CCAMLR Science, Vol. 5 (1998): 1–8

BIAS IN THE ESTIMATION OF KRILL YIELD FROM USING A DETERMINISTIC FORMULATION OF THE MEDIAN UNEXPLOITED SPAWNING BIOMASS

A.J. Constable and W.K. de la Mare
Australian Antarctic Division
Channel Highway, Kingston 7050
Tasmania, Australia

Abstract

Two Monte Carlo simulation models, the krill yield model and the generalised yield model (GYM), are currently available to CCAMLR that can be used for estimating yields according to decision rules that relate spawning stock status to the median unexploited spawning biomass. These models are used in order to account for uncertainty in the biological parameters and abundance of the stock being assessed. CCAMLR currently uses results from the krill yield model as a basis for setting catch limits in the krill fishery, while the GYM is used for assessing yield in other finfish fisheries but can also be used for krill. The decision rules relate to the effects of a specified long-term annual yield on (i) the probability of the spawning stock being reduced below a set proportion of the median pre-exploitation spawning biomass during a projection trial and (ii) the median status of the spawning stock at the end of the projection trial (as a proportion of the median pre-exploitation spawning biomass). These rules require that the median pre-exploitation spawning biomass is known prior to a projection so that in each trial a direct assessment can be made of (i) whether the stock became critically depleted in that trial and (ii) the status of the stock at the end of the trial. These values from all trials are used to determine the probability of critical depletion and the median level of escapement respectively. The Monte Carlo simulations take account of uncertainty in the biological parameters used to estimate yield. In this respect, the biological parameters may change between individual projection trials. Consequently, the median pre-exploitation biomass needs to be estimated prior to each trial in order for it to be based on the parameters for that trial. The krill yield model uses a biased estimate of the median pre-exploitation spawning biomass with a method for correcting this bias in the level of escapement. The GYM uses an unbiased estimate of the median pre-exploitation spawning biomass and, thus, requires no correction. This paper examines the effects of the biased estimates of the median pre-exploitation spawning biomass on the estimates of krill yield. The results show that the biased estimate results in a bias of the probability of critical depletion, while the level of escapement is not appreciably sensitive to the method of estimating the median pre-exploitation spawning biomass. This bias in the krill yield model will result in the catch level given for a set probability of critical depletion being too high. However, this will not affect the estimates of long-term precautionary yield currently adopted by CCAMLR for the krill fishery because the level of escapement is the binding rule in this case. The results indicate that the GYM using the unbiased estimator of the pre-exploitation biomass is the preferable model for assessing long-term annual yields.

