THE CHOICE OF PROCEDURE FOR DECIDING WHEN TO CLOSE FISHERIES REGULATED BY CCAMLR: A SIMULATION MODEL

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Abstract

The methods, described in CCAMLR Conservation Measures, used for deciding the closure date for fisheries monitored by the Secretariat of CCAMLR, have been difficult to implement because of the variation in catch rates shown by the fisheries. Non-fluctuating random and fluctuating random catch histories are simulated and the performance of four models for making closure decisions is investigated under a variety of circumstances.

The model described in the existing conservation measures is shown to have a high probability of allowing large over- or under-shoots of the TAC. The most successful model determines the trend of catch rates using linear regression over the latest four reporting periods, and closes the fishery if these rates indicate that the TAC will be taken before the next report is received by the Secretariat. The probability of large over-shoots of the TAC is reduced if reporting periods are small (five days) and the reporting delay is minimal.

It is recommended that in future conservation measures, methodologies for deciding the date of closure of fisheries should incorporate a formulation of Model 4, given in this paper.

Résumé

Les méthodes décrites dans les mesures de conservation de la CCAMLR, servant à déterminer la date de fermeture des pêcheries contrôlées par le secrétariat de la CCAMLR, sont difficiles à appliquer en raison de la variation des taux de captures des pêcheries. L'historique des captures aléatoires fluctuantes et non fluctuantes sont simulées et la performance de quatre modèles de décision de fermeture soumis à des conditions diverses est examinée.

Avec le modèle décrit dans les mesures de conservation en vigueur, le taux de capture a toutes les chances d'être bien en-dessous ou bien au-dessus du TAC. Le meilleur modèle détermine la tendance des taux de captures par une régression linéaire effectuée sur les quatre dernières périodes de déclaration; il ferme la pêche si ces taux indiquent que le TAC sera atteint avant que la prochaine déclaration ne parvienne au secrétariat. La probabilité d'un dépassement important du TAC est réduite lorsque les périodes sont courtes (cinq jours) et le délai de déclaration minime.

Il est recommandé, pour les prochaines mesures de conservation, d'inclure la description du Modèle 4 donnée dans cette communication dans toute méthodologie relative à la décision d'une date de fermeture des pêcheries.

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Резюме

В связи с колебаниями уловов в период промысла, в прошлом было сложно использовать метод расчета сроков закрытия тех промыслов, которые контролируются Секретариатом АНТКОМа. Эти метод описан в соответствующих мерах по сохранению. Сформулированы модели, описывающие случайно генерированные серии уловов с колебаниями и без колебаний. Изучена эффективность четырех моделей принятия решений о закрытии промысла в зависимости от разных обстоятельств.

Показано, что описанная в существующих мерах по сохранению модель имеет высокую вероятность получения бо̀льших превышений или недополучений ТАС. Самая эффективная модель определяет тенденцию изменения в размерах вылова с использованием линейной регрессии за последние четыре отчетные периоды и закрывет промысел в том случае, если интенсивность вылова указывает на достижение ТАС до поступления следующего отчета в Секретариат. Вероятность больших превышений ТАС меньше, если отчетные периоды коротки (пять дней) и промежуток времени до получения отчета минимален.

Рекомендуется, что в дальнейших мерах по сохранению методы принятия решений о сроках закрытия промысла должны включить в себя какую-либо формулировку Модели 4, приведенной в настоящей работе.

Resumen

Los métodos contemplados en las medidas de conservación de la CCRVMA y que han sido utilizados para decidir el cierre de las pesquerías controladas por la Secretaría de esta organización, han sido difíciles de llevar a la práctica debido a la variación en los índices de captura experimentada por la pesquería. Se simulan las capturas históricas aleatorias fluctuantes e invariables y se prueba la aplicación de cuatro modelos para decidir el cierre de las pesquerías bajo diversas condiciones. Se ha constatado que el modelo descrito en las medidas de conservación actuales tiene una alta probabilidad de permitir excesos y déficit significativos con respecto al TAC. El modelo más exitoso determina la tendencia de los índices de captura mediante una regresión lineal de los últimos cuatro períodos y determina el cierre de la pesquería cuando estos índices indican que el TAC será alcanzado antes de que la Secretaría reciba el próximo informe. La probabilidad de que se exceda el TAC de manera considerable se ve reducida si los períodos de notificación son cortos (cinco días) y el tiempo entre notificaciones es mínimo.

Se recomienda que en las futuras medidas de conservación, la formulación del Modelo 4 (presentado en el documento) sea incorporado en los métodos para decidir la fecha de cierre de las pesquerías.

1. INTRODUCTION

CCAMLR manages fisheries in its Convention Area[1] by a number of traditional means (mesh size regulation, closed areas, Total Allowable Catches (TAC) etc.). At present CCAMLR has no rationally managed quota system for ensuring TAC control on the fisheries. Instead, TACs are administered by the CCAMLR Secretariat. Reports of catches are made to the Secretariat by all countries engaged in a specific fishery, and the Secretariat determines when the TAC has been taken.

