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A SIMULATION FRAMEWORK TO EVALUATE MANAGEMENT STRATEGIES FOR ATLANTIC TUNAS: A PRELIMINARY EXAMPLE BASED ON EAST ATLANTIC BLUEFIN

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SUMMARY

The Ad Hoc Working Group on the Precautionary Approach (SCRS/99/11) recommended the development of a simulation modelling framework to investigate the performance of stock specific management strategies under a variety of realistic hypothesis about population and fishery dynamics. This paper describes a preliminary simulation model based on East Atlantic bluefin tuna developed using flexible software that allows the implications for management of a variety of plausible hypotheses about stock and fishery dynamics to be explored. The intention is to illustrate the ways in which such models can be used and the types of advice that they can provide

RÉSUMÉ

Le Groupe de travail ad hoc sur l'Approche de précaution (cf. document SCRS/99/11) a recommandé l'élaboration d'une structure de modélisation par simulation pour évaluer la performance de stratégies spécifiques de gestion du stock selon diverses hypothèses réalistes concernant la dynamique des populations et de la pêche. Le présent document décrit un modèle préliminaire de simulation fondé sur le thon rouge est-atlantique en utilisant un logiciel flexible permettant d'étudier les implications sur la gestion de diverses hypothèses plausibles concernant la dynamique du stock et de la pêcherie. Le but recherché était d'illustrer la façon d'utiliser des modèles de ce genre et les types d'avis qu'ils peuvent fournir.

RESUMEN

El Grupo de trabajo Ad Hoc sobre el Enfoque Precautorio (SCRS/99/11) recomendó el desarrollo de un sistema de modelos de simulación para investigar el comportamiento de las estrategias de ordenación específicas del stock bajo varias hipótesis realistas acerca de la población y la dinámica de pesquería. Este documento describe un modelo de simulación preliminar basado en el atún rojo del Atlántico este, que ha sido desarrollado empleando un programa flexible que permite explorar las implicaciones de ordenación de una serie de hipótesis plausibles acerca de la dinámica de stock y de pesquería. El objetivo es ilustrar las diversas formas mediante las cuales pueden ser utilizados tales modelos,y los tipos de asesoramiento que pueden aportar.

Introduction

The Ad Hoc Working Group on the Precautionary Approach (SCRS/99/11) recommended the development of a simulation modelling framework to investigate the performance of stock specific management strategies under a variety of realistic hypothesis about population and fishery dynamics. The recommendation was made because it was recognised that the evaluation of management options is best performed in the context of entire management procedures; that is, the combination of a particular stock assessment technique with particular control rules and their implementation (ICES, 1994). The approach is well established in the resource management context (e.g. de la Mare, 1985, 1986; IWC, 1993; Punt & Butterworth, 1995, Kell et al. in press) and is already being applied to highly migratory tuna stocks (Polacheck et al, in press).

This paper describes a preliminary simulation model based on East Atlantic bluefin tuna. This stock was specifically chosen because it displays large natural long-term fluctuations (SCRS/99/54) and it was thought important to investigate the performance of management strategies based on the typically short time series of data used in assessment which ignore longer term trends.

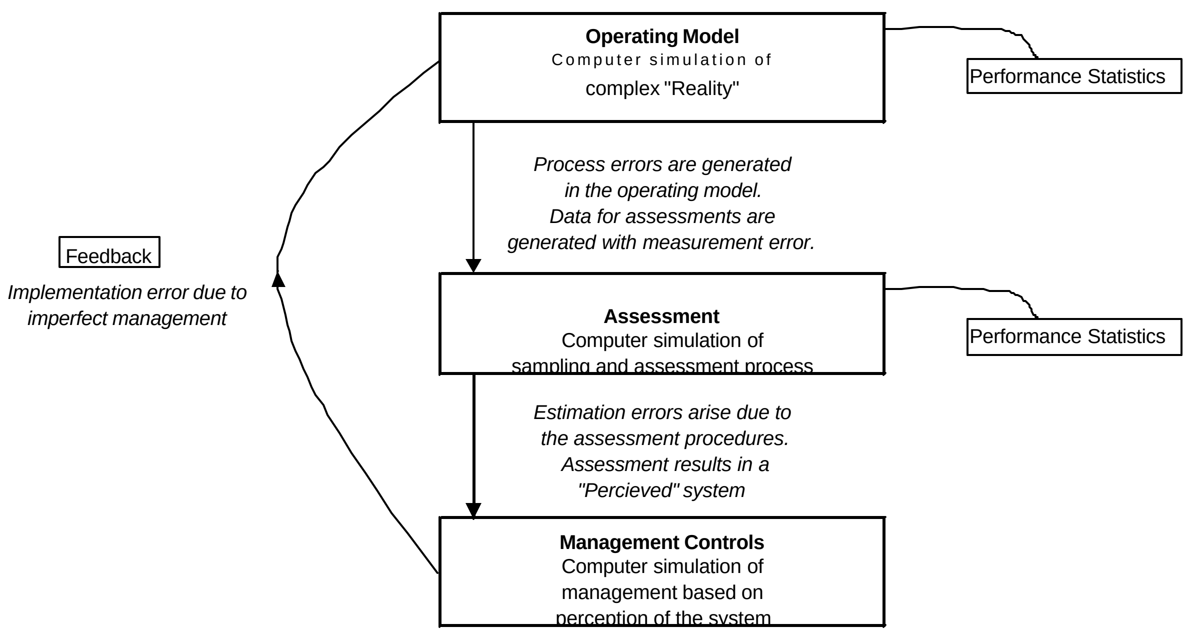
This paper describes a flexible framework that will allow the implications for management of a variety of plausible hypotheses about stock and fishery dynamics to be explored and is to illustrate the ways in which such models can be used and the types of advice that they can provide Although the simulation model includes some of the important characteristics of the stock and it's fisheries it is not yet refined enough to provide advice to managers. The intention is to eventually build realistic simulation models that can incorporate alternative hypothesis about stock status and to evaluate management advice on a case specific basis.

Simulation Model Structure

The simulation model is illustrated in Figure 1. The "true" stock and fishery dynamics are represented by an operating model, from which pseudo-data are sampled. These data are then used within an assessment procedure to determine the status of the stock and depending on the perception gained management controls are applied to the fishery.

Monte Carlo simulation is used to run the model and generate performance statistics in the form of probability distributions which are used to evaluate the performance of a given management strategy. Performance statistics are normally related to the management objectives and typically include the probability of the stock being above some minimum threshold and value of the fishery over time.

Figure 1. Simulation model structure (after ICES, 1994a).



This approach is able to model a variety of uncertainties that were categorised by Rosenberg and Restrepo (1994). Namely **process error** due to natural variation in dynamic processes (e.g. recruitment, somatic growth, natural mortality), **measurement error** generated when collecting observations from a population, **estimation error** that arises from trying to model the dynamic process (i.e. during the assessment process) and **implementation error** since management actions are never implemented perfectly.

