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ICES Advisory Committee

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Report of the Inter-Benchmark Protocol on Baltic Salmon (IBPSalmon)

By correspondence 2012

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Contents

Executive summary

The Inter-Benchmark Protocol for Baltic Salmon [IBPSalmon] (Chair: Johan Dannewitz, Sweden) met by correspondence between May and December 2012. The work was carried out by members of the Assessment Working Group on Baltic Salmon and Sea Trout (WGBAST) and two external reviewers, with support from ICES Headquarters, comprising a total of 17 persons.

The main objective of the IBP was to improve parts of the assessment model used for Baltic salmon, and produce a Stock Annex to be implemented in 2013 assessment work. The prioritized issues handled during the IBP had earlier been discussed and agreed upon at the WGBAST meeting in 2012. Outcomes of the IBP include 1) inclusion in the assessment model of additional data on survival at sea of reared salmon, which is assumed to increase precision in estimates of relative abundance of wild and reared salmon, 2) updated correction factors for discard proportions, and for underreporting of tag recaptures, catches and fishing effort, and 3) an updated assessment model where maturation rate is allowed to vary over time due to e.g. climate variation, which is assumed to improve estimates of salmon survival and abundance at sea.

A few additional issues; inclusion of ecosystem data to improve salmon survival estimates and stock projections, inclusion of southeastern rivers stocks in the full assessment model, and an update of the hierarchical stock–recruit model were also handled but for different reasons the work could not be finalized during the IBP. For these issues, recommendations on progress to be made and identification of data needs are presented.

Introduction

This report describes the work carried out in connection with an Inter-Benchmark Protocol for Baltic Salmon (IBPSalmon). An initial video conference meeting, where the planned work was presented, was held in February 2012. Members of the Assessment Working Group on Baltic Salmon and Sea Trout (WGBAST), one of two appointed external reviewers for IBPSalmon and one participant from the Baltic Sea Regional Advisory Council (BSRAC) participated in the initial meeting. The work has then primarily been carried out by correspondence during summer and autumn 2012 by a core group within WGBAST, with some guidance from the rest of the working group and from external reviewers. A list of participants is presented in Annex 1. The external review of the IBP report, with responses from the working group, is presented in Annex 4 and a Stock Annex in Annex 5.

Terms of reference

2011/2/ACOM44 Inter-Benchmark Protocol for Baltic Salmon (IBPSalmon) that will serve as an Inter-Benchmark Protocol, chaired by ICES Convenor Johan Dannewitz, Sweden, and with invited external experts Kevin Friedland, USA, and Rebecca Whitlock, Finland, will convene by correspondence to:

a) Review the proposed updates in data analysis and assessment methodology as described in the stock issue list.

b) Prioritize the issues and provide guidance to stock experts on methods with which to solve issues.

c) Describe the choice of preferred method for data analysis and assessment in a concise report. Include recommendations on progress to be made in cases where work is not yet finalized.

d) Describe the resulting data analysis procedure and assessment methodology in the Stock Annex.

e) Countries should provide the necessary data to be able to include assessment unit five stocks into the full life-history model.

f) Evaluate the applied measures and stock status of the potential salmon rivers (appointed under Salmon Action Plan).

g) Review and agree on the resulting Stock Annex.

IBPSalmon will report by 31st December for the attention of ACOM.

Comments to terms of reference

Sections 1–3 in this report describe the achievements reached for the issues listed in the initial stock issue list (Table 1). In addition, a few more issues have been identified by working group members as being important for future improvements of the assessment methodology. These additional issues have also been handled during IBPSalmon and are described in Sections 4–6. The inclusion of these additional issues increased the working load and resulted in that ToR f) "Evaluate the applied measures and stock status of the potential salmon rivers (appointed under Salmon Action Plan)" could not be handled during the IBP. In cases where the work has not been completely finalized during the IBP, recommendations on progress to be made and identification of data needs are presented. Part of the outcome of this IBP has been implemented in the Stock Annex (Annex 5). More detailed information about the planning of IBPSalmon can be found in ICES (2012).

Table 1. Initial stock issue list produced by the Assessment Working Group on Baltic Salmon and Sea Trout (WGBAST). Detailed information about the identification of ways to improve the assessment and the planning of IBPSalmon could be found in ICES (2012).