There have now been two seasons for which the Secretariat has had to implement a closure of fisheries regulated by catch limits in Subarea 48.3. The history of these fisheries is described in CCAMLR (1990 and 1991).

TAC conservation measures set at CCAMLR-VIII and CCAMLR-IX specified that:

- catches should be reported to the Secretariat by 5-day reporting period, reports falling due at the end of the period following that in which catches are taken;
- the Secretariat should calculate the date of closure of the fishery using the catch rate from the most recent reporting period; and
- when the cumulative catch is 90% (Conservation Measure 17/VIII) or 80% (Conservation Measure 25/IX) of the TAC the Executive Secretary shall notify Members that the fishery will be closed from the date shown by his calculations to be that on which the TAC will have been taken.

The central problem in all closure methods is that it is not possible to close the fishery at exactly the same time that the TAC is reached because of the time delay between catches being reported to Member countries, those catches being reported to the Secretariat, and any notification of a closure decision being transmitted from the Secretariat to fishermen via their national management bodies. This means that the Secretariat must attempt to predict dates of closure.

The types of predictive method outlined in conservation measures to date rely upon fishing effort being constant and having low variance. In the case of the *Champsocephalus gunnari* fishery in 1989/90 and the *Dissostichus eleginoides* fishery in 1990/91, this method was inadequate for predicting the correct date of closure of the fishery. Contributing factors to this failure were:

- the variation of catch rates was quite high (coefficient of variation 0.2 to 0.3);
- the catch rates were high in the *C. gunnari* fishery in 1989/90 (about 1% of the TAC per day) and very low in the *D. eleginoides* fishery in 1990/91 (0.05 to 0.5% of the TAC per day); and
- catch rates sometimes varied in an almost cyclic way, by a factor of 10 or more.

The catch history for the 1991 *D. eleginoides* fishery is shown in Figure 1.

As a result of these factors, catches were greater than the TAC in 1990 by 1% and the method was found to be unworkable in 1991. In this latter year, a second method was developed (Model 2 in this paper) that resulted in catches being 4.3% less than the TAC.

This paper describes a simulation model constructed in order to investigate further the performance of various methods of arriving at a closure decision and to develop methods with a higher performance than those presently in use.

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[1] Except in the French EEZ around Kerguelen which is managed by France.

2. MODEL PARAMETERISATION

The model was constructed so that it would reflect the progress of a real fishery as much as possible. Whilst the fishery was modelled on a daily basis, the only information available to the Secretariat was assumed to be the catch for a single reporting period.

2.1 Catch Rates

Catch histories for fisheries were modelled on a daily basis in order to allow different reporting periods to be tested. All catches were expressed as proportions of a TAC.

Two models were used:

- Type I catch - random catch rates

$$C = \bar{c} + S_c \cdot \rho$$

where C is the catch rate for one day, $\bar{c}$ = mean catch, S_c = standard deviation (derived from the coefficient of variation cv_c), and ρ is a normally distributed random deviate; and

- Type II catch - regularly changing catch rates, modelled by a sine function overlaid with a variance that is proportional to catch rate

$$C = \bar{c} + \alpha \cdot \bar{c}, \ \sin(\theta) + \delta \cdot S_c \cdot \rho$$

where α is the amplitude of the sin wave, θ is the position of the sinusoidal cycle at time t computed from the equation $\theta = \theta_o + \pi / \lambda$ (t is time in days, λ = period of sin wave in days, θ_o = start position, randomly determined), and δ is an adjustment of the variance that is proportional to C.

An example of a simulated Type II catch is given in Figure 2 and can be compared with the catch history of the *D. eleginoides* fishery in 1991 (Figure 1).

2.2 Catch Reporting

The date that a catch report arrives at the Secretariat was modelled by:

$$D = P + \bar{d} + s_d \cdot \rho$$

where D is the total time from the end of a reporting period to the arrival of the report at the Secretariat in days, P = length of the reporting period in days, $\bar{d}$ = mean delay, s = standard deviation and ρ is a normally distributed random deviate.

Unless other values are mentioned in the text, the following values should be assumed for the simulation runs:

$P = 5$	(reporting period in 1990 and 1991 was 5-days)
$\bar{c} = 0.005, 0.01, 0.02$	(0.5%, 1%, 2% of TAC per day; similar to mean rates for *D. eleginoides* in 1991 (see Figure 2) and *C. gunnari* in 1990 respectively)
$cv_c = 0.2$	(coefficient of variation, slightly lower than CV of catch by period in 1989/90; see discussion under 'results')
$\bar{d} = 5$	(mean reporting delay in 1990/91)
$cv_d = 0.5$	(coefficient of variation of reporting day in 1990/91)
$\alpha = 0.5$	(amplitude of cycles in 1990/91 is approximately 0.5)
$\lambda = 80$	(period of cycles in 1990/91 is about 80 days)
$L = 0.8$	(limit for decision in Model 1 as given in Conservation Measure 25/IX)

