Investigating the stock status of Indian Ocean Bigeye tuna using the a4a statistical catch-at-age assessment method.

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Introduction

A recently developed statistical catch-at-age stock assessment method, a4a, designed for evaluating the status of stocks with intermediate data quality, is applied here to Indian Ocean bigeye tuna. The method provides huge flexibility for the rapid evaluation of the effects in parameter estimates and uncertainty of different submodels for fishing mortality-at-age (the F model), CPUE catchability-at-age (the Q model), stock recruitment (the R model) and observation variance (the V model).

The model does not attempt to substitute more complex stock assessments that make use of all sources of data, including tagging, but to provide a tool for rapid exploration of the influence of different assumptions and data sources. This capability is achieved by combining a powerful optimization engine (ADMB) with an intuitive user interface using linear models as expressed in the R language. The model is implemented as part of the FLR framework (Kell et al. 2007), and thus can make use of the available tools for estimation of reference points, projections under different scenarios, plotting and diagnostics.

The a4a stock assessment model

The a4a assessment model is an age structured model based on the Baranov catch equation and an assumption of constant mortality rates throughout the year.

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The numbers in the population at age a and year y, N_{ay}, are modelled in terms of the initial age structure N_{-a_0,y_0}, recruitment $N_{a_0,y}$ and fishing mortality F_{ay}. Natural mortality, M_{ay} is assumed known. The full matrix of numbers at age can be written in terms of these quantities:

$$N_{ay} = \begin{cases} N_{a_0,y} & a = a_0 \\ N_{a_0,y-a+a_0} \exp\left\{-\sum_{a'=a_0}^{a-1} Z_{a',y-a'+a_0}\right\} & a > a_0 \text{ and } a - a_0 > y - y_0 \\ N_{a-y+y_0,y_0} \exp\left\{-\sum_{a'=a-y+y_0}^{a-1} Z_{a',y-a'+a_0}\right\} & a > a_0 \text{ and } a - a_0 \leq y - y_0 \end{cases}$$

where $Z_{ay} = F_{ay} + M_{ay}$. In the case of a plus group the numbers in the oldest age class are given by the equation above plus additional individuals coming from the previous years' cohort.

The same quantities allow the prediction of catches and it is assumed that the log of the observed catches are independently normally distributed about the log of the predicted catches

$$\exp\{E[\log C_{ay}]\} = \frac{F_{ay}}{Z_{ay}}(1 - \exp\{-Z_{ay}\})N_{ay}$$

An additional quantity giving the catchability of a survey, Q_{ay}, allows us predict survey indices, and as with catches is it assumed that the log of the observed survey indices are independently normally distributed about the log of the predicted indices. Indices may be observations of abundance at age:

$$\exp\{E[\log I_{ays}]\} = Q_{ays}N_{ay}$$

or of biomass

$$\exp\{E[\log B_{ys}]\} = \sum_a Q_{ays}N_{ay}W_{ay}$$

in which W_{ay} is the stock weight at age and year. The variance of the relationships are allowed to vary by age. These equations, defined by the quantities, $N_{a_0,y}$, N_{-a_0,y_0}, F_{ay} and Q_{ays}, provide the full description of the stock.

recruitment modelling

It is possible to provide some internal structure to the population model in the form of a stock recruit relationship in which recruits are considered to be related to previous biomass

$$\exp\{E[\log N_{a_0,y}]\} = f\left(\sum_a N_{a,y-1}W_{a,y-1}m_{a,y-1},\, \theta\right)$$

where m is the maturity, assumed known, and $f(.)$ is a function such as the ricker or beverton and holt stock rectuit relationship with parameters θ.

