SCRS/1996/062

Col.Vol.Sci.Pap. ICCAT, 46 (2) : 225-227 (1997)

AN EXAMINATION OF ALTERNATIVE METHODS FOR PROJECTING STOCK RECOVERY FROM VIRTUAL POPULATION ANALYSES (DRAFT)

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SUMMARY

A simulation framework is constructed for the purpose of evaluating methods of using Virtual Population Analyses to predict rates of stock recovery under a range of future catch levels. Some candidate methods are evaluated using this framework. Preliminary applications to bluefin tuna data are illustrated.

RÉSUMÉ

Un cadre de simulation a été élaboré pour évaluer les méthodes d'utilisation de la VPA pour produire des taux de rétablissement des stocks dans plusieurs hypothèses de niveaux de capture. Des méthodes choisies ont été évaluées dans ce cadre de simulation. Les applications provisoires aux données du thon rouge sont présentées.

RESUMEN

Se establece un contexto simulado a efectos de evaluar los métodos que utilizan Análisis de Población Virtual para predecir tasas de recuperación de stock con un rango de futuros niveles de captura. Se evalúan algunos métodos candidatos utilizando este contexto. Se ilustran las aplicaciones preliminares efectuadas a los datos de atún rojo.

INTRODUCTION

At its 1995 meeting, ICCAT requested the SCRS to develop recovery plans for the eastern and western Atlantic bluefin tuna stocks, based on stock projections involving recovery to MSY levels with 50% probability in 10-20 years. In responding to this request, the SCRS will need to choose a suitable method of stock projection on which to base these recovery plans. This further raises the question of on what criteria such a choice should be based. The following criteria suggest themselves initially, although there may be further considerations to take into account:

(i) when the assumptions of the method are met, the probability of recovery within the specified time period should approximate to the requested value of 50%, when this is possible;

(ii) the recovery probability should be reasonably robust to departures from the assumptions;

(iii) the variance of the future stock trajectory around the intended level should not be too great: given two methods for determining catch levels that correspond to a 50% recovery probability, the method which yields a lower probability of setting the catch substantially too high or too low would tend to be preferred.

This paper presents a simulation framework for evaluating the expected performance of recovery plans against these criteria. As an illustration, it is applied to a 'naive' recovery plan for an hypothetical scenario.

THE SIMULATION FRAMEWORK

Stock dynamics

Growth and recruitment

The stocks are simulated by size, age, and area. The evolution of the size/age structure of

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each stock over time is simulated in the manner described in SCRS/95/78. The mean growth curve is specified by the parameters of a von Bertalanffy curve, with an age-specific variance of size about the mean. The annual recruitment to the zeroth age class is related to the spawning stock size by a Beverton-Holt, power-law or Ricker stock recruitment curve. The effective spawning stock is defined by a size-specific fecundity curve. The annual recruitment is assumed to be log-normally distributed about the value predicted by the curve, with: (i) a specified variance of the log-recruitment about its expected value; and (ii) a specified year-on-year serial correlation coefficient between deviations of the log recruitment from its expected value in successive years. The initial stock size and structure is set to a random starting point roughly corresponding to the expected distribution in the absence of fishing by simulating the stock for 100 years without fishing prior to each run.

Spatial dynamics
Multiple areas can be specified, for example to correspond to the West Atlantic, East Atlantic and Mediterranean. The interchange between areas is given by either of the two models discussed in SCRS/95/80: (a) the diffusion model, in which each fish has a fixed annual probability of moving (permanently) to another area according to a specified matrix of transition probabilities; or (b) the overlap model, in which each fish remains faithful to its parent stock but the feeding areas of the stocks overlap according to a specified matrix of overlap proportions.

Natural mortality
The mean instantaneous natural mortality rate is a linear, decreasing function of size. The actual natural mortality rate in each size class in each year is log-normally distributed about its expected value with a specified, fixed variance.