2.3 Decision Making Models (DMM)

Four decision making models were tested:

	Decision to Close Fishery	Rate Determined By	Closure Effective From
1. Percentage model: this is the model described in the existing conservation measures	If cumulative catch is greater than a specified level L	Catch rate of most recent period	The end of the reporting period within which the predicted date[2] of TAC completion falls
2. Time delay: used as an *ad hoc* method by the Secretariat in 1990/91	If predicted date falls in the period immediately following the period in which the report was received, or sooner	Catch rate of most recent period	The end of the reporting period within which the predicted date falls, or the end of the period in which the report was received, whichever is later
3. Time delay: Modified 1	If predicted date falls before the next report is expected (taking into account the reporting delay and its variance)	Catch rate of most recent period	The predicted date, or the date that the report was received, whichever is later
4. Time delay: Modified 2	If predicted date falls before the next report is expected (taking into account the reporting delay and its variance)	Catch rate is predicted using the trend of catch rates from the last *n* reporting periods (a linear regression is performed)	The predicted date, or the date that the report was received, whichever is later

The Fortran code for these decision models is given in Appendix A.

2.4 Performance

The performance of DMMs was assessed by monitoring the final catch that would be taken by the time of the decided closure of the fishery and comparing this to the TAC. An example of a frequency distribution of these differences ("over-shoot") is given in Figure 3. Differences between the observed catch and the TAC were characterised by the mean and

[2] Predicted date means the date on which predictions show that the TAC is expected to be taken. It is calculated using the catch rate determined by the previous box and the quantity of TAC that remains to be caught. The predicted date is always rounded down, so that a predicted date of 145.56 days becomes 145 days.

standard deviation of the magnitude of the over-shoot, the proportion of runs that produced a catch greater than the TAC, i.e., greater than the TAC+5% and greater than the TAC+10%, and were calculated from 20 x 400 iterations of the simulation.

Mean over-shoot was almost always positive, and in many cases the frequency histogram of over-shoot values was quite heavily skewed (Figure 3). Over-shoots rather than under-shoots were considered as performance indicators because they are potentially more damaging to the fish stocks. The chances of similar magnitudes of under-shoot were almost always lower than for the over-shoots because of the skewed nature of the distributions.

3. RESULTS

All models were highly sensitive to catch rates as a proportion of TAC ($\bar{c}$), to the length of the reporting period (P), and to the length of the reporting delay ($\bar{d}$).

In general the mean over-shoot and its standard deviation increased with increasing catch rate. However, Model 1 showed local minima of the probability of significant over-shoot that occurred at different values of L for different levels of $\bar{c}$ (Figure 4). Best performance was attained with L = 0.9 if $\bar{c}$ was 0.005, L = 0.8 if $\bar{c}$ = 0.1 and L = 0.6 if $\bar{c}$ = 0.02. This implies that the use of Model 1 in a conservation measure must incorporate a mechanism for adjustment of the limit for a decision, L, in relation to the catch rate.

All models showed decreases in performance with increasing length of reporting period (Table 1), and this was exacerbated by increasing catch rates.

All models performed less well with the Type II catch than with Type I. However, although there was little difference between the performance of Model 1 and Model 2 at low catch rates and with Type I catches, the performance of Model 1 was significantly lower at higher catch levels and Type II catches than Model 2 (Table 2). DMMs of classes similar to Model 2 are clearly preferable to Model 1 under most circumstances.

Two refinements to Model 2 were made, creating Model 3 and Model 4 by changing the decision path and the way the rate was determined. Individual simulations established that the optimal number of periods to use for the calculation of trend for Model 4 was four. Table 4 shows that Model 4 performs more successfully with changing catch rates (Type II) than either Models 2 or 3, although it appears to perform less well with catches of Type I than Model 3.

The effect of the coefficient of variation (CV) of the mean catch rate is unpredictable. For instance, increasing cv_c from 0.2 to 0.8 with catch = 0.01 and using catch Type II with Model 4 decreases the chance of more than 5% over-shoot but increases the chance of greater than 10% over-shoot. The CV used for the simulations (0.2) is similar but slightly lower than that found for the catches of *Champsocephalus gunnari* reported by 5-day period in 1989/90. The CV of catches by period (cv_c) computed by the simulation is less than this, about 0.15, because the cv_c is applied to each catch by day, and adding catches by period removes some of this variation. However, it was considered that since no direct information on CV of catches by day was available, and vessels may change their fishing strategy by 5-day (week) periods rather than by day, that the cv_c value of 0.2 was realistic until further information becomes available.

4. DISCUSSION

There is clear evidence that Models 2 to 4 perform more successfully than Model 1. Models 2 to 4 all use a decision based on the time to completion of the TAC in relation to reporting periods, whereas Model 1 was based on a proportion of the TAC. This means that the time interval over which it is necessary to predict catch rates is reduced. Since the uncertainties in all these models arise because they have to use information from past catch rates to extrapolate future catches up to when the TAC is taken, models that reduce the extrapolation time should reduce the over- or under-shoot in TAC.