Issue	Problem/Aim	Work needed/possible direction of solution	Data needed to be able to do this: are these available/where should these come from?
1	There are indications of discrepancies between model outputs on relative abundance of wild/reared salmon and results on catch composition based on mixed-stock analyses, indicating a potential bias in the assessment model.	Inclusion of data on return rate of reared salmon to rivers would feed the model with necessary information on abundance of reared salmon at sea. In addition, the model could be fitted to information on catch composition in Main Basin, derived from mixed-stock analyses (based on scale reading and genetic data), to increase empirical information about relative abundance of wild and reared salmon on Baltic Sea or assessment unit level. This could be further developed to include also information on relative abundance of individual stocks.	Data on return rate of reared salmon is available for a few Swedish rivers, but it may be necessary with further compilation and analyses of data before it could be used for this purpose. Data from scale readings and a genetic baseline including a majority of stocks is available, and mixed-stock analyses are already carried out but are not included in current assessment model. Samples from the offshore fishery in the Southern Main Basin (where salmon stocks are assumed to occur mixed during the feeding migration) are available to the working group.
2	Improving estimates of current abundance and projections into the future. There are studies indicating that e.g. post-smolt survival is positively correlated with recruitment of herring in Gulf of Bothnia, indicating that the precision of estimates of survival and abundance parameters would possibly increase by feeding the assessment model with additional data on e.g. prey abundance. Also, stock projections may be improved by utilising available M-74 data in a biologically more realistic way in scenario analyses.	The assessment model could be updated for inclusion of important covariates, and the modelling of M-74 in scenario analyses could be improved to better mirror M-74 dynamics in the past.	There are data available on potentially important covariates (e.g. herring recruitment) that could be further evaluated and used in assessment.
3	At present, rivers in assessment unit (AU) 5 (Latvia and Lithuania) are modelled separately from Gulf of Bothnia and southern Sweden (AU 1–4) rivers, and assessment results are less reliable for AU 5 stocks. Also, there might be a need in the near future to upgrade some rivers, which presently are defined as potential salmon rivers, and include them in the list of wild salmon rivers.	The assessment model could be updated to prepare for inclusion of more detailed data from AU 5 rivers, and from potential rivers in all assessment units where self-sustaining wild populations have been established.	There is an increased data need from AU 5 if these stocks should be modelled together with AU 1-4 stocks. More detailed data on e.g. smolt-age distribution, maturation rate and possible differences in migration patterns compared to northern stocks, which will affect populations' susceptibility to exploitation. Also, data on coastal and river catches in AU5 should be improved if possible. Some data is already available, but there is a need to complement these. The availability of additional data from the countries concerned will be investigated during the benchmark process, and future data needs will be identified.

1 Relative abundances of wild and reared salmon

1.1 Background

Previous comparisons between estimates of the proportions of wild and reared salmon in catches from Main Basin generated from the assessment model and from independent mixed-stock analyses (MSA) indicated that the assessment model overestimated the proportion of reared salmon (ICES 2010, Section 2.7.2). It was concluded that the assessment model would likely be improved by including additional empirical information on return rates of reared salmon, as well as information on relative abundance of wild and reared salmon in catches from the feeding grounds in Southern Main Basin. Scale reading data as well as information on return rate of reared salmon to River Dalälven in Sweden was implemented in the assessment model in spring 2012 (ICES 2012a, Section 5.3.9). The inclusion of data on return rate and relative abundance of reared salmon on the feeding grounds is expected to have considerably improved estimates of e.g. sea survival and abundance of reared salmon.

1.2 Achievements during IBPSalmon

As mentioned above, we have noticed a tendency in the full life-history model to overestimate the survival of reared salmon compared to the wild. During IBPSalmon, the model has been fitted to additional information on reared salmon, namely to return rate of reared salmon to River Luleälven in Sweden. Data from a mark–recapture study carried out in the river in 1996–1997 and 2001 was used. The data consists of two mark–recapture experiments per year. These experiments have been described in detail in a previous working paper (ICES 2002). In short, mark–recapture experiments were carried out quite late in the season when it was assumed that all salmon had reached the uppermost part of the river accessible to salmon (close to the broodstock fishery). At that time of the season, most of the exploitation had already taken place in the river. It was further assumed that the salmon are moving around randomly in the upper parts of the river and that all individuals have the same probability to enter the trap. Data on number of tag returns in the broodstock fishery in combination with information on total number of released tagged individuals were used to estimate catchability of the trap during the experimental periods.

