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PROBABILISTIC ASSESSMENT OF TAC BASED FISHERIES MANAGEMENT OF BALTIC SALMON STOCKS

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ABSTRACT

Fisheries management of mixed fisheries of wild and reared Baltic salmon stocks was studied. Equation for allowed fishing mortality as a function of needed parent stock and estimation procedure for separate estimation of northern and southern stocks were derived. Recruitment of northern wild stocks seemed to constitue about 25 % of the total wild stock recruitment. A probabilistic simulation model for the TAC decision was constructed. Results show, that if the wild stock will decrease further, the cost of the management will be very high in terms of lost reared salmon production. The realization of the TAC of the intermediate year seemed to be the most important source of uncertainty in the prediction of the stock. The uncertainty in the estimates of reared stock was more crucial than the uncertainty in the estimates of wild stock. An area based TAC would probably be more effective management method, because it fixes more precisely the fishing mortality values of different agegroups during the intermediate year between the data and the target year.

1. Introduction

Baltic wild salmon stocks are continuously subjected to heavy fishing pressure. In the northern rivers of the Gulf of Bothnia, number of female spawners has been very low; For example, in the Tornionjoki River, the smolt production has reached only 15 % of the potential production (Anon 1991). Even though the safeguarding the wild Baltic salmon stock has been set as the primary goal of the management, it is not easy to achieve this goal in practice. Effective assessment and management of Baltic salmon stocks is difficult and uncertainties are high. There are at least the following reasons for this:

1) The life cycle of salmon is very short and fishing pressure is high. The time needed for the management procedure - stock assessment and TAC decision - is long compared to the life cycle of the species.

2) Fishing pressure should be based on the state of the weakest wild salmon year class. The estimation of the size of the whole wild stock is substantially inaccurate due to general uncertainties involved in the assessment methods, and uncertainties in the distinction between wild and reared salmon in scale studies (Anon. 1991). Also the areal distribution of scale samples has not been sufficient in contrast to the areal distribution of the catch. Separate estimation of the size of the northern and southern stocks is even much more difficult. The allowed fishing mortality is, however, bound to be based on this uncertain estimate of the wild stock (Anon. 1991).

3) The overwhelming part of the catch in coastal trapnet fisheries is concentrated within two months in a year. Therefore, it is difficult to follow the accumulation of the total catch. Total quota should be shared individually. Catch of trapnet fisheries consists of spawners and therefore regulation of trapnet fisheries is the most essential management problem of the salmon fisheries.

4) Because the Gulf of Bothnia is long and narrow in shape, the catchability of trapnet fisheries stays on high levels during the whole migration. Therefore, even effective regulation of open sea fisheries might be useless for the northern wild stocks, if trapnet fishing is not regulated properly.

The aims of our study were:

1) To derive the needed equations for the allowed fishing mortality as a function of wild parent stock and to show the dependence of TAC on the size of wild stock.

2) To analyse the uncertainties of different information sources in the prediction of future stock. This theme has become more important now, when the fisheries is based for the first time on TAC.

2. Management and assessment procedures

2.1 Allowed fishing mortality as a function of needed parent stock

The allowed fishing mortality can be determined by the size of the wild stock and by the size of the needed parent stock. Fishing mortality should be such, that there is enough male and female salmon in the rivers after fishing season. Because wild and reared stock are fished in a mixed fashion, the total TAC must be based on this highest allowed fishing mortality and on the size of the both stocks.

The following calculation procedure is based on the assumption, that fishing mortality is roughly equal for reared and wild stocks. Because the drift net fishery is very selective (Karlsson & Eriksson 1990) and the northern wild salmon have lower growth rate than reared stock do (Anon. 1991), fishing mortality of the northern wild stock might be somewhat lower during the second winter at sea. If the spawning migrations of reared and wild stocks begin at same size, the resulting fishing mortality in the open sea area is, however, about equal for both stocks.

The parent stock is assumed to consist of a certain proportion of age groups A2 to A4. Because the number of male grilse is usually sufficient in the rivers, the TAC must be based on the needed amount of females. In a linear form the size of the parent stock in the end of the fishing season can be expressed as:

$$N(parent) = aN_{(A2)}(1-F_{(A2)}-M) + bN_{(A3)}*(1-F_{(A3,A4)}-M) + cN_{(A4)}(1-F_{(A3,A4)}-M) \quad (1)$$

Where $N(parent)$ = size of parent stock in the end of season

$N_{(A2)}$, $N_{(A3)}$, $N_{(A4)}$ = size of age groups in the beginning of the year

$F_{(A2)}$, $F_{(A3,A4)}$ = proportional fishing mortality during the fishing season

a = proportion of mature females in the agegroup A2

b = proportion of mature females in the agegroup A3

c = proportion of mature females in the agegroup A4

Fishing mortality in age groups A3 and A4 is assumed to be equal. The F(2)/F(3,4) ratio can be estimated by the data. Denoting this relationship with d, equation (1) can be redefined as:

$$F_{(A3,A4)} = (1-M)*(adN_{(A2)}+bN_{(A3)}+cN_{(A4)} - N(parent)/(dN_{(2)} + bN_{(A3)}+cN_{(A4)}) \quad (2)$$

By this equation the allowed fishing mortality can be calculated as a function of wild salmon stock.

