

## ASSESSMENT OF WILD BALTIC SALMON STOCKS: HOW TO COMBINE DIFFERENT SOURCES OF INFORMATION

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### ABSTRACT

Fisheries stock assessment can be hampered by the fact that data are often limited and patchy as is the case for wild Baltic salmon. Appropriate use of data from related populations i.e. Atlantic salmon populations and hatchery-reared salmon, can reduce the uncertainty regarding the status of the wild stock. This paper provides an overview of the methodology to estimate the abundance of wild Atlantic salmon in the Baltic Sea, using different data sets: mark-recapture data of wild and hatchery-reared salmon, stock-recruit data of other Atlantic salmon populations, data on catches and fishing effort of the different fisheries in the Baltic Sea and smolt abundance data. The output of the mark-recapture analysis and the hierarchical meta-analysis of stock-recruit data of Atlantic salmon stocks provide information on the fishing mortality rates of wild salmon in the different fisheries and about the likely form and parameter values of the stock-recruit function of Atlantic salmon. These parameter estimates are used as informative prior knowledge in an age-structured life-history model, fitted to catch and smolt abundance index data, to estimate the status of wild salmon in the Baltic Sea. The results of the methodology are presented in appropriate formats for regional and local managers.

## 1. Introduction

Within the Baltic, wild and hatchery-reared salmon are caught in a mixed stock fishery and the wild salmon population consists of many different stocks with different resilience to exploitation (Karlsson and Karlström, 1994; Romakkaniemi *et al.*, 2003). Current assessment methodology for Baltic salmon (ICES, 2003) comprises of

- an assessment of the wild salmon population i.e. an estimation of the abundance and fishing mortality rate of wild salmon. This assessment within the Baltic Sea is complicated by the fact that the large amount of stocked hatchery-reared salmon conceals trends in wild salmon abundance in catch and effort data (Eriksson and Eriksson, 1993).
- a prediction of future wild salmon abundances under different assumptions about future states of nature.
- an evaluation of potential consequences of alternative management actions and summarise the results of the methodology in formats suitable for regional and local management advice.

Because the methodology presented in this paper is still in the process of being developed and optimised, the results presented here are only exemplary.

## 2. Assessment of wild Baltic salmon population

### 2.1. Available data

The available data on wild Baltic salmon are smolt index data and tagging data. Overall these data contain limited information. Smolt index data do not provide much information about what happens to the salmon at sea and only 9000 wild salmon have been tagged between 1987-99. Additional data include total catch and effort data which are uninformative about trends in wild salmon abundance because of the large amount of stocked hatchery-reared salmon within the Baltic Sea area. Relying on these limited and uninformative data series would allow us only to apply simple assessment methodology for wild Baltic salmon. The assessment methodology therefore uses additional information from related populations i.e. other Atlantic salmon populations and hatchery-reared Baltic salmon. More specifically, it uses stock-recruit data for different Atlantic salmon populations and tagging data for hatchery-reared salmon. Around 670,000 hatchery-reared animals have been tagged and released between 1987-1999. The additional information contained in these data sets allows obtaining more informative results for wild Baltic salmon.

### 2.2. Accounting for uncertainty in and variability between wild Baltic salmon stocks

The assessment methodology for wild Baltic salmon is based on an age-structured life history model fitted to catch data of the different fisheries and smolt index data (Figure 1) (Michielsens, 2003). It uses a probabilistic set of values for the different model input parameters for wild and hatchery-reared stocks such as the catchability coefficient of the different fisheries, the natural mortality rates, the homing rates and the steepness parameter of the stock-recruit function. These informative probability distributions for different model parameters are obtained through analyses of the stock-recruit data and the mark-recapture data through specialised methodologies.

The probability distributions for the catchability coefficients of the different fisheries, the natural mortality rates and the homing rates are obtained through a state-space mark-recapture model of both wild and hatchery-reared tagged salmon. Because of the limited amount of tagging data for wild salmon, this tagging data is modelled together with tagging data of hatchery-reared salmon and the model structure expresses the relationship between wild and hatchery-reared salmon:

- the homing rate of wild grilse is lower than that of hatchery-reared salmon due to the slower growth rate compared to hatchery-reared salmon (Kallio-Nyberg and Koljonen, 1997, Jutila *et al.*, 2003).
- the post-smolt mortality rate of hatchery-reared salmon is higher than that of wild salmon (Olla *et al.*, 1998, Brown and Laland, 2001).
- the post-smolt mortality rate differs from year to year (Salminen *et al.*, 1995) in similar fashion for wild and hatchery-reared salmon.
- the adult natural mortality is higher for hatchery-reared than that for wild salmon.