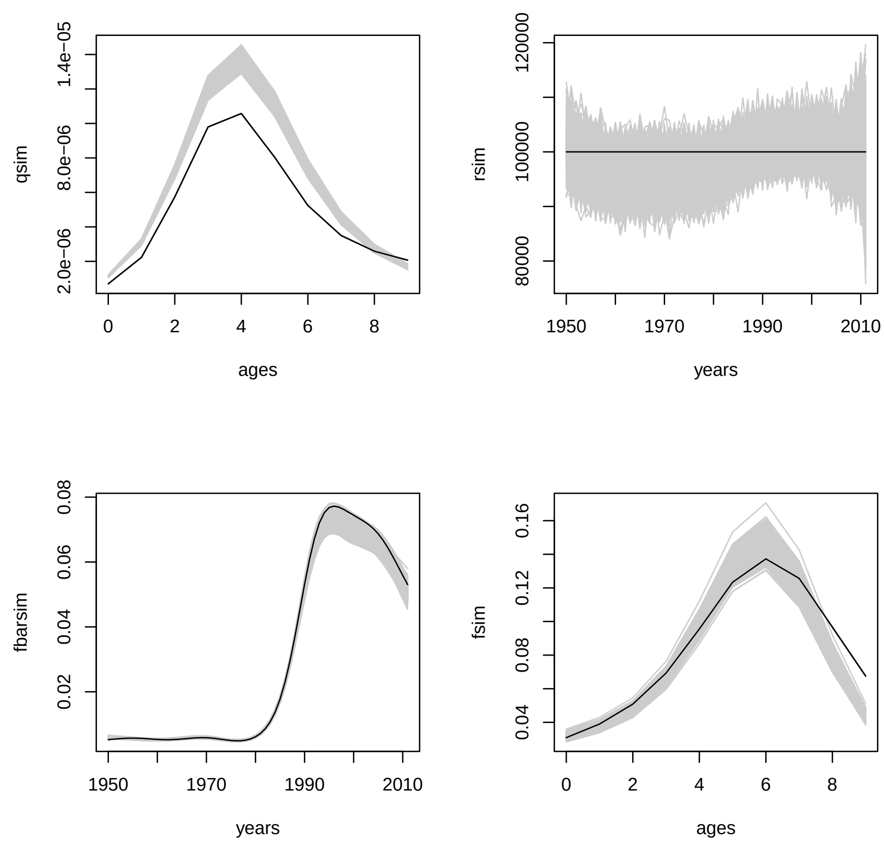

Figure 1: Simulation results for a big eye Tuna like stock with age based indices.

Implementation

The models presented above are the basis for many stock assessment models. Often the difference between models is the way in which the individual quantities are modelled. Catchability is often modelled as a parametric function such as a scaled logistic or a scaled double normal. In a4a linear and additive formulas on the log scale are used in place of parametric forms. To give a concrete example, to model a seperable fishing mortality in a4a the user specifies log F $\sim$ age + year. Where '$\sim$' should be read 'is modelled as', and, here, age and year are catagorical variables. Splines may also be used to model selectivity over age and/or year, for example a seperable model with fewer parameters than the aforementioned is log F $\sim$ s(age) + s(year). Similarly catchability at age can be modelled using splines: log Q $\sim$ s(age), fits a spline for survey catchability.

Splines are the main tool for reducing parameterisation in a4a. For reasons of efficiency the use of random effects have been avoided and the user is required to specify the degrees of freedom of the splines.

Data

The a4a stock assessment model is an age-based model, and requires a matrix of catch-at-age information that includes all fleets and areas, on a yearly time step. This is then combined with an abundance index, in this case a standardized total catch-per-unit-effort series for the Japanese longline fleet (Matsumoto, Satoh, and Okamoto 2013).

Catch-at-age

The catch-at-age dataset made available by the IOTC Secretariat [1] was used.

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CPUE index

Model structure and assumptions

Fixed parameters

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[1] http://iotc.org/files/proceedings/2013/wptt/BET_ASPMv2.zip, 27/09/2013

Estimated parameters

Model runs

Simulation of catchability fitting

The use of a biomass survey in FLa4a as an observation of stock abundance is being used for the first time on BET. In order to investigate the validity of this in the context of the a4a assessment model, a small simulation study has been conducted. The details of the simulation are as follows

- model settings were selected that were thought to be appropriate for approximating BET dynamics. A seperable model for F, with splines for both age and year. Independent recruitment for each year, and the intitial age structure is estimated seperately for each age. The observation variance is constant accross age and year with a seperate variance for the catch and survey.
- The estimated F-at-age and N-at-age from a recent SS3 assessment of BET (REF langley) was used to fit the F and N models, variance was fixed corresponding to 10% cv for both the catch and survey. Also using (REF langley) three survey catchability forms were defined: “domed”, “logistic”, and “flat”.
- given the parameter values defined in the previous point, 1000 data sets were simulated and the a4a model fitted to each. The model setup in the fitting was exactly that used to simulate the data.
- finally the model estimates of catchability at age, recruitment, Fbar and F-at-age in the final year are plotted along with the values used to simulate the observations.

The purpose of the simulation is to test that, in the case where we have the model right, how well are the model

Results

Population trajectories

Reference points

Residual diagnostics

Discussion

Appendix I: a4a model population dynamics

Appendix II: Code of final run

References

Kell, Laurence Thomas, Iago Mosqueira, Philippe Grosjean, Jean-Marc Fromentin, Dorleta Garcia, Richard Hillary, Ernesto Jardim, et al. 2007. "FLR: an open-source framework for the evaluation and development of management strategies." *ICES Journal of Marine Science* 64 (4) (apr): 640–646. doi:10.1093/icesjms/fsm012.

Matsumoto, Takayuki, Keisuke Satoh, and Hiroaki Okamoto. 2013. *Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM.*