These values are proportional and they must be changed using equation F(moment)= -ln(1-F) to get momentary values which can be compared to yearly VPA values. If the size of the stock used in equations is supposed to equal the stock size in the beginning of the year, the fishing mortality in the equation is the allowed fishing mortality during the whole fishing season. Table 1 shows the allowed fishing mortality as a function of wild stock and needed parent stock. In table 2 TAC is calculated as a function of reared and wild stock. Needed parent stock is supposed to be 6000 females (Anon. 1991). These calculations are made to demonstrate the effect of the size of the wild stock on the total catch and therefore age groups are not separated.

2.2 Estimation of the recruitment of northern and southern wild stocks

Owing to the mixed fisheries of reared and wild salmon stocks, the allowed fishing mortality should be based on the state of the weakest stocks. These stocks are probably the northern stocks of the Gulf of Bothnia. Therefore, it would be essential to estimate the size of the northern stocks separately.

In order to obtain a minimum estimate for the size of the northern year classes it is assumed that almost all the fish entering the Gulf of Bothnia will be caught. The resulting figure is then added to the assumed mortality during the sea phase in the Baltic Main Basin. Thus, the minimum estimate for the year class of northern wild salmon at the age of recruitment to the fishery is:

$$N = \frac{CGB(A2)}{\exp(-F(sea)-M(sea))} + \frac{CGB(A3)}{\exp((-F(sea)-M(sea))*2)} \qquad (3)$$

Where N = size of the yearclass
CGB(A2), CGB(A3) = catch of one agegroup of certain yearclass in the Gulf of Bothnia
F (sea) = fishing mortality per year in the Main Basin
M (sea) = natural mortality per year in the Main Basin

Catches of age group A4 have been so low, that they can be discarded from the calculations at this stage. In case they will increase, they should be added to the equation as a third element. In these calculations it is supposed, that roughly 60 % of the salmon are caught before some of them return to the coast at age A2. Moreover, a natural mortality of 0.1/year is assumed. Thus, the total mortality is supposed to be 0.95/year. The same mortality is assumed for those salmon, which stay one more year in the sea.

For this type of calculations, a tagging data showing the areal distribution of the catches of the wild northern stock would be essential. It is not yet possible to determine the home river by scale samples.

The estimated year classes of the northern stocks are given in table 3. These estimates are very rough, and they must be used with care. However, the mean recruitment of the northern year classes is probably usable. It is about 25 % of the total recruitment. This value can be used in the determination of the allowed fishing mortality for the whole stock. In Anon. (1991, table 4.9.1) it is assumed, that the wild smolt production of the northern rivers is 45 % of the total production. Part of this difference can be explained by the lower post-smolt mortality of the southern stocks, which can be seen also in the stocking results of reared southern and northern stocks (Anon. 1991, fig. 9.3).

If the needed parent stock of the northern wild stocks is assumed to be 3 500 (Anon. 1991) and the percentual amount of northern stock in the whole wild stock is 25 %, the needed parent stock for the whole Baltic is 14 000 wild salmon individuals. This is the case as far as there is no area based TAC separately for the Main basin and the Gulf of Bothnia.

2.3. Simulation model

In order to analyse the uncertainties of the management decisions we constructed a spreadsheet based simulation model. @Risk program (Palisade 1990) was used, which is an Add-in program for most commonly used spreadsheet programs. It enables the use of 24 different probability distributions, including continuous and discrete ones. The distributions can be applied both as probabilistic inputs or procedures in further steps of a model. They can be used together with and in the same manner as other spreadsheet functions. Distributions are not merged analytically in computation, but instead stochastic simulation is used, using either Monte Carlo or Latin Hypercube sampling. In this study, we used Latin Hypercube sampling with 3000 iterations in each simulation.

The aim was to re-analyse the TAC proposal of recent year (TAC for year 1992) made by the ICES Baltic Salmon and Trout Working Group. Because the structure of the fisheries has changed remarkably (Anon. 1991, table 4.11b), the data did not allow the estimation of most of the uncertainties of this new situation. There will probably be clear change in the fishing pattern of the stock. Therefore, the uncertainties involved were mostly based on the subjective assessment by the authors.

The model is documented in detail in table 5. The names of the variables are those used in our spreadsheet model, only the line number is omitted. Even though it is written for the @Risk program, it can be used also with expected values in a normal spreadsheet program. The following list gives some comments on selected variables and coefficients. Because the model is based on the assessment of the TAC 1992, the time (t) is year 1991 and (t+1) is 1992 in this case.

Reared and wild stock in the beginning of t

To predict the year classes of 1990 and 1991 we used data presented by Kuikka (1991, tables 5 and 6). Moreover, the reared smolt production was assumed 4 100 000 smolts per year.

The probability distribution of year class 1990 (age group A2 of reared stock) was assessed with table 6 in Kuikka (1991). Mean growth of postsmolts in 1990 was 3.6 cm and the mean temperature at Valassaaret in May was 4.5 ^{0}C. The expected value was assumed to be 670 000 (16.3 % survival) and coefficient of variation of lognormal distribution to be 0.15.