The Operating Model

The operating model in the current example is an aged structured population in which recruitment, exploitation pattern, growth, maturity and natural mortality are modeled as random processes There is an historical period of twenty years before the stock is assessed and management is implemented. At the start of the historical period (*Year* = 0) the asymptotic recruitment in the Beverton and Holt stock recruitment model was either 3,000,000 or 4,000,000, corresponding to a period of either low or high mean recruitment respectively. The stock is exploited by five fleets with different selection patterns and catches. All parameters are given in appendix A.

Initial stock biomass is at a level corresponding to a long term steady catch of 10,000 mt. The actual biomass and fishing mortality levels will depend on the level of recruitment (i.e. either 3,000,000 or 4,000,000) used in run. Future status is determined by the "management procedure" which combines the perception of the stock, resultant management and its implementation.

Growth

Growth was assumed to follow a Von Bertalanffy growth model

$$Length_{Age} = L_{Infinity}\{1.0 - e^{-K(Age - t_0)}\}$$

and weight at age by the length weight relationship

$$Weight_{Age} = aLength_{Age}{}^{b}$$

Expected length at age can vary by year-class or year, modelled by assuming that the parameters had a multivariate normal distribution given by their variance covariance matrix. In addition a random error term was included to model additional process error In the current example only the random error term was modelled.

i.e.

$$\log(Length_{Age}) \sim N(Length_{Age}, s^2) - \frac{s^2}{2}$$

Weight at age in the stock and catch correspond to the weights at the beginning of the year and middle of the year respectively.

Maturity

Maturity at age was assumed to be the same as that used by the bluefin species group i.e. 50% mature at age 4, with all younger fish immature and all older fish mature. Uncertainty in the proportion mature was modelled as a normal random deviate after a logistic transformation.

$$\text{logit } P \sim N\left(\log\left(\frac{m}{1-m}\right), \left(\frac{cv}{1-m}\right)^2\right)$$

with a given CV and where P is on the open interval (1,0).

Natural Mortality

Natural mortality was assumed to vary at age and since no appropriate data exist for Atlantic bluefin tuna the natural mortality estimates for southern bluefin tuna (a similar species) were used. Uncertainty was modelled assuming a normal distribution error and a particular CV. Alternatives based on ecological theory linking natural mortality to growth and/or density dependence were not explored, but this could easily be done using the framework if appropriate models could be developed.

Fishing mortality

Fishing mortality is modeled as the sum of the partial Fs of fleets with different selection patterns.

$$F_{age,stock} = \sum_{fleet}^{NFleets} \sum_{area}^{NAreas} Selectivity_{age,fleet,area,stock} \times Selectivity_{year,fleet,area,stock} \times q()_{age,fleet,area,stock} \times Effort_{fleet,area}$$

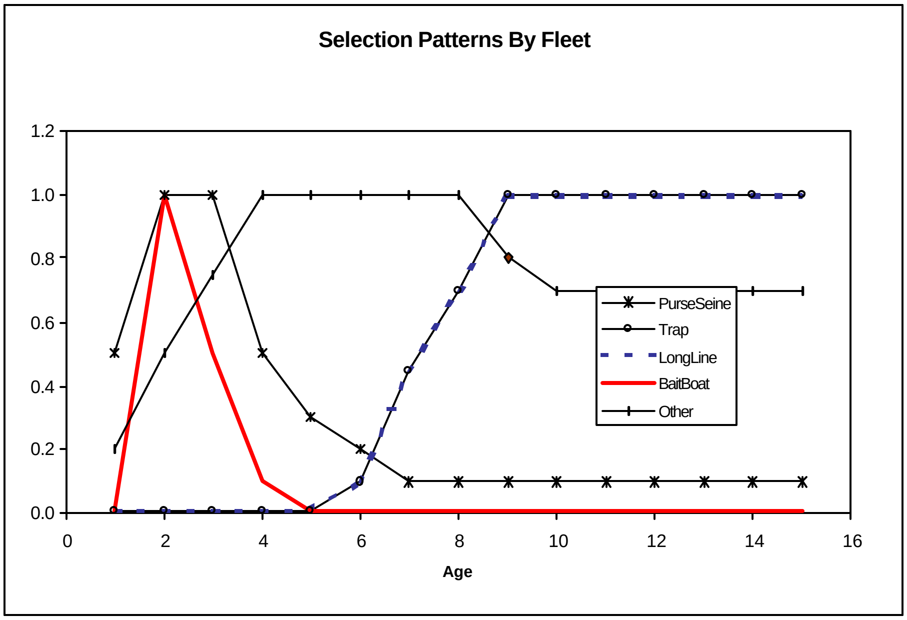
Selectivity was decomposed into age and year effects which were modelled as log normal random variables. Year effects were thought to be important in purse seine fleets. The average selection patterns for the fleets were selected to correspond to fleets primarily exploiting either immature or mature fish since it was not possible in the time available to analyse the actual catch data. q() in this example is constant but could a more complex function modelling spatial or temporal effects. Five fleets representing bait boats, long liners, purse seiners, traps and others were included in the model.

Fishing Fleets

There are five fleets approximately corresponding to purse seine, long line, trap, bait boat and other, These are not claimed to be provide realistic representation of the fleets fishing for bluefin tuna but are intended to model the change in overall selection pattern due to changes in fleet effort and population structure. Between Year=0 and Year=20 the catches of purse seiners and bait boats doubled, whilst those of the traps halved, long liners increased by 50% and the others remained the constant. The total catch in the first year was 10,000 mt which had risen to 15,000 mt by the first year in which an assessment is performed (Year =

20). The relative ratios of for purse seine : trap : long line : bait boat : other catches are 3 : 1: 3 : 1 : 2 and 12 : 1: 9 : 4 : 4 in Year = 0 and Year = 20 respectively.

Figure 2. Selection pattern by fleet in the operating model.



Catch-at-age

Catch-at-age is modeled by the catch equation

$$Catch_{age,fleet} = N_{age} \frac{F_{age,fleet}}{F_{age} + M_{age}} (1 - \exp(-F_{age} - M_{age}))$$

Effort was constrained to never decrease by more than 30% in any year, this means that fleets will misreport catches when quotas are cut if the implied effort decreases by more than 30%. Catches taken over quota are not reported to the working group.

Recruitment

It had been intended to derive a stock recruitment relationship that would capture long term trends seen in Mediterranean traps catches (SCRS/99/54) which suggest cyclic fluctuations in abundance.

