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AUTOCORRELATED STOCK RECRUITMENT PENALTIES APPLIED TO THE 1996 SCRS ASSESSMENT OF WEST ATLANTIC BLUEFIN TUNA

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SUMMARY

A penalty function that imposes a Beverton and Holt (1957) type spawner-recruitment relationship with an auto-correlated error structure was incorporated into the population models used by the SCRS to assess the status of west Atlantic bluefin tuna. The penalty had very little effect on the model outcomes except for the recruitment in the most recent years, which were substantially higher with the penalty but still very low compared with the 1970s. Therefore, the 1996 SCRS would have arrived at similar conclusions regarding the historical abundance of west Atlantic bluefin had it employed this particular penalty. On the other hand, the recruitment in adjacent years appears to be significantly auto-correlated, which may have had an impact on the SCRS' decisions regarding the spawner-recruit model to employ in the projections. The SCRS's advice to management would have been the same if it had remained with the two-line model (which is insensitive to the most recent recruitments), but may have been quite different had it used the auto-correlated Beverton and Hold model. The estimated high auto correlation suggests that the latter (or some similar idealism) may be more appropriate in the future.

RÉSUMÉ

Une fonction de pénalisation qui impose une relation de type reproducteur-recrutement Beverton et Holt (1957) avec une structure d'erreur autocorrélée a été incorporée aux modèles de population utilisés par le SCRS pour évaluer le statut du thon rouge de l'Atlantique Ouest. La pénalisation a eu très peu d'incidence sur les résultats du modèle, si ce n'est pour le recrutement au cours des années les plus récentes, qui a été notablement plus élevé avec la pénalisation mais très faible par rapport aux années 70. Par conséquent, le SCRS de 1996 serait arrivé à des conclusions similaires en ce qui concerne l'abondance historique du thon rouge ouest-atlantique s'il avait employé cette pénalisation spécifique. Par ailleurs, le recrutement lors des années avoisinantes semble être autocorrélé de manière significative, ce qui pourrait avoir un impact sur les décisions du SCRS relatives au modèle reproducteur-recrutement à employer dans les projections. L'avis de gestion du SCRS aurait été le même s'il avait conservé le modèle à deux lignes (qui est insensible aux recrutements les plus récents), mais il aurait pu être très différent s'il avait utilisé le modèle autocorrélée de Beverton et Holt. L'autocorrélation estimée, élevée, suggère que ce dernier (ou une conception similaire) pourrait être plus approprié à l'avenir.

RESUMEN

Se incorporó una función penalizadora a los modelos de población utilizados por el SCRS para evaluar el status del atún rojo del Atlántico oeste, que impone una relación tipo reproductor-reclutamiento de Beverton y Holt (1957), con una estructura de error autocorrelativo. La penalización tuvo un efecto muy escaso sobre los resultados del modelo, excepto sobre el reclutamiento en los años más recientes, que era sustancialmente superior con la penalización, pero aún muy bajo en comparación con el de los años 70. Por tanto, el SCRS en 1996 habría llegado a conclusiones similares con respecto a la abundancia histórica de atún rojo del Atlántico oeste si hubiera aplicado esta determinada penalización. Por otra parte, el reclutamiento en años contiguos parece estar significativamente correlacionado, lo que podría tener un impacto sobre las decisiones del SCRS con respecto al modelo reproductor-recluta a emplear en las previsiones. El asesoramiento del SCRS en cuanto a gestión habría sido el mismo si hubiese seguido el modelo de curvas estriadas (que es insensible a los reclutamientos más recientes) pero podría haber sido bastante diferente si hubiera empleado el modelo autocorrelativo de Beverton y Holt. La alta autocorrelación estimada sugiere que este último (o alguna concepción similar) podría ser más adecuado en el futuro.

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The 1996 SCRS working group on bluefin tuna suggested incorporating a spawner-recruitment penalty with an autocorrelated error structure into the ADAPT VPA model used in previous assessments. Several participants felt that the management advice might change substantially because the recruitment in the most recent years were very imprecise and probably biased low (SCRS, in press). This paper addresses this topic by incorporating a Beverton-Holt type spawner-recruit (BH) penalty into the objective functions of the ADAPT VPA used by SCRS (in press) and an alternative model that allows for errors and missing years in the catch at age matrix (CATCHEM--Porch and Turner, in press).

