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STATISTICAL INFERENCES REGARDING THE "HIGH" AND "LOW" RECRUITMENT SCENARIOS BASED ON THE OUTPUT FROM THE 2012 AND 2014 STOCK ASSESSMENTS FOR WESTERN ATLANTIC BLUEFIN TUNA: A PRELIMINARY ANALYSIS USING THE AICc MODEL SELECTION CRITERION

Bluefin Species Group

SUMMARY

This paper documents a preliminary analysis of a selection criterion applied to western Bluefin tuna stock-recruitment models that were fitted to time series of estimated spawning stock biomass and recruitment from the 2012 and 2014 VPAs, and reflects discussions held during and after the 2014 Bluefin Species Group meeting on selecting between the low and high recruitment hypotheses.

RÉSUMÉ

Le présent document contient une analyse préliminaire d'un critère de sélection appliqué aux modèles de stock-recrutement du thon rouge de l'Atlantique Ouest qui ont été ajustés aux séries temporelles de la biomasse estimée du stock reproducteur et du recrutement provenant des VPA de 2012 et 2014. Il fait également état des discussions tenues pendant et après la réunion du groupe d'espèces sur le thon rouge de 2014 en ce qui concerne la sélection des hypothèses de recrutement élevé et faible.

RESUMEN

Este documento presenta un análisis preliminar de un criterio de selección aplicado a los modelos stock reclutamiento del atún rojo occidental que fueron ajustados a la serie temporal de la biomasa reproductora del stock estimada y al reclutamiento de los VPA de 2012 y 2014, y refleja las discusiones mantenidas durante y después de la reunión del Grupo de especies de atún rojo de 2014 sobre la elección entre las hipótesis de alto y bajo reclutamiento.

KEYWORDS

Bluefin tuna, Stock-recruitment models

1. Introduction

During the SCRS western Bluefin tuna species group work session, probability inferences were made about two alternative recruitment models using the AICc criterion as a measure of each model's ability to fit to estimates of spawning stock biomass (SSB) and recruitment derived from the 2012 and 2014 stock assessments. After the results were reviewed and accepted by the Bluefin Species Group, an error was discovered in the calculation of the likelihood that was used for the model selection criterion. This was brought to the attention of the SCRS during its plenary session, whereupon it was agreed that interested parties should meet to consider the best way to rectify the situation. The participants of this meeting (hereafter referred to as the subgroup) reached a consensus to add a sentence to the BFTW Executive Summary and to remove the errant calculations from the detailed report. They also agreed, in consultation with the SCRS Chair and ICCAT Secretariat, to present the revised results in an SCRS document. This document presents those revisions, but is considered preliminary as its contents were not reviewed by all participants in the 2014 bluefin species group or by the 2014 SCRS.

2. Material and Methods

Two alternative stock-recruitment (SR) models were fit to estimates of spawning stock biomass (SSB) and recruitment from the 2012 and 2014 base VPAs of western bluefin tuna: the Beverton-Holt model (high recruitment potential scenario) and a "three-line" model intended to reflect a hypothesized regime shift to a less productive state (the low recruitment potential scenario). The "three-line" model uses the geometric mean recruitment (μ) for the years 1971-1975 to represent the early, high-productivity period, and then uses the "two-line model" from the assessment to represent the presumed lower-productivity period after 1975 (the two-line model is defined by the geometric mean of the recruitment estimates since 1975, but allows recruitment to decrease proportionate to SSB when the SSB falls below the average of the estimates for the lowest six years on record, 1990-1995). In this way both models could be fit to the entire time series from 1971 forward (excluding the last three years, which were deemed unreliable by the bluefin species group) while remaining as consistent as possible with the specifications of the last two assessments (see SCI/033/2012). Note that the year where the shift occurred is an implied estimable parameter because the value used (1976) was originally based on a visual inspection of the data. A single log-recruitment standard deviation parameter (σ_R), estimated by maximum likelihood, was assumed for the entire time period for both the Beverton-Holt and the three-line models. The number of model parameters (k) used for the model selection criterion was therefore equal to three for the Beverton-Holt (alpha, beta, and σ_R) and four for the three-line model ($\mu_{1971\text{-}1975}$, $\mu_{1976\text{-}2010}$, σ_R, and the year when the shift occurred). Maximum likelihood estimates for the parameters were calculated by minimizing the negative log-likelihood (-LL) under the assumption that the "observed" recruitments estimated by the assessment were lognormally distributed with expectations given by the respective SR models and the corresponding estimates of SSB from the assessment:

$$-LL = n \cdot log_e(\sigma_R) + \frac{1}{2\sigma_R{}^2} \cdot \sum_{i=1971}^{Y} \left[log_e\left(R_{obs_i}\right) - log_e\left(R_{pred_i}\right)\right]^2$$

where:
n is the number of year-classes in the sample
R_{obs} is the estimated recruitment from the base VPA,
R_{pred} is the SR model-predicted recruitment for the SSB from the base VPA, and
σ_R refers to the standard deviation of the residuals as described above
Y is the last year used in the analysis (2008 for the 2012 base VPA and 2010 for the 2014 base VPA)