A prior for the steepness parameter of the stock-recruit function is obtained through a hierarchical meta-analysis of stock-recruit data of Atlantic salmon populations (Liermann and Hilborn, 1997; Myers *et al.*, 1997; Myers and Mertz, 1998; Dorn, 2002). The steepness is the expected fraction of the number of recruits at the deterministic equilibrium when stock abundances are reduced to 20% of their virgin level (Mace and Doonan, 1988; Francis, 1992). Stocks with a higher resilience to exploitation will have a higher steepness. Using an hierarchical model structure it is possible to obtain a probability distribution for the steepness parameter of the stock-recruit function derived from the mean steepness across Atlantic salmon stocks and the variance of the different stocks around the mean steepness (Gelman *et al.*, 1995). Uncertainty in the structural form of the stock-recruit function is taken into account by reparameterising both the Beverton-Holt and Ricker stock-recruit function in terms of steepness and calculating the probability of each stock-recruit model given the Atlantic salmon stock-recruit data.

The results of the hierarchical meta-analysis and the state-space mark-recapture analysis provides informative inputs for the model parameters of the abundance estimation model fitted to catch data and smolt index data. By doing so the information contained in the tagging data and the stock-recruit data are incorporated within this age-structured life history model and help to obtain more informative estimates of the abundance of wild Baltic salmon and maximum smolt production (Hilborn and Lierman, 1998). When fitting the abundance estimation model to the catch and smolt index data, the prior probability distributions for the different model parameters and the probabilities of the different stock-recruit function are updated.

### **2.3. Predicting future salmon abundance**

The results of the abundance estimation model are used within a forward projection model to evaluate the potential biological consequences of different management options under different assumptions about the state of nature. The model uses the probability distributions of the catchability coefficients, the natural mortality rates, the homing rates and the steepness parameter as inputs to calculate the future size of the wild Baltic salmon population given a time series of future catches. Projecting the

salmon population into the future requires accounting for key uncertainties regarding the future: uncertainty regarding future population dynamics of Baltic salmon, uncertainty regarding future outbreaks of M74 (yolk-sac-fry mortality) (Karlstöm, 1999) and uncertainty regarding the implementation of future management actions.

### **3. Management of wild Baltic salmon population**

#### **3.1. Management advice within the ICES working group**

In the case of Baltic salmon, two main management objectives are currently being used within the ICES working group dealing with the assessment of Baltic salmon (ICES, 2003), i.e.

- 1) to reach 50% of the natural smolt production capacity of each river by 2010.
- 2) to reach preliminary harvest rate reference points.

These harvest rate reference points are based on the entire Baltic salmon population and are defined for the most common life history type i.e. the salmon that spawn after two winters at sea (ICES, 2002). The limit fishing mortality rate reference point for Baltic salmon is assumed to equal the fishing mortality rate reference point that maximises the long-term average catch of wild Baltic salmon. The limit reference point can be used to derive the precautionary fishing mortality rate reference point, reflecting the uncertainty in the assessment and management of Baltic salmon. Because different Baltic salmon stocks have different resilience to exploitation, an additional reference point has been developed to be applicable for the management of weaker salmon stocks.

The results of the population projection to evaluate alternative management actions under different assumptions about the state of nature can be summarised in decision tables (Table 1 and 2) (Berger, 1985; Ianelli and Heifetz, 1995; Punt and Hilborn, 1997; McAllister and Kirkwood, 1998). The decision tables present the probability of reaching different management objectives under different assumptions about the underlying stock-recruit functions and future M74 outbreaks. The probability of future M74 outbreaks have been determined through expert knowledge based on the fact that current mortality rates due to M74 mortality are low and there is a high correlation between M74 mortality rates of successive years. The probability of each alternative stock-recruit function has been determined through the hierarchical meta-analysis and the abundance estimation model. Using these probabilities it is possible to calculate the weighted average or expected value for each of the management actions.