For the prediction of year class 1991 (A1 (t+1)) the mean temperature of May at Valassaaret (4.5 ^{0}C) and the monthly values of May - July were obtained from the Finnish Marine Research Institute. Temperature values (^{0}C) were as follows: May: 7.2, June: 11.0, July: 17.2. The mean temperature of August was not available, because these analysis were made in the beginning of August. Because of the low temperature values in the beginning of the summer, the mean temperature is most probably in the lowest class of table 5 in Kuikka (1991). The expected value was supposed to be 700 000 and the coefficient of variation of lognormal distribution to be 0.2.

The estimates of all other age groups of reared and wild stock were based on the VPA estimates given in Anon. (1991). The coefficient of variation was supposed to be 0.1 for each age group. Figure 1 shows the lognormal distributions calculated using variation coefficients 0.1 and 0.2.

TAC (t) and remaining stock

Year 1991 was the first year when a TAC was introduced for the Baltic salmon fisheries. It is, however, possible that the total quota is exceeded or not reached because of marketing problems. The age distribution of the catch, and hence the real number of the fish, is also uncertain. This uncertainty is included in the model by assuming a normal distribution with coefficient of variation of 0.1 for the TAC. TAC of 3350 tonnes was changed to numbers by assuming a mean weight of 4.2 kg. Thus, the quantitative TAC was assumed to be 800 000 salmon individuals.

Because this being the first year when TAC has been applied, it is uncertain how the fishing mortality will change in different age groups. Therefore, half of the age group A1 was assumed to belong to the recruited part of the stock and all other age groups are totally recruited. This assumption is mostly based on the fact, that fishing mortality is clearly higher in older age groups because of the effective trapnet fishing. Fishing mortality in age group A1 has been usually slightly less than 50 % of the fishing mortalities of older age groups (table 4). TAC is subtracted from this recruited stock and the same age distribution is assumed for the remaining stock (variables K and M to T in table 5). These assumptions were made also for year t+1.

Remaining wild parent stock

This variable is the objective of the management. Because there is usually enough male grilse in the rivers, the number of female spawners is the critical variable. Needed amount of parents is assumed 14 000 for whole Baltic as given above. The proportion of mature females in each age group is difficult to estimate, but assuming all trapnet catches in the Gulf of Bothnia to consist of mature spawning migrators, the minimum estimate of the mature females can be calculated by tagging data. The following ratio should give this minimum estimate:

$$\frac{\text{female trapnet catches of the age group}}{\text{total catch of the age group}} \qquad (4)$$

By the Finnish tagging data this ratio was calculated to be 28 % for age group A2 and 43 % for age group A3. Number or returns was too low in age group A4 for reliable estimates. Moreover, some of the mature salmon are caught before they reach the coast. Therefore, the proportion of mature fish is apparently somewhat higher than these estimates show. In simulations we assumed, that the amount of mature females of each age group in the end of the year is 30 % in age group A2, 50 % in age group A3, and 80 % in age group A4 (see variable AF in table y). The high amount of females in older age groups can be explained by the higher mortality of male grilse salmon in age group A1.

3. Simulation results

3.1 Distribution of the parent stock as a function of TAC

The prior results obtained from the model simulations deal with the analysis of the TAC decision and uncertainties involved in it. The 80 % confidence limits and expected values as a function of TAC of target year (year 1992 in this case) are shown in figure 2. Lower line shows the level, where in nine year out of ten year the parent size is at least on the level shown by the line. In terms of risk attitude, the domain below the expected line represents risk averse and the upper line risk prone attitude. The resulting shape of the distribution appeared quite near the normal distribution, with skewness of 0.1 and kurtosis of 3.1. By these distributions the proposed TAC for year 1992 seems to be somewhat on the risk prone side of the distribution of parent stock.

3.2 Probabilistic sensitivity analyses

The sensitivity of the model was studied by two different approaches. We made percentual changes to the expected values and calculated the percentual changes of the resulting parent stock. Moreover, we changed the variation coefficients of some input variables and calculated the resulting 80 % confidence area. Each analysis was made using the value 688 000 for the TAC (t+1), which is the proposed TAC for 1992.

In the expected value sensitivity study, the density functions of each probability distribution were multiplied by 0.7, 0.85, 1.15 and 1.3, and the resulting computed values of remaining wild parent stock were compared with the values calculated using the nominal values. The reared year classes A1 (t & t+1) and A2 (t) and the wild A1 (t) appeared very sensitive (table aa), but the distribution yielding the most sensitive outcome in the remaining wild parent stock was the TAC of year t. The model sensitivity was high probably due to the fact that the model structure includes the calculation of the remaining stocks in two phases, using differences.

In the second sensitivity analysis, the coefficients of variation of the probability distributions, except age group A4, were given values 0, 0.05, 0.1, 0.15 and 0.2. Additionally, the effect of uncertainty in the percetual amount of mature female in each agegroup were studied using same variation coefficient values. The results (figure 3) showing the width of the 80% confidence domain of the distribution for the remaining wild parent stock, showed the same overall properties for the model as the sensitivity study documented above. Figure 4 shows the results as relative values, calculated using the equation ((b-a)/a)/r, where a is the confidence interval with variation coefficient value 0%, b is the interval width with given non-zero coefficient of variation r, introduced to the distribution under study. Thus, these values describe how much the uncertainty of the whole model decreases per one unit of the coefficient of variation of each variable. These results were obtained using stochastic simulation, and they thus are subjected to some noise.