Table 4 shows that there is a significant advantage in using a model that combines the features of short extrapolation periods with an element of trend analysis. In this case, using the past four reports to infer a trend gave the best results (but under other conditions of α and λ, for example, this could change). The decrease in probability of greater than 5% over-shoot from 0.47 to 0.27 with a change from Model 1 to Model 4 (catch = 0.01) demonstrates the increased performance of the latter model.

A fifth model was trialed, which used mean catch rates over a number of previous periods to calculate closure date (i.e., trend assumed zero). This offered no advantages over Model 3 and was not pursued further.

It must be emphasised that extrapolation of information from past catch rates will always contain an element of uncertainty, for some methods more than others. The more complex the analysis of trend the better the model might be expected to perform, but in this paper only simple linear regression techniques have been used. Large, unpredictable changes in rate such as happened at the end of the 1991 *D. eleginoides* fishery, can never be realistically anticipated by these models without further information being provided, such as anticipated changes in fleet structure.

Model 4 performs better under fluctuating conditions (Type II catches) than the others described here, although it appears to perform slightly worse than Model 3 when catches are of Type I. The choice of model may thus depend on the type of catches from the fishery. However, it should be noted that a fishery need not be cyclical to benefit from the adoption of Model 4; if a fishery starts consistently and then declines or increases effort towards the end of the season, Model 4 will perform better than others.

The latter situation can often be expected since fishermen receive feedback on the progress of the fishery from the Secretariat. If Method 4 had been used in 1991, the fishery would not have been closed when it was, but later, and would probably have avoided some of the 4.3% shortfall in catches from the TAC.

The probability of serious over- or under-shoot of a TAC can be further minimised by:

- low catch rates and coefficient of variation (at catch rates of less than 0.005, Models 3 and 4 perform similarly);
- short reporting periods (5-days); and
- short reporting delays.

The details that should be incorporated into a conservation measure based on the implementation of Model 4 are given in Appendix B.

REFERENCES

CCAMLR. 1990. Implementation of Conservation Measures in 1989/90. Document *CCAMLR-IX/BG/14*. CCAMLR, Hobart, Australia.

CCAMLR. 1991. Implementation of Conservation Measures in 1990/91. Document *CCAMLR-X/9*. CCAMLR, Hobart, Australia.

Table 1: Effect of length of reporting period on performance. Mean over-shoot and probability of greater than 5% over-shoot (in parentheses).

Model 1, catch Type I, L = 0.8	Catch[2] = 0.005	0.01	0.02
5-day reporting period	0.007 (0.027)	0.015 (0.071)	0.093 (0.715)
10-day reporting period	0.019 (0.073)	0.052 (0.511)	0.294 (0.982)

Model 2, catch Type I,	Catch = 0.005	0.01	0.02
5-day reporting period	0.005 (0.002)	0.010 (0.038)	0.018 (0.220)
10-day reporting period	0.013 (0.012)	0.023 (0.220)	0.034 (0.209)

[2] As proportion of TAC

Table 2: Performance of Models 1 and 2 with Catch Types I and II. Mean over-shoot and probability of greater than 5% over-shoot in parentheses.

Model 1, L = 0.8	Catch = 0.005	0.01	0.02
Catch Type I	0.007 (0.027)	0.015 (0.071)	0.093 (0.715)
Catch Type II	0.046 (0.435)	0.061 (0.466)	0.155 (0.817)

Model 2	Catch = 0.005	0.01	0.02
Catch Type I	0.005 (0.002)	0.010 (0.038)	0.018 (0.220)
Catch Type II	0.014 (0.073)	0.026 (0.417)	0.155 (0.521)

Table 3: Performance of Models 2, 3 and 4 under Catch Types I and II. Probability of over-shoots greater than 5% and 10% (in parentheses) (mean over-shoot is not given).

Catch Type I	Catch = 0.005	0.01	0.02
Model 2	0.002 [0]	0.038 [0.001]	0.220 [0.040]
Model 3	0 [0]	0.025 [0]	0.219 [0.025]
Model 4	0.001 [0]	0.036 [0.001]	0.230 [0.038]

Catch Type II	Catch = 0.005	0.01	0.02
Model 2	0.073 [0.001]	0.417 [0.087]	0.521 [0.341]
Model 3	0.050 [0]	0.350 [0.035]	0.478 [0.254]
Model 4	0.025 [0]	0.269 [0.023]	0.342 [0.167]

