CATCH-AT-AGE ANALYSIS APPLIED TO NEW FISHERIES: THE CASE OF *DISSOSTICHUS ELEGINOIDES*

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Abstract

Traditionally, the approach used in the assessment of new fisheries has been based on research surveys, making it possible to estimate the standing stock and potential yield of a resource by coarse methods. The main aim of such surveys is to monitor fishing operations in order to develop a comprehensive sampling design which will provide data in line with assessment procedures that are quite similar to those commonly used in the statistical sampling theory. These procedures are, to a certain extent, limited by the complex fishing strategies of the operators and by the movements of fish stocks, which seriously affect model assumptions. This paper demonstrates that for the new fishery, analyses using catch-at-age data derived from reseach cruises may provide an alternative to other methods of estimating the parameters of fish stocks. This alternative method is applied to the new fishery of *Dissostichus eleginoides* off the south of Chile which is being conducted in accordance with CCAMLR regulations.

Résumé

L'approche de l'évaluation des pêcheries nouvelles est traditionnellement fondée sur les campagnes de recherche, permettant ainsi l'évaluation du stock existant et du rendement potentiel par des méthodes approximatives. L'objectif principal de ces campagnes est de contrôler les opérations de pêche afin de développer un modèle d'échantillonnage détaillé, propre à fournir des données conformes à des procédures d'évaluation quasi-similaires à celles généralement utilisées par la théorie de l'échantillonnage statistique. Dans une certaine mesure, ces procédures sont limitées par les stratégies de pêche complexes des opérateurs et par les déplacements des stocks de poissons qui affectent grandement les hypothèses du modèle. Les auteurs démontrent que pour la nouvelle pêcherie, des analyses utilisant des données sur la capture à un âge donné provenant des campagnes de recherche peuvent s'avérer une nouvelle méthode d'évaluation des paramètres des stocks de poissons. Cette nouvelle procédure est appliquée à la nouvelle pêcherie de *Dissostichus eleginoides* menée conformément à la réglementation de la CCAMLR au large du sud du Chili.

Резюме

Традиционный подход к оценке новых промыслов основан на научно-исследовательских съемках и дает возможность оценить биомассу и потенциальный вылов какого-либо ресурса с применением "приблизительных" методов

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расчета. Главной целью таких съемок является проведение мониторинга промысловых операций с тем, чтобы разработать всеобъемлющую схему взятия проб, результаты которой в достаточной мере будут соответствовать процедурам расчетов, обычно используемых в статистической теории взятия проб. В какой-то степени эти процедуры ограничены сложными стратегиями промысловиков и передвижением запасов рыб, что в значительной мере влияет на допущения в моделях. Данная работа показывает, что в случае нового промысла проведение анализа с помощью данных по составу уловов по возрасту, полученных в результате научно-исследовательских рейсов, может послужить альтернативой другим методам оценки параметров рыбных запасов. Этот альтернативный метод применяется к новому промыслу *Dissostichus eleginoides* около южного побережья Чили, который ведется в соответствии с мерами АНТКОМа.

Resumen

Tradicionalmente el enfoque de la evaluación de las nuevas pesquerías ha estado basado en pescas de investigación, procedimiento que permite una estimación del "standing stock" de un recurso y su rendimiento potencial utilizando métodos crudos. Las características de estas operaciones es el control sobre las operaciones de pesca y su énfasis está en desarrollar un plan de muestreo exhaustivo, el que proporcionará información en conjunto con los modelos de evaluación que no difieren escencialmente de procedimientos comunes en la teoría estadística de muestreo. Estos métodos están, en cierta forma, limitados por las complejas tácticas de pesca de los pescadores y por los movimientos de las poblaciones de peces, que vulneran las presunciones del modelo.

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1. INTRODUCTION

At the 1990 and 1991 Meetings of CCAMLR, concerns were expressed about the problem of new and developing fisheries (SC-CAMLR, 1990; SC-CAMLR, 1991). In relation to this subject, the Working Group on Fish Stock Assessment (WG-FSA) has specified the definition of a new fishery, and also identified the information required to evaluate the initial catch level for such a fishery. Traditionally, the methods used in evaluating new fisheries are based on research fishing procedures which provide information for evaluation of the standing stock of a resource and its potential yield utilising coarse methods similar to those proposed by Gulland (1971). Typically, these evaluations require monitoring of fishing operations and implementation of a comprehensive, statistically-based sampling plan. In developed fisheries, the evaluation strategy is usually based on information obtained from long term sampling programs of commercial fisheries, managed so as to collect series of data which can be analysed in conjunction with stock dynamics models.

