbiascv: Log-normal coefficient of variation for sampling persistent bias in MSY. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.5

Brefbiascv: Log-normal coefficient of variation for sampling persistent bias in BMSY. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.5

Depletion bias and imprecision: Dbiascv, Dobs

Dbiascv: Log-normal coefficient of variation for sampling persistent bias in stock depletion. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.5

Dobs: Log-normal coefficient of variation controlling error in observations of stock depletion among years. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.05, 0.1

Recruitment compensation and trend: hbiascv, Recbiascv

hbiascv: Log-normal coefficient of variation for sampling persistent bias in steepness. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.1

Recbiascv: Log-normal coefficient of variation for sampling persistent bias in recent recruitment strength. Uniform distribution lower and upper bounds. Positive real numbers. Specified Value(s): 0.05, 0.1

IMP PARAMETERS

Output Control Implementation Error: TACFrac, TACSD

TACFrac: Mean fraction of TAC taken. Uniform distribution lower and upper bounds. Positive real number. Specified Value(s): 0.85, 1

Bounded by 0.85 and 1; During the time of the 2-year quota (since 2015), the lowest proportion of quota taken has been 85%. Assume this would be the case moving forward, so bounded by 0.85 and 1. Needs to be adjusted if MPs change.

TACSD: Log-normal coefficient of variation in the fraction of Total Allowable Catch (TAC) taken. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0.02, 0.05

Set relatively low; no reason to believe drastic change or bias in fraction of TAC taken.

Effort Control Implementation Error: TAEFrac, TAESD

TAEFrac: Mean fraction of TAE taken. Uniform distribution lower and upper bounds. Positive real number. Specified Value(s): 0.85, 1

Not used (no effort-based MP), so set to the same as TACFrac.

TAESD: Log-normal coefficient of variation in the fraction of Total Allowable Effort (TAE) taken. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0.02, 0.05

Not used (no effort-based MP), so set to the same as TACsd.

Size Limit Control Implementation Error: SizeLimFrac, SizeLimSD

SizeLimFrac: The real minimum size that is retained expressed as a fraction of the size. Uniform distribution lower and upper bounds. Positive real number. Specified Value(s): 0.85, 1

Not used (no size-based MP), so set to the same as TACFrac.

SizeLimSD: Log-normal coefficient of variation controlling mismatch between a minimum size limit and the real minimum size retained. Uniform distribution lower and upper bounds. Non-negative real numbers. Specified Value(s): 0.02, 0.05

Not used (no size-based MP), so set to the same as TACsd.

MANAGEMENT PROCEDURES

```
MP1<-function (x, Data, reps = 500, plot = FALSE, yrsmth = 4, xx = 0)
{
  dependencies = "Data@Cat, Data@CV_Cat"
  if (length(Data@Year) < 1) {
    Rec <- new("Rec")
    Rec@TAC <- rep(as.numeric(NA), reps)
    return(Rec)
  }
  yrlast <- match(Data@LHYear[1], Data@Year)
  yrfirst <- yrlast - yrsmth + 1
  C_dat <- Data@Cat[x, yrfirst:yrlast]
  TAC <- (1 - xx) * trlnorm(reps, mean(C_dat), Data@CV_Cat/(yrsmth^0.5))
  Rec <- new("Rec")
  Rec@TAC <- TACfilter(TAC)
  if (plot) {
    op <- par(no.readonly = TRUE)
    on.exit(par(op))
    par(mfrow = c(1, 1))
    ylim <- c(0, max(c(Data@Cat[x, ], TACfilter(TAC))))
    plot(c(Data@Year, max(Data@Year) + 1), c(Data@Cat[x,
                                              ], NA), type = "l", lwd = 2, las = 1, bty = "l",
         xlab = "Year", ylab = paste0("Catch (",
                                 Data@Units, ")"), cex.lab = 1.5, cex.axis = 1.25,
         ylim = ylim)
    abline(v = Data@LHYear[1], lty = 3, col = "darkgray")
    lines(Data@Year[yrfirst:yrlast], rep(mean(C_dat), yrsmth),
          col = "blue", lwd = 3)
    boxplot(Rec@TAC, at = max(Data@Year) + 1, add = TRUE,
            axes = FALSE)
  }
  Rec
}

class(MP1)<-"MP"

MP2<- function (x, Data, reps = 500, plot = FALSE, yrsmth = 4, xx = 0.5)

MP3<- function (x, Data, reps = 500, plot = FALSE, yrsmth = 4, xx = 1)
```