However, it was not possible to model the trap data in the short time available and therefore expected recruitment was modelled by a Beverton and Holt stock recruitment relationship

$$R_t = \frac{aSSB_{t-RecruitAge}}{b + SSB_{t-RecruitAge}}$$

Variation in the recruitment process was modeled by a first order autoregressive process AR(1).

i.e.

$$R_{t+1} = f(SSB_t)e^{-\sigma^2/2}e^{\varepsilon_{t+1}},$$

where

$$\varepsilon_{t+1} = \rho\varepsilon_t + \eta_{t+1}$$
$$\eta \sim N(0,\sigma_\eta^2).$$
$$\sigma^2 = \ln(CV^2+1)$$
$$\sigma_\eta^2 = (1-\rho^2)\sigma^2$$

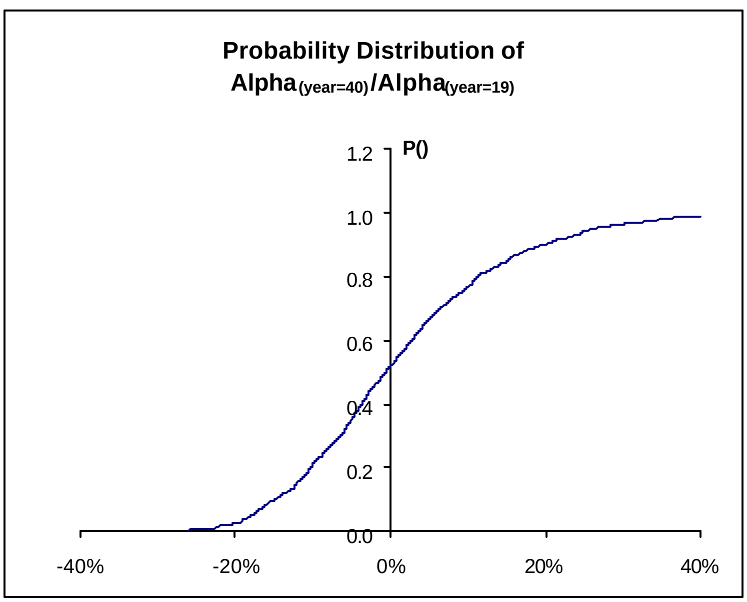
Variability in the expected level of recruitment was modelled as a random walk in Alpha

i.e.

$$Alpha_{t+1} = r\,Alpha_t + h_{t+1}$$
$$\eta \sim N(0,\sigma_\eta^2).$$

Sigma was arbitrarily chosen as 0.02 as this allowed Alpha to vary within an acceptable range, see figure 3.

Figure 3. Probability distribution of the relative value of Alpha after twenty one years when sigma = 0.02.



Initial-conditions

At the start of the simulation (*Year* = 0) fishing mortality had been constant at a level corresponding to an equilibrium catch of 10,000mt. The realised biomass and fishing mortality depend on historic recruitment levels.

Annual Z in year < 0 was assumed to have a log normal distribution with a given CV

The Sampling Procedure

Length data are sampled from the operating model to provide CPUE indices and total catch at age simulating the length sampling and slicing process.

Since the operating model is age based, length frequency distributions are generated from a growth model and the numbers-at-age. Growth was assumed to follow a Von Bertalanffy growth model and the distribution of lengths at a particular age to follow a log normal distribution.

It is assumed that a given number of length measurements are sampled randomly from each fleet in each period, and then length slicing is performed to assign the sample into age classes. The age composition of the total catch by fleet is then obtained by raising the sample to the total catch size. If not all fish are sampled then measurement error is generated by the sampling process. This process is modelled as a multinomial process where individuals are sampled randomly without replacement.

The variance in the estimated number in the population as a function of the population (N) and the sample size (n) is

$$Var(\hat{N}) = \frac{N(N-n)p(1-p)}{n-1}$$

The (N-n) bit is the finite sample size correction and p is the proportion in the age-class of interest.

If all individuals were sampled then the sampling error will be zero. The difference between sampling with and without replacement is probably only significant if the sample size is greater than 5 or 10%.

Assuming that the probability of an individual being sampled is proportional to its abundance in the population ignores how samples are selected. If samples are drawn from a small number of schools, rather than being randomly taken from the catch, then the variance will be underestimated. In practice the desired level of sampling variance can be obtained by selecting a value of *n* that generated the desired sampling CV.

The generated sample of catch-at-length-at-age are then converted to age using the length slicing algorithm where an individual is assigned into age-class i if it's length falls into the bin

$$(Length_{Age-Offset}, Length_{Age+Offset}]$$

Effort is assumed to be measurable without error although since selectivity includes a year effect the fishing mortality that a given level of effort implies will vary.

Sampling of biological parameters such as growth, maturity and natural mortality was not modelled values were the same as that used in the 1998 assessment and did not vary between years.

The Management Procedure

The management procedure combines the assessment method, the calculation of biological reference points and the management rule used to set catches. Assessments were performed every two years and management targets set consistent with the strategy of maining stock biomass close to B_{MSY}

