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Estimation of Mortality Components for some Baltic Herring Stocks in 1979

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Abstract

The mortality parameters (fishing, migration and natural) in the herring stocks in Baltic subdivisions 25+27 and 28+29 South are estimated using stock estimates from hydroacoustic surveys and the catch in numbers from the commercial landings. The analysis is only relevant for 2-group and older herring. An error analysis shows that a 10 % general standard error in the observations will allow the estimation of the fishing mortality coefficients with about 20 % and of the migration and natural mortality coefficients with 60-70 % standard error.

The natural mortality found is about twice the value so far assumed by the Baltic Pelagic assessment working group for these stocks.

Introduction

The Baltic Sea herring complex is assessed in seven units by the Working Group on Assessment of Pelagic Stock in the Baltic, Anon (1980) employing VPA techniques. In October 1978 and again in October 1979, the research vessels "Argos" (Sweden) and "Eisbär" (GDR) conducted acoustic surveys for herring and sprat in the subdivisions 24 to 29 south, Håkansson et al (1979) and Anon (1980). The surveys give stock estimates in numbers by age group (and therefore the total mortality for each stock component can be obtained directly).

The 1979 catches in number by age group are given in Anon (1980) for the herring assessment units covered by the surveys. It should be possible to obtain the catches by quarter and thus arrive at the numbers caught from October 1978 to October 1979. In this preliminary report has, however, the catch for 1979 been used.

Some herring in the Baltic migrates widely and the analysis of the catch and survey data must allow for this.

This paper attempts a preliminary analysis of the herring stocks in subdivisions 25-27 and 28+29 south. These stocks were chosen as additional difficulties appear for the other herring stocks as a consequence of incomplete covering by the surveys.

The data on which this preliminary analysis is based are the stock in numbers by age group at October 1978 and 1979 together with catches in numbers by age group for the subdivision 25-27 and 28+29 south for the period between the two surveys approximated by the 1979 catch in numbers.

The model used for the estimation of parameters includes fishing, natural and migration instantaneous mortality coefficients.

Theory

Let us consider an area with one stock and let the stock exchange members with some outside stock of the same species. If the number of individuals of stock 1 at time t is N_1 (t) then, assuming continous mortalities and exchanges

$$\frac{d}{dt} N_1(t) = \underbrace{-(F_2+M)\,N_1(t)}_{\text{Fishery and "other" mortalities}} - \underbrace{E_1 N_1(t)}_{\text{Migration out of the area}} + \underbrace{E_2 N_2(t)}_{\text{Migration into the area}} \qquad (1)$$

and

$$\frac{d}{dt} N_2(t) = -(F_2+M)\,N_2(t) + E_1 N_1(t) - E_2 N_2(t)$$

where the terms are defined analogously. The present data, of which the catches are cumulated over a time interval and the stock estimates refers to certain points in time, makes it impossible to estimate both E_1 and E_2 only the net in- or outflow is accessible, therefore either E_1 or E_2 must be zero in the model.

Assuming the mortalities to be constant over time and, say, $E_2 = 0$ the solutions to the equations above are

$$N_1(t) = N_1(0)\exp(-Z_1 t)$$

$$N_2(t) = N_2(0)\exp(-Z_2 t) + E_1 N_1(0)\exp\left(-\frac{Z_1+Z_2}{2}t\right)\frac{\sinh\left(\frac{Z_1-Z_2}{2}t\right)}{(Z_1-Z_2)/2}$$

where

$$Z_1 = F_1+M+E_1$$

$$Z_2 = F_2+M$$

For Z_1 close to Z_2 the solution will still be valid if the limit

$$\frac{\sinh xt}{x} \longrightarrow t \qquad \text{for } x \longrightarrow 0$$

is introduced.