MODEL STRUCTURE

The autocorrelated model used here is the AR(1) model described in Seber and Wild (1989):

$$\begin{aligned} R_{y+1} &= \hat{R}_{y+1} e^{-\varepsilon_{y+1}} \\ \varepsilon_{y+1} &= \rho\,\varepsilon_y + \eta_{y+1} \end{aligned} \qquad (1)$$

in which ε is the autocorrelated random error, ρ is the correlation coefficient (with absolute value less than 1) and η is a normally distributed random variable with expectation 0 and variance σ^2. The expected recruitments ($\hat{R}$) were modeled with the asymptotic function developed by Beverton and Holt (1957):

$$\hat{R}_{y+1} = \frac{a * SSF_{y+1-\alpha}}{b + SSF_{y+1-\alpha}} \qquad (2)$$

The spawning stock fecundity (SSF) was presumed proportional to the spawning stock biomass SSB (age 8 and older) as in previous SCRS assessments. The parameter α is the age of recruitment-- here equal to 1. The negative log-likelihood function corresponding to (1), ignoring the constant terms, is

$$\begin{aligned} L = (Y-1)\ln(\sigma) - \frac{1}{2}\ln(1-\rho^2) + \frac{1}{2\sigma^2}\{(1-\rho^2)(R_2-\hat{R}_2)^2 \\ + \sum_{y=3}^{Y}(R_y-\hat{R}_y-\rho\,(R_{y-1}-\hat{R}_{y-1}))^2\} \end{aligned} \qquad (3)$$

Here R is the recruitment estimated by ADAPT or CATCHEM, Y is the number of years, and the subscript y denotes the year relative to the first year in the data (e.g., y=2 corresponds to 1971 in the VPA and 1961 in CATCHEM). The estimate of recruitment in the first year is disregarded since an estimated of SSB in the preceding year is unavailable. Expression (3) was added directly to the objective functions of ADAPT and CATCHEM and the minimization procedure conducted as usual.

Four sets of runs were made for each of the two models. The first reproduced the SCRS analysis of Western Atlantic bluefin tuna referred to in the 1996 SCRS detailed report as "west base case 1." The second run invoked the spawner-recruit penalty to estimate the parameters a and b, assuming no autocorrelation (ρ =0) and σ^2 = 0.1484 (which is equivalent to the CV of 0.4 suggested by the bluefin working group). The third run was identical to the second except that ρ was also estimated. The fourth run estimated all parameters, including σ^2 by its MLE:

$$\hat{\sigma}^2 = \frac{1}{Y-1}\{(1-\rho^2)(R_2-\hat{R}_2)^2 + \sum_{y=3}^{Y}(R_y-\hat{R}_y-\rho\,(R_{y-1}-\hat{R}_{y-1}))^2\}$$

RESULTS AND DISCUSSION

The ADAPT VPA estimates of historical abundance generally changed very little with the addition of the recruitment penalty (Figure 1). The biggest differences were in the recruitment after 1992, which were about twice as large with the stock recruitment penalty (but still much lower than earlier levels). The estimates of the BH parameters, however, changed substantially (Table 1, Figure 2). The VPA recruitments without the penalty were significantly autocorrelated (ρ = 0.46) and the BH parameter estimates had high coefficients of variation (CV). The VPA recruitments with the penalty were less correlated (around 0.15) and the BH parameters a and b had substantially lower CV's. The penalty had little effect on the VPA parameters except for N_3, the number of age 3 fish at the beginning of year Y+1 (see Table 2).

It is evident from the above results that the historical abundance and mortality estimates considered by the SCRS would not have been very different had the BH penalty been used during the 1996 assessment. While it is true that the most recent recruitment were substantially higher with the penalty, the SCRS routinely discounts them because they are poorly estimated by VPA. More importantly, the main effects of the penalty seem to be a flattening of the fitted BH relationship (Figure 2) and a sharp decrease in the estimated autocorrelation. These could be important for medium and long-term projections into the future, particularly if the autocorrelation factor is included (by use of equation 1 with the estimated values of ρ, σ^2, and ε_Y).

The 1996 SCRS elected to use the two-line spawner-recruit relationship whereby the expected recruitment is equal to (1) the geometric mean of the VPA estimates from 1981 to 1992 if the projected SSB was greater than the average of the VPA estimates from 1985-1991 or (2) prorated linearly from the geometric mean to zero if the projected SSB was less than the 1985-1991 average. Since neither the 1981-1992 VPA recruitment nor the 1985-1991 VPA SSB differed substantially with the penalty, the advice given by the 1996 SCRS would have been the same if the penalty had been used. However, it is quite possible that the SCRS would have used the autocorrelated BH model had it been available. In that case the results of the projections and the advice generated from them would likely have been different.