3.3 Possible decrease in wild stock recruitment

The recruitment values of the wild salmon stock have been suggested to follow a decreasing trend (Anon. 1991, table 4.12.8). Because this hypothesis is based on few observations, it is difficult to study with statistical tests. In this study we were forced to use the sensitivity analysis approach, evaluating the model with a range of linear trend values for the decrease of the recruitment. The range analyzed was from no trend to 50% decrease from the mean of the years 1980 to 1989 to the target year. Results are given in table 7.

4. Discussion

4.1 Roles of different sources of information and uncertainty in the management

The results of the sensitivity analysis describe conditions in one single year - the present situation. Studied conditions were remarkably different from those in 1980's. Because of the increased growth levels of salmon, the TAC in 1991 was quite low compared with the size of the stock, and therefore the size of the age group A3 is expected to be unusually high in 1992. This is apparently the reason for the sensitivity of the parent stock for the size of the age group A2 in year t. Model is more sensitive to the reared stock, because the overall fishing mortality of the intermediate year is determined mostly by the size of the reared stock. Wild stock has the same fishing mortality and therefore the size of the parent stock is that sensitive to the size of reared stock.

Neglecting natural mortality from the equations may affect the results. The actual uncertainty involved in the model is predominated, however, by other issues and therefore the natural mortality was not included in the study. Moreover, the natural mortality of salmon is probably very small, even smaller than 0.1 per year, as is usually assumed.

In the results of the second sensitivity analysis, and especially in figure 4, it seems that the marginal benefit due to reduced uncertainty is decreasing. I.e. the relative decrease in the confidence domain of the joint distribution for remaining wild parent stock is greater with high variation coefficient values than with small ones. This was most evident in the cases of the most sensitive distributions: Reared A1 (t) and A2 (t), and TAC (t). In practice this means, that there is no reason to pay for very good estimates of some of the variables, if the uncertainty in other variables stays on high levels.

Results show, that prediction uncertainty is very sensitive to the TAC of the year between the data and the target year. TAC decreases uncertainty in itself, because it fixes the fishing mortality of the intermediate year. The estimation or assessment of the accuracy of the realization of the TAC decision during the target year is thus of high importance. The more accurately the realized catch of each age group can be controlled by TAC, the less uncertainty remains to the estimate of parent stock. An area based TAC would therefore decrease the uncertainty, because the fishing mortalities of different age groups would be known more accurately.

The decreasing trend in recruitment of wild salmon stocks is - as mentioned above - impossible to test and quantify with present data. Assuming an annual decrease of 5% in recruitment from 1980, and fixing the level using the mean value of 1980 to 1989 to represent the year 1984, one gets an approximation of 35% decrease from the mean value to the year 1991. This study does not assume any trend, but table 7 can be used to get a quantified estimate of a range of trends on the impact on the wild parent stock. The simulation results suggest, that the estimation of the reared year classes is even more essential than the estimation of the wild year classes. It is also probable, that a too low parent stock in one single year is not alarming, if the mean size of the parent stock stays appropriate.

According to this study, the computational approach used appeared efficient and applicable in the analysis of management of fish stocks under high uncertainty. Spreadsheet based environment is very user friendly, and most experts are familiar with working with spreadsheets. We recommend the use of the software and computational approach in further studies and in the working groups within ICES.

The term "safeguarding wild salmon stocks", used by the IBSFC, can be comprehended to mean risk averse attitude in management. If the exact risk attitude of managers could be estimated and an acceptable objective function constructed, it would be possible to give a point estimate of the allowed TAC. Because this is not the case presently, we suggest the use of distributions as in fig. 2 instead. This means, that the proper risk level has to be fixed less analytically. It is more correct to include the risk attitude to the decision phase, not to the estimation procedure of the stocks. The definition of the acceptable risk level should be made by decision makers, not by scientists.

4.2 Fishing of mixed stocks as a management problem

Table 2 shows quite clearly one of the basic problems of the baltic salmon management. If the wild stock goes down to very low levels, the cost of the management is high in terms of lost reared salmon production. If the state of the wild stock was good, the fisheries could utilize both stocks.

No further decrease in the size of the wild stock should be allowed due to the increasing management costs in terms of lost reared salmon production. It would be also politically difficult to justify low quotas, if the reared stock was on high level.

Because the aim of the management is to save wild parent stock, and the most critical stocks are those in the northern part of the Gulf of Bothnia, the control of the trapnet fisheries of the Gulf of Bothnia must be effective. A total TAC for whole Baltic is not appropriate, because it allows the fishing of the whole spawning stock. Most trapnet catches are taken before August, and in a case of high trapnet catches only the open sea fisheries would be regulated.