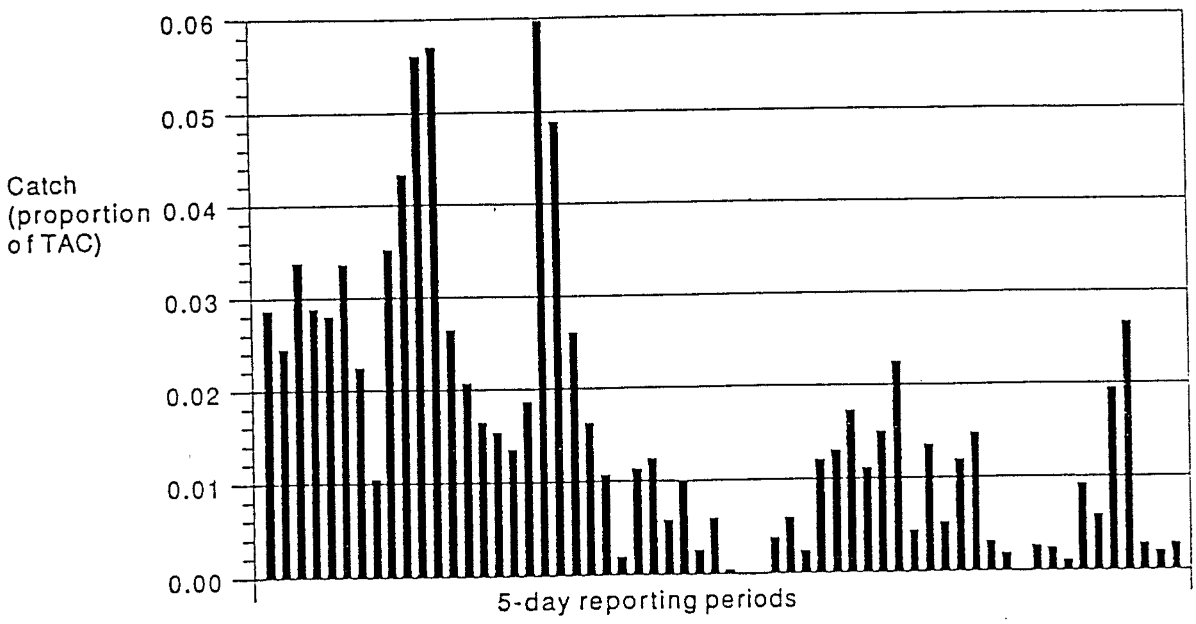

Figure 1: Progress of the *D. eleginoides* fishery in 1991. Catches are by five-day period and are expressed as a proportion of the TAC of 2 500 tonnes.

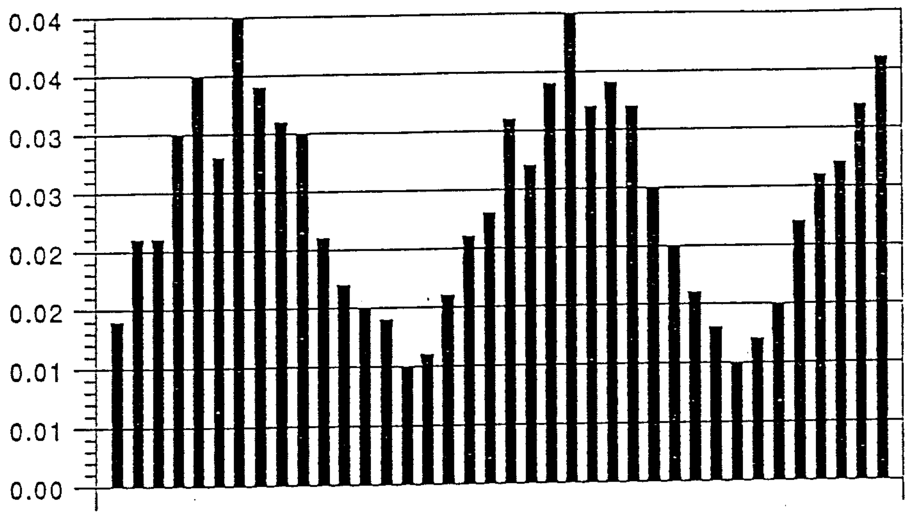

Figure 2: Simulated progress of a fishery with Catch Type II: mean catch = 0.005 of the TAC day^{-1}, with other sin parameters as given in the methods. Catches are given by five-day period.