Within the mark–recapture experiments, the number of days that the trap was fishing has an influence on the total number of caught fish. Thus, the data must be standardized first by calculating the mean catchability per day from the mark–recapture data and secondly, by standardizing the total catch of the trap with the number of days of the experiment. An average length of the experiment periods was 28 days, so the final recapture rates and total catches have been calculated for 28 days. See data in Table 1.1.

Table 1.1. Mark–recapture data for river Luleälven from years 1996, 1997 and 2001. (RR=recapture rates).

year	N tagged	N recaptured	N days	RR/ 1 day	RR/ 28 days	Tot catch	Tot catch/ 1 day	Tot catch/28 days
1996	224	28	32	0.004	0.11	2062	64	1804
1996	207	21	17	0.006	0.16	1175	69	1935
1997	249	10	38	0.001	0.03	2252	59	1659
1997	224	32	18	0.008	0.22	1319	73	2052
2001	253	68	37	0.007	0.20	2379	64	1800
2001	270	53	23	0.009	0.23	1611	70	1961

The first experiment from year 1997 was decided to be left out from the analysis since the tagged fish were in a bad shape and the recapture rate was low (these data are marked with grey in Table 1.1). The average of the standardized total catches was taken over the experiments of one year, resulting into 1870, 1856 and 1881 individuals for years 1996, 1997 and 2001, respectively.

The standardized recapture rates were used to estimate a prior distribution for the catchability of the trap with the following model:

```
model{
for(i in 1:6){
# Nrel, Nrec: number of released and recaptured salmon in tag recapture study
  Nrec[i]~dbin(p[y[i]],Nrel[i])
}
for(j in 1:3){
#p: probability for a tagged salmon to be caught by the trap on year i
  p[j]~dbeta(a,b)
}
a<-mu*eta
b<-(1-mu)*eta
# uninformative priors for the mean and the variation of the catchability of the trap
mu~dbeta(2,2)
eta~dlnorm(10,0.1)
}
```

For simplicity, it was assumed that the catchabilities are exchangeable over the years and over the experiment periods. The following prior distributions were considered to correspond to the mean catchability of the trap and its variation over the years:

```
muL~dbeta(40,170)
etaL~dlnorm(4.1,3.16)
```

Within the full life-history model, the mean standardized trap catches were fitted with the model predicted abundances of reared fish in assessment unit 2 after coastal fishing (NrR). The observed river catches (including the broodstock catch before the experiments) were subtracted from the model predicted abundance. Correction factor LuleProp is the smolt cohort specific proportion of released reared salmon smolts in river Luleälven, compared to the total of unit 2.

```
# Luleälven trap
####################

for(i in 1:3){ # calendar years 1996-1997 and 2001
# NtotLule: the model predicted number of salmon surviving back to Luleälven
```

```
NtotLule[i]<-(NrR[i-1,2,3]*LuleProp[i-1]+NrR[i-2,3,3]*LuleProp[i-2]+
                              NrR[i-3,4,3]*LuleProp[i-3]+NrR[i-4,5,3]*LuleProp[i-4]+NrR[i-
5,6,3]*LuleProp[i-5])*1000-LuleCatchR[i]
# LuleTrapTot: standardized total number of salmon observed in the trap
LuleTrapTot[i]~dbin(pLule[i],NtotLule[i])
# pLule: probability for a salmon that survives to the river mouth to end up in the trap
pLule[i]~dbeta(aL,bL)
}
aL<-muL*etaL
bL<-(1-muL)*etaL
# priors for for the mean and the variation of the catchability of the trap based on mark-
recapture studies
etaL~dlnorm(4.1,3.16)
muL~dbeta(40,170)
```

Unfortunately we did not have enough time during IBPSalmon to run the full life-history model with this additional data from river Luleälven. However, this analysis will be tested, included in the Stock Annex and utilized in the 2013 assessment model run.

2 Improving survival estimates and stock projections

2.1 Background

Post-smolt survival is a key factor influencing salmon abundance at sea. In the assessment model, post-smolt stage is defined as the period from the start of the sea migration to the end of March, next year. During this period some fishing mortality due to bycatching of smolts may occur (this is estimated by tag recaptures), but the bulk of mortality is of natural origin.