Fishing
In each area, one or more fishing fleets can be specified, each with their own size-specific selectivity curve. The fishing mortality exerted by a given fleet on each size class is proportional to the size-specific selectivity for that fleet. The total catch in biomass in each past year for each fleet is normally set to the recorded historical catch, or to a different specific value, such as a fixed multiple of the recorded catch. The catch in biomass for each fishery in future years is set either to fixed values specified in a candidate recovery plan, or, in the case of dynamic recovery plans, to variable values determined by the recovery plan on the basis of new data collected up to that time. For each fishery, a maximum level of fishing mortality is specified, so that high TAC's are not fully taken. Additionally, an annual level of fishing mortality, coupled with a size-specific selectivity function, can be specified to account for completely unrecorded catch.

The number of fish tagged and released, plus a size-specific tagging selectivity function, can be specified for each area and year.

Data
The generation of four kinds of data is simulated:
- total recorded catch in biomass by fishery
- samples of catch at size by fishery
- tag recoveries by area and year
- annual effort indices by fishery.

The total catch is assumed either to be recorded correctly, or to be subject to a log-normally distributed multiplicative error with a specified bias and variance.

The sample of catch by size by fishery in each year is specified as a random sample of a specified number. Overdispersion in the size samples can be simulated by specifying a sample smaller than the actual ones.

Tags are assumed to be fully dispersed after one full year at sea: for each area and size class, tagged fish are assumed to be caught randomly at the same rate as untagged fish.

The annual recorded effort by fishery is log-normally distributed such that the expected value of the CPUE is proportional to the (size-selectivity weighted) abundance of fish for the given area, year and fishery. The variance of the CPUE is of the three-parameter form proposed in SCRS/96/63. The standardisation of the CPUE is not simulated: it is presumed that the data have been pre-standardised. In the current implementation, the variance parameters are assumed known, but it is intended to modify this to introduce stochastic uncertainty in the values of the variance parameters.

Artificial catch at age estimates are generated by age-slicing the size samples and scaling up to the total catch in biomass. Whether these estimates are used, depends on the recovery plan. The collection of real age data is not simulated. It is assumed that the growth curve parameters and the variance of size at age are known.

Conditioning
In order to use the simulation model for testing recovery plans under conditions reasonably similar to the apparent current state of the stocks, it is appropriate to condition at least some of the parameters on the observed data, especially the parameters affecting the initial stock size. The following method of conditioning has been selected. For each parameter to be conditioned, a prior distribution is specified. The model is run a fairly large number of times, typically 1,000-2,000, drawing each conditioning parameter from its prior distribution. The stochastic components in the model are simulated in the usual way. From this set of runs, the run providing the best fit to the available data, in terms of the likelihood of the abundance indices and catch at size samples, is selected. The set of runs is then sampled, with replacement: each run that is sampled is accepted with probability α, where α is the significance level of the log likelihood ratio of the likelihood of that run compared to the best-fitting run. It is assumed that this ratio is distributed as $\frac{1}{2}\chi_n^2$, where n is the number of conditioning parameters. The process is continued until 100 runs have been selected. The sub-sample of 100 runs will involve some duplicates. If it contains less than about 70 different runs, then the size of the original sample of runs should be increased.

The sub-sample of 100 runs is then used to evaluate the recovery plan as described in the next section.

This is not the most "correct" way to condition in a probabilistic sense, but is a compromise approach designed to be computationally feasible. Preliminary exploration reveals that the method works acceptably if the available data are not too informative (for example, performance was acceptable with a 20-year CPUE series with an annual c.v. of 0.4). With more informative data sets, the initial sample size of runs required to obtain 70 or more distinct runs in the final sample rapidly becomes impracticably large.

SPECIFICATION AND EVALUATION OF THE RECOVERY PLAN

Elements of a recovery plan

The recovery plan is a procedure for setting TAC's for each fishery for the next 20 years. It can either be a one-step plan, in which the TAC's for the entire period are set now, or a dynamic plan in which the TAC's are updated periodically based on the data collected up to that time. In the examples below it is assumed that a new assessment is conducted, and the TAC's updated, every five years. The final time horizon of 20 years from the present is kept fixed.

A recovery plan contains at least two elements:
(i) a procedure for assessing the status of the stock;
(ii) a rule for setting TAC levels based on the assessment.