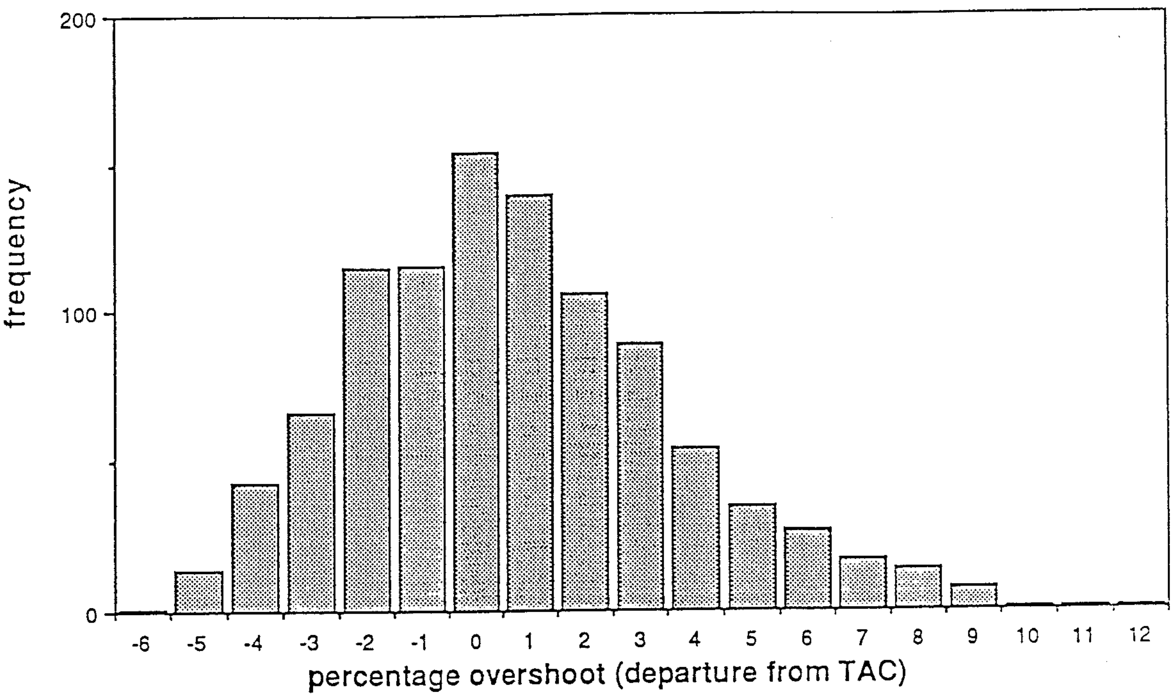

Figure 3: Frequency distribution of overshoots expressed as percentage of TAC, after 1 000 simulation runs. This was produced using Model 1, Catch Type I, c = 0.005, L = 0.70 and had the characteristics of mean and SD over-shoot = 0.0071 and 0.029 respectively, and a probability of >5% and >10% over-shoot of 0.086 and 0.002 respectively.

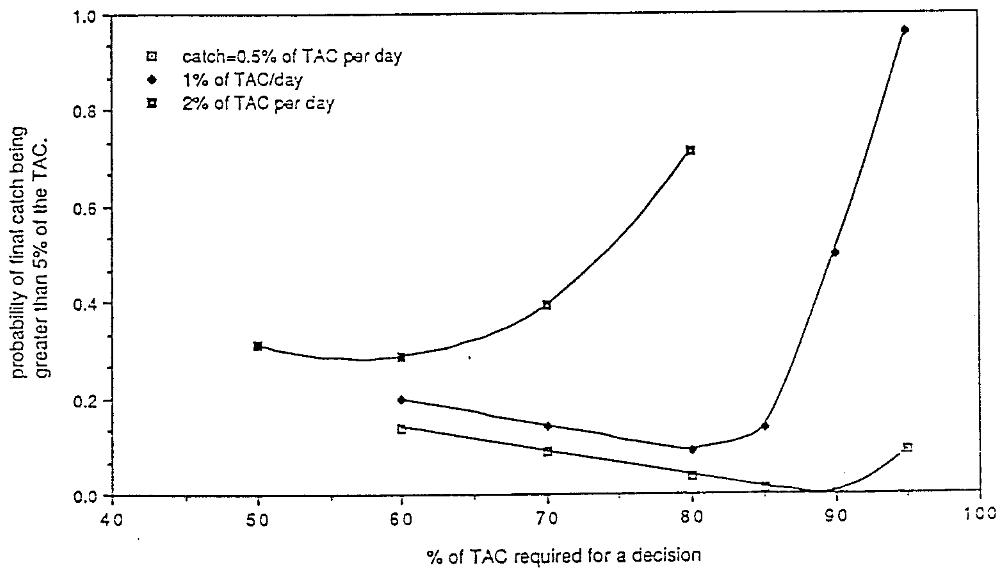

Figure 4: Model 1 (currently defined in Conservation Measure 25/IX) with Catch Type I. The effect of L, the catch limit required to trigger a closure decision, on the performance of Method 1 expressed as the probability of the final over-shoot in catch being greater than 5% of the TAC. The curves are interpolated by computer, and show local minima which occur at different values of L with different catch rates.

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Figure 2: Déroulement simulé d'une pêcherie avec des captures de type II : capture moyenne = 0,005 du TAC jour^{-1}, avec d'autres paramètres sinus tels qu'ils sont donnés dans les méthodes. Les captures sont présentées par période de cinq jours.

Figure 3: Distribution de fréquence des dépassements exprimés en pourcentage du TAC, après 1 000 simulations. Elle est dérivée du Modèle 1, pour une capture de Type I, $\underline{c}$ = 0,005, L = 0,70 et présente les caractéristiques de dépassement moyen et d'écart-type = 0,0071 et 0,029 respectivement et une probabilité de dépassement >5% et >10% de 0,086 et 0,002 respectivement.