Résumé

La CCAMLR dispose actuellement de deux modèles de simulation de Monte Carlo, le modèle de rendement de krill et le modèle de rendement généralisé (GYM), pouvant tous deux servir à estimer les rendements tout en suivant les critères de décision qui établissent un rapport entre l'état des stocks reproducteurs et la biomasse moyenne reproductrice inexploitée. Ces modèles permettent de tenir compte de l'incertitude liée aux paramètres biologiques et à l'abondance du stock étudié. À l'heure actuelle la CCAMLR se base sur les résultats du modèle de rendement de krill pour fixer les limites de capture de la pêcherie de krill, et utilise le GYM, qui peut aussi servir pour le krill, pour calculer le rendement des pêcheries de poisson. Les critères de décision portent sur les effets d'un rendement annuel à long terme donné sur i) la probabilité qu'au cours d'un essai de projection, le stock reproducteur tombe en dessous d'une proportion donnée de la biomasse reproductrice moyenne d'avant l'exploitation et ii) l'état moyen du stock reproducteur en fin d'essai de projection (en tant que proportion de la biomasse reproductrice moyenne d'avant l'exploitation). Ces critères requièrent de posséder, avant de procéder à une projection, une connaissance de la biomasse reproductrice moyenne d'avant l'exploitation pour que lors de chaque essai on puisse directement déterminer i) si le stock a subi une diminution critique pendant l'essai ii) l'état du stock en fin d'essai. Ces valeurs, déduites de tous les essais, sont respectivement utilisées pour déterminer la probabilité d'un épuisement critique et le niveau moyen d'évitement. Les simulations de Monte Carlo tiennent compte de l'incertitude des paramètres biologiques utilisés pour estimer le rendement. À cet égard, il est possible que les paramètres biologiques changent d'un essai de projection à un autre. En conséquence, la biomasse reproductrice moyenne d'avant l'exploitation doit être estimée avant chaque essai de manière à être fondée sur les paramètres de cet essai. Le modèle de rendement de krill utilise une estimation biaisée de la biomasse reproductrice moyenne d'avant l'exploitation avec une méthode de correction de ce biais dans le niveau d'évitement. Le GYM, lui, utilise une estimation non biaisée de la biomasse reproductrice moyenne d'avant l'exploitation et ne demande donc aucune correction. Les auteurs examinent ici les effets des estimations biaisées de la biomasse reproductrice moyenne d'avant l'exploitation sur les estimations de rendement de krill. Les conclusions indiquent que l'estimation biaisée donne un biais dans la probabilité d'un épuisement critique, alors que le niveau d'évitement n'est pas sensible de manière appréciable à la méthode d'estimation de la biomasse reproductrice moyenne d'avant l'exploitation. De ce biais dans le modèle de rendement de krill résultera un taux de capture donné trop élevé pour la probabilité convenue d'un épuisement critique. Cela n'affectera toutefois pas les estimations du rendement préventif à long terme adoptées actuellement par la CCAMLR pour la pêcherie de krill étant donné que le niveau d'évitement est dans ce cas la règle à suivre. Selon les conclusions, le GYM utilisant l'estimateur non biaisé de la biomasse d'avant l'exploitation serait le modèle préférable pour évaluer les rendements annuels à long terme.

Резюме

Модель вылова криля и обобщенная модель вылова (GY-модель) – две симуляционных модели по методу Монте-Карло – применяются учеными АНТКОМа для оценки вылова в соответствии с правилами принятия решений, которые соотносят состояние нерестового запаса с медианной девственной нерестовой биомассой. Эти модели используются для учета неопределенности в биологических параметрах и численности исследуемого запаса. В настоящее время АНТКОМ использует модель вылова криля для определения ограничений на вылов криля, в то время как GY-модель применяется для расчета вылова плавниковых рыб, хотя она может использоваться и для криля. Правила принятия решений относятся к эффектам, оказываемым заданным объемом долгосрочного годового вылова на (i) вероятность спада нерестового запаса ниже указанной доли медианной девственной нерестовой биомассы в ходе одного экстраполяционного периода и (ii) медианное состояние нерестового запаса в конце этого периода (выражаемое как доля медианной девственной нерестовой биомассы). Согласно этим правилам, до проведения прогона модели необходимо знать медианную девственную нерестовую биомассу для того, чтобы для каждого варианта расчета оценить, произойдет ли критическое истощение запаса, и состояние запаса в конце расчета. Эти значения, полученные по всем вариантам расчета, используются соответственно для определения вероятности критического истощения и медианного уровня необлавливаемого резерва. Имитации по методу Монте-Карло учитывают неопределенность в биологических параметрах, используемых для расчета вылова. В связи с этим биологические параметры могут колебаться между отдельными вариантами расчета. Следовательно, до каждого прогона необходимо оценить медианную девственную биомассу с тем, чтобы она была основана на параметрах для данного прогона. В модели вылова криля используется смещенная оценка медианной девственной нерестовой биомассы в сочетании с методом поправки смещения в размере необлавливаемого резерва. В GY-модели используется несмещенная оценка медианной девственной нерестовой биомассы и не нуждается в поправке. В настоящей работе рассматривается влияние смещенной оценки медианной девственной нерестовой биомассы на оценки вылова криля. Результаты показывают, что смещенная оценка приводит к смещению вероятности критического истощения, в то время как размер необлавливаемого резерва не очень чувствителен к методу получения оценки медианной девственной нерестовой биомассы. Это смещение в модели вылова криля приведет к тому, что уровень вылова, рассчитанный для заданной вероятности истощения, будет слишком высоким. Тем не менее это не скажется на оценках долгосрочного предохранительного уровня вылова криля, принятых АНТКОМом, поскольку в данном случае обязательным является размер необлавливаемого резерва. Результаты показывают, что для оценки долгосрочного годового вылова предпочтительной моделью является GY-модель, в которой используется несмещенная оценка девственной биомассы.

