Evaluating productivity parameter uncertainty using ASPM

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Summary

Management strategy evaluation (MSE) evaluates how robust a feedback-control management strategy is to uncertainties using forward simulation. These uncertainties include process uncertainty, parameter uncertainty, model uncertainty, data and observation systems error, and implementation uncertainty. Among these uncertainties, the productivity parameters, length at age 3, natural mortality for age 2 and older, and steepness of the stock-recruitment relationship, are shown to greatly impact the historical trajectory of Pacific bluefin tuna spawning stock biomass in the 2022 assessment. Potential combinations for the values of these parameters are enormous and some options may not be plausible for the stock, given the fishing history and life-history traits. We used the age-structured production model diagnostic to select plausible productivity parameters to consider in the MSE uncertainty grid based on the improvement of the fits of the adult indices from the short time series model.

Introduction

Fishery managers and decision-makers nowadays rely on the outcomes from management strategy evaluation (MSE) to select management strategies for implementation in the fishery. MSE uses a forward simulation approach to determine how robust feedback-control management strategies are to uncertainties (Smith 1994). MSE takes account of the collection and use of future data and uncertainties in the managed system.

One notable benefit of an MSE is the incorporation of a range of uncertainties in the system. Uncertainties are five folds in MSE: (1) process uncertainty, (2) parameter uncertainty, (3) model uncertainty, (4) errors in data and observation systems when conducting assessments, and (5) implementation uncertainty, as outlined in Punt et al. 2016. Process uncertainty is the random variation in parameters such as future recruitment and time-varying selectivity. Parameter uncertainty is the uncertainty in the parameter values fixed in the operating models (e.g., steepness, natural mortality). Model uncertainty is the uncertainty in the form of the biological relationship (e.g., whether the stock-recruitment relationship is Beverton-Holt or Ricker, whether fishery selectivity is asymptotic or dome-shaped). Errors in data and observation systems related to collecting data, such as catches, size compositions, or surveys. Implementation uncertainty may arise from imperfectly implemented management actions.

The ISC Pacific bluefin tuna (PBF) working group is tasked to develop an MSE to help inform a long-term management strategy for PBF once the stock is rebuilt to the

second rebuilding target of 20%SSB_0 (JWG 2022). Tommasi and Lee 2022 outlined the general MSE framework for PBF and addressed process uncertainty, data and observation systems errors, and implementation uncertainty. In this working paper, we aim to evaluate the parameter uncertainties that greatly impact the historical trajectory of the stock.

Methods

In the 2022 stock assessment, the ISCPBF working group identified productivity parameters as the most influential and uncertain among all the uncertainties examined (including model uncertainty and errors in data and observation systems; ISC 2022). The productivity parameters are length at age 3 (L_2), natural mortality for age 2 and older (M_2), and steepness of the stock-recruitment relationship (h). Parameters M_2 and h are less informative due to a lack of direct data to estimate them. Length at age 3 (L_2) was estimated externally from ageing data, but it highly correlates with the asymptotic length that influences the historical trajectory of the stock. The potential combinations of the values of these three productivity parameters are enormous and some options may not be plausible for the stock, given its fishing history and life-history traits. We used the age-structured production model diagnostic (ASPM; Maunder and Piner 2015) to select a plausible uncertainty grid for the productivity parameters based on the improvement of the fits of the adult indices from the short time series model (ISC 2022).

Results

The likelihood values of the indices' component were obtained from the ASPM models that varied the values of natural mortality for age 2 and older and steepness (Table 1). Given a range in steepness of 0.999 to 0.91, the stock prefers higher natural mortality rates. Natural mortality rates smaller than 0.25 reduced the fit to the adult indices. For each M value from 0.25 to 0.3, the best fit was at a steepness of 0.999. The plausible range of steepness expands when M is higher than 0.25. For example, when the natural mortality for age 2 and older is at 0.25, no other steepness value showed a better or equal fit of adult indices than the base model. However, when the natural mortality for age 2 and older is at 0.3, the steepness ranging from 0.95 to 0.999 showed a better or equal fit of adult indices than the base model. We limit the natural mortality rate for age 2 and older at a maximum of 0.3, given that an M higher than 0.3 seems biologically implausible (there was no fish left at age 19 and above without fishing). We only showed one additional ASPM fit that was statistically worse than the base value given each M or h. We left the rest of the grids with substantially degraded the fits blank as these grids are deemed implausible for the stock.

Table 1. The likelihood values of the indices' component from the ASPMs that varied the values of natural mortality for age 2 and older and steepness. The red value is the adult indices' likelihood from the base ASPM model (M2 = 0.25 and h=0.999). The yellow highlights are the adult indices' likelihood values that statistically (around 2 likelihood unit) improved from the base ASPM model. The blank grids indicate substantial degradation from the base ASPM model.

		Natural mortality for age 2 and older				
		0.24	0.25	0.26	0.28	0.3
Steepness	0.91					
	0.93					18.40
	0.95				17.90	5.56
	0.97			15.40	3.97	-0.54
	0.99		6.85	3.76	-1.63	-6.28
	0.999	8.34	4.55	1.50	-3.93	-8.57

The likelihood values of the indices' component were further obtained from the ASPM models that varied the values of the length at age 3, natural mortality for age 2 and older, and steepness (Table 2). The stock generally prefers larger length at age 3 regardless of values of the natural mortality for age 2 and older. The exception is when M is 0.3, the smaller length at age 3 at 116 cm showed a better or equal fit of adult indices than the base model for steepness values at 0.99 and 0.999 (Table 2c). For each length at age 3 value from 116 to 124 cm, the best fit was at a steepness of 0.999. The plausible range of steepness expands when M is higher and the length at age 3 is larger. For example, when the length at age 3 is 124 cm, the plausible steepness ranges from 0.97 to 0.999 for M of 0.24 but from 0.89 to 0.999 for M of 0.3. We limit the length at age 3 at a maximum of 124 cm, which seems high as asymptotic length of 262.5 cm. The length at age 3 of 116, 118.57, 120, and 122 corresponds to the asymptotic length of 239.3, 244.2, 249.9, 253.2, and 257.9 respectively.

Table 2. The likelihood values of the indices' component from the ASPMs that varied the values of length at age 3 and older and steepness when natural mortality for age 2 and older is at (a) 0.24, (b) 0.25, and (c) 0.3. The red value is the adult indices' likelihood from the base ASPM model (L2 = 118.57 and h=0.999). The yellow highlights are the adult indices' likelihood values that statistically (around 2 likelihood unit) improved from the base ASPM model. The blank grids indicate the substantial degradation from the base ASPM model.

a. M2=0.24

		Length at age 3 (asymptotic length)					
		114	116	118.57	120	122	124
		(239.3)	(244.2)	(249.9)	(253.2)	(257.9)	(262.5)
Steepness	0.95						8.77
	0.97					9.64	6.45
	0.99				7.21	4.90	3.80
	0.999			8.34	5.57	3.91	1.77

b. M2=0.25

		Length at age 3					
		114	116	118.57	120	122	124
Steepness	0.93					7.04	7.26
	0.95					6.26	6.20
	0.97				7.21	2.90	3.63
	0.99			6.85	3.27	-0.05	0.57
	0.999		15.20	4.55	1.69	-0.94	-0.91

c. M2=0.3

		Length at age 3					
		114	116	118.57	120	122	124
Steepness	0.87						26.57
	0.89					7.27	4.92
	0.91				10.70	4.91	1.80
	0.93			18.40	6.17	1.31	-1.73
	0.95			5.56	0.37	-3.41	-5.41
	0.97		9.11	-0.54	-4.26	-6.33	-9.16
	0.99		4.18	-6.28	-9.06	-8.54	-8.71
	0.999	11.89	1.98	-8.57	-10.02	-10.67	-11.86

Discussion

MSE should consider influential uncertainties if not all the uncertainties. However, not all parameters' values are plausible given the fishing history and life-history of the stock. We showed that ASPM is a useful tool to select the reasonable range of uncertainty to consider for productivity parameters. The PBF stock prefers larger length at age 3 and higher natural mortality for age 2 and older. The larger the length at age 3 and natural mortality for age 2 and older are, the wider range of potential steepness parameters. This work could be the basis of ISCPBF working group discussions to select the uncertainty range in productivity to consider for the MSE operating model(s) (i.e., 'conditioning' the operating model(s) to data).

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