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CATCH-AT-AGE ANALYSES OF WEST ATLANTIC BLUEFIN TUNA INCORPORATING DATA FROM 1960 TO 1994 (PRELIMINARY RESULTS)

Porch, C.E., S.C. Turner[1]

SUMMARY

A catch-at-age model that explicitly accounts for errors in the catch-at-age matrix was used to estimate the abundance and mortality of west Atlantic bluefin tuna between 1960 and 1994. The model assumes the same underlying population dynamics as ADAPT and, unlike the ADAPT-VPA approach, does not require a complete catch-at-age matrix. This feature is especially useful for Atlantic bluefin tuna because the age composition of the catch is unknown for some segments of the fishery prior to 1970. Like the ADAPT-IPA approach (Porch, in press), the present model assumes that the fishing mortality rate is separable into age and year effects. The present model, however, allows one to further relax the separability assumption by specifying different selectivities for each of several fishing fleets and for different blocks of years.

RÉSUMÉ

Un modèle de prise par âge tenant compte explicitement des erreurs dans la matrice de prise par âge a été utilisé pour estimer l'abondance et la mortalité des thons rouges de l'Atlantique Ouest entre 1960 et 1994. Le modèle suppose fondamentalement la même dynamique de stock qu'avec la méthode ADAPT. Contrairement à l'approche ADAPT-VPA, ce modèle n'exige pas une matrice complète de prise par âge. Cette caractéristique est particulièrement utile pour le thon rouge de l'Atlantique dans la mesure où la composition par âge de la capture n'est pas connue dans certains segments de la pêcherie avant 1970. A l'instar du modèle ADAPT-IPA (Porch, à paraître), ce modèle suppose que le taux de mortalité par pêche peut être distingué par âge et par année. En outre, ce modèle permet d'atténuer la séparation en spécifiant les différentes sélectivités de chacune des diverses flottilles de pêche et les différents blocs d'années.

RESUMEN

Para estimar la abundancia y mortalidad del atún rojo del Atlántico oeste, entre 1960 y 1994, se empleó un modelo de captura por edad que de forma explícita tiene en cuenta los errores en la matriz de captura por edad. El modelo asume la misma dinámica básica de población que el ADAPT y, a diferencia del ADAPT-VPA, no necesita una matriz completa de captura por edad. Esta característica es de especial utilidad para el atún rojo atlántico debido a que se desconoce la composición por edad de la captura para algunos segmentos de la pesquería en el período previo a 1970. Igual que el ADAPT-VPA (Porch, en preparación), este modelo asume que la tasa de mortalidad por pesca puede separarse por edad y años. Este modelo, sin embargo, permite una mayor relajación en lo que se refiere al supuesto de separación, diferenciando las selectividades de varias flotas de pesca y diferentes grupos de años.

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[1] NMFS-Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, Florida 33149, U.S.A.

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INTRODUCTION

SCRS assessments of bluefin tuna and other species have relied heavily on virtual population analyses (VPA) tuned to indices of abundance. In recent years, however, the SCRS has examined the results from several other models: CAGEAN[1] (Collie, 1988), stock synthesis[2] (Porch et al., 1994), separable sequential population analysis (Kimura and Scott, 1994), and ADAPT-IPA (Porch, in press). The VPA approach, while having the advantage of being more familiar and computationally simpler than the alternatives mentioned above, has the disadvantage of assuming the catch at age data are perfect and complete. In principle the uncertainty in the catch data can be incorporated into a VPA using Monte Carlo methods (Turner and Restrepo, 1992). However, approaches that explicitly integrate uncertainty in the catch data directly into the estimation may be preferable as they are more amenable to hypothesis testing and confidence interval estimation.

Perhaps the greatest drawback of tuned VPA's is that they require a complete catch at age matrix. The historical abundance of Atlantic bluefin tuna, for example, has not been estimated for the years prior to 1970 because information on the age composition of the catch is missing for some segments of the fishery.

This article analyzes the catch and abundance index data for West Atlantic bluefin tuna using a new catch-at-age model. The model, hereafter referred to as the catch-error model (CATCH'EM), is an extension of the ADAPT-IPA model of Porch (in press) that considers errors and missing data in the catch at age matrix. The results from the new model are compared to corresponding VPA-based ADAPT assessments.