The effect of the penalty on the abundance estimates from CATCHEM was even less than for the ADAPT VPA (Figure 3). Thus, if the results of CATCHEM had been used instead of the VPA, then again the advice given by the SCRS regarding the present status of the stock would have changed very little. Unlike ADAPT however, the penalty did not reduce the perceived autocorrelation; the estimates of ρ were near 0.7 with CV's of less than 20 percent for all four runs. The reason CATCHEM estimates much larger ρ values than ADAPT is uncertain, but probably has much to do with the fact that CATCHEM uses a longer time series of catches and somewhat different indices of abundance (see Porch and Turner, in press). The strength of the estimated autocorrelation again suggests that it would be most prudent to include the autocorrelation in future projections.

Future deliberations by the SCRS should consider the merits of including a stock recruitment penalty within the stock assessment model--whether ADAPT or some other approach. Important considerations to keep in mind are: (1) the autocorrelation factor ρ is likely to be poorly estimated within ADAPT and appears, perhaps spurriously, to be lower with the penalty; (2) the best way to estimate the value of ε_Y, i.e, from the last two recruitments or some sort of historical average; (3) the appropriateness of the Beverton and Holt model, and (4) consistently including the same spawner-recruit penalty in the assessments as is used for the projections.

REFERENCES

Beverton, R. J. H., and Holt, S. 1957. On the dynamics of exploited fish populations. Reprinted in 1993 by Chapman and Hall, London. 533 pp.

Porch, C. E., and Turner, S. C. In press. Catch-at-age analyses of West Atlantic bluefin tuna incorporating data from 1960 to 1994 (Preliminary results). ICCAT Col. Vol. Sci. Pap. 46(2): 276-279.

SCRS. 1996. Report of the ICCAT SCRS bluefin tuna stock assessment session. Genoa, Italy. SCRS/96/26.

Seber, G. A. F, and Wild, C. J. 1989. Nonlinear regression. John Wiley and Sons, Inc., New York. 768 pp.

Table 1. Parameter estimates for the BH model fitted to VPA estimates of recruitment and SSB with various treatments of the BH penalty function. These estimates are almost identical to the estimates from the penalized VPA's themselves (except of course for ρ and σ^2 in the cases where they are fixed in the penalty). Penalty types are (1) $[a,b]$ estimated, ρ and σ^2 fixed at 0 and 0.15; (2) $[a,b,\rho]$ estimated, σ^2 fixed at 0.15; and (3) $[a,b,\rho,\sigma^2]$ all estimated.

PARAMETER	PENALTY TYPE			
	NONE	1	2	3
a	266,374	189,848	196,691	200,477
b	43,554	20,651	22,497	23,550
ρ	0.46	0.13	0.17	0.20
σ^2	0.25	0.21	0.21	0.22
CV of a	65	30	32	34
CV of b	95	54	56	58
CV of ρ	40	152	115	100

Table 2. Parameter estimates for the VPA with various treatments of the BH penalty function. Penalty types 1, 2, and 3 are as described in Table 1. F is the fishing mortality rate and N the abundance at age at the beginning of year $Y+1$ (Y being the last year in the data).

PARAMETER	PENALTY TYPE			
	NONE	1	2	3
N_3	4,760	13,413	11,819	11031
N_5	14,893	13,463	13,812	13710
N_7	35,101	27,433	28,623	30265
N_9	7,410	7,117	7,133	7191
F_{10+}/F_9	0.561	0.552	0.561	0.560
CV of N_3	36	30	37	43
CV of N_5	25	21	21	21
CV of N_7	27	26	26	27
CV of N_9	16	16	16	16
CV of F_{10+}/F_9	19	19	20	19

