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Simulation of some Baltic Salmon Exploitation Patterns.

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Notation

$N_i(t)$	Stock in numbers at time t in area i
$C_i(t)$	Catch in numbers in timeinterval (t,t+t) from area i
M	Natural mortality,instantaneous coefficient
$F_i(t)$	Fishing mortality instantaneous coefficient. The area is i and the stock is exposed to this mortality in the period t to t + 1
$E_{ij}(t)$	Migration instantaneous coefficient. The fish is migrating from area i to area j in the period t to t + 1. $E_{ii}(t) = 0$ for all t.
$Z_i(t)$	Total mortality coefficient. Equal $M + F_i(t) + {}_j E_{ij}(t)$

Introduction

The stock of Baltic Salmon is a complex of wild and artificial reared stock from some 3o rivers. This complex has been assessed with the objective of establishing a TAC for 1981, Anon (198o).
This study is intended for a more detailed investigation of the estimation of parameters in Anon (198o) and also the sensitity of the yield to various exploitation patterns is studied.

The model applied in Anon (198o) is an ammended version of Lassen (1978) described.
The problem of optimizing the yield from a salmon population has been discussed by Parker (1963), Larkin (1977) reviews the Pacific Salmon problems. Sych (1976) and (198o) analyse the population dynamics of the Baltic Salmon stocks using a simulation model.

The model simulations are carried out on basicly the same data as in Anon (198o), however, the intention is not to establish an alternative assessment and no results in this paper should be interpreted as a disagreement with the ACFM recommendations on Baltic Salmon for 1981.

Theory

The model is a deterministic cohort description of the life-history of the Baltic Salmon. The model includes natural mortality, migration and fisheries in three areas into which the Baltic is splitted.
The equations are

Stock in numbers $N_i(t)$

$$N_i(t+1) = N_i(t) \exp(- \ _i(t))$$

$$+ \sum_{jEarea} N_j(t) \frac{E_{ji}(t)}{Z_j(t)} \quad 1-\exp(-Z_j(t))$$

Catch in numbers $c_i(t)$

$$C_i(t) = N_i(t) \frac{F_i(t)}{Z_i(t)} (1-\exp(-Z_i(t)))$$

The estimation of M, $F_i(t)$ and $E_{ij}(t)$ is based on tagging results. It is, however, as shown below not possible to obtain an estimate of all these parameters from tagging data only. As will be discussed in a subsequent section additional information are required.

The estimation problem may be formulated as finding the maximum likelihood function 2 and its maximum. It is assumed that the catch in numbers originates from a poisson probability distribution function with the mean equal the catch equal the catch equation.
We may write

$$L = \Pi p\{c \mid F \text{ and } E\}$$

assuming M to be known.
Taking logaritens and partial differentiation with the parameter α (=$F_K(t)$ or $E_{kk_1}(t)$) we find the estimation equations.

$$\sum_{i,t} \left[c_i(t) - N_i(t) F_i(t) e^{-Z_i(t)/2}\right]\left[\frac{\partial \log N_i(t)}{\partial \alpha} + \frac{\partial \log F_i(t)}{\partial \alpha}\right]$$

$$-\frac{1}{2} \sum_{i,t} \left[c_i(t) - N_i(t) F_i(t) e^{-Z_i(t)/2}\right]\left[\frac{\partial F_i(t)}{\partial \alpha} + \sum_j \frac{\partial E_{ij}(t)}{\partial \alpha}\right]$$

after applying the approximation

$$\frac{1-e^{-Z}}{Z} = e^{-Z/2} \frac{\sinh \frac{Z}{2}}{Z/2} \sim e^{-Z/2}$$

We then note that

$$\frac{\delta F_i(t)}{\delta \alpha} + \sum \frac{\delta E_{ij}(t)}{\delta \alpha} = \begin{cases} 1 & \alpha = F_i(t) \text{ ot } E_{ij}(t) \\ 0 & \text{otherwise} \end{cases}$$

and therefore the estimation equations reduces to

$$\sum_{i,t} \left[e_i(t) - N_i(t)\ F_i(t) e^{-Z_i(t)/2} \right] \left[\frac{\delta \log N_i(t)}{\delta \alpha} + \frac{\log F_i(t)}{\delta \alpha} \right]$$

$$- 1/2 \left[C_k(t_1) - N_k(t_1) e^{-Z_k(t)/2} \right] = 0$$

for $\alpha = F_k(t_1)$ or $E_{kk_1}(t_1)$

If the expression in the first parenteses under the summation is identical zero for all i and t, the estimation equations will be fulfilled.
It is also noted that other equations cannot arise. This means that at most the number of area times the number of time intervals parameters may be estimated although some observations, the stock by area at release, are available.
It may well be that among the remaining equations some interrelations exist, and therefore even fewer parameters are actually estimable.