Figure 4: Modèle 1 (défini dans la mesure de conservation 25/IX) pour une capture de Type I. Effet de L, limite de capture à l'origine de la décision d'une fermeture, sur l'efficacité de la Méthode 1, exprimé en tant que probabilité selon laquelle le dépassement final de la capture est supérieur à 5% du TAC. Les courbes sont tracées par ordinateur et illustrent les minima localisés pour différentes valeurs de L et différents taux de capture.

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Таблица 3: Эффективность моделей 2, 3 и 4 с выловом типов I и II. Вероятность получения превышений более 5% и 10% (в скобках) (среднее превышение не дается).

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Tabla 2: Funcionamiento de los modelos 1 y 2 con capturas de tipo I y II. Exceso medio del objetivo y probabilidad de exceder el objetivo superior al 5% (en paréntesis).

Tabla 3: Funcionamiento de los modelos 2, 3 y 4 con capturas de tipo I y II. Probabilidad de exceder el objetivo superior al 5 y 10% (en paréntesis) (no se presenta el exceso medio del objetivo).

Lista de las figuras

Figura 1: Desarrollo de la pesquería de *D. eleginoides* en 1991. Las capturas se presentan por períodos de cinco días y se expresan como una proporción del TAC de 2 500 toneladas.

Figura 2: Desarrollo empírico de una pesquería con capturas de typo II: captura media = 0.005 del TAC por día, con otros parámetros del seno, según se ha especificado en los métodos. Las capturas se presentan por períodos de cinco días.

Figura 3: Distribución de frecuencia de exceder el objetivo expresada como porcentaje del TAC, luego de 1 000 simulaciones. Esta fue producida utilizando el modelo 1, captura de tipo I, c = 0.005, L = 0.70, y dio un exceso medio del objetivo de 0.0071, con una desviación típica de 0.029 y una probabilidad de exceder el TAC superior al 5% = 0.086 y superior al 10% = 0.002.