The surplus of the reared stock will be quite high, if the TAC will be implemented in the future as proposed here. If the safeguarding of wild stock is, however, the real aim of the management, this is an inevitable consequence. It would be possible to utilize the reared stock on the stocking areas in the end of the fishing season, when wild spawners are already in the rivers. As a consequence of such management all nations would utilize the wild stock in equal proportions and, moreover, the smolt producing countries would utilize the surplus. This would actually mean quotas for wild salmon.

5. Conclusions

1) Further decrease in the size of the wild stock should not be allowed. Otherwise the cost of the management in terms of lost reared production is likely to go beyond politically acceptable level.

2) The level of realization and the age distribution of the quota of the year between data and target year is very essential in the prediction of the target year stock size.

3) An area based TAC would decrease the uncertainty of the stock prediction by fixing the age distribution of the catch. Total TAC of the whole Baltic is not a sufficient management method, since it allows very effective trapnet fishing of the mature stock in the beginning of the fishing season.

4) More use of probabilistic decision analysis within ICES is suggested.

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Table 1. Allowed fishing mortality as a function of wild stock in the beginning of the year and needed parent stock. Stock sizes are in thousands. Fishing mortality is in 1/year. Natural mortality = 0.1/year.

Wild Stock	Needed Parent stock											
	1	2	3	4	5	6	7	8	9	10	11	12
2.5	.87	.17										
5	1.56	.87	.46	.17				no fishing at all				
7.5	1.96	1.27	.87	.58	.36	.17	.02					
10	2.25	1.56	1.15	.87	.64	.46	.31	.17	.06			
12.5	2.48	1.78	1.38	1.09	.87	.68	.53	.40	.28	.17	.08	
15	2.66	1.96	1.56	1.27	1.05	.87	.71	.58	.46	.36	.26	.17
17.5	2.81	2.12	1.71	1.43	1.20	1.02	.87	.73	.61	.51	.41	.33
20	2.95	2.25	1.85	1.56	1.34	1.15	1.00	.87	.75	.64	.55	.46
22.5	3.06	2.37	1.96	1.68	1.45	1.27	1.12	.98	.87	.76	.67	.58
25	3.17	2.48	2.07	1.78	1.56	1.38	1.22	1.09	.97	.87	.77	.68
7.5	3.26	2.57	2.17	1.88	1.65	1.47	1.32	1.18	1.07	.96	.87	.78
30	3.35	2.66	2.25	1.96	1.74	1.56	1.41	1.27	1.15	1.05	.95	.87
2.5	3.43	2.74	2.33	2.04	1.82	1.64	1.49	1.35	1.23	1.13	1.03	.95
35	3.51	2.81	2.41	2.12	1.90	1.71	1.56	1.43	1.31	1.20	1.11	1.02
7.5	3.57	2.88	2.48	2.19	1.96	1.78	1.63	1.49	1.38	1.27	1.18	1.09
40	3.64	2.95	2.54	2.25	2.03	1.85	1.69	1.56	1.44	1.34	1.24	1.15

Table 2. TAC in numbers as a function of reared stock and wild stock. Needed parent stock is supposed to be 6 000 individuals (Anon. 1991). Allowed fishing mortality (1/year) is on the left.

All. F-mort	Wild stock	Reared stock											
		0	25	50	75	100	125	150	175	200	225	250	275
.46	10	4	13	22	31	40	49	58	67	76	85	94	103
.87	15	9	23	37	51	65	79	94	108	122	136	150	165
1.15	20	13	30	47	64	81	97	114	131	148	164	181	198
1.38	25	18	37	55	73	92	110	128	147	165	183	202	220
1.56	30	23	43	62	81	101	120	140	159	178	198	217	236
1.71	35	28	48	68	89	109	129	149	169	189	209	229	250
1.85	40	33	54	74	95	116	137	157	178	199	219	240	261
1.96	45	38	59	80	101	123	144	165	186	207	228	249	270
2.07	50	43	64	86	107	129	150	172	193	215	236	258	279
2.17	55	48	70	91	113	135	157	179	200	222	244	266	287
2.25	60	53	75	97	119	141	163	185	207	229	251	273	295
2.33	65	58	80	102	124	147	169	191	213	235	258	280	302
2.41	70	63	85	107	130	152	175	197	219	242	264	287	309
2.48	75	68	90	113	135	158	180	203	225	248	271	293	316
2.54	80	73	95	118	141	163	186	209	231	254	277	299	322
2.60	85	78	100	123	146	169	191	214	237	260	283	305	328

Table 3. Estimates of the northern wild stock yearclasses. Calculations are explained in the text.

Yearclass	Coastal catches of A2	Coastal catches of A3	Size of the whole wild yearclass	Size of the Gulf of Bothnia year class
1980	11800	4100	155155	35812
1981	11300	2800	47141	32839
1982	13900	6400	206770	44216
1983	22200	4200	119933	62833
1984	10900	4300	231628	33744
1985	6200	1800	125741	18359
1986	2100	1100	153622	6852
1987	11400	900	79111	30641
Average =	11225	3200	140000	33000

Table 4. Mean fishing mortalities in different agegroups of wild and reared salmon stocks and their percentual values. Source of information: table 4.12.5 in Anon. (1991).