Post-smolt survival has declined during the last 15 years and has remained low since 2005 (ICES 2012a, Section 5.3.9; Figure 2.1), which has suppressed the recovery of wild salmon stocks. Although the exploitation rate has declined considerably since the 1990s, which has resulted in increased wild smolt production, the decline in natural survival has had an overriding effect on the abundance of salmon at sea; the combined wild and reared salmon pre-fishery abundance is currently less than half of what it was at the beginning of the 2000s (ICES 2012a). The decline in pre-fishery abundance has reduced fishing possibilities considerably.

Because young of the year herring are a very important prey for salmon post-smolts (see below), fitting the assessment model to data on herring abundance may improve estimates of post-smolt survival rate. This may be the case especially for the very recent years for which data on the youngest salmon cohorts at sea are sparse. This will, in turn, improve estimates of current and near future pre-fishery abundance and thus the precision of short-term stock projections which form the basis of ICES advised catch levels.

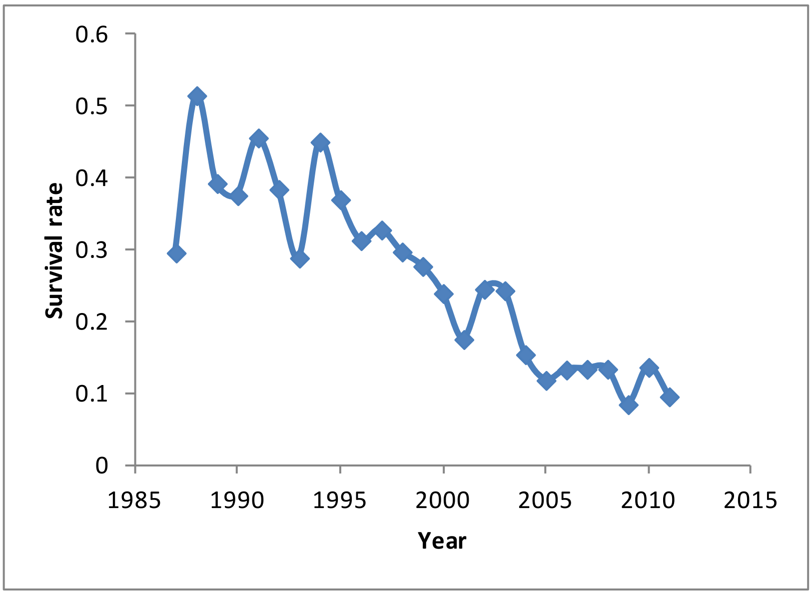

Figure 2.1. Estimates (median values) of post-smolt survival rate for wild salmon (ICES 2012a).

At the planning stage of IBPSalmon, it was decided that work to include information on recruitment of herring in the assessment model should, if possible, be carried out. Previous work has shown that herring recruits (age 0+) is the most important food supply for salmon post-smolts when they become piscivorous during their first year at sea (e.g. Salminen *et al*., 2001). Post-smolt survival rate has been partly associated with the herring recruitment in the Gulf of Bothnia (Mäntyniemi *et al*., 2012); much of the annual variation in post-smolt survival seems to be explained by variation in herring recruitment. In contrast, the downgoing trend in post-smolt survival coincides with an increase in the Baltic grey seal population, but it is unclear if this represents a causal relationship (Mäntyniemi *et al.*, 2012).

It is plausible to assume that the correlation between annual variation in post-smolt survival and herring recruitment is causal: the bulk of the Gulf of Bothnian post-smolts enter the sea in May–June, and they gradually migrate southward along the Gulf (June–September) and finally enter the northern parts of the central Baltic Sea in September–December (Ikonen, 2006). Post-smolts become piscivorous mostly during the late summer and early autumn, i.e. when many or most of them are still in the Gulf. At that time 0+ herring leave the archipelago and become available as a prey item for salmon. However, the exact time and place for a post-smolt to become piscivorous must depend on the initial size of the smolt (note the size difference between wild and reared smolts; Salminen, 2000), timing and location of the entrance to the sea, and the speed and the rate of orientation of migration. Therefore, some post-smolts may start feeding on 0+ herring already in the Bothnian Bay (i.e. in the northern part of the Gulf of Bothnia) while some may reach the central Baltic before becoming piscivorous.