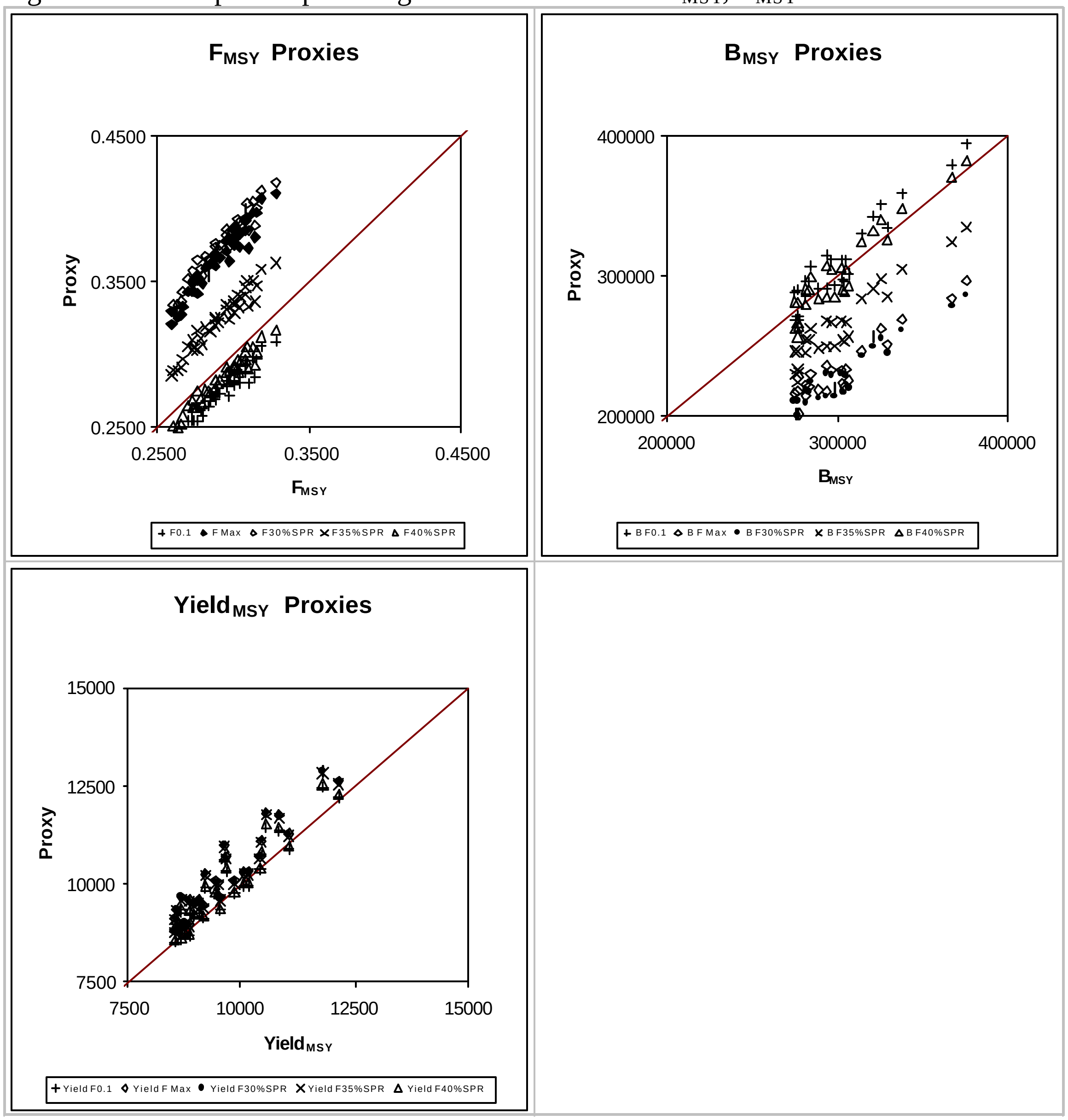
The assessment method

The assessment method used was FADAPT Ver 4. (Restrepo, pers. comm.). Age based indices were generated from the CPUE indices using partial catches and all the fleets were used to tune the VPA. The F ratio (i.e. the ratio between F in the plus group and the oldest true age) was assumed to be 1.0 when the reported catch data were sampled perfectly and a single estimate was made for all years when the catch was sampled by length slicing. In the latter case it was found that FADAPT fitted the data better when the catch data were biased due to length slicing even though the true F ratio was 1.0. Selection pattern in the first assessment year, natural mortality, maturity, weights–at-age are given in the appendix. Natural mortality, maturity and weights–at-age did not vary and were the same as the expected values used in the operating model. Selection pattern was set for the first assessment year and subsequently was estimated using ten years of data from the converged part of the VPA.

Calculation of Reference points

Reference points were calculated using the Precautionary Approach software developed for ICES working groups. In order to determine which proxy to use for MSY a single stochastic simulation (where asymptotic recruitment = 3,000,000) was run for a range of catches that that were likely to be seen in the simulations. Potential proxies for F_{MSY}, B_{MSY} and MSY were calculated and then plotted against the true value in figure 4. From this figure it can be seen that $F_{40\%\ SPR\ Max}$ performed best and so this reference point was used to decide management targets.

Figure 4. Potential proxies plotted against the true values of F_{MSY}, B_{MSY} and MSY



Management

The management objective is to maintain the stock at a level that will support the Maximum Sustainable Yield (MSY), if the stock is below this level then it has to be rebuilt to this level within an appropriate time scale whilst maintaining a viable fishery. The management rule was therefore of the following simple form rather than a harvest control rule (HCR) based on fishing mortality and biomass as used in some fora (ICES, 1998, NAFO 1998).

If $Biomass_0 < BMSY_0 * 0.6$ then

Catch$_t$ = Catch that causes a recovery to BMSY in 30 years

Else If $Biomass_0 < BMSY_0 * 0.8$ then

Catch$_t$ = Catch that causes a recovery to BMSY in 15 years

Else

Catch$_t$ = MSY

Experimental Design

A number of experiments were designed to illustrate the utility of the approach, rather than to explore all plausible hypothesis about the dynamics of the stock and its fisheries and possible management strategies.

A base line simulation (Run 0) was specified which comprised an historical period with a level of asymptotic recruitment of 3,000,000. Biological parameters were the same as those assumed by the 1998 bluefin species group and the assessment estimated F and N without error. The future component of the operating model is equivalent to the type of stock projection performed by stock assessment working groups. The future is therefore essentially a traditional projection and corresponds to the "best case". When additional uncertainty is introduced in the form of measurement, estimation and implementation errors and feedback between the various components is included the ability to manage the stock will be reduced.

The factors investigated with different levels were

Recruitment

Asymptotic Recruitment = 3,000,000
Asymptotic Recruitment = 4,000,000

Assessment

Perfect (i.e. true F and N are known to working group)
Adapt

Catch Sampling

Perfect
Length Slicing

Table 1. Experimental Treatments (i.e. a particular combination of levels of all the factors)

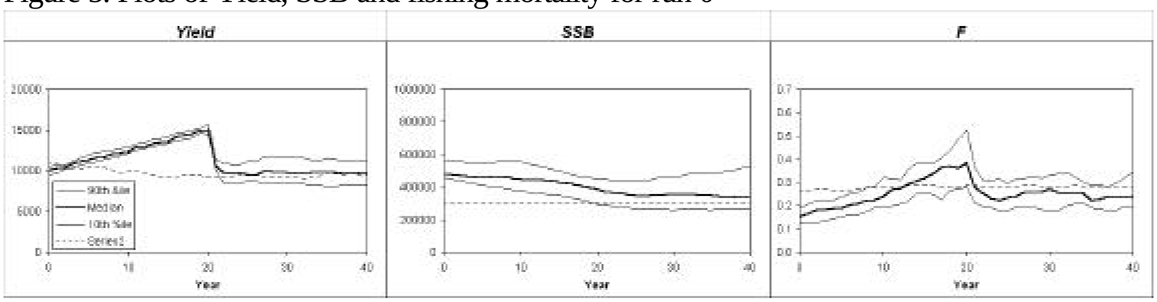
	Treatment or Run					
Factor	0	1	2	3	4	5
Asymptotic Recruitment	3,000,000	4,000,000	3,000,000	4,000,000	3,000,000	4,000,000
Assessment	Perfect	Perfect	ADAPT	ADAPT	ADAPT	ADAPT
Sampling	Perfect	Perfect	Perfect	Perfect	Length Slice	Length Slice

To allow experiments to be analysed efficiently and to explore the iteractions between levels of the different treatments a factorial experiment could have been designed. When combined with generalised linear models this is a particularly powerful way to analyze the results of simulation models

Results

One hundred and fifty iterations were made for each run, this is not a magic number but simply all there was time for. The results are presented in the form of summary statistics that allow the performance of management, judged against the objectives, to be compared across treatments. The management objectives are to maintain the stock at a level that will support MSY whilst maintaining a viable fishery, the summary statistics therefore describe the true Yield, biomass and fishing mortality relative to MSY, B_{MSY} and F_{MSY}

