AN ABUNDANCE MODEL OF SWORDFISH IN THE NORTH ATLANTIC OCEAN, BASED ON RELATIVE ABUNDANCE DATA MEASURED WITH ERROR

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SUMMARY

This paper explores a method devised to estimate total population size from abundance indices, catches, and knowledge of the natural mortality rate. The method was applied to data on north Atlantic swordfish. Although no believable parameter estimates were obtained, the method may prove useful in this application after more research.

RESUME

Ce document explore une méthode élaborée pour estimer l'ampleur du total de la population à partir d'indices d'abondance, prises, et connaissance du taux de mortalité naturelle. La méthode a été appliquée aux données obtenues sur l'espadon de l'Atlantique nord. Bien qu'aucune estimation de paramètre croyable n'ait été obtenue, la méthode peut s'avérer utile dans ce fonctionnement après des recherches plus poussées.

RESUMEN

Este documento explora un método ideado para estimar el tamaño total de la población a partir de índices de abundancia, capturas y conocimiento de la tasa de mortalidad natural. El método se aplicó a la obtención de datos de pez espada del Atlántico norte. Si bien no se obtuvieron parámetros creíbles, el método puede demostrar su utilidad en esta aplicación después de llevar a cabo más investigación.

Introduction

An important problem in fishery biology is conversion of relative abundance estimates to estimates of absolute stock size. Such conversion requires estimation of a scaling factor, or catchability coefficient, q. The catchability coefficient can be estimated by many means; for example, production models usually

provide an estimate of q. However, estimates of q from production models are often imprecise, reflecting insufficient information in the data to fix this parameter precisely (Hilborn and Walters 1992; Prager 1993).

An alternative approach to estimating q was provided by Collie and Sissenwine (1983). They presented two version of their approach; in the simpler one, the following information is used to estimate q: two series of relative-abundance estimates (one for the pre-recruit group, the second for recruited fish), the time series of catch in numbers, and an estimate of the natural mortality rate M. The Collie-Sissenwine approach uses more information than a typical production model (i.e., an additional CPUE index and the estimate of M), but uses fewer assumptions (recruitment is represented by the second CPUE index, rather than assumed to follow a functional form). In addition, the error structure is more complex, as explained below. The present study explores whether this approach might provide useful estimates of q for swordfish in the North Atlantic Ocean.

Model Structure and Fitting

The structure of the model comprises relatively few equations. The description here is abstracted from Collie and Sissenwine (1983), and largely follows their notation. The basic equation is a first-order difference equation relating the population size in numbers of fully-recruited (henceforth, "adult") fish N_t at the start of year t to the population size of adults in the following year:

(1) $$N_{t+1} = (N_t - C_t + R_t)e^{-M},$$

where R_t is the abundance (in numbers) of pre-recruits in year t, C_t is the catch of adults in year t, and M is the natural mortality rate. For simplicity, (1) assumes that catch and recruitment occur instantaneously at the start of the year and that natural mortality is continuous. Collie and Sissenwine (1983) found only a small bias from these assumptions in their application.

The relative abundance n_t of adult fish is related to their absolute population size N_t by the time-invariant catchability coefficient of the adults, q_n:

(2) $$n_t = q_n N_t.$$

Also, the relative abundance r_t of pre-recruits is related to the absolute number of pre-recruits R_t by the time-invariant catchability coefficient of the pre-recruits, q_r:

(3) $$r_t = q_r R_t.$$

Collie and Sissenwine were able to assume $q_n = q_r$, but that assumption was not possible here. Substituting (2) and (3) into (1) gives a population-dynamics equation in units of the adult relative-abundance index:

(4) $$n_{t+1} = (n_t - q_n C_t + r_t)e^{-M+\varepsilon_t},$$

where ε_t, the *process error* or unexplained natural variability in the population dynamics, is distributed normally with mean zero. The multiplicative error structure of (4) is a departure from the additive error assumed by the original authors. Two final equations relate the true relative abundance of adults and pre-recruits to their observed relative abundances, $\tilde{n}$ and $\tilde{r}$:

(5) $$\tilde{n}_t = n_t e^{\eta_t}$$

(6) $$\tilde{r}_t = r_t e^{\delta_t}$$

The quantities δ_t and η_t are the random errors in observating (measuring) relative abundance. Each is assumed normally distributed with mean zero. For T years of data, (4) and (6) are applied for $t = \{1, 2, ..., T-1\}$, and (5) is applied for $t = \{1, 2, ..., T\}$. Given the data described above, the model estimates true relative abundances of adults in years 1 to T, of pre-recruits in years 1 to $T-1$, and the two catchability (scaling) coefficients q_n and q_r. Estimation is done by minimizing the total sum of squares SS_Θ, which is conditional on assumed values (estimates) for all the parameters:

(7) $$SS_\Theta = \sum_{t=1}^{T-1} \varepsilon_t^2 + \sum_{t=1}^{T} \eta_t^2 + \sum_{t=1}^{T-1} \delta_t^2.$$

Equation (7) implicitly assumes that the variances of the three error terms are equal. An alternative method would be to use iteratively reweighted least squares, in which variances are estimated along with the parameters.

Application, Results, Discussion

To explore its feasibility for use on swordfish, the model described above was applied to data on north Atlantic swordfish. Data for 1981 through 1991 were obtained from Part I of the ICCAT Report for 1992-93. The pre-recruit relative abundance data were taken as the average of US and Spanish age-4 abundance indices in SWO-Table 5. The adult relative abundance data were taken as the average of US and Spanish age-5^+ abundance indices in the same table. Annual catch of the 5^+ group was obtained by summing the catches of Japan, Spain, the US, Canada, and Others in SWO-Table 3. Natural mortality M was set at 0.2/yr. Optimization was performed using the simplex (polytope) algorithm. Restarts were used to avoid local minima.

Several sets of estimates were obtained, most requiring over 50 restarts for full convergence. (This suggests a very irregular sum-of-squares surface.) The first three sets of estimates ignored the catch of age-4 fish (pre-recruits). The unconstrained estimates of q_n and q_r were 7.1×10^{-8} and 1.4×10^{-6} respectively. These estimates imply a stock of adult fish three orders of magnitude larger than that estimated by VPA; the result does not seem credible. The second set of estimates was made by constraining the ratio $S \equiv q_r/q_n$ to a maximum of 8.0. The resulting estimates were at the boundary, and still estimated much larger stock sizes than other assessments. The third set of estimates was made by fixing S to be 1.33, a value obtained by inspecting the VPA stock estimates in 1983, a year when both relative-abundance indices were standardized to 1.0. Under this assumption, the method estimated a steadily declining stock of adult swordfish, from 380,000 fish in 1981 to 87,000 fish in 1991. Again, this result does not seem credible when compared to results of VPAs and production models of this stock.

Three additional sets of estimates were made by modifying equation (4) to account for the catch of age-4 fish. Results were essentially similar to the first three sets of estimates.

The work presented here is quite preliminary, and constitutes a progress report on investigating a technique that may yet prove useful. Mendelssohn (1988) gave modifications to improve this model; perhaps better results might be obtained from his modifications. Another avenue of improvement might involve a better approximation than placing all catch (and recruitment) at the beginning of the year; this was mentioned by Collie and Sissenwine (1983). Fixing the ratio of catchabilities *a priori* might be necessary, although not sufficient, to constrain the problem.

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References Cited

Collie, J. S., and M. P. Sissenwine. 1983. Estimating population size from relative abundance data measured with error. Can. J. Fish. Aquat. Sci. 40:1871–1879.

Conser, R. J., and J. Idoine. 1992. A modified deLury model for estimating mortality rates and stock sizes of American lobster populations. Appendix to CRD-92-07. Res. Doc. SAW 14/7. NMFS Northeast Fisheries Science Center, Woods Hole.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, NY. 570 pp.

Mendelssohn, R. 1988. Some problems in estimating population sizes from catch-at-age data. Fish. Bull. (US) 86:617–630.

Prager, M. H. 1993. A suite of extensions to a nonequilibrium surplus-production model. Contribution MIA-92/93-58, Miami Laboratory, NMFS, NOAA. In press, Fish. Bull. (US) 92(2).