2.2 Achievements during IBPSalmon

2.2.1 Analyses of factors important for salmon survival at sea

Within IBPSalmon, the importance of herring and sprat recruitment and spawning–stock biomass, and changes in the seal population was investigated further using the most updated data on the explanatory variables and survival estimates of wild salmon post-smolts. Illustrations of the development in the analysed explanatory variables are presented in Figures 2.2 and 2.3.

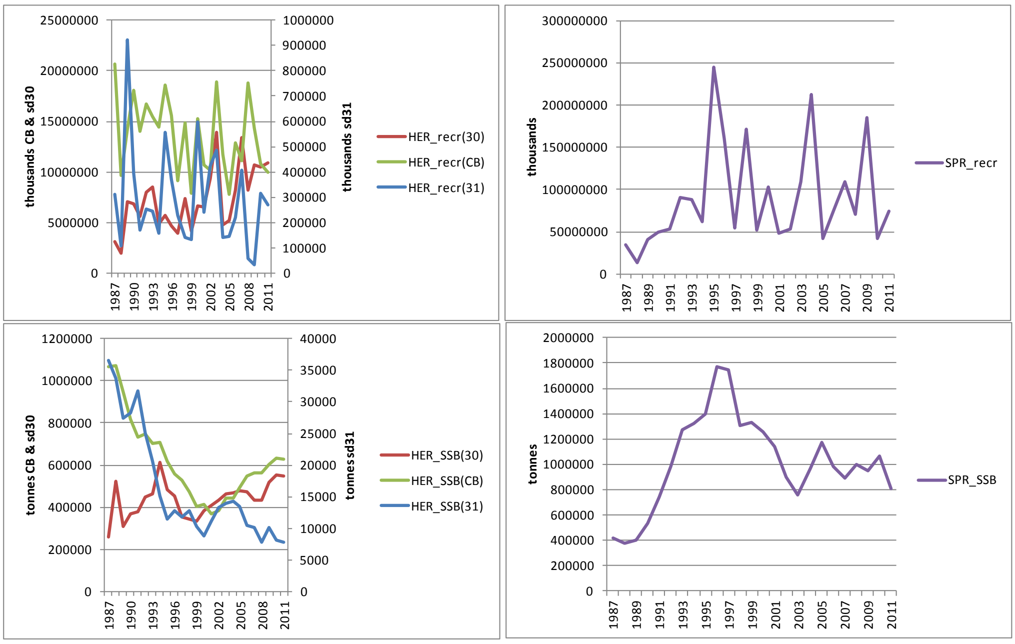

Figure 2.2. Spawning–stock biomass (SSB) and recruitment (recr) of 1+ Baltic herring (HER) and sprat (SPR) in Bothnian Bay (31), Bothnian Sea (30) and the Central Baltic Sea (CB) (data from ICES 2012b).

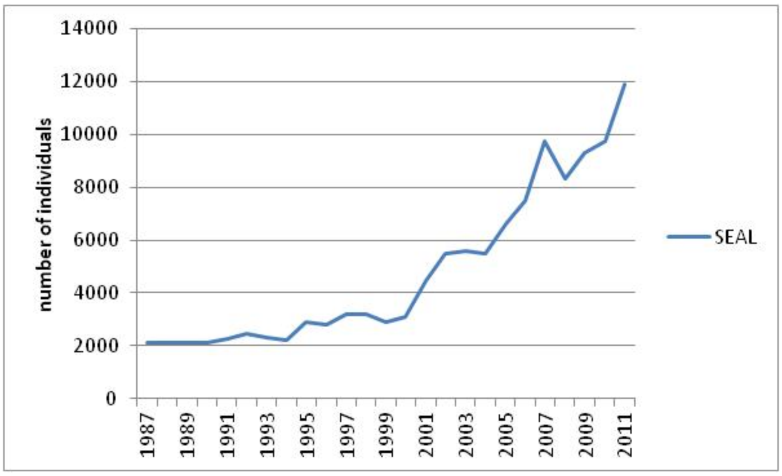

Figure 2.3. Counted number of seals along the Swedish Baltic Sea coast. Although this time-series does not represent the whole Baltic Sea, it is regarded as a good index of development in the total grey seal population (Mäntyniemi *et al.*, 2012).

For herring and sprat, there are no time-series available on 0+ recruits. Estimates of 1+ herring and sprat abundance (ICES 2012b) were therefore used as a proxy for the abundance of 0+ recruits (by shifting the time-series one year, cf. Mäntyniemi *et al.*, 2012). In addition, the spawning–stock biomass (SSB) could be related to salmon post-smolt survival, either indirectly as a predictor of herring recruitment or, less likely, as a direct food source for larger post-smolts.