An interim approach is to conduct research surveys designed to find a compromise between the objectives of the commercial fishery and those of stock evaluation. Information obtained from such surveys can be used to evaluate the viability of the fishery, not only from an economic point of view, but especially in terms of its sustainability. Regarding this last aspect, conditions for conducting commercial fishery operations should be flexible, whilst maintaining the requirement for the acquisition of information from scientific research programs. From the point of view of a developing country, this option appears to be the best way of performing scientific research in remote areas in an economically feasible manner. A common way of utilising information from a new fishery is to apply CPUE methods such as De Lury methods (Ricker, 1975). These methods are, to some extent, limited by complex fishery tactics which adversely affect model assumptions. Another way of optimising this type of research is to use evaluation methods based on catch composition data. This paper explores the application of catch-at-age analysis for the *Dissostichus eleginoides* fishery south of Chile, where a new fishery is beginning, with objectives similar to those of CCAMLR, i.e., to estimate levels of fish abundance and potential yields so as to ensure that initial levels of exploitation are potentially sustainable (de la Mare, 1986).

CCAMLRs concept of a new fishery specifically stresses the lack of information as being the distinctive attribute qualifying such a fishery. According to this concept, various fisheries can belong to this category: those that have developed in the past and for which no information has been received for at least the last two fishing seasons, as well as those based on previously unexploited stocks. The catch-at-age model proposed below relates to this last type of fishery.

2. EVALUATION MODEL

The basic assumptions of the catch-at-age model are as follows:

- the stock of *D. eleginoides* belongs to a closed population;
- the stock is in a state of equilibrium before the commencement of research surveys (recruitment = mortality); and
- fishing mortality is separable by age (Doubleday, 1976).

Catch-at-age for all recruited year classes i ($i = t_r, t_r + 1, \ldots, t_m$) can be expressed as

$$C_i = \mu_i N_i \tag{1}$$

where

$$\mu_i = \frac{F_i}{Z_i}\left(1 - e^{-\tau Z_i}\right) \tag{2}$$

$$N_i = R \exp(-M(i - t_r + \Delta)), \tag{3}$$

$$Z_i = F_i + M, \text{ and} \tag{4}$$

$$F_i = r_i F \tag{5}$$

where
C_i = catch at age i during survey
N_i = numbers at the beginning of the research survey
μ_i = exploitation rate
F_i = fishing mortality
r_i = relative fishing mortality coefficient at age
F = fishing mortality for completely recruited fish
M = natural mortality
τ = research survey duration (in years)
R = recruitment
t_r = age at recruitment
t_m = terminal age
Δ = time between the beginning of the year and the beginning of the research survey.

So as to reduce the number of parameters, the specific exploitation pattern at age, r_i, can be estimated by

$$r_i = \frac{i^a \exp(-b \cdot i)}{\max\left(i^a \exp(-b \cdot i)\right)} \tag{6}$$

where a and b are constants (Deriso *et al.*, 1985).

This function was particularly suitable for representing patterns of partial recruitment for the very old fish characteristic of longline fishing.

3. ESTIMATION OF MORTALITIES

Since the slope of the catch curve gives information on mortality, and recruitment is only a scale factor on this curve, mortality can be estimated from the proportion of the total catch of a research survey to the catches at age:

$$p_i = \frac{\frac{F_i}{Z_i} \cdot e^{(-M \cdot i)}\left(1 - e^{-\tau Z i}\right)}{\sum \frac{F_i}{Z_i} \cdot e^{(-M \cdot i)}\left(1 - e^{-\tau Z i}\right)} \tag{7}$$

The parameters of model (6) can be estimated using a non-linear least-squares approach, which minimises the function

$$SSQ = \sum_i (p_i - \hat{p}_i)^2 + \lambda P(\theta) \tag{8}$$

where λ is a penalisation factor and $P(\theta)$ is a quadratic function which represents a number of restrictions that permit the introduction of values of some estimated parameter from an independent source (e.g., M) or mark off the parametric space within the most probable range.

4. RECRUITMENT ESTIMATION

Replacing (3) in (1) and summing over all ages, we may calculate recruitment:

$$R = \frac{\sum_i C_i}{\sum_i \mu_i \exp\left(-M(i - t_r + \Delta)\right)} \tag{9}$$

5. ESTIMATION OF INITIAL TAC

A TAC for a new fishery can be calculated in the usual way, by performing the following steps:

- projecting stock size at the beginning of the fishing season, based on stock age composition estimated at the beginning of the research survey;
- estimating or calculating recommended fishing mortality level; and
- totalling catches at age by weight.

6. APPLICATION TO A NEW FISHERY SOUTH OF CHILE

During the period September 1991 to June 1992, a research survey was carried out by a fleet of seven longliners south of Chile, over the continental slope area, between parallels 47° and 57°S. This fishing operation was authorised by the Chilean Subsecretaría de Pesca de Chile, under an agreement on technical collaboration between the Instituto de Fomento Pesquero (IFOP) and national fishery companies, with the purpose of expanding the exploitation options of the southern demersal fishery, currently targeting hake (*Merluccius australis*) and pink ling (*Genypterus blacodes*).