The complete solution to (1) is then

$$N_1(t) = N_1(0) \exp(-Z_1 t) \tag{2a}$$

$$N_2(t) = \begin{cases} N_2(0) \exp(-Z_2 t) + E_1 N_1(0) \exp\left(-\frac{Z_1+Z_2}{2} t\right) \frac{\sinh x t}{x} & x \neq 0 \\ N_2(0) \exp(-Z t) + E_1 N_1(0)\, t \exp(-Z t) \quad (Z_1 = Z_2 = Z) & x = 0 \end{cases} \tag{2b}$$

$$x = \frac{Z_1 - Z_2}{2}$$

The catch from area i is found from

$$\frac{d}{dt} C_i = F_i N_i$$

or integrations from time 0 to time 1

$$C_1 = N_1(0) \frac{F_1}{Z_1} (1 - \exp(-Z_1)) \tag{3a}$$

$$C_2 = N_2(0) \frac{F_2}{Z_2} (1 - \exp(-Z_2)) + E_1 N_1(0) \frac{F_2}{Z_2 - Z_1} \left(\frac{1 - \exp(-Z_1)}{Z_1} - \frac{1 - \exp(-Z_2)}{Z_2} \right) \tag{3b}$$

or if $Z_1 = Z_2 = Z$

$$C_2 = N_2(0) \frac{F_2}{Z} (1 - \exp(-Z)) + E_1 N_1(0) \frac{F_2}{Z} \left(\frac{1}{Z} (1 - \exp(-Z)) - \exp(-Z) \right) \tag{3c}$$

The parameters F_1, F_2, E_1 and M may be obtained if $N_1(0)$, $N_1(1)$, $N_2(0)$, $N_2(1)$, C_1 and C_2 are observed. The stock estimates can be obtained from hydroacoustic surveys while C_1 and C_2 are reported from commercial catches. The analysis will have to be done on each yearclass.

The estimation of the four parameters F_1, F_2, E_1 and M is done by noting that Z_1 can be found from equ (2a) and inserting Z_1 into equ (3a) gives F_1 equ (3b). The three remaining equations on C_2, $N_2(1)$ and $E_1 + M = Z_1 - F_1$ gives F_2, E_1 and M.

Error Analysis

This section attempts an evaluation of the effect an uncertainty of, say 10 %, in the observed quantities X (N_1 (0), N_1 (1), N_2 (0), N_2 (1), C_1 and C_2) has on the estimated parameters β (F_1, F_2, E and M).

Let the uncertainties around the observations $\hat{x}$ be Δx. Then we seek the uncertainties $\Delta\beta$ in the estimated parameter

$$\Delta\beta = \left(\frac{\partial\beta}{\partial x}_{x=\hat{x}} \right) \cdot \Delta x$$

The matrix $\frac{\partial\beta}{\partial x}_{x=\hat{x}}$ may be evaluated from the estimation equations

$$f(\beta; x) = 0$$

and noting

$$\frac{\partial f}{\partial x} = - \frac{\partial f}{\partial \beta} \cdot \frac{\partial \beta}{\partial x} \equiv -J \frac{\partial \beta}{\partial \lambda}$$

J^{-1} is used for solving the estimation equations (Newton iteration). Conveniently, we may write

$$\frac{\partial \beta}{\partial x} = - J^{-1} \frac{\partial f}{\partial x}$$

where the evaluation of $\frac{\partial f}{\partial x}$ is straight forward.

The matrix $\frac{\partial\beta}{\partial x}$ may be expressed relatively to the parameters $\hat{\beta}$ and the observations $\hat{x}$. That is what relative uncertainty will be caused by a relative uncertainty in the observations. This matrix

$$\frac{\partial(\beta/\hat{\beta})}{\partial(x/\hat{x})}$$

will be called the sensitivity matrix.

Catches in numbers by age group

The 1979 catches in numbers by age group for the assessment units subdivisions 25-27 and 28+29 south are given in table 1, from Anon (1980). Quarterly catches from 4-th quarter 1978 and 1979 will be available for most countries and will be included in the final analysis.

The commercial catches of 1-group herring in subdivision 25 includes a component of Rügen Spring Spawning herring. These are subtracted from the commercial catches in subdivision 25-27 and added to the stock referred to subdivision 22+24, Anon (1980) and Anon (1979). This makes the catch data and survey data incompatible for the 1-group herring. Therefore the analysis do not include age group 1.

Stock in numbers by age group

The 0-group is possibly poorly sampled in the hydroacoustic surveys, Håkansson et al (1979). This is caused by the 0-group preference for shallow waters not covered by the surveys. It was therefore decided to exclude the 0-group from this analysis.