Initial analyses looking at single explanatory variables indicated that post-smolt survival is correlated with herring recruitment. When the effects of long-term trends in survival and herring recruitment (see Figures 2.1 and 2.2) were removed by using residuals, herring recruitment in all three basins correlated positively with post-smolt survival (Figure 2.4a–c). Also sprat recruitment (total estimate for ICES Subdivisions 22–32) was positively correlated with salmon survival when the analysis was based on residuals (Figure 2.5). Furthermore, it seems that herring recruitment in the two basins of Gulf of Bothnia (Bothnian Sea and Bothnian Bay) is correlated (Figure 2.6), indicating that herring population dynamics in these two areas are largely affected by the same variables/drivers.

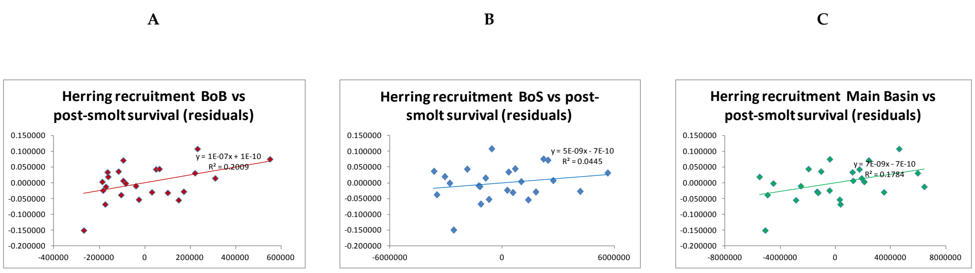

Figure 2.4. Correlations between herring recruitment in a) Bothnian Bay (BoB), b) Bothnian Sea (BoS) and c) Main Basin, and post-smolt survival estimates for wild salmon (derived from the 2012 assessment). All analyses are based on residuals for both variables.

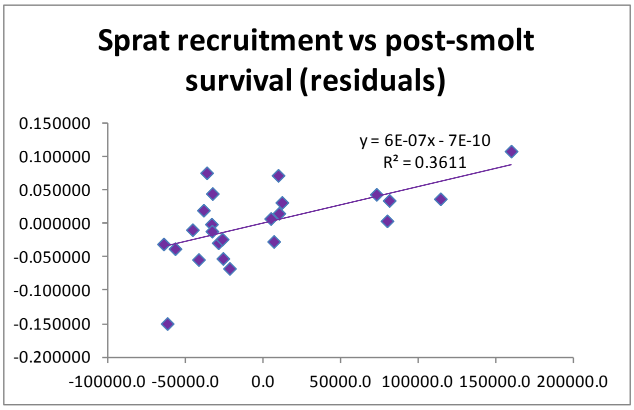

Figure 2.5. Correlation between sprat recruitment and post-smolt survival estimates for wild salmon (derived from the 2012 assessment). The analysis is based on residuals.

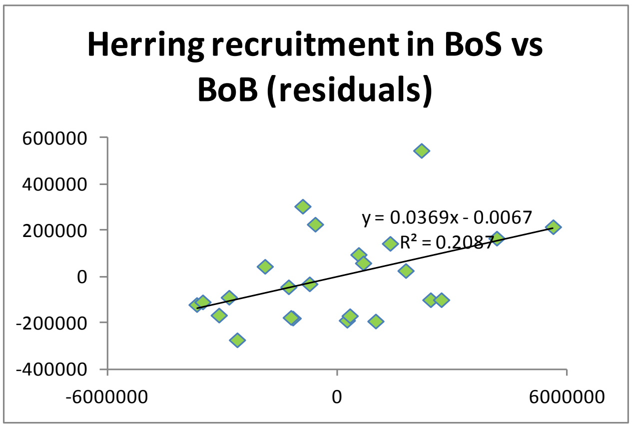

Figure 2.6. Correlation between herring recruitment in Bothnian Sea and Bothnian Bay. The analysis is based on residuals.