Resumen

Actualmente la CCRVMA dispone de dos modelos de simulación del tipo Monte Carlo: el modelo de rendimiento del kril y el modelo de rendimiento generalizado (GYM), que pueden ser utilizados para la estimación del rendimiento según criterios de decisión que relacionan el estado del stock en desove con la mediana de la biomasa del stock en desove sin explotar. Se utilizan estos modelos para dar cuenta de la incertidumbre de los parámetros biológicos y de la abundancia de los stocks bajo evaluación. La CCRVMA utiliza los resultados del modelo de rendimiento del kril como base para fijar los límites de captura de la pesquería de kril, mientras que el modelo GYM se usa para evaluar el rendimiento de otras pesquerías de peces, aunque también se le puede aplicar a las pesquerías de kril. Los criterios de decisión se refieren a los efectos de un determinado rendimiento anual a largo plazo en (i) la probabilidad de que el stock en desove se reduzca a menos de una proporción determinada de la mediana de la biomasa del stock en desove antes de la explotación durante una prueba de proyección y (ii) la mediana del estado del stock en desove al final de la proyección (como proporción de la mediana de la biomasa del stock en desove antes de la explotación). Estos criterios requieren que el valor de la mediana de la biomasa del stock en desove antes de la explotación se conozca antes de la proyección de modo que en cada prueba se pueda hacer una evaluación directa para determinar (i) si el stock disminuyó de manera crítica en esa prueba y (ii) el estado del stock al final de la prueba. Los valores de todas las pruebas se utilizan para determinar la probabilidad de reducción crítica y la mediana del nivel de escape, respectivamente. Las simulaciones del tipo Monte Carlo toman en cuenta la incertidumbre de los parámetros biológicos que entran en la estimación del rendimiento y que pueden variar entre pruebas individuales de la proyección. Por consiguiente, la mediana de la biomasa antes de la explotación debe ser estimada antes de cada prueba a fin de que se base en los parámetros utilizados en esa prueba. El modelo de rendimiento del kril utiliza una estimación sesgada de la mediana de la biomasa del stock en desove antes de la explotación y un método para corregir este sesgo en el nivel de escape. El modelo GYM utiliza una estimación sin sesgos de la mediana de la biomasa del stock en desove antes de la explotación y por lo tanto no requiere corrección. Este trabajo examina los efectos de las estimaciones sesgadas de la mediana de la biomasa del stock en desove antes de la explotación en las estimaciones de rendimiento del kril. Los resultados indican que la estimación sesgada produce a su vez un sesgo en la probabilidad de reducción crítica, mientras que el nivel de escape no aparenta ser sensitivo al método de estimación de la mediana de la biomasa del stock en desove antes de la explotación. El sesgo en el modelo de rendimiento de kril tendrá como consecuencia que el nivel de captura correspondiente a una probabilidad de reducción crítica determinada será demasiado alto. Sin embargo, esto no afectará las estimaciones del rendimiento precautorio a largo plazo adoptadas actualmente por la CCRVMA con respecto a las pesquerías de kril, porque la regla obligatoria en este caso es el nivel de escape. Los resultados indican que el modelo GYM que utiliza la estimación sin sesgos de la biomasa antes de la explotación es el modelo preferible para la evaluación de rendimientos a largo plazo.