Age	Fish.mort. of reared stock	In %	Fish.mort. of wild stock	In %	Mean (%) used in calculations
A1	0.26	23	0.32	27	25
A2	0.86	57	0.87	58	57
A3	1.26	71	1.19	69	70
A4	No estimates available, supposed to be as in agegroup A3				

Table 5. Structure of the simulation model. Symbol of the variable, meaning of the variable and the distribution (expected value, variance) or equation of the variable. Sizes of agegroups are in thousands.

Symbol	Meaning	Distribution (expected value, variance) or equation
B	Agegroup A1 (t), Reared stock	Lognormal (670,100.5)
C	Agegroup A2 (t), Reared stock	Lognormal (560,56)
D	Agegroup A3 (t), Reared stock	Lognormal (100,10)
E	Agegroup A4 (t), Reared stock	Lognormal (2,0.2)
F	Agegroup A1 (t), Wild stock	Lognormal (135,141.8)
G	Agegroup A2 (t), Wild stock	Lognormal (47,4.7)
H	Agegroup A3 (t), Wild stock	Lognormal (4.2,0.4)
I	Agegroup A4 (t), Wild stock	Lognormal (0.2,0.02)
J	TAC of year t	Normal (800,80)
K	Recruited stocks (t)	B*0.5+c+d+e + f*0.5+g+h+i
L	Remains of both stocks	K-J
M	Agegroup A1 (t+1), Reared stock	Lognormal (700,140)
N	Agegroup A2 (t+1), Reared stock	0.5*B+(0.5*B/K)*L
O	Agegroup A3 (t+1), Reared stock	(C/K)*L
P	Agegroup A4 (t+1), Reared stock	(D/K)*L
Q	Agegroup A1 (t+1), Wild stock	Lognormal (135,27)
R	Agegroup A2 (t+1), Wild stock	0.5*F+(0.5*F/K)*L
S	Agegroup A3 (t+1), Wild stock	(G/K)*L
T	Agegroup A4 (t+1), Wild stock	(H/K)*L
U	TAC (t+1)	Decision variable
V	Recruited stocks (t+1)	M*0.5+N+O+P + Q*0.5+R+S+T
W	Remains of boths stocks	V-U
X	Remains of A2(t+1),Reared stock	W*(N/V)
Y	Remains of A3(t+1),Reared stock	W*(O/V)
Z	Remains of A4(t+1),Reared stock	W*(P/V)
AA	Remains of A2(t+1),Wild stock	W*(R/V)
AB	Remains of A3(t+1),Wild stock	W*(S/V)
AC	Remains of A4(t+1),Wild stock	W*(T/V)
AD	Remaining reared stock	X+Y+Z
AE	Remaining wild stock	AA+AB+AC
AF	Remaining wild parent stock	0.3*AA+0.5*AB+0.8*AC

Table 6. Sensitivity analysis of the model. The expceted value of each variable is changed by the percentual value given in each column. The number in the table is the percentual change in the size of the parent stock.

Variable	Percentual change in the expected value			
	- 30 %	- 15	+ 15	+ 30
Reared A1 (t)	- 39	- 19	+ 17	+ 33
Reared A2 (t)	- 39	- 19	+ 18	+ 35
Reared A3 (t)	- 7	- 3	+ 3	+ 7
Reared A4 (t)	- 0.1	- 0.06	+ 0.06	+ 0.11
Wild A1 (t)	- 29	- 15	+ 16	+ 32
Wild A2 (t)	- 9	- 4	+ 5	+ 9
Wild A3 (t)	- 1.1	- 0.56	+ 0.57	+ 1.1
Wild A4 (t)	- 0.011	- 0.006	+ 0.006	+ 0.011
TAC (t)	+ 64	+ 31	- 30	- 58
Reared A1 (t+1)	- 15	- 7	+ 7	+ 13
Wild A1 (t+1)	- 3	- 1	+ 1	+ 3
Percentual amount of females in each agegroup (variable AF):				
A2 (30 %)	- 23	- 12	+ 12	+ 23
A3 (50 %)	- 6	- 3	+ 3	+ 6
A4 (80 %)	- 0.8	- 0.4	+ 0.42	+ 0.85

Table 7. Decrease of the expected parent stock as a function of assumed decrease in the recruitment level of wild stock.

Percentual decrease in recruitment from the mean value	Percentual decrease in the size of parent stock
5	5.5
10	10.8
15	16.1
20	21.2
25	26.2
30	31.2
35	36.0
40	40.7
45	45.3
50	49.8