The bias-corrected Akaike Information Criteria (AICc) was calculated from the number of estimable model parameters and the estimated negative log-likelihood for each SR model:

$$AICc = 2 \cdot k \left(\frac{n}{n-k-1}\right) - 2 \cdot LL$$

where k is the number of estimable model parameters described above. The models were then compared based on the difference in AICc values.

3. Results and Discussion

The spawning stock biomass and recruitment estimates used in the analysis were taken from the base VPA models of the 2012 and 2014 assessments (**Tables 1 and 2**, respectively). The Beverton-Holt and three-line curves fitted are plotted in **Figure 1** and the maximum likelihood estimates for the parameters are tabulated in **Table 3**. The corresponding negative loglikelihoods (-LL) and AICc statistics are shown in **Table 4**. The three-line model provided the best overall fit (lowest –LL) and also the most parsimonious fit (lowest AICc) to both the 2012 and 2014 sets of estimates. It also exhibited smaller residuals than the Beverton-Holt model through most of the time series (**Figure 2**). When taken at face value, th**e** AICc weights calculated from the 2012 VPA estimates indicate 24 times the statistical weighting favoring the three-line model over the Beverton and Holt model (0.96/0.04). The AICc weights calculated using the 2014 VPA estimates indicate almost no statistical weighting in favor of the Beverton and Holt model.

The subgroup could not reach a consensus on the utility of this statistical approach for identifying the more likely of the two recruitment scenarios. Some members of the subgroup expressed concern that the approach was not statistically appropriate because it does not use direct observations of recruitment and spawning biomass, but only estimates derived from the VPA (which may be subject to a number of biases). It was also pointed out the approach used here assumes that the spawning biomass is known without error, when in fact the errors in the VPA estimates of spawning biomass are comparable to, or may even exceed, the errors in recruitment. Some called into question the assumption that a better statistical fit to the estimates alone constituted a sufficient basis to accept or reject a regime shift hypothesis, when the low recruitments estimated from the mid-1970s onwards could instead be a consequence of other biological mechanisms. On the other hand, other members of the group cited examples where similar statistical approaches have been employed in other areas (Szuwalski *et al*. 2014, Vert-pre *et al*. 2013).

Finally, the subgroup drew attention to a paper by Rosenberg *et al*. (2013) that used estimates from the base VPA from the 2010 assessment and different model selection criteria (F-tests and Bayes factors). That paper concluded that, while there was perhaps more support for the Beverton and Holt model, the use of any particular stock-recruitment relationship has little foundation in the stock and recruitment estimates from the VPA. It was pointed out that the 2014 VPA results reflect not only an addition of several years of stock and recruit estimates, but also a different pattern of historical stock and recruitment when compared to the VPA estimates obtained in 2010 which were used in Rosenberg *et al*. (2013), and also when compared to the 2012 VPA estimates. The subgroup did not explore how these differences might affect results if the Rosenberg *et al*. (2013) method were applied to the 2014 VPA results. The subgroup recommended exploring the matter further and using other model selection criteria, particularly as more data become available, and taking advantage of recent methodological developments that will allow assessments to estimate spawning biomass and recruitment further back in time. It also drew attention to the benefits of independent evidence to corroborate the hypothesized regime shift or a change in recruitment potential, though differing views were expressed as to whether this was essential to be able to accept such a hypothesis. Further points raised were that, even if such a shift had occurred to produce the apparent historical recruitment pattern, it is possible that conditions could have changed again, though that may be difficult to detect; furthermore, it would be desirable to try to identify the factors/conditions which caused the shift in order to then be able to take them into account when making projections. The subgroup agreed that allowing the stock biomass to continue to increase above current levels would improve the ability to distinguish between the two scenarios (or other alternatives).

References

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Table 1. Spawning stock biomass (mt) and recruitment estimates from the 2012 base VPA (note that results for the last three years were not included in the AICc computations because the bluefin species group considered them to be unreliable).