METHODS

CATCHEM: Model structure

CATCHEM is an age-structured maximum likelihood model that estimates a variety of parameters from fleet-specific data on the total catch, age-composition of the catch, catch per unit effort, and survey indices of abundance. As mentioned earlier, an advantage of this sort of approach over VPA (and the impetus behind the development of this model) is the ability to accommodate gaps in the historical record. The primary disadvantage is that the fishing mortality rates are not uniquely determined by the recursions as in VPA, but must be estimated as parameters. In practice, the number of data points available is insufficient to justify attempting to estimate the fishing mortality rates for every fleet, age and year so that some simplifying assumptions must be made. CATCHEM assumes that the selectivity pattern of each fishing fleet is constant during specific blocks of years (but may vary among 'blocks' of years).

The mathematical details, including the population dynamics equations, error models and parameter estimation are presented in the appendix.

Fleet definitions and assessment data

The definition of the West Atlantic stock of bluefin tuna follows the protocol described by the 1994 SCRS (ICCAT, 1995). Seven fisheries were defined: (1) US rod and reel fishery for small fish [ages 1-5]; (2) nearshore mixed-gear fishery for large fish [ages 6+]; (3) Canadian tended line [age 10+]; (4) US purse-seine [ages 1-5]; (5) NW Atlantic longline [ages 1-9]; (6) Gulf of Mexico and Brazil longline [ages 10+]; and (7) an 'other' category lumping the remaining fisheries [all ages]. The indices of abundance used were the same as for the 1994 assessment (ICCAT, 1995) except that the standardized longline CPUE from NMFS (1984) was used in place of the US and Japanese Gulf of Mexico indices to provide an index with a historical perspective prior to 1970. The larval survey used in the 1994 SCRS assessment was also included. No indices were included for the US purse-seine and 'other' fisheries. Fish older than nine years were lumped together in a plus group.

The selectivity-at-age parameters for some of the fisheries were allowed to vary among several blocks of years (eras) corresponding to time periods with potentially significant changes in the fishing methods or fishing grounds. Fishery 2, the nearshore mixed-gear fishery, was divided into three eras: 1960-66, when some fish younger than age 6 were caught; 1967-81, when young fish were no longer caught; and 1982-93, when the total catches increased substantially. Fishery 5, the NW Atlantic longline fleet, was also divided into three eras: prior to 1971 (about the time that deep freezers were introduced to the Japanese fleet); 1971-88; and 1989-93 when Japan ceased fishing within the exclusive economic zone. A separate era was also created for 1960-61 of the US purse seine fleet because no 1 or 2 year-olds were caught then.

RESULTS AND DISCUSSION

The CATCHEM assessment presented here should be regarded as an example only. It is meant to illustrate the potential of the methodology rather than to make a definitive statement on the status of the western Atlantic bluefin resource. We recognize that the fishery definitions and CPUE indices used in this example may not be the most appropriate. Refinements in the input specifications for the model may be made through discussion and analysis at the 1996 ICCAT SCRS bluefin assessment.

The estimates of abundance from CATCHEM are compared with the ADAPT VPA results reported by the 1994 SCRS in Figure 1. The two sets of estimates were generally quite similar over the years they had in common. Both indicate that the abundance of age 1, 2-5, and 8+ fish has declined substantially since the 1970's. The CATCHEM model did, however, give somewhat more optimistic appraisals of age 6-7 fish than did the VPA (indicating that their abundance in the 1990's may have been greater than at any time since the 1960's). The fact that the CATCHEM model confirmed the VPA predictions of the abundance of age 8+ fish in the 1970's is particularly significant inasmuch as the CATCHEM model used data from as far back as 1960. For the same reason, it was possible to estimate the abundance during these early years with the understanding that the abundance of the older age groups during the early 1960's is likely to be poorly estimated (just as they are poorly estimated by the VPA in the early 1970's). These 1960's estimates suggest that the high recruitments observed during the early 1970's were not anomalous, but typical of the era from 1960-1975. Moreover, the abundance of age 2 and older fish may have been nearly double what they were in the 1970's.

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APPENDIX: MODEL DESCRIPTION

Calculation of population statistics

The number of age a fish alive at the start of year y ($N_{a,y}$) is calculated as follows:

$$N_{a,y} = \begin{cases} P_a & y=1 \\ R_y & a=1,\ y>1 \\ N_{a-1,y-1}\, e^{-Z_{a-1,y-1}} & a>1,\ y>1 \end{cases} \qquad (1)$$

where

R_y	initial abundance of youngest age class (recruits) in year y,
P_a	initial abundance of age class a in the first year of the time series,
$Z_{a,y}$	is the instantaneous total mortality rate for age class a in year y.