Keywords: krill, modelling, estimation bias, yield, spawning biomass, CCAMLR

INTRODUCTION

Two Monte Carlo simulation models are currently available to CCAMLR that can be used for estimating yields according to decision rules that relate spawning stock status to the median unexploited spawning biomass (see SC-CAMLR, 1994 – paragraphs 5.18 to 5.26 for a discussion of the application of the decision rules). The first model, the krill yield model, has been developed specifically for krill (Butterworth et al., 1994; SC-CAMLR, 1994 – paragraphs 5.15 to 5.17), while the second is a generalised yield model that can be used for any fish stock, including krill (Constable and de la Mare, 1996; SC-CAMLR, 1995 – paragraph 4.36). These models are used in order to account for uncertainty in the biological parameters and abundance of the stock being assessed. CCAMLR currently uses results from the krill yield model as a basis for setting catch limits in the krill fishery.

The decision rules relate to the effects of a specified long-term annual yield on (i) the probability of the spawning stock being reduced below a set proportion of the median pre-exploitation spawning biomass during a projection trial and (ii) the median status of the spawning stock at the end of the projection trial (as a proportion of the median pre-exploitation spawning biomass). These will be referred to as the probability of critical depletion and level of escapement respectively. In the case of krill yield, the long-term annual yield is specified as a proportion of the estimated pre-exploitation biomass, γ.

These rules require that the median pre-exploitation spawning biomass is known prior to a projection so that in each trial a direct assessment can be made of (i) whether the stock became critically depleted in that trial and (ii) the status of the stock at the end of the trial. These values from all trials are used to determine the probability of critical depletion and the median level of escapement respectively. The Monte Carlo simulations take account of uncertainty in the biological parameters used to estimate yield. In this respect, the biological parameters may change between individual projection trials. Consequently, the median pre-exploitation biomass needs to be estimated prior to each trial in order for it to be based on the parameters for that trial.

Butterworth et al. (1994) use a deterministic method for estimating the median pre-exploitation spawning biomass ($\tilde{S}_0$ in Constable and de la Mare, 1996), where $\tilde{S}_0$ is a single calculation of the spawning biomass in a population with a deterministic age structure based on the mean recruitment used in the projection trial (see Butterworth et al., 1994 for a complete mathematical description). This method gives a biased estimate of the median pre-exploitation spawning biomass, a problem noted and discussed by the authors. As a result, the median level of escapement at the end of the projection period with no catches will not be equal to 1. They advise that the level of escapement for a particular catch level should be corrected by dividing it by the value for escapement obtained when the projections are undertaken with no catches. However, they did not provide advice on how the biased estimate, $\tilde{S}_0$, might affect the probability of critical depletion.

Constable and de la Mare (1996) describe an alternative method for estimating the median pre-exploitation biomass (S_0), where S_0 is determined prior to a projection trial as the median spawning biomass from multiple random determinations of a pre-exploitation age structure (the number of determinations is able to be set by the user) (see Constable and de la Mare, 1996 for a complete description of this method). In this way, S_0 is an unbiased estimate and the median level of escapement at the end of the projection period should be equal to 1 when no catches are taken (stochastic variability will mean that this will not be achieved but it should be very closely approximated with a very large number, say 10 001, of replicate determinations of the pre-exploitation biomass). Thus, no correction is required.

This paper examines the implications for estimates of krill yield of using the biased estimator of the median pre-exploitation spawning biomass with the method of correction used by Butterworth et al. (1994). The GYM is used with both forms of estimating the median pre-exploitation spawning biomass in order, firstly, to compare directly the outputs of the generalised yield and the krill yield model and, secondly, to examine the bias in estimates of krill yield.

RESULTS FROM THE KRILL YIELD MODEL

Results for the krill yield model are taken from Butterworth et al. (1994). A subset of these results is shown in Tables 1 and 2 and used as the basis for the runs with the GYM. The values of γ given by Butterworth et al. (1994) are used in the runs of the GYM.