Year	*SSB*	*Recruitment (Age 1)*
1970	51074	
1971	50820	322112
1972	51227	278368
1973	51500	150701
1974	46209	465421
1975	40993	164002
1976	36133	134799
1977	30995	111875
1978	27696	94538
1979	24503	99236
1980	22215	80743
1981	19091	79956
1982	17957	81497
1983	17203	103201
1984	16337	92009
1985	14724	97312
1986	15076	100847
1987	14454	88453
1988	14328	134320
1989	13889	116810
1990	13308	110211
1991	13007	89498
1992	12614	76928
1993	12764	71082
1994	12640	80360
1995	13186	105261
1996	14287	80001
1997	15241	63203
1998	15466	78339
1999	14920	80650
2000	14949	81597
2001	14517	80308
2002	14103	68981
2003	13861	134999
2004	14077	131369
2005	14200	49309
2006	14141	43473
2007	15326	84741
2008	16140	44558

Table 2. Spawning stock biomass (in mt) and recruitment estimates from the 2014 base VPA (note that results for the last three years were not included in the AICc computations because the bluefin species group considered them to be unreliable).

Year	***SSB***	***Recruitment (Age 1)***
1970	51113	363640
1971	50857	322392
1972	51266	278521
1973	51539	150973
1974	46241	465746
1975	41025	164391
1976	36159	135241
1977	31021	112512
1978	27718	95145
1979	24534	99656
1980	22252	81299
1981	19138	80599
1982	18020	82285
1983	17279	104287
1984	16438	93252
1985	14850	98867
1986	15239	102505
1987	14630	91424
1988	14523	138821
1989	14103	121629
1990	13546	114105
1991	13283	94800
1992	12927	83580
1993	13133	77333
1994	13055	88548
1995	13721	114612
1996	14996	92054
1997	16121	75317
1998	16494	101446
1999	16136	104719
2000	16445	90853
2001	16249	91803
2002	16103	105420
2003	16178	173337
2004	16797	149469
2005	17324	63186
2006	18047	86729
2007	20301	96287
2008	21323	74561
2009	21706	65547
2010	22700	80317

Table 3. Parameter estimate comparisons between the Beverton-Holt and three-line stock recruitment models fitted to the 2012 and 2014 VPA spawning stock biomass and recruitment estimates for western Atlantic bluefin tuna.

	2014 VPA	*2012 VPA*
Beverton-Holt		
alpha	360,230	414,268
beta (mt)	45,287	58,916
σ_R	0.32	0.34
Three-Line		
$\mu_{1971\text{-}1975}$	253,066	252,748
$\mu_{1976\text{-}2010}$	96,542	86,728
SSB_{pivot} (mt)	13,278	12,920
σ_R	0.25	0.30

Table 4. Comparison of AICc between the 3-line and Beverton-Holt stock recruitment hypotheses for western Atlantic bluefin tuna based on spawning stock biomass and recruitment estimates from the 2012 and 2014 base VPAs.

Assessment	*Model*	*n*	*k*	*-LL*	*AIC*	*AICc*	*deltaAICc*	*Akaike weight*
2014 VPA	3Line	40	4	-35.4	-62.8	-61.6	0.0	1.00
	BH	40	3	-25.1	-44.1	-43.5	18.1	0.00
2012 VPA	3Line	38	4	-26.4	-44.7	-43.5	0.0	0.96
	BH	38	3	-22.0	-37.9	-37.2	6.3	0.04