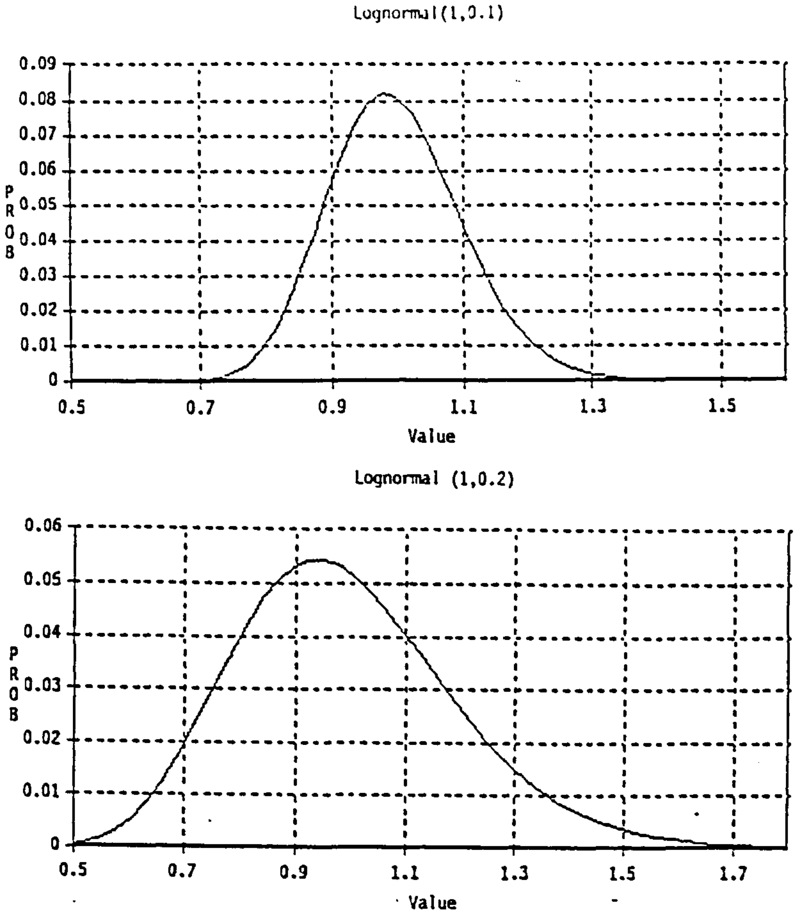

Figure 1. Lognormal distributions with coefficient of variation of 0.1 (upper figure) and of 0.2 (lower figure).

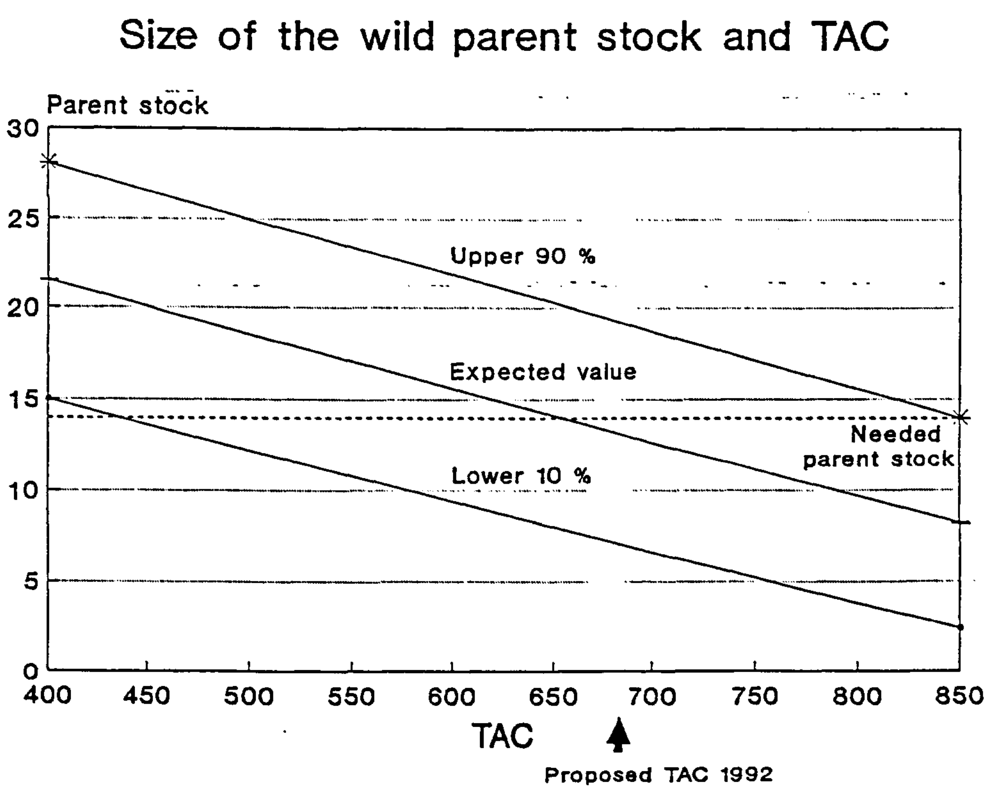

Figure 2. The 80 % confidence area of wild parent stock as a function of TAC. The needed parent stock is marked by a line to the figure and the proposed TAC for 1992 is marked by arrow.