Figura 4: Modelo 1 (definido actualmente en la Medida de conservación 25/IX) con una captura de tipo I. El efecto que produce L, la captura máxima que se requiere para instituir el cierre, en el funcionamiento del modelo 1, expresado en términos de la probabilidad de exceder el objetivo final de captura superior al 5% del TAC. Las curvas fueron interpoladas por computador y muestran el mínimo local que ocurre a distintos valores de L con diferentes índices de captura.

```
      SUBROUTINE MODEL1(CUMCAT,ILASDAY,EFFRATE,IREPDAY,
     &DECLIM,IPERIOD,IENDDAY)

C cumulative catch CUMCAT assumed to be out of 1 so amount to go =1-cumcat
C ILASDAY is the day the report came in
C EFFRATE is the effective rate of catching used (calculated in main prog)
C DECLIM is the limit of catch for decisions
C IREPPER is the end date of the report period
C IEND is the end date
C IENDPER is the end date of the end period
C
C IENDDAY is the returned date of the closure; set to -1 if no closure decision
C
      IEND=ILASDAY+INT((1.-CUMCAT)/EFFRATE)
      IENDPER=IPERIOD*(((IEND-1)/IPERIOD)+1)
      IREPPER=IPERIOD*(((IREPDAY-1)/IPERIOD)+1)
C      WRITE (*,*) IEND,EFFRATE,CUMCAT,DECLIM
      IF (CUMCAT.GE.DECLIM.AND.IENDPER.GE.IREPPER) THEN
       IENDDAY=IENDPER
      ELSE IF (CUMCAT.GE.DECLIM.AND.IENDPER.LT.IREPPER) THEN
       IENDDAY=IREPPER
      ELSE
       IENDDAY=-1
      ENDIF
      RETURN
      END

C **********************************************************

      SUBROUTINE MODEL2(CUMCAT,ILASDAY,EFFRATE,IREPDAY,IPERIOD,IENDDAY)

C  cumulative catch CUMCAT assumed to be out of 1 so amount to go =1-cumcat
C  ILASDAY is the day of last catch
C  EFFRATE is the effective rate of catching used (calculated in main prog)
C  IREPDAY is the date the report was recieved by Secretariat
C  IPERIOD is the number of days in the period for reporting
C  IENDDAY is the date of the closure; set to -1 if no closure decision
C
      IEND=ILASDAY+INT((1.-CUMCAT)/EFFRATE)
      IENDPER=IPERIOD*(((IREPDAY-1)/IPERIOD)+2)
      IREPPER=IPERIOD*(((IREPDAY-1)/IPERIOD)+1)
      IF (IEND.LE.IENDPER.AND.IEND.GT.IREPPER) THEN
        IENDDAY=IENDPER
      ELSE IF (IEND.LE.IREPPER) THEN
        IENDDAY=IREPPER
      ELSE
        IENDDAY=-1
      ENDIF
      RETURN
      END

C **********************************************************
```

```
      SUBROUTINE MODEL3(CUMCAT,ILASDAY,EFFRATE,IREPDAY,IPERIOD,IENDDAY)

C same as model 2 except with closure date on that date rather than on
C the end of the period, and with determination by catch within next
C xx days, where xx=IPERIOD
C
      IF (EFFRATE.EQ.0.) EFFRATE=.000000001
      IEND=ILASDAY+INT((1.-CUMCAT)/EFFRATE)
      IENDPER=IPERIOD+IREPDAY
      IF (IEND.LE.IENDPER.AND.IEND.GT.IREPDAY) THEN
        IENDDAY=IENDPER
      ELSE IF (IEND.LE.IREPDAY) THEN
        IENDDAY=IREPDAY
      ELSE
        IENDDAY=-1
      ENDIF
      RETURN
      END


C **********************************************************

      SUBROUTINE MODEL4(CUMCAT,ILASDAY,ARREG,NO,
     &IREPDAY,IPERIOD,IENDDAY)

C this model fits a regression line to the last "NO" data points
C (data point = catch/period) and calculates the change in catch rates
C fitting this to estimate next catch level
C ARREG(30) holds the latest reported catch
C NO is the number of previous catch reports to be used in the regression
C IENDDAY is the returned date of closure
C
C regression model: linear
C
      REAL ARREG(30)

       SUMX=0.
       SUMY=0.
       SSUMX=0.
       SUMXY=0.

C this code fills up ARREG from the bottom with the latest "NO" catches
      DO 10 N=1,NO
       IF (N.LT.NO) THEN
         ARREG(N)=ARREG(N+1)
       ELSE
         ARREG(N)=ARREG(30)
       ENDIF
C       WRITE (*,'(5X,I5,F8.4)') N,ARREG(N)
       SUMX=SUMX+N
       SUMY=SUMY+ARREG(N)
       SSUMX=SSUMX+N**2
       SUMXY=SUMXY+N*ARREG(N)
 10   CONTINUE

      IF (ARREG(1).NE.-1.) THEN
C the equation of the fitted line is Y=A+B(X)
       B=(NO*SUMXY-SUMX*SUMY)/(NO*SSUMX-SUMX**2)
       XMEAN=SUMX/NO
       YMEAN=SUMY/NO
       A=YMEAN-B*XMEAN
C find the catch rate appropriate to the first unreported period
       RATESTART=NO*B+A
C set up a safetycatch for number of periods
       MAXPERIOD=IREPDAY-ILASDAY+2
C calculate remaining catch, and find last catch=totcat2
       REMAIN=1-CUMCAT
       TOTCAT2=ARREG(NO)
C       WRITE (*,'(4F8.4)') B,A,RATESTART
       DO 20 I=1,MAXPERIOD
C use equation for uniform accelleration to calculate catch in period I
        TOTCAT1=RATESTART*I+0.5*B*(I**2)
C        WRITE (*,'(3X,I4,F8.4)') I,TOTCAT1
        IF (TOTCAT1.GT.REMAIN) GOTO 30
        TOTCAT2=TOTCAT1
```

```
20      CONTINUE
          IENDDAY=-1
          GOTO 40
C find proportion of last period at which TAC was taken
C from this find total number of periods (real) at TAC, and then days
C if limit was found, iend is the day before it was reached,
C otherwise iend is a safetycatch day, maxperiod

30      IEND=ILASDAY+INT(IPERIOD*(REAL(I)
     &-(TOTCAT1-REMAIN)/(TOTCAT1-TOTCAT2)))

C the rest is identical to Model 3
        IENDPER=IPERIOD+IREPDAY
        IF (IEND.LE.IENDPER.AND.IEND.GT.IREPDAY) THEN
          IENDDAY=IENDPER
        ELSE IF (IEND.LE.IREPDAY) THEN
          IENDDAY=IREPDAY
        ELSE
          IENDDAY=-1
        ENDIF
       ELSE
         IENDDAY=-1
       ENDIF
40       RETURN
       END
C ***********************************************************
```

**CONSERVATION MEASURES INCORPORATING MODEL 4
WOULD HAVE THE FOLLOWING FEATURES:**

- Catches should be reported by 5-day period to the Secretariat, the deadline being the end of the reporting period following that in which the catches are taken.

- The progress of the fishery should be reported by the Secretariat to all Members every month, and to Members fishing for that species being reported at the end of each reporting period.

- The Secretariat should calculate the trend in catches using linear regression on the last four catch reports.

- This catch rate trend should be extrapolated to calculate the "predicted date", the day on which the TAC is expected to be taken, using a rounding down function.

- If the predicted date is within one reporting period of the date on which the Secretariat received the report of the catches <u>the fishery will close on that day or on the day on which the report was received, whichever is the later</u> (i.e., if the calculation indicates that the TAC will be taken before another report would be received by the Secretariat [received day plus one reporting period], the fishery should close).