An additional equation is needed when the calculations are censored at age A (i.e., members of the population aged A or older are lumped together in a 'plus group'):

$$N_{A,y} = N_{A,y-1}\, e^{-Z_{A,y-1}} + N_{A-1,y-1}\, e^{-Z_{A-1,y-1}} \quad . \qquad (2)$$

The instantaneous total mortality rate $Z_{a,y}$ is partitioned into coefficients for the instantaneous natural mortality rate M_a and the instantaneous fishing mortality rate $F_{a,y}$. The latter is further partitioned into gear-specific mortality rates such that

$$F_{a,y} = \sum_{g=1}^{G} F_{a,y,g} \quad .$$

The formula for the catch at age of each fleet (gear) g is then

$$C_{a,y,g} = \frac{F_{a,y,g}}{Z_{a,y}} N_{a,y} \left(1 - e^{-Z_{a,y}}\right) \quad . \qquad (3)$$

The parameters to be estimated are the recruitments R_y, initial population structure P_a, natural mortality rates M_a, and gear-specific fishing mortality rates $F_{a,y,g}$. This constitutes a total of 2A+Y+AYG parameters, but the maximum number of data points is AYG + nY (Y is the number of years, G the number of fisheries (gears) and n is the number of auxiliary data sources). This leaves very few degrees of freedom-- (n-1)Y - 2A. To ameliorate this problem we follow Methot (1989) in assuming the age dependent effects are constant within a fishery type (g) during certain blocks of years (b); i.e.,

$$F_{a,y,g} = F_{y,g}\, s_{a,b(y),g} \quad . \qquad (4)$$

In program CATCHEM the 'selectivities' ($s_{a,b,g}$) are relative values conditioned on the magnitude of the annual fishing mortality effects ($F_{y,g}$). Thus, the selectivity of one age group for each block can be fixed and the others estimated relative to the fixed value so that the number of fishing mortality rate parameters is reduced from AYG to $(A-1)B^gG$ + YG.

The indices of abundance are calculated as

$$I_{y,g} = q_g \sum_a s_{a,y,g} N_{a,y,g} h_{a,y,g} \quad . \tag{4}$$

The parameters q_g are index-specific catchability coefficients to be estimated. The correction factor h translates numbers into biomass (if appropriate) and allows for changes in abundance during the year. When the index is the CPUE from a fishery, the selectivities used are identical to those used to compute the catches for that fishery. When the index is a fishery-independent survey, the selectivities are either assumed or estimated from the survey's age-composition data.

Parameter estimation

The objective function to be minimized is the maximum likelihood expression

$$\sum_{y,g} \frac{([C_{y,g}] - [\hat{C}_{y,g}(\Theta)])^2}{2\sigma^2[C_{y,g}])} + \frac{(\ln[I_{y,g}] - \ln[\hat{I}_{y,g}(\Theta)])^2}{2\ln(V_{y,g}^2 + 1)} + \sum_{a,y,g} n_{y,g}\, p_{a,y,g} \ln[\hat{p}_{a,y,g}(\Theta)] \ , \tag{5}$$

where the first term describes normally-distributed total catches, the second lognormally-distributed indices and the third multinomially-distributed age compositions. The term $p_{a,y,g}$ represents the relative proportion of the catch sample identified as age a and $n_{y,g}$ is the sample size (for a given year and gear type). The variables without hats represent the observed values and the variables with hats represent the values predicted from the parameter set Θ using equations (1) through (4) above. The parameters σ^2 and V are the respective variances and coefficients of variation. In the present application the V's were fixed to 10 percent and the variances of the total catch were estimated to be proportional to the expected value of the catch (analogous to an over-dispersed Poisson distribution). The sample sizes from the age composition data were not allowed to exceed 200 to prevent particularly large data sets from dominating the objective function.

The parameters Θ that minimize equation (5) are found using the Nelder-Mead simplex algorithm AMOEBA (Press et al., 1994). The algorithm was restarted multiple times to avoid being fooled by local minima in the solution surface. New initial vertices were selected for each such restart using the formula

$$\rho_{ij} = \rho_{0j} e^{0.5\lambda\delta_i} \quad (i,j = 1,\ldots,\omega) \quad ,$$

where ρ_{ij} is the value of the j'th coordinate (parameter) in the i'th vertex of the initial simplex, λ is a standard normal variate, and δ_i is equal to one if i equals j and zero otherwise. Subsequent 'restarts' continued until five consecutive sets of parameter estimates differed by less than one percent.