COMPARABILITY OF THE TWO MODELS

The first set of runs with the GYM used the deterministic formulation of the median pre-exploitation spawning biomass, $\tilde{S}_0$, in order to compare directly the output of this model with the krill yield model. The test used in this comparison was the summer fishing model (December–February) with $\gamma = 0.136$, a critical depletion level of 0.2 and using a deterministic formulation of the median pre-exploitation spawning biomass. The parameter inputs for all the runs were those described for Model 2 in Butterworth et al. (1994). This test was undertaken 100 times with 1 001 trials per test. The mean probability of depletion below 0.2 of the estimated median pre-exploitation spawning biomass (±95% confidence intervals) was 0.084 ± 0.016. The result of Butterworth et al. (1994) was 0.1, which is at the upper limit of this range. On the basis of this test and the analysis of escapement below, it is concluded that the generalised yield model provides results comparable to the krill yield model.

TEST OF BIAS

Two sets of runs were undertaken using the GYM to test for bias in the deterministic method of estimating the median pre-exploitation spawning biomass. In all cases, the parameter inputs were those described for Model 2 in Butterworth et al. (1994). The first set of runs used the deterministic estimate of the median pre-exploitation spawning biomass, $\tilde{S}_0$, while the second set used 10 001 replicate random initial age structures to estimate S_0.

Two types of comparisons are made. In the first case, the probability of critical depletion is examined for three different fishing seasons – summer, winter and all year – and three critical levels of depletion – 0.2, 0.4 and 0.6 of the median pre-exploitation spawning biomass. The projection period was 20 years. A subset of runs was undertaken to examine the effect of extending the projection period to 30 years on the probability of critical depletion to 0.2 of the median pre-exploitation spawning biomass.

In the second comparison, the level of escapement was examined for three fishing seasons as above and for three levels of γ – 0.15, 0.2 and 0.4. Projections for 20 years and 30 years were undertaken for all combinations of γ and fishing season.

The results comparing the probabilities of critical depletion between the two models are shown in Table 1 and the comparisons of the levels of escapement are shown in Table 2.

Results from unbiased estimates of the median pre-exploitation spawning biomass show that the krill yield model will underestimate the probability of critical depletion. This underestimation becomes substantially greater with increases in the critical level of depletion (as a proportion of the median pre-exploitation spawning biomass). The relative bias is not appreciably altered with differences in the relationship between spawning and fishing seasons, although there is less bias for a low critical level of depletion (0.2) and a direct overlap between summer fishing and the summer spawning season.

In contrast, the method for calculating the level of escapement is not sensitive to the manner in which the median pre-exploitation spawning biomass is estimated. The results presented here for the generalised yield model were not appreciably different to those presented in Butterworth et al. (1994).

CONCLUSIONS

The deterministic method for estimating the median pre-exploitation spawning biomass results in a biased estimate of the probability of critical depletion while the level of escapement is not appreciably sensitive to the method of estimating the pre-exploitation spawning biomass. This bias in the krill yield model will result in the catch level, γ, given for a set

Table 1: The probability of depleting the spawning biomass during 20-year projections for different levels of γ for three fishing seasons using the Generalised Yield Program (Version 3.00). The median of pre-exploitation spawning biomass for each trial is calculated deterministically (as in Butterworth et al., 1994) and from 10 001 randomised starts. Three critical levels of depletion are examined as proportions of the median pre-exploitation spawning biomass. Results are compared to values given in Butterworth et al. (1994). Values in parentheses are probabilities of depletion over a 30-year projection period.