Figure 5. Plots of Yield, SSB and fishing mortality for run 0

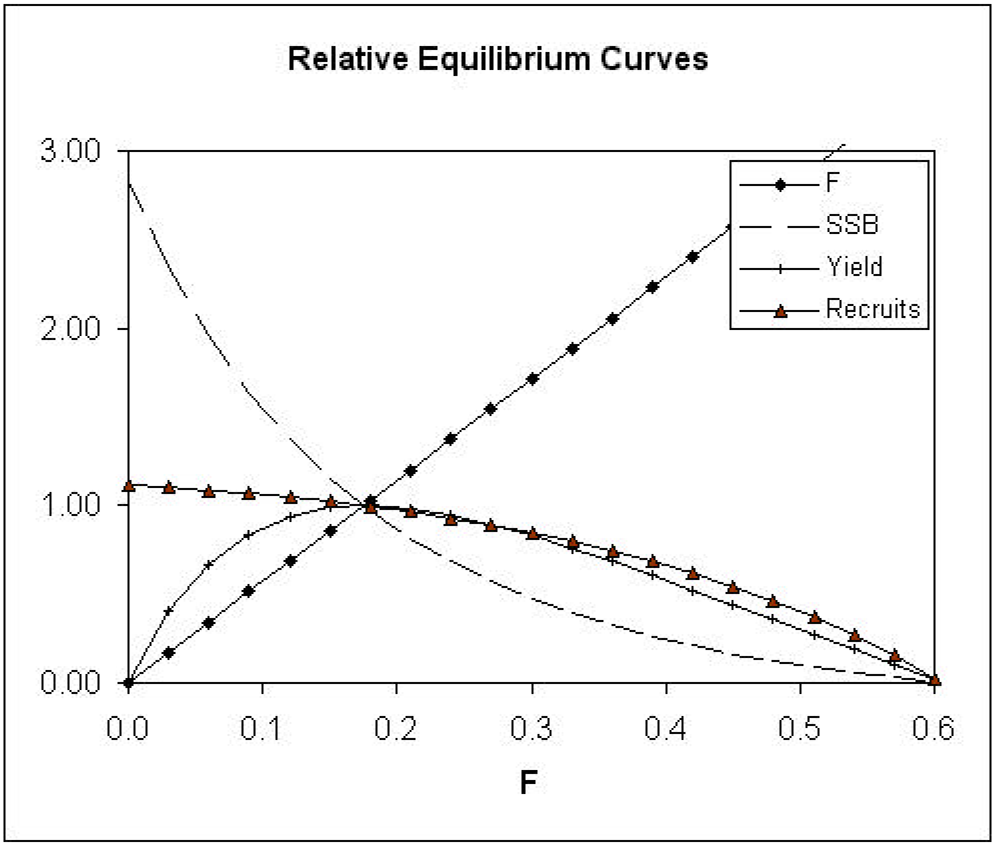


The results from run 0 are summarised in figure 5, the uncertainty in the both the historical and future is quantified by the 10^{th} and 90^{th} percentiles. For comparison the medians of MSY, B_{MSY} and F_{MSY} are plotted as the hatched lines. It should be noted that MSY is not constant due to changes in selection pattern and the expected value of asymptotic recruitment. The yield increases from *Year*=0 to *Year*=19 causing SSB and fishing mortality to decrease and increase respectively. Yield is above MSY after *Year*=3 but fishing mortality continues to remain below F_{MSY}, this is because SSB is only depleted slowly.

In *Year*=21 as a result of management catches are reduced to about 10,000 mt (i.e. near the MSY level) whilst SSB and fishing mortality stablise near B_{MSY} and F_{MSY} respectively.

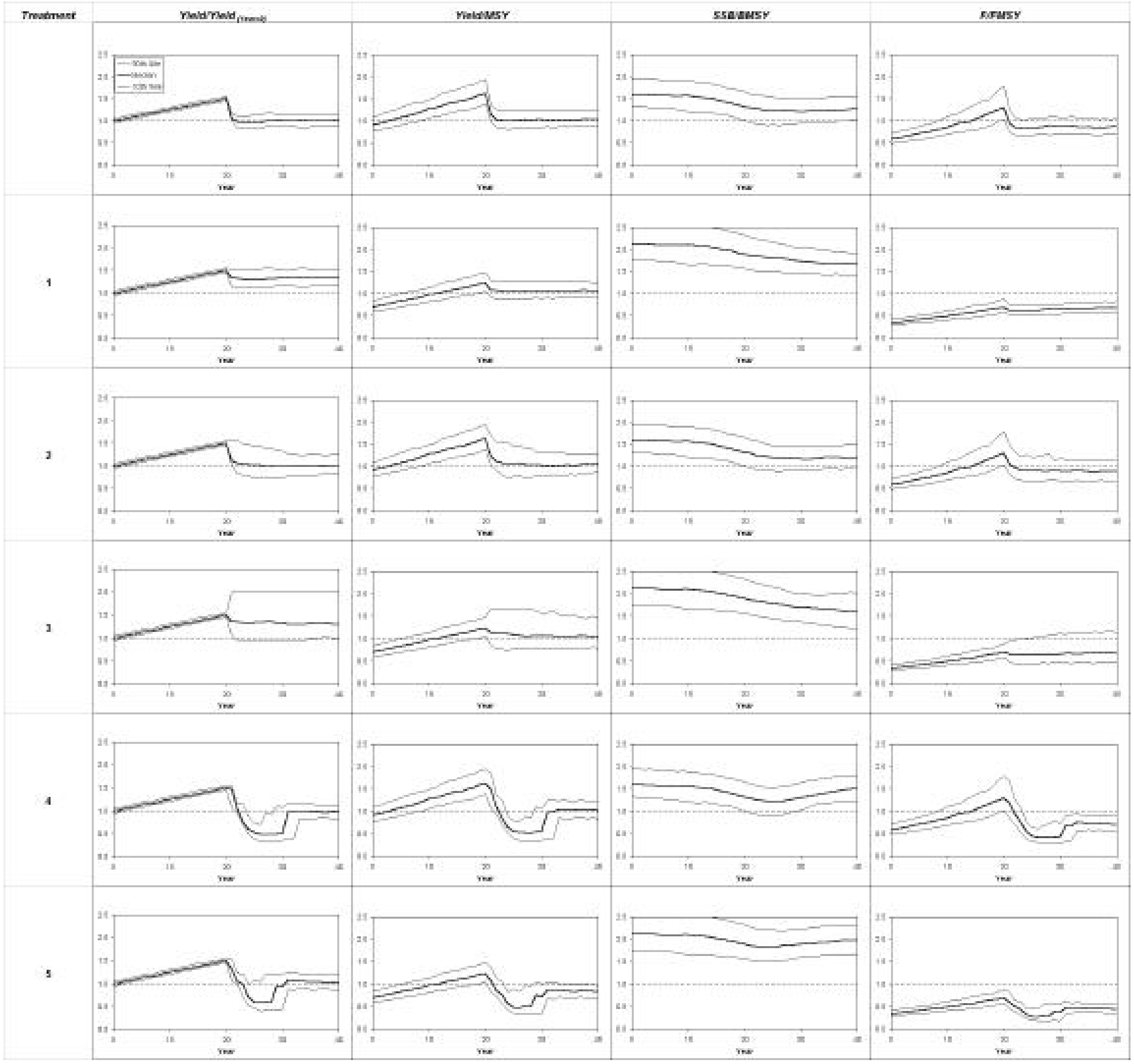
Figure 6 shows the equilibrium curves for fishing mortality, SSB, yield and recruitment plotted against fishing mortality, scaled so that their values at F_{MSY} are 1.0. It should be noted that all the curves are independent of the value of asymptotic recruitment. At F_{MSY} a small change in yield will have a relatively large effect on SSB and fishing mortality. For example if yield decreases by about 10% both SSB and fishing mortality will change by about 40%.