Not all of the members of the parameter set Θ must be estimated in the AMOEBA search. The natural mortality rate M and coefficients of variation corresponding the catch and index likelihoods ($V_{C,a,y}$ and $V_{i,y}$) were fixed to constants. The index-specific catchabilities q_i were estimated from the observed values of the indices and the estimates of abundance by use of the lognormal maximum likelihood formula

$$q_i = e^{\frac{1}{n_i}\sum_y \ln(I_{i,y}/D_{i,y})}$$

where n_i is the number of observations (years) and

$$D_{iy} = \sum_a \hat{s}_{i,a,y} \hat{N}_{a,y} \hat{h}_{i,a,y}$$

(recall that the hats indicate the latest estimates from equations 2 and 3).

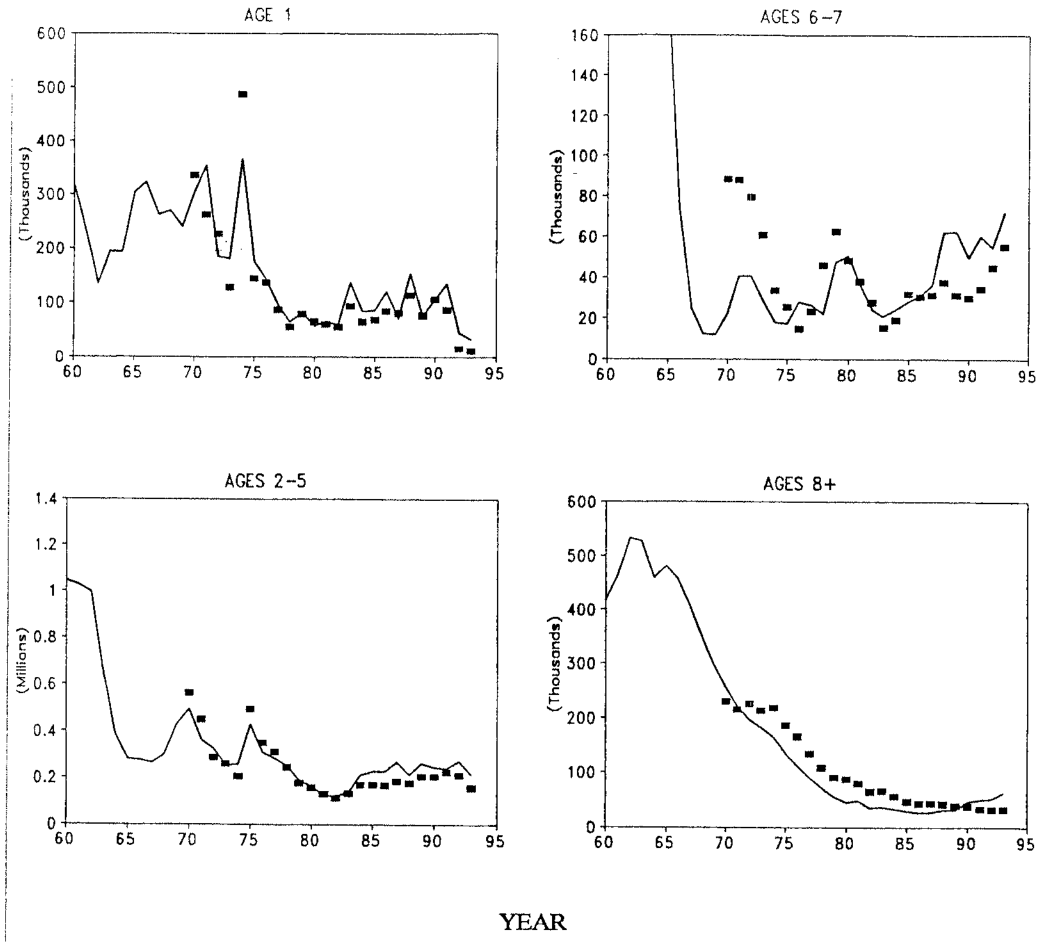

Figure 1. Estimates of historical abundances of West Atlantic bluefin tuna from program CATCHEM (lines) compared with the corresponding SCRS estimates using ADAPT-VPA (squares).