Fishing Season	Critical Depletion Level											
	0.2				0.4				0.6			
	γ	Butterworth et al. (1994)	GY Deter-ministic $\tilde{S}_0$	GY Un-biased S_0	γ	Butterworth et al. (1994)	GY Deter-ministic $\tilde{S}_0$	GY Un-biased S_0	γ	Butterworth et al. (1994)	GY Deter-ministic $\tilde{S}_0$	GY Un-biased S_0
December–February	0.136	0.1	0.081 (0.114)	0.106 (0.146)	0.080	0.1	0.094	0.142	0.008	0.1	0.091	0.198
April–September	0.202	0.1	0.083 (0.124)	0.125 (0.175)	0.089	0.1	0.096	0.141	0.010	0.1	0.092	0.201
Whole year	0.165	0.1	0.087 (0.125)	0.123 (0.168)	0.083	0.1	0.094	0.139	0.009	0.1	0.092	0.200

Table 2: Escapement of spawning biomass at the end of 20 and 30-year projections for different levels of γ for three fishing seasons using the Generalised Yield Program (Version 3.00). The median pre-exploitation spawning biomass for each trial is calculated deterministically (as in Butterworth et al., 1994) and from 10 001 randomised starts. Results are compared to values given in Butterworth et al. (1994).

Fishing Season	Years in Projection	γ								
		0.15			0.20			0.40		
		Butterworth et al. (1994)	GY Determin-istic $\tilde{S}_0$[1]	GY Un-biased S_0[2]	Butterworth et al. (1994)	GY Determin-istic $\tilde{S}_0$[1]	GY Un-biased S_0[2]	Butterworth et al. (1994)	GY Determin-istic $\tilde{S}_0$[1]	GY Un-biased S_0[2]
December–February	20	0.645	0.642	0.641	0.511	0.519	0.510	0.279	0.293	0.288
	30		0.638	0.640		0.508	0.510		0.292	0.289
April–September	20	0.673	0.676	0.676	0.573	0.580	0.578	0.434	0.437	0.436
	30		0.675	0.678		0.576	0.580		0.437	0.443
Whole year	20	0.656	0.657	0.658	0.539	0.549	0.543	0.372	0.380	0.379
	30		0.655	0.659		0.542	0.547		0.381	0.383

1 Runs using the GYM with $\tilde{S}_0$ estimated for each trial using the deterministic equation of Butterworth et al. (1994). The median ratio of spawning biomass after 20 and 30 years relative to median $\tilde{S}_0$ in each run with no fishing was 1.099 and 1.088. These values were used to correct the ratios derived under fishing as described in Butterworth et al. (1994).

2 Runs using the GYM with the median of S_0 estimated prior to each trial from 10 001 replicates.

probability of critical depletion being too high. However, this will not affect the estimates of long-term precautionary yield currently adopted by CCAMLR for the krill fishery because the level of escapement is the binding rule in this case. The results indicate that the GYM using the unbiased estimator of the pre-exploitation biomass, S_0, is the preferable model for assessing long-term annual yields.

ACKNOWLEDGEMENTS

Many thanks to Geoff Kirkwood for his constructive comments and suggestions for improving this manuscript.

REFERENCES

Butterworth, D.S., G.R. Gluckman, R.B. Thomson, S. Chalis, K. Hiramatsu and D.J. Agnew. 1994. Further computations of the consequences of setting the annual krill catch limit to a fixed fraction of the estimate of krill biomass from a survey. *CCAMLR Science*, 1: 81–106.

Constable, A.J. and W.K. de la Mare. 1996. A generalised yield model for evaluating yield and the long-term status of fish stocks under conditions of uncertainty. *CCAMLR Science*, 3: 31–54.

SC-CAMLR. 1994. *Report of the Thirteenth Meeting of the Scientific Committee (SC-CAMLR-XIII)*. CCAMLR, Hobart, Australia: 450 pp.

SC-CAMLR. 1995. *Report of the Fourteenth Meeting of the Scientific Committee (SC-CAMLR-XIV)*. CCAMLR, Hobart, Australia: 460 pp.

Liste des tableaux

Список таблиц

Lista de las tablas