On board each vessel, the IFOP used technical personnel to perform intensive haul-by-haul sampling of catches, with the aim of identifying the growth parameters presented in Table 1.

Catch data were available for two years (1991 and 1992), which could be analysed independently, extending the evaluation to two seasons; however, in order to illustrate the procedure, data are presented as belonging to a single season - 1991/92 (split-year).

Available information, originating from an exploratory fishery carried out previously in the same area by the longliner *Frio Sur V*, suggested the following restrictions:

- $F \geq 0$
- $M = 0.2$
- $T_c = 10$ and 10.5 years
- $b = b_o$ $(0.8 \leq b_o \leq 1.6)$

These were incorporated into the objective function

$$SSQ = \sum_i (p_i - \hat{p}_i)^2 + \lambda\left((M-0.2)^2 + (\max(0,-F))^2 + \left(\left(t_c{}^a \exp(-b \cdot t_c)\right)/\max\left(t_c{}^a \exp(-b \cdot t_c)\right) - 0.5\right)^2 + (b-b_o)^2\right) \qquad (10)$$

In order to obtain the least-square parameters, a simplex minimiser algorithm (Nelder-Mead) from the program library 386-MATLAB was used, with $\lambda = 20$ and a tolerance factor of 0.01.

The smallest residual (SSQ = 0.0014) was obtained for $t_c = 10$, F = 0.85, $a = 20.9$ and $b = 1.6$. Another satisfactory result (SSQ = 0.0052) was obtained with $t_c = 10.5$, F = 0.51, $a = 20.6$, M = 0.2 and $b = 1.5$.

A value of M = 0.15 improved the residual (SSQ = 0.0012) with other parameters constant. When natural mortality continued to decrease (e.g., M = 0.1) the residuals increased (SSQ = 0.0028). It was also observed that, for these values of natural mortality, F decreased to values close to 0.65 and the coefficient a of the exploitation pattern stabilised at a value of 20.

The recruits (calculated from equation (9)), for the estimated parameters corresponding to the residuals SSQ = 0.0014 and SSQ = 0.0012, were 1.4 and 1.0 million fish respectively.

7. DISCUSSION

This paper shows that for new fisheries, analyses using catch-at-age data derived from research cruises may provide alternatives to other methods of estimating the parameters of fish stocks.

In the absence of a time series of data, efficient use of catch-at-age methods may require additional information from the fishery in order to restrict the model parameter space to within reasonable bounds. However, the generation of the base data, catches at age, is relatively rapid given good techniques for age determination of fish, and so the total data demand may be quite modest.

When time series data or other qualitative data are available, the sums-of-squares function provides an objective way of incorporating these data in the model. On the other hand, because of the low ratio of the number of observations to the number of parameters, the sums of squares is very sensitive to the tails of age distributions. This suggests that the target function should be weighted by the variance of the data.

The ability to estimate abundance and fishing mortality at age gives the possibility of estimating the TAC early in the history of a fishery for a certain biological reference point, for example $F_{0.1}$, and of evaluating the effect of regulations on the exploitation pattern.

Regarding the results, the most interesting feature of the analysis is the detection of patterns of partial recruitment at ages greater than 12. This raises doubts about estimates of M and Z obtained from catch curves that assume a constant recruitment pattern after a certain age. In fact, this could explain the high M obtained with these methods when they are fitted to catch curves that come from virgin stock. Also, the results suggest that the most reasonable value of M would be within the range 0.1 to 0.2, perhaps very close to 0.15.

It is too early to assess the usefulness of this method at present. It is necessary to test it for other sets of data, and to analyse its operation in relation to procedural and observational errors, such as, for example, variations in the accuracy of recruitment and catch data.

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Table 1: Growth and age composition parameters of the *Dissostichus eleginoides* catches south of Chile, from the 1991/ 92 survey.

K = 0.066		t_o = - 0.477 years		W_∞ = 97.153 kg	
Age	Catch (N)	Age	Catch (N)	Age	Catch (N)
4	3.846	10	116.126	16	32.309
5	13.280	11	129.356	17	18.416
6	18.017	12	145.641	18	14.378
7	18.451	13	105.385	19	1.796
8	42.519	14	79.372	20	1.058
9	83.937	15	56.400		

Légende des tableaux

Tableau 1: Paramètres de croissance et de composition en âges des captures de *Dissostichus eleginoides* effectuées au cours de la campagne d'évaluation de 1991/92 au sud du Chili.

Список таблиц

Таблица 1: Параметры роста и возрастного состава в уловах *Dissostichus eleginoides*, полученных в ходе съемок на юге от Чили - съемка за сезон 1991/1992 г.

Lista de las tablas

Tabla 1: Parámetros de la composición por edad y de crecimiento de las capturas de *Dissostichus eleginoides* en el extremo sur de Chile obtenidas de la prospección realizada de 1991 a 1992.