Simulating the observed tag return pattern

As shown in the previous section a infinite number of parameter sets will reproduce the observed tag return pattern. Therefore any proposed parameter set must be corroborated by additional information. In the last section the additional information necessary to estimate the entire parameter set is discussed.

Anon (198o) established a parameter set, table 1, and in table 2 these simulated tag return pattern are compared with results of the Swedish smolt tagging programme for the years 1969 to 1974.
Varying the fishing mortalities with a factor applied to the entire exploitation pattern we may compare the average 1969-74 situation with the simulated results, table 3.

It should be noted that an exact fit could be obtained for the 1969-74 average situation, this however would ignore information from other sources (cpue, effort o.a.).

Information required for estimation of the complete parameter set.

It was noted in the theory section that in the presented model only 3 x 8 parameters can at most be estimated from the tagging experiments. However, the model requires 49 parameters to be available. These parameters are with the number of parameters given in parentes are M [1] , $F_i(t)$ [24] and $E_{ij}(t)$ [24] as $E_{ij}(t) = 0$ and if $E_{ij}(t) > 0$ then $E_{ji}(t) = 0$.

The availability of effort and catches per unit of effort (cpue) information makes estimation of $M + \sum E_{ij}(t)$ possible.

Christensen and Larsson (1979) gives cpue by age-group for A.1 + and A.2+ Salmon separately and total effort for the Main Basin. Calculating Z = - log [cpue(A.1+)/cpue(A.2+)] and plotted against effort (fig. 1.) the regression model

$$Z_i = M + q\text{x}effort + \sum_j E_{ij}$$

may be fitted. Fig.1. (Christensen pers. comm.) gives $M + \sum E_{ij} \sim 1$ and $q \sim 0.085$. These estimates reduce the number of parameters to be estimated from tagging experiments by 1 + 2 as the analyses only apply to the A.1+ group in the Main Basin. Similar information are available for the A.2+, but the cpue of the A.3+ is very low and the Z estimate is thus subject to major uncertainties.

Data on effort and cpue for other areas would be greatly appreciated.

Literature

Anon	(198o)	Report of the Baltic Salmon Assessment Working Group C.M.198o/M:3
Christensen O. and Larsson P.O.	(1979)	Review of Baltic Salmon Research ICES Coop.Res.Rep. No. 89.
Larkin P.A.	(1977)	Pacific Salmon Chapter 8 in Fish Population Dynamics ed. J.A. Gulland John Wiley & Sons.
Lassen H.	(1978)	An assessment model applied to the Baltic Salmon C.M.1978/M:25
Parker R.R.	(1963)	On the problem of maximum yield from North Pacific Sockeye Salmon Stocks J.Fish.Res.Bd.Can.2o(6)p.1371
Sych R.	(1976)	A numerical model of the commercial exploitation of fish. Ichthyologica 8 p.155-162
Sych R.	(198o)	On the modelling of the Baltic Salmon and Sea Trout stock exploitation Report to the 27th meeting of the Baltic Salmon Working Group 2-3 September 198o, Tvärminne, Finland.

Table 1a Migration pattern applied in calculating the yeild of the Salmon stock. Area I: Coastal Gulf of Bothnia, II Bothnian Sea, III Main Basin. From Anon (1980).

From Area	To Area	Age	Half of the year	Migration mortality per year
I	II	A.0+	2	3.0
I	III	A.0+	2	3.0
II	I	A.0+	1	0.7
II	III	A.0+	1	1.0
II	I	A.1+	1	0.5
III	I	A.1+	1	0.5
II	I	A.2+	1	1.4
III	I	A.2+	1	1.4
II	I	A.3+	1	1.4
III	I	A.3+	1	1.4

Table 1b Exploitation pattern derived from Finnish and Swedish tagging 1969-76. F is per year. Area I: Coastal Gulf of Bothnia, II Bothnian Sea, III Main Basin.

F	1. half of the year			
Area	0+	1+	2+	3+
I	.075	-	-	-
II	.075	.45	.45	.45
III	.075	1.05	1.20	1.20
	2. half of the year			
Area	0+	1+	2+	3+
I	.075	.50	.60	.60
II	.075	.75	.90	.90
III	.075	1.05	1.20	1.20

Natural mortality M = 0.1 per year for all age groups throughout the life span.

Table 2 Comparison between observed tag returns and simulated results 1969-74. The percentase observed tag returns from P.-O. Larsson (pers. comm.) and Anon (198o). The seasons are A:1/9 - 31/12 and S: 1/1 - 15/6(1/7). The fishery is closed 15/6 (1/7) to 31/8.