Figure 6. Equilibrium SSB, yield and recruits plotted against fishing mortality, all values are scaled so that their values at F_{MSY} are 1.0. N.B. curves are independent of the value of asymptotic recruitment.



All the runs are summarized in figure 7, scaled (Yield/Yield$_{(Year=0)}$, Yield/MSY, SSB/B$_{MSY}$ and F/F$_{MSY}$,) rather than absolute values are presented for ease of comparison between runs. These summary statistics allow statements about the sustainable level of yield that the fishery can support and the performance of management relative to the objective of harvesting the stock at MSY to be made. The first column of figure 7 allows the potential yields under different recruitment regimes and with different levels of precision in the assessment to be compared. Whilst the second, third and fourth columns allow the performance of the management procedure to be judged against the objective of maintaining SSB near B$_{MSY}$.

Figure 7. Stochastic trajectories of Yield/Yield$_{(Year=0)}$, Yield/MSY, SSB/B$_{MSY}$ and F/F$_{MSY}$, Inner line is the median and outer lines are the 10th and 90th percentiles



There are two conclusions that can be drawn from 7, unsurprisingly if asymptotic recruitment is 4,000,000 rather than 3,000,000 then potential yield is greater and our ability to manage the stock is affected by our ability to assess it. Bias in the data are probably the most important factor in influencing the latter.

If run 2 is compared to run 4 and run 3 is compared to run 5 the effect of length slicing can be seen. The length slicing algorithm biases the catch-at-age and hence the estimates of fishing mortality and population abundance. This results in fishing mortality being overestimated and stock size underestimated and management acts to reduce catches. However, if the implied effort falls by over 30% in any year then catches are misreported. This is because "true effort" is constrained to never decrease by more than 30% in any year and so over quota catches can occur. Since these over quota catches are not reported and hence not included in the catch at age matrix the true stock size will be underestimated following the management action.

The results clearly illustrate the importance of feedback and of considering the management assessment processes as a whole. The Ad-Hoc working group on the precautionary approach recognized this linkage and stated that "The regulation on catch and/or fishing operation changes the quality and quantity of fishery information and deteriorates information on the stock status. These increase the uncertainty in the stock assessment and then more severe regulation will be introduced." This is particularly important in that ICCAT stock assessments rely almost entirely on commercial catch and effort data.

One of the objectives of the study was to investigate the effect of long-term fluctuations on the biological reference points and hence management based upon them. Allowing asymptotic recruitment to vary as a random walk in the future part of the model simply added to the variance of MSY, B_{MSY} and F_{MSY} as there was no upward or downward trend in these reference points. This can be seen in figure 5 where the median values of MSY, B_{MSY} and F_{MSY} were plotted. Comparing runs 3 and 5 it can be seen that length slicing has resulted in the long-term yield being reduced at higher recruitment levels. This might be because of the way in which the selection pattern in the terminal year for ADAPT was set rather than due to length slicing.

In retrospect the way in which the model was set up does not appear to answer fully the question of long-term verses short-term estimates of carrying capacity and more work still needs to be done. Despite this it is still possible to use the existing results to investigate the effect of trends in recruitment. The ratio of $SSB_{(Year=40)}$ to B_{MSY} is an index of how well the management objectives of maintaining or rebuilding the stock to B_{MSY} have been met. Therefore a plot of $SSB_{(Year=40)}$ / B_{MSY} against Asymptotic $Recruitment_{(Year=40)}$ /Asymptotic $Recruitment_{(Year=40)}$ is a simple way of investigating the relationship between the direction of any trend in recruitment and the ability to meet management objectives.

Figure 8. A plot of $SSB_{(Year=40)}$ / B_{MSY} against Asymptotic $Recruitment_{(Year=40)}$ /Asymptotic $Recruitment_{(Year=40)}$ for runs 4 and 5 (Adapt with length slicing), a lowess smoother is fitted to the data.

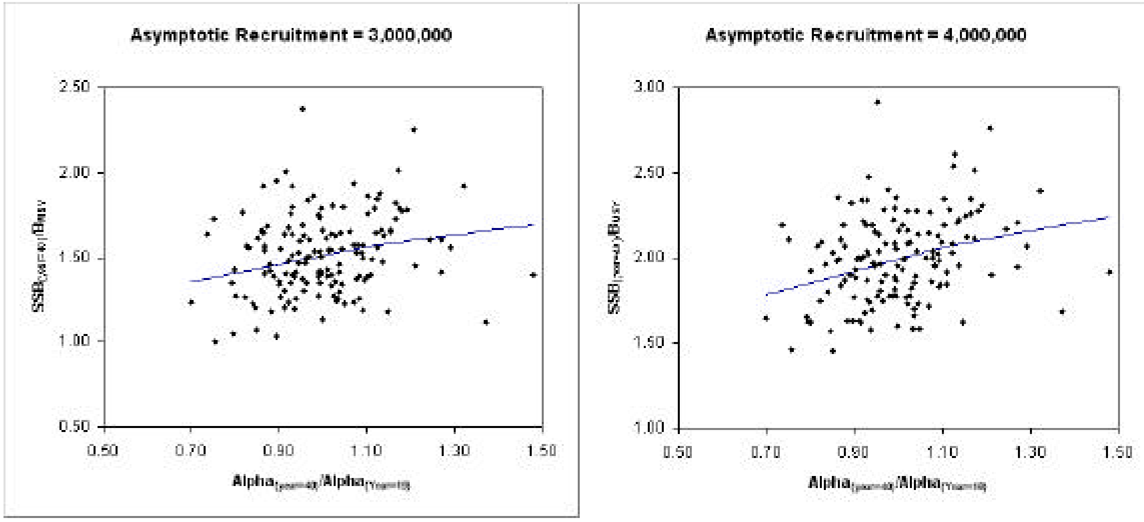
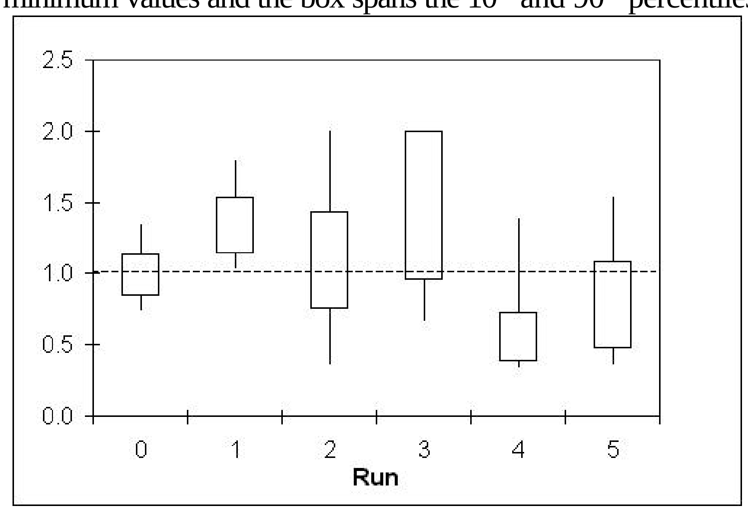