Regarding spawning–stock biomass (SSB) for clupeids, positive correlations with post-smolt survival (MPS) were found for herring in Gulf of Bothnia and Central Baltic Sea, whereas no such relationships were observed for herring in Bothnian Sea or for sprat (Figure 2.7). In general, SSB show less annual variation than recruitment (Figure 2.2), and when removing trends in the time-series no correlation seems to exist between SSB and post-smolt survival (exemplified by herring in Bothnian Bay in Figure 2.8). Hence, it is not obvious whether or not the correlations between SSB and MPS in certain areas of the Baltic Sea (Figure 2.7) are causal.

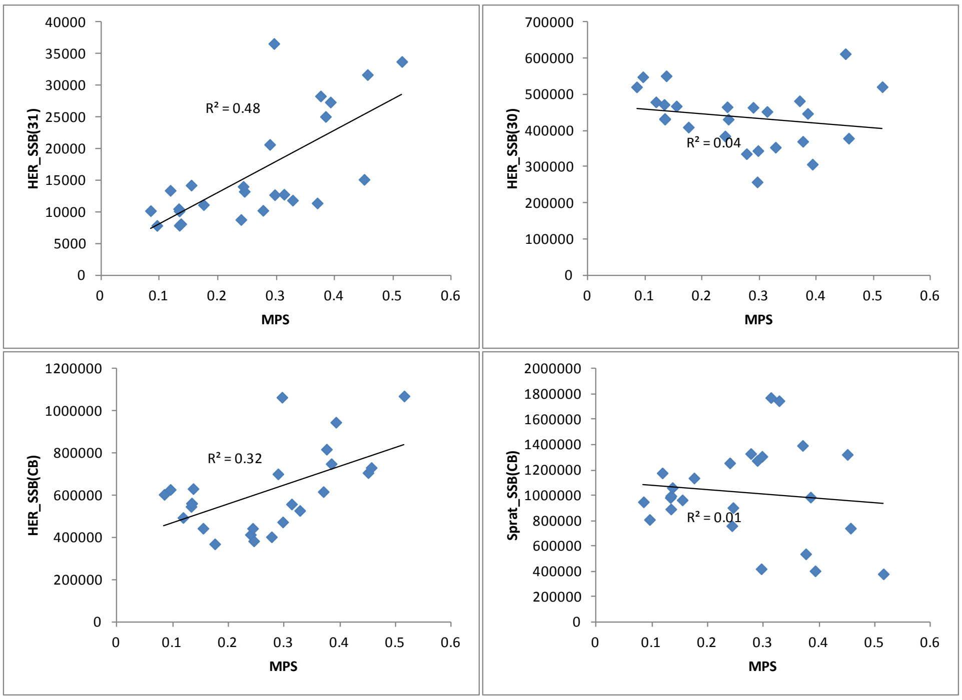

Figure 2.7. Correlations between annual estimates of post-smolt survival (MPS) and herring (HER) and sprat (SPR) spawning–stock biomass (SSB, in tonnes) for Bothnian Bay (31), Bothnian Sea (30) and Main Basin (central Baltic, CB).

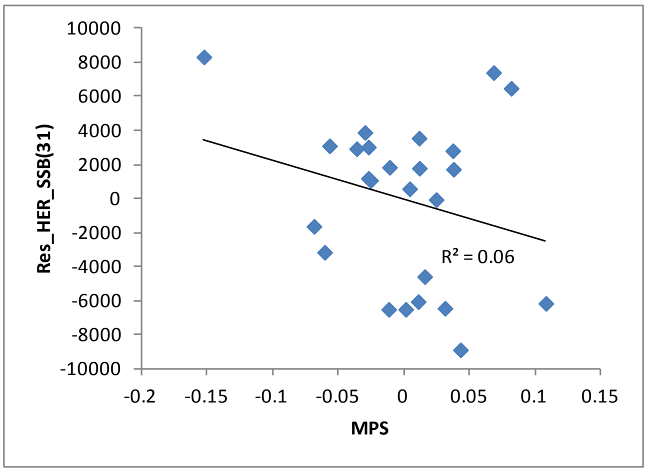

Figure 2.8. Correlation between post-smolt survival (MPS) and herring spawning–stock biomass (SSB) in Bothnian Bay when the analysis is based on residuals.

For a more in-depth multivariate analysis of the relationship between MPS and all the explanatory variables, an updated version of the Bayesian model applied in Mäntyniemi *et al*. (2012) was used. The explanatory variables are listed in Table 2.1, where also the previously analysed time-series are indicated.

Table 2.1. Data used in the salmon post-smolt survival analysis of IBP Salmon. Time-series