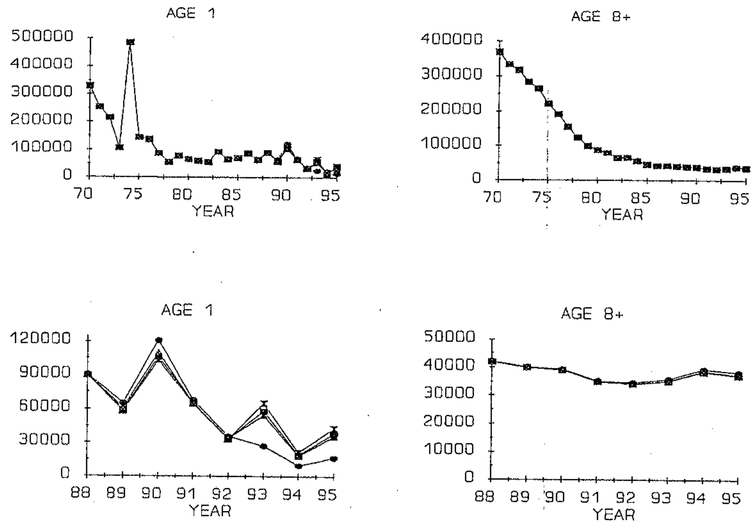

Figure 1. VPA estimates of the abundance of new recruits and spawning age bluefin tuna without the penalty (circles) and with the penalty (three alternatives marked by squares, triangles, and hourglasses). In most years the four VPA's are virtually indistinguishable. The specific way of implementing the penalty was much less important than the fact that a penalty was used.

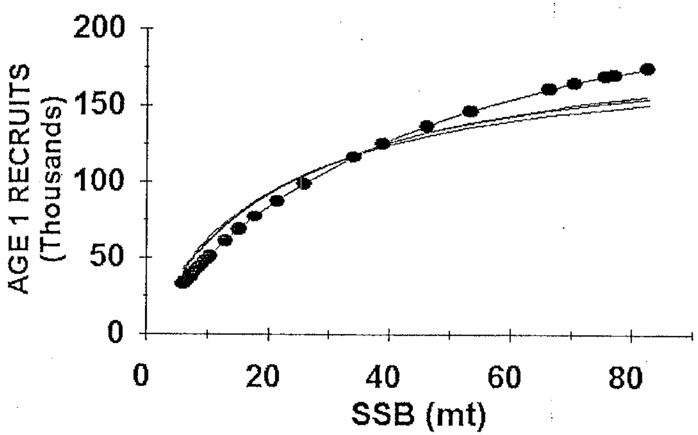

Figure 2. Fitted Beverton-Holt spawner-recruit curves without the penalty (line with circles) and with the penalty (three nearly identical lines without symbols).

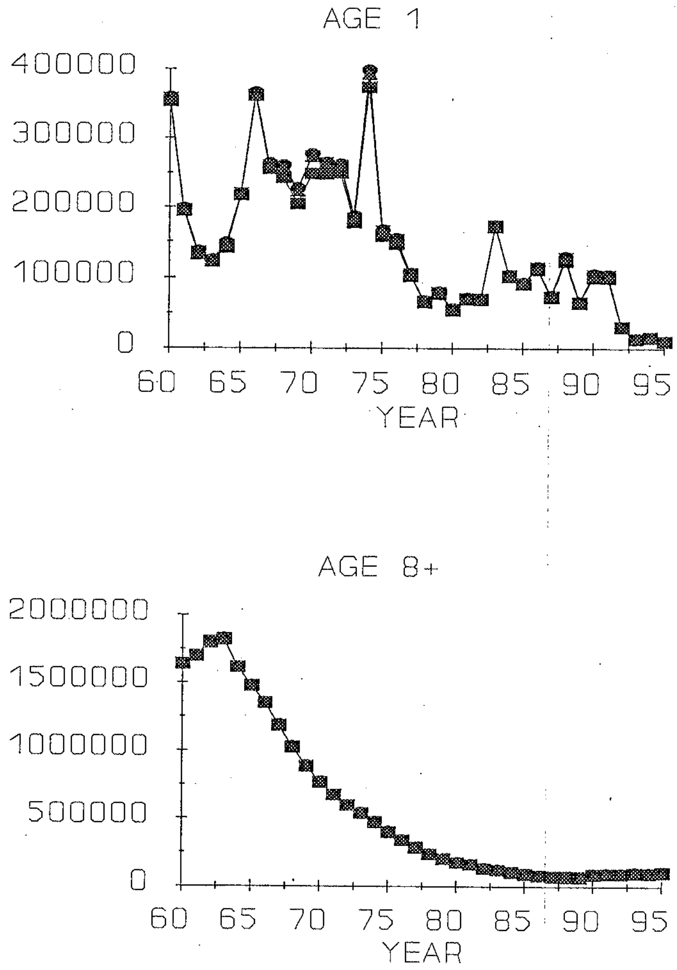

Figure 3. CATCHEM estimates of the abundance of new recruits and spawning age bluefin una without the penalty (circles) and with the penalty (three alternatives marked by squares, triangles, and hourglasses).