Figure 8 quite clearly shows that if recruitment is increasing the SSB in $Year=40$ is likely to be higher than if the trend in recruitment is downward. That is if recruitment is increasing then management that attempts to conserve the stock is likely to be more successful, with hindsight not a particularly surprising result. However, this simple example demonstrates the flexibility of the approach. More sophisticated analysis could be performed using generalised linear or additive models and these would be particularly useful when the experimental design is more complicated than that used in this paper.

An alternative way of looking at the results is in the form of probability plots these are similar to an analysis of variance and can be used to make inferences about the effect of the various experimental treatments.

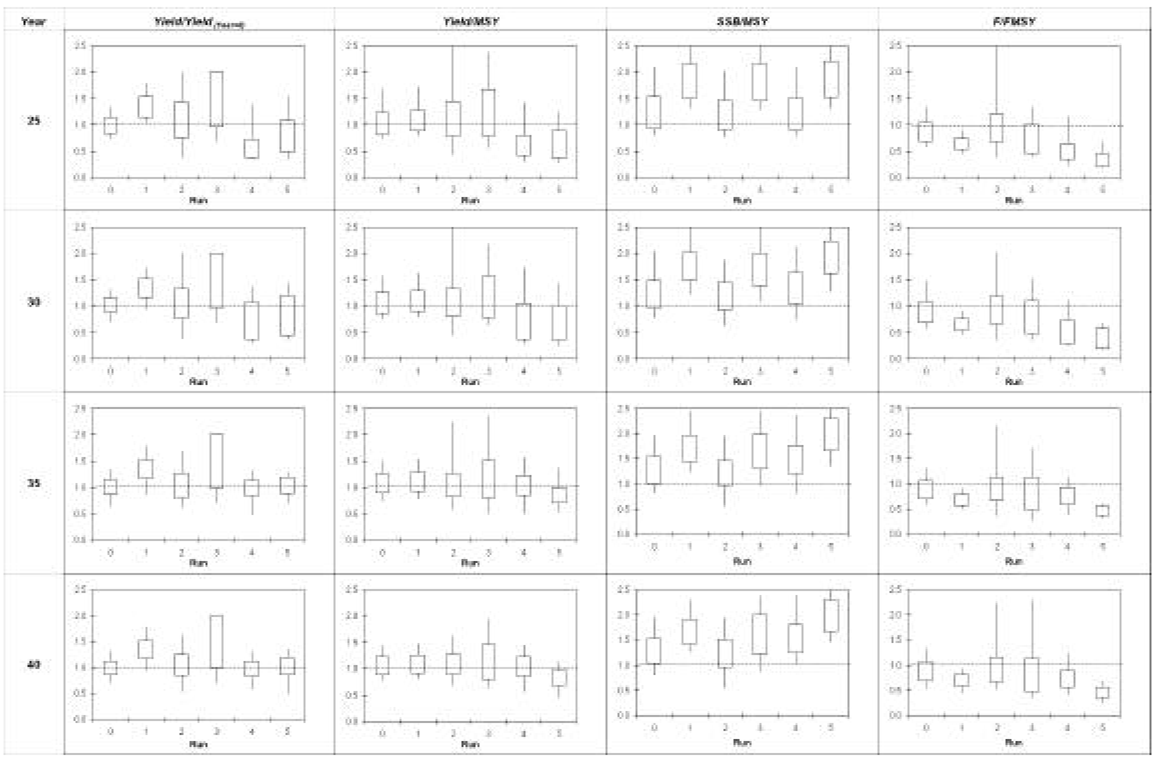
Figure 9. A comparison of Yield/$Yield_{(Year=0)}$, in $Year=25$ for all runs, Whisker are the maximum and minimum values and the box spans the 10th and 90th percentiles range.



The figure shows that the yield is greater in *Year*=25 when asymptotic recruitment is 4,000,000. Assessing the stock using Adapt (runs 2 and 3) increases the uncertainty in the yield but the expected values are about the same. When bias in the data sampling process is included (runs 4 and 5) the yield in *Year*=25 are significantly decreased.

Similar plots for *Year*=30, *Year*=35 and *Year*=40 are presented in figure 10, where in addition to Yield/Yield$_{(Year=0)}$, Yield/MSY, SSB/B$_{MSY}$ and F/F$_{MSY}$ are also plotted.

Figure 10. A comparison of Yield/Yield$_{(Year=0)}$, Yield/MSY, SSB/B$_{MSY}$ and F/F$_{MSY}$, in *Year*=25, *Year*=30, *Year*=35 and *Year*=40, Whisker are the maximum and minimum values and the box spans the 10th and 90th percentiles range.



As powerful as these figures are the authors do not wish to over interpretate the results of what is a preliminary study. It is clear, however, that the figures do make it is possible to make statements about how well the management objectives are met under the different treatments.

Conclusions

The authors do not wish to make too much of these preliminary results or provide specific management advice as the intention of this paper was to illustrate the ways in which simulation models can be used and the types of advice that they can provide. However, if the model is refined to incorporate more realistic stock and fishery dynamics on a case by case basis then it will be possible to use such a framework to determine safe limits under which stocks can be harvested, to evaluate management options proposed by the Commission or to investigate the benefits of improved data collection and scientific understanding. The paper therefore takes an important first step towards developing a flexible framework that will allow the implications for management of a variety of plausible hypotheses about stock and fishery dynamics to be explored.

However, more work needs to be done first to refine the assumptions and the models. This will require detailed analysis of the various available data sets and will be a large undertaking.

The Software

The software used to build the simulation model was originally developed at the CEFAS Lowestoft Laboratory, with partial funding from the European Union (EC Study Project 94/110: Core Program Development for the Modelling of Fishery Management Strategies). The main routines are in the form of Dynamic Link Libraries (DLLs) that run under Windows 95, Windows 98 or Windows NT. These DLLs contain a variety of fishery, mathematical, statistical and utility routines that can be combined in a flexible way using Visual Basic. They have been previously been used for a variety of modelling and assessment tasks within the International Fisheries community. The modular approach makes it easy to incorporate these routines into or integrate them with other applications or packages. It also makes it easy to implement new applications quickly and flexibly.