Current analyses suggest that there is a high probability that the wild salmon production will reach 50% of the smolt production capacity by 2010, given the higher probability of a Beverton-Holt stock-recruit function (Table 1). However, if the underlying stock-recruit model is a Ricker function or if future M74 values are high, keeping the TAC or fishing effort constant is unlikely to result in wild smolt abundance above 50% of the carrying capacity. Applying the same TAC or fishing efforts as in 2002 is unlikely to cause the total harvest rate to drop below the precautionary reference point by 2010 (Table 2). By reducing the TAC or the fishing effort by 10% annually, it is likely that the precautionary reference point will be reached, regardless of the assumed underlying stock-recruit function or expected M74 mortality levels.

### 3.2. Assessment information for local fisheries managers

Decision Tables provide good overview of the results of alternative management actions under different assumptions about the state of nature but are not very useful for local fisheries management e.g. for the restoration of Salmon Action Plan (SAP) rivers. Therefore the abundance estimation model has been used to produce probabilistic estimates of indicators of density and abundance at various life history stages (Table 3). The values of these indicators are useful when discussing the effectiveness of different management measures. The values provided in the table are preliminary and are conditional on current fishing mortality rates. These figures convey the current best available knowledge based on current input values and may change as the model parameters are updated by using additional data. A river with poor productivity relates to a river with a low productivity of juvenile salmon. This can be caused by poor water or habitat quality or poor genetic adaptation to the river. In addition, the mortality due to M74 decreases the number of smolts per spawning stock. The number of smolts produced by one mean sized female saved from the river fishery describes the changes to produce smolts if a salmon has reached the spawning stage within the river. The number of adults produced by one spawning female salmon describes the trade-off between killing a salmon today or allowing it to spawn.

### 4. Directions to extend the methodology

Current methodology distinguishes between wild and hatchery-reared salmon but does not assess individual wild salmon stocks. Catches of wild salmon could be divided into smaller management or conservation units consisting of groupings of sub-populations with similar genetic and phylogenetic make-up (Koljonen, 2001; Pell and Masuda, 2001). Their groupings can be obtained through stock identification methods (Koljonen and Pella, 1997). The model can also be expanded by including electro-fishing survey data and mark-recapture data obtained through the tagging of migrating juveniles leaving the rivers. The tagging data from particular rivers can be used in a Bayesian mark-recapture analysis to estimate the abundance of juveniles within those rivers (Mäntyniemi and Romakkaniemi, 2002). This mark-recapture analysis can be extended to include fish density data from electro-fishing in order to obtain the relationship between fish densities and corresponding abundances in the river (Mäntyniemi *et al.*, 2003). In order to estimate the abundance for rivers with electro-fishing data but without tagging data, the model can be given a hierarchical structure.

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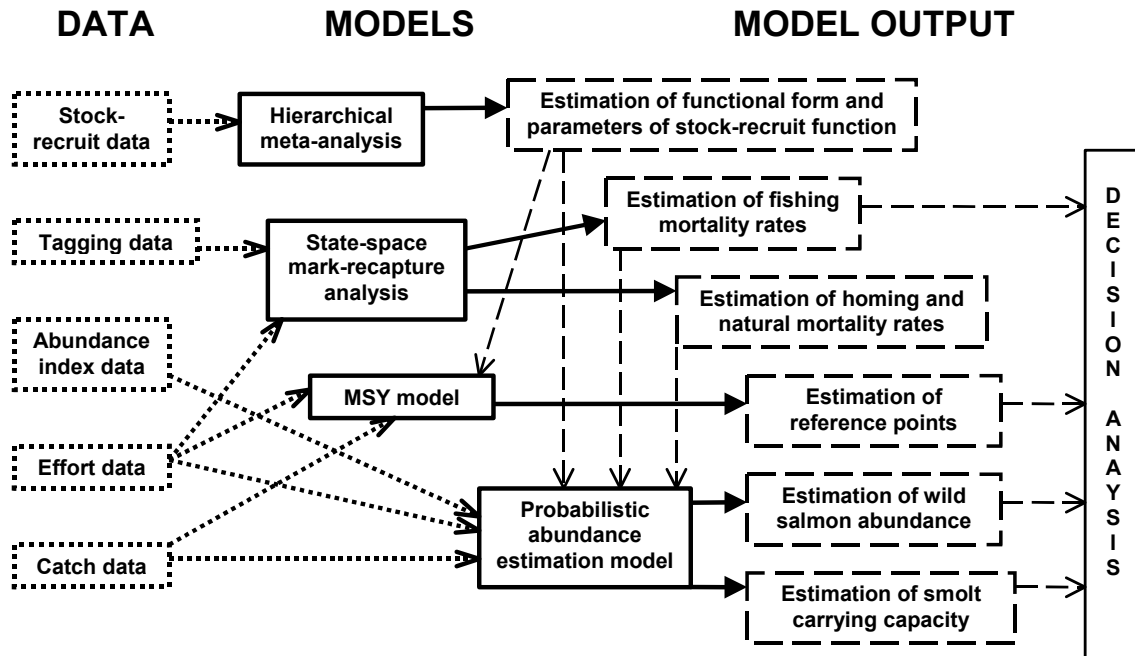