The stock in numbers by age group for October 1978 and October 1979 are given in table 1 from Anon (1980) for the yearclasses 1976 and older.

Results

The revision of the catch data were not completed when the deadline set by ICES for submitting papers for the 1980 statutory meeting became actual. Therefore the calculations presented are based on the 1979 catch data as given in Anon (1980).

The analysis showed that the migration for yearclass 1976 and older was directed from subdivisions 28+29 south into subdivisions 25-27.

Based on the data given in table 1 the mortality coefficients given in table 2 are found.

The mean sensitivity matrix, with the mean taken over all yearclasses in the analysis, is shown in thable 3. The sum presented in the last column of table 3 shows the amplification factor on the relative error in the mortalities from the overall relative error in the observations.

Discussion

The analysis shows migration of adult herring from subdivisions 28+29 south into subdivisions 25-27. The 3 and 4 group herring (yearclass 1976 and 1975) show a smaller proportion of migrants while older herring seems to migrate to a larger extent. Such migration will seriously effect the assessments of these stocks, based on VPA see Ulltang (1979) and Pope (1978).

The natural mortality estimates are about 0.4 per year, table 2. This is about twice the value of 0.2 per year, assumed by the Baltic Pelagic Assessment Working Group, Anon (1980). It must, however, be noted that the estimates in table 2 are associated by large standard errors, see table 3.

The herring stock estimates from VPA, Anon (1980) and from the hydroacoustic surveys, Håkansson et al (1979) and Anon (1980) differ markedly especially for the adult stock component. This may partly be due to the fact that the assessment by VPA does not take migration into account.

The hydroacoustic surveys have only recently been initiated in the subdivisions and little is therefore known about the precision achieved in the stock estimates.

Litterature

Anon., 1979: Report of the Working Group on Assessment of Pelagic Stocks in the Baltic. - C.M. 1979/J:4 and appendix.

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Pope J.G., 1978: Some consequences for fisheries management of aspects of the behaviour of pelagic fish. - Symposium on the Biological Basis of Pelagic Fish Management No. 12 (ICES, Aberdeen 1978).

Ulltang Ø., 1977: Sources of errors in and limitations of Virtual Population Analysis (Cohort Analysis). - J. Cons. int. Expl. Mer. 37 p. 249-260.

Tab. 1. Catches and stocks in numbers (mill) by age group for herring stocks in subdivisions 25-27 and 28+29 south (from Anon 1980).

Yearclass	Catch 1979		Stock Oct. 1978		Stock Oct. 1979	
	25-27	28+29 S	25-27	28+29S	25-27	28+29S
1976	495	114	2667	2537	1572	1398
1975	267	301	2413	3625	1737	2004
1974	124	56	892	1089	1046	464
1973	115	59	1001	944	994	403
1972	126	43	1286	952	1026	390
1971	80	27	604	530	627	226

Tab. 2. Estimated fishing (F), migration (E) and natural (M) mortality coefficients by yearclass for the herring stocks in subdivisions 25-27 and 28+29 south for 1979. The total mortality coefficients Z are given.

	Subdivisions					
	25-27		28+29 S			
Yearclass	F	Z	F	E	Z	M
1976	0.25	0.70	0.06	0.09	0.60	0.45
1975	0.14	0.54	0.11	0.08	0.59	0.40
1974	0.14	0.48	0.08	0.44	0.86	0.34
1973	0.13	0.50	0.09	0.39	0.85	0.37
1972	0.12	0.60	0.07	0.35	0.90	0.48
1971	0.14	0.47	0.08	0.45	0.86	0.33

Tab. 3. Sensitivity Matrix. Mean over all yearclasses.

	N_1 (0)	N_1 (1)	N_2 (0)	N_2 (1)	C_1	C_2	$\sum$ lxl
F_1	-0.57	-.43	0.00	0.00	1.01	0.00	2.01
E	1.48	-1.91	-1.52	1.87	-0.18	0.27	7.23
F_2	0.14	-0.09	-0.56	-0.45	-0.01	1.00	2.25
M	2.16	-1.34	0.84	-1.27	-0.27	-0.13	6.01