In principle, it could contain as a third element a programme for collection of data. However, for simplicity we assume here that data collection is independent of the recovery plan, except in so far as the size of the TAC will affect the level of effort and hence the c.v. of abundance indices.

In some approaches to fishery management, for example the Revised Management Procedure of the IWC, elements (i) and (ii) have become so tightly coupled that they effectively constitute a single calculation. However, the wording of the ICCAT request suggests that some demarcation between the assessment component and the TAC-setting component is still expected.

Performance measures

Table 1 lists a suggested initial set of performance statistics that could be used to compare the relative performances of candidate recovery plans. It is tailored specifically to the ICCAT request. To date, there is insufficient experience with such recovery plans to enable one to judge what level of performance it is reasonable to expect. It is therefore suggested that these performance measures be used to compare the relative merits of different recovery plans, rather than to set some kind of absolute yardstick. Poor performance of a given plan in the simulations does not necessarily imply that the plan itself is poor: it may be a genuine reflection of the difficulty of the situation given the limitations of the data. Only if another plan can be found that performs substantially better, would one reject the original plan. For any given plan, multiple copies of Table 1 would be produced to cover a range of plausible scenarios. Ideally one would like to find a plan that gives reasonable overall performance, relative to other plans, across all scenarios.

EXAMPLE APPLICATION

A test scenario with the parameters listed in Table 2 was constructed for the purpose of initial screening and tuning of candidate plans. It has not yet been conditioned on the available data for bluefin tuna. For testing purposes, a deliberately 'naive' recovery plan was constructed. Under this plan, the current stock size and the stock recruitment parameters are jointly estimated by maximum likelihood from the abundance data and calculated catch at age in a VPA framework. The TAC is chosen so as to hit the MSY target in exactly 15 years on on a deterministic projection, if this is possible, otherwiuse the TAC is set to zero. The assessment is performed in the current year and in years 5, 10 and 15. The performance results are listed in Table 3. As expected, performance is not too good: the chance of recovery to MSY level is much less than 50%. The average TAC ranges from zero to values much too high to be taken.

The point of this example is to emphasise that a recovery plan should be subjected to at least a minimum level of testing before being put forward. This is liable to be an iterative process: a few rounds of testing and modification will help to produce a plan that performs well.

At the time of writing, a candidate recovery plan is under development but due to lack of time could not be included in this version of this paper.

Table 1. Provisional set of performance statistics

		Lower 5%-ile	Median	Upper 95%-ile
Stock size as fraction of MSY level:				
	after 0 years	*	*	*
	10 years	*	*	*
	15 years	*	*	*
	20 years	*	*	*
Mean TAC	1-10 years	*	*	*
	11-20 years	*	*	*

Table 2. Parameters of the test scenario

Stock dynamics
von Bertalanffy growth curve with $k = 0.1$, $t_0 = 0$
Length/weight exponent 3.0
c.v. of size at age: 0.2.
Natural mortality at length L:
mean = $1.0 - 0.9\ L/L_{max}$, c.v. = 0.5
Relative fecundity at length L:
$f(L) = L^3(1 - 1/(1 + \exp(5(L/L_{max} - \frac{1}{2}))))$
Spawning stock = $\Sigma_L\ f(L)\ N(L)$
Stock recruitment relationship: $R = a(B/B_0)^{\frac{1}{2}}$
(a chosen so that average stock level is B_0 in absence of fishing).
S.D. of log-recruitment: 0.5
Serial correlation in successive years: 0.5
1 stock only. 1 area only.

Fishing
1 fleet, uniform fishing mortality on sizes above $L_{max}/4$.
Fishing for last 40 years with F = 0.1.
Maximum possible F = 0.5.

Data
Annual abundance index for last 20 years. Fixed c.v. 0.4.
Sample of size 100 for size distribution in each year.
No tags.

Table 3. Performance results for the test scenario

		Lower 5%-ile	Median	Upper 95%-ile
Stock size as fraction of MSY level:				
	after 0 years	0.14	0.26	0.45
	10 years	0.07	0.22	0.77
	15 years	0.06	0.27	1.02
	20 years	0.09	0.34	1.13
Mean TAC	1-10 years	0.00	0.87	6.41
	11-20 years	0.00	0.81	3.20