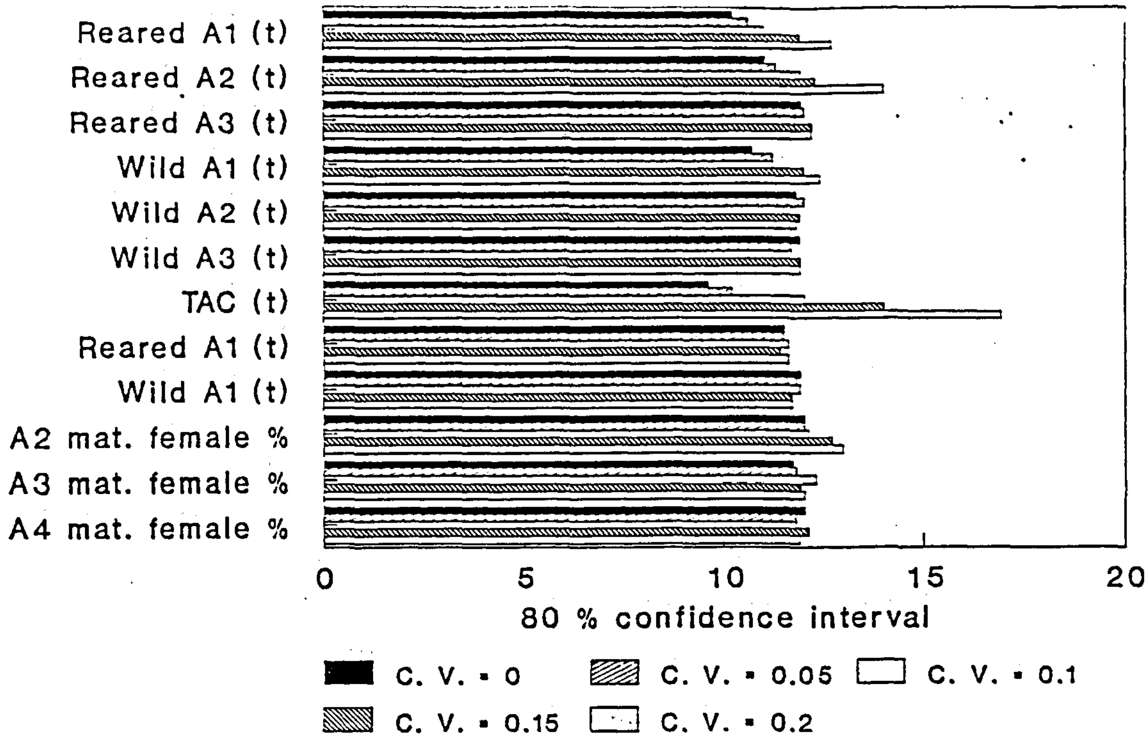

Figure 3. The width of the 80 % confidence area of parent stock when the coefficient of variation of each variable is changed.

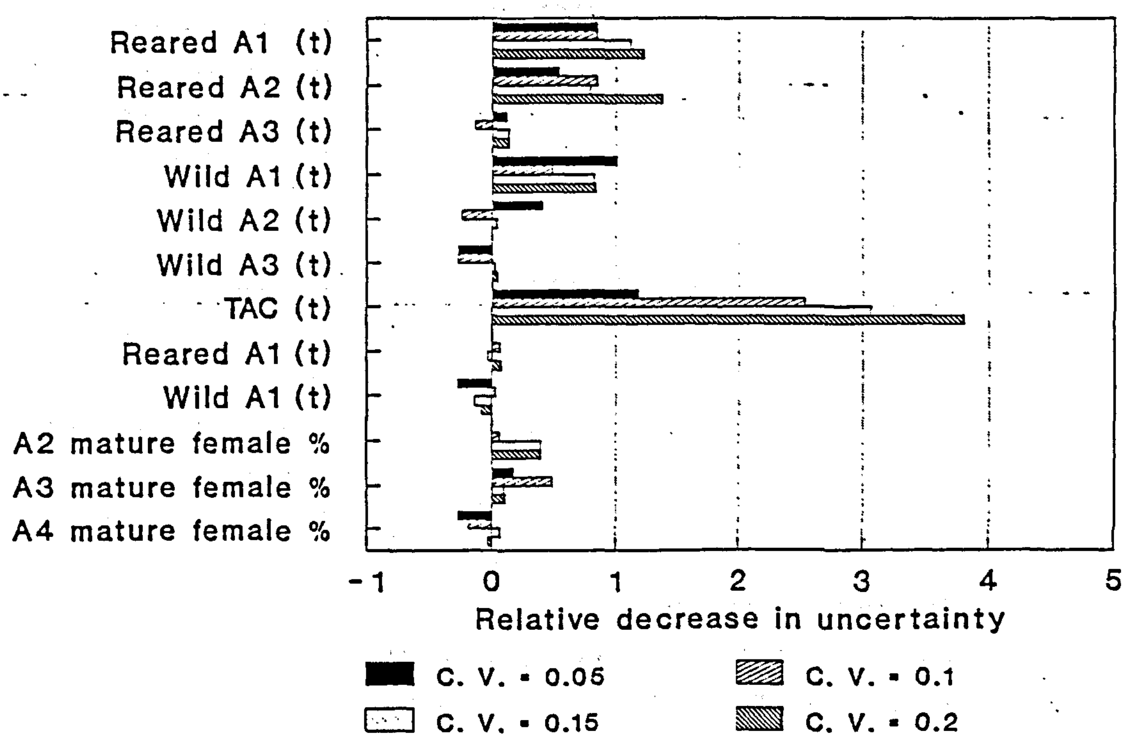

Figure 4. Relative changes in uncertainty with respect to changes in the coefficient of variation of each variable. Explanation of the value is given in the text.