Figure 1: Overview of the current assessment methodology for Baltic salmon

Table 1: Decision table indicating the probability (expressed in percentages) of reaching 50% of the smolt production capacity by 2010 when applying different TACs or fishing efforts under different assumptions about the state of nature. The expected values for the probabilities of reaching 50% of the smolt production capacity by applying different management actions, are obtained by weighting the probabilities under each management action with the probabilities assigned to the different states of nature. The probabilities of the severity of future outbreaks of M74 are determined through expert opinion while the probability for the different stock-recruit functions have been determined through the calculation of Bayes' posteriors. The results presented in this table are only preliminary as the underlying methodology is undergoing future development.

SR probability	Beverton-Holt SR function			Ricker SR function			Expected Value
	0.78			0.22			
	Low M74	Average M74	High M74	Low M74	Average M74	High M74	
M74 probability	0.4	0.35	0.25	0.4	0.35	0.25	
Constant TAC	94	86	37	29	11	0	64
TAC - 10%	98	93	52	45	20	0	71
TAC - 20%	99	96	63	57	30	0	77
Constant Effort	96	89	29	40	11	0	64
Effort - 10%	98	93	47	54	24	0	72
Effort - 20%	99	96	59	63	35	1	77



*Table 2: Decision table indicating the probability (expressed in percentages) of reaching the precautionary fishing mortality reference point for the average sub-population by 2010 when applying different TACs of fishing efforts under different assumptions about the state of nature. The probabilities of the severity of future outbreaks of M74 are determine through expert opinion while the probability for the different stock-recruit functions have been determined through Bayes' posteriors. The results presented in this table are only preliminary as the underlying methodology is undergoing future development.*

SR probability	Beverton-Holt SR function			Ricker SR function			Expected Value
	0.78			0.22			
	Low M74	Average M74	High M74	Low M74	Average M74	High M74	
M74 probability	0.4	0.35	0.25	0.4	0.35	0.25	
Constant TAC	49	44	31	23	17	8	37
TAC - 10%	91	89	80	83	78	63	85
TAC - 20%	100	100	99	100	99	97	99
Constant Effort	2	2	2	5	5	5	3
Effort - 10%	77	77	77	72	72	72	76
Effort - 20%	100	100	100	100	100	100	100

*Table 3: Expected outcome values of the current assessment methodology to describe the impacts of stock changes and environmental and habitat impacts on the salmon stocks. The results presented in this table are conditional on current estimates of fishing mortality rates and are only preliminary as the underlying methodology is undergoing future development.*

INDICATORS	EXPECTED VALUE	95% PROBABILITY INTERVAL
Number of smolts produced by one mean sized female saved from the river fishery, assuming average river productivity and average M74	501	324-7658
Number of smolts produced by one mean sized female saved from the river fishery, assuming poor river productivity and average M74	197	127-3027
Number of smolts produced by one mean sized female saved from the river fishery, assuming average river productivity and high M74	220	142-3381
Number of smolts produced by one mean sized female saved from the river fishery, assuming poor river productivity and high M74	86	55-1326
Number of smolts produced by one mean sized female saved from the river fishery, assuming average river productivity and low M74	673	436-10244
Number of smolts produced by one mean sized female saved from the river fishery, assuming poor river productivity and low M74	265	171-407
Number of adults produced by one mean sized female saved from the river fishery, assuming average river productively and average M74	54	35-82
Number of adults produced by one salmon saved from the offshore fishery in the Main Basin	35	22-53
Number of adults produced by one salmon saved from the coastal fishery in the Gulf of Bothnia	48	31-73
Number of returning wild salmon per 1000 wild smolts for salmon from the Gulf of Bothnia rivers	28	16-50
Number of returning salmon per 1000 hatchery-reared salmon released in the Gulf of Bothnia rivers	19	11-30