Age	Season	1969	197o	1971	1972	1973	1974	1969-74	Simulated
O+	A								
O+	S								
1+	A								
1+	S								
2+	A								
2+	S								
3+	A								
3+	S								
No Returns									
No. Released		58461	59748	83613	52oo2	53315	51848		
% returns.									

Table 2 Comparison between the relative simulated tag return pattern using data from Anon (1980) and the tag return pattern for the 1969 to 1974 experiments (P.-O. Larsson pers.comm.) Season A: (autumn) is the period 1/9-31/12, while S is 1/1-1/7. The per centages are relative to the number of releases.

Gulf of Bothnia Coastal Fishery

Age	Season	1969	1970	1971	1972	1973	1974	1969-74	Simulated
A.0+	S	.019	.015	.032	.054	.026	.033	.029	.03
A.1+	A	.388	.676	.513	1.185	1.253	1.304	.841	.6
A.1+	S	.034	.050	.349	.164	.170	.209	.174	} .4
A.2+	A	.470	.807	.958	.909	.662	.851	.787	}
A.2+	S	.057	.167	.142	.204	.092	.145	.134	} .2
A.3+	A	.155	.127	.149	.227	.133	.199	.162	}
A.3+	S	.026	.018	.012	.027	.013	.006	.017	-
Number returned		5693	7645	7757	6315	7037	7227	41674	
Number released		58461	59748	83613	52002	53315	51848	358987	

Table 2 (continued)

Bothnian Sea

Age	Season	1969	1970	1971	1972	1973	1974	1969-74	Simulated
A.0+	S	.054	.033	.026	.073	.015	.085	.045	.2
A.1+	A	.588	.619	.273	.383	.398	.901	.507	1.1
A.1+	S	.096	.147	.179	.354	.325	.440	.245	.4
A.2+	A	.273	.310	.118	.309	.259	.399	.264	.5
A.2+	S	.096	.119	.136	.181	.050	.120	.118	.1
A.3+	A	.025	.018	.015	.044	0.029	.077	.032	.1
A.3+	S	.016	.023	.009	.019	.008	.025	.016	.03

Table 2 (continued)

Main Basin

Age	Season	1969	1970	1971	1972	1973	1974	1969-74	Simulated
A.0+	S	.089	.083	.072	.063	.114	.345	.121	0.3
A.1+	A	4.779	5.467	3.044	4.480	4.631	3.196	4.195	4.5
A.1+	S	1.139	2.186	1.681	1.404	3.078	3.254	2.071	2.3
A.2+	A	0.992	1.347	1.085	1.217	1.191	1.604	1.223	1.2
A.2+	S	0.247	0.270	.286	0.592	0.577	0.611	.411	0.5
A.3+	A	0.109	0.122	.102	0.151	0.102	0.133	.118	0.2
A.3+	S	0.028	0.018	.058	0.023	0.032	0.046	.036	0.06

<u>Table 3</u> Comparison between the mean 1969-74 observed tag return pattern and three simulated exploitation levels. The factor given applies to all fishing mortalities as given in table 1.

		Gulf of Bothnia				Bothnian Sea				Main Basin			
Age	Season	1969-74	0.75	1.0	1.25	1969-74	0.75	1.0	1.25	1969-74	0.75	1.0	1.25
A.0+	S	.029	.02	.03	.04	.045	.2	.2	.3	.121	.2	.3	.4
A.1+	A	.841	.5	.6	.7	.507	.8	1.1	1.3	4.195	3.6	4.5	5.3
A.1+	S	.174 }	.4	.4	.4	.245	.4	.4	.5	2.071	2.1	2.3	2.3
A.2+	A	.787 }				.264	.4	.5	.5	1.223	1.3	1.2	1.1
A.2+	S	.134 }	.3	.2	.2	.118	.1	.1	.1	.411	.6	.5	.4
A.3+	A	.162 }				.032	.1	.1	.1	.118	.2	.2	.1
A.3+	S	.017				.016	.03	.03	.02	.036	.1	.06	.04

Table 3 Simulated tag return pattern for various levels of exploitation. The unit level is given in table 1. The seasons are A:1/9-31/12 and S: 1/1-15/6 (1/7). The fishery is closed 15/6(1/7) to 31/8.

Age	Season	Gulf of Bothnia Coastal Fishery				Bothnia Sea				Main Basin			
			Simulated level				Simulated level				Simulated level		
		1969-74	.75	1	1.25	1969-74	o.75	1	1.25	1969-74-74	o.75	1	1.25
0+	A												
0+	S												
1+	A												
1+	S												
2+	A												
2+	S												
3+	A												
3+	S												

Fig.1 Total mortality from cpue of A.1+ and A.2+ Salmon against total effort, for the Main Basin (Christensen O. pers. comm.).