FADAPT Version 4 is a Fortran program that was integrated into the library and is now available as a DLL.

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Appendix. Parameters used in simulation model

Stock Recruit Relationship

Beverton and Holt

Alpha	2.50E-07
Beta	0.0200
Sigma	0.3853
Rho	0.0000
CV	0.4000

Growth

Von Bertalanffy

		Variance Covariance		
		Linf	K	t0
Linf	318.85	101	0	0
K	0.093	0	0.00008	0
t0	0.97	0	0	0.000002
Cond Fact	3.0E-08			
Power	2.89896			
CV	0.1			
Instantaneous time of				
Spawning	0.5			
Capture	0.5			
Vary By	Year Class			

Biological Parameters

	Expected values				***Error (CVs)***		
Age	***Sel***	***M***	***Maturity***	***Age***	***Sel***	***M***	***Maturity***
1	0.18	0.490	0.0	1	0.10	0.10	
2	1.00	0.240	0.0	2	0.10	0.10	
3	0.68	0.240	0.0	3	0.10	0.10	
4	0.27	0.240	0.5	4	0.10	0.10	0.10
5	0.14	0.240	1.0	5	0.10	0.10	
6	0.12	0.200	1.0	6	0.10	0.10	
7	0.11	0.175	1.0	7	0.10	0.10	
8	0.12	0.150	1.0	8	0.10	0.10	
9	0.13	0.125	1.0	9	0.10	0.10	
10	0.13	0.100	1.0	10	0.10	0.10	
11	0.13	0.100	1.0	11	0.10	0.10	
12	0.13	0.100	1.0	12	0.10	0.10	
13	0.13	0.100	1.0	13	0.10	0.10	
14	0.13	0.100	1.0	14	0.10	0.10	
15	0.13	0.100	1.0	15	0.10	0.10	

Selection Patterns

Expected values

Age	PurseSeine	Trap	LongLine	BaitBoat	Other
1	0.5	0.0	0.0	0.0	0.2
2	1.0	0.0	0.0	1.0	0.5
3	1.0	0.0	0.0	0.5	0.8
4	0.5	0.0	0.0	0.1	1.0
5	0.3	0.0	0.0	0.0	1.0
6	0.2	0.1	0.1	0.0	1.0
7	0.1	0.5	0.5	0.0	1.0
8	0.1	0.7	0.7	0.0	1.0
9	0.1	1.0	1.0	0.0	0.8
10	0.1	1.0	1.0	0.0	0.7
11	0.1	1.0	1.0	0.0	0.7
12	0.1	1.0	1.0	0.0	0.7
13	0.1	1.0	1.0	0.0	0.7
14	0.1	1.0	1.0	0.0	0.7
15	0.1	1.0	1.0	0.0	0.7
Fishing	TRUE	TRUE	TRUE	TRUE	TRUE
Tuning	TRUE	TRUE	TRUE	TRUE	TRUE

Error (CVs)

Age	PurseSeine	Trap	LongLine	BaitBoat	Other
1	0.30	0.10	0.10	0.10	0.10
2	0.30	0.10	0.10	0.10	0.10
3	0.30	0.10	0.10	0.10	0.10
4	0.30	0.10	0.10	0.10	0.10
5	0.30	0.10	0.10	0.10	0.10
6	0.30	0.10	0.10	0.10	0.10
7	0.30	0.10	0.10	0.10	0.10
8	0.30	0.10	0.10	0.10	0.10
9	0.30	0.10	0.10	0.10	0.10
10	0.30	0.10	0.10	0.10	0.10
11	0.30	0.10	0.10	0.10	0.10
12	0.30	0.10	0.10	0.10	0.10
13	0.30	0.10	0.10	0.10	0.10
14	0.30	0.10	0.10	0.10	0.10
15	0.30	0.10	0.10	0.10	0.10
Year	0.30	0.10	0.10	0.10	0.10

Historical Targets

Relative

Year	Purse Seine	Trap	Long Line	Bait Boat	Other
0	1.00	1.00	1.00	1.00	1.00
1	1.05	0.98	1.03	1.05	1.00
2	1.10	0.95	1.05	1.10	1.00
3	1.15	0.93	1.08	1.15	1.00
4	1.20	0.90	1.10	1.20	1.00
5	1.25	0.88	1.13	1.25	1.00
6	1.30	0.85	1.15	1.30	1.00
7	1.35	0.83	1.18	1.35	1.00
8	1.40	0.80	1.20	1.40	1.00
9	1.45	0.78	1.23	1.45	1.00
10	1.50	0.75	1.25	1.50	1.00
11	1.55	0.73	1.28	1.55	1.00
12	1.60	0.70	1.30	1.60	1.00
13	1.65	0.68	1.33	1.65	1.00
14	1.70	0.65	1.35	1.70	1.00
15	1.75	0.63	1.38	1.75	1.00
16	1.80	0.60	1.40	1.80	1.00
17	1.85	0.58	1.43	1.85	1.00
18	1.90	0.55	1.45	1.90	1.00
19	1.95	0.53	1.48	1.95	1.00
20	2.00	0.50	1.50	2.00	1.00
Fleet Share 0	0.3000	0.1000	0.3000	0.1000	0.2000
Fleet Share 20	0.4000	0.0333	0.3000	0.1333	0.1333

Error (CVs)

Year	Purse Seine	Trap	Long Line	Bait Boat	Other
0	0.20	0.20	0.20	0.20	0.20
1	0.20	0.20	0.20	0.20	0.20
2	0.20	0.20	0.20	0.20	0.20
3	0.20	0.20	0.20	0.20	0.20
4	0.20	0.20	0.20	0.20	0.20
5	0.20	0.20	0.20	0.20	0.20
6	0.20	0.20	0.20	0.20	0.20
7	0.20	0.20	0.20	0.20	0.20
8	0.20	0.20	0.20	0.20	0.20
9	0.20	0.20	0.20	0.20	0.20
10	0.20	0.20	0.20	0.20	0.20
11	0.20	0.20	0.20	0.20	0.20
12	0.20	0.20	0.20	0.20	0.20
13	0.20	0.20	0.20	0.20	0.20
14	0.20	0.20	0.20	0.20	0.20
15	0.20	0.20	0.20	0.20	0.20
16	0.20	0.20	0.20	0.20	0.20
17	0.20	0.20	0.20	0.20	0.20
18	0.20	0.20	0.20	0.20	0.20
19	0.20	0.20	0.20	0.20	0.20
20	0.20	0.20	0.20	0.20	0.20

Initial Conditions

In first simulation year

Min Year	0
Catch	10000
Residual	0.0000
P(Residual)	0.5000
Z CV	0.0000
Recruitment	4000000