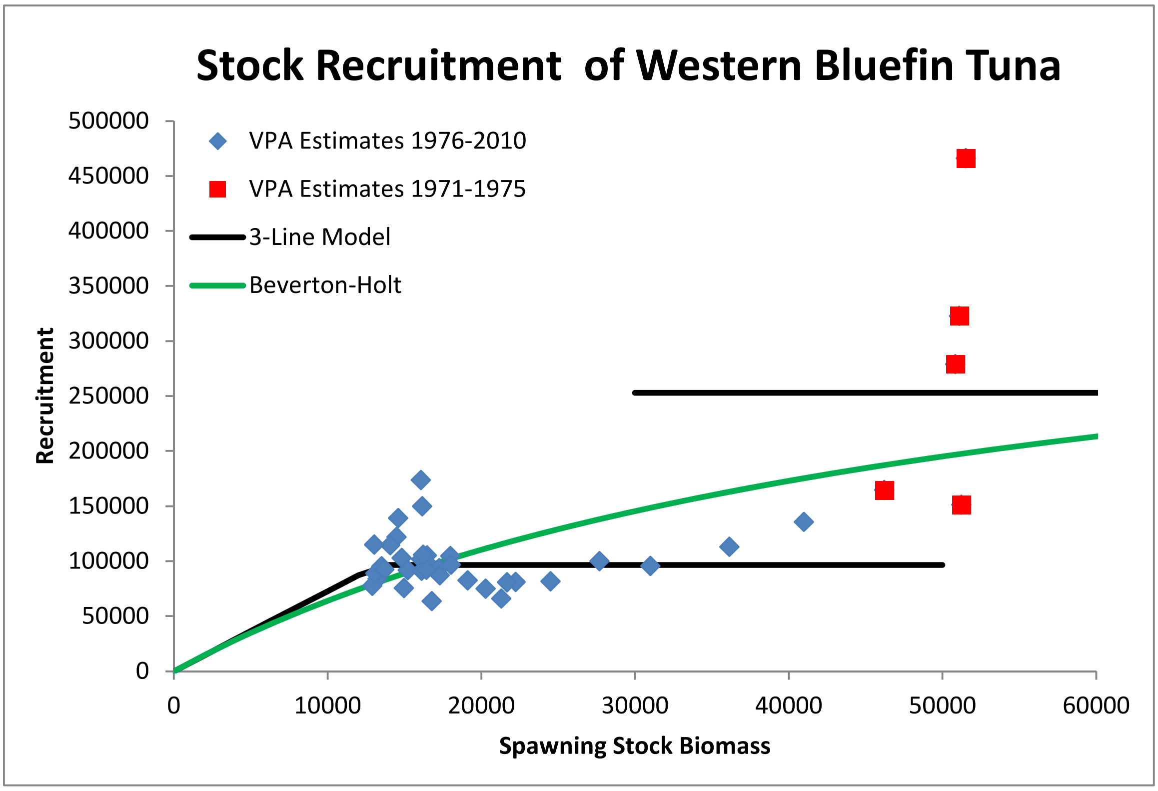

Figure 1. Hypotheses of stock recruitment of western Atlantic bluefin tuna used in AICc model selection between the Beverton-Holt model and a 3-line model of recruitment regime shift occurring after 1975 (as fit to data from the 2014 base VPA).

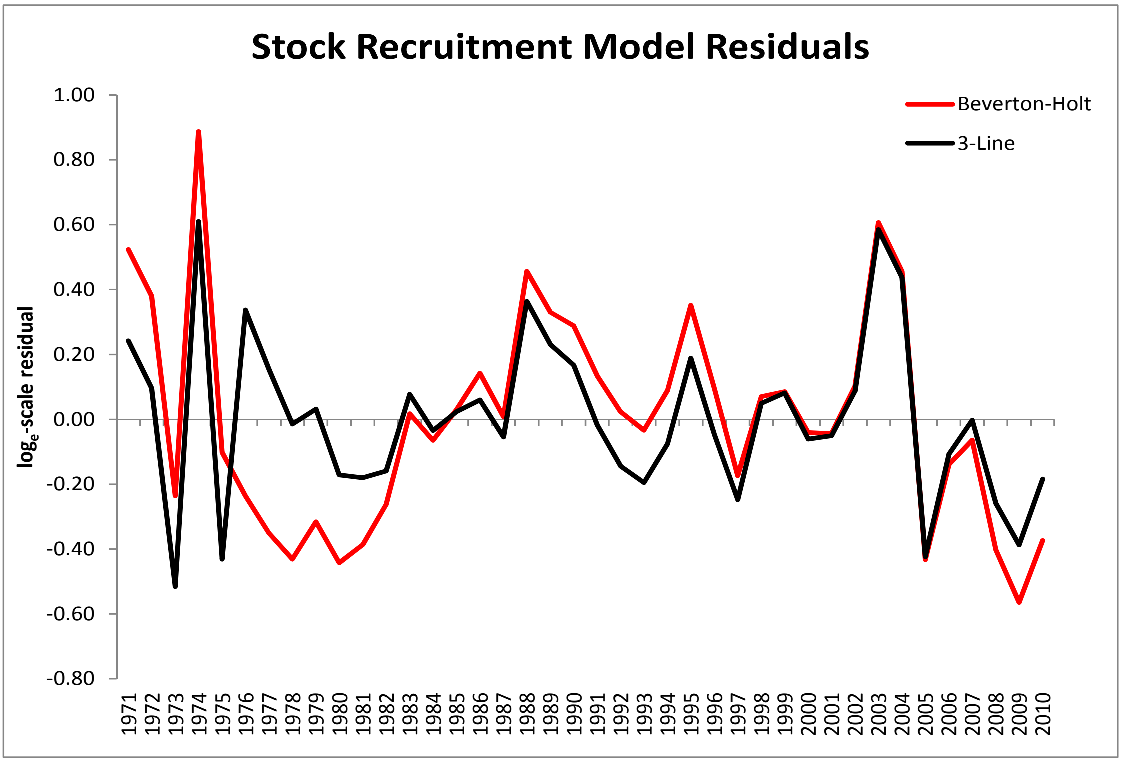

Figure 2. Stock-recruitment model residuals to estimates of recruitment from the 2014 VPA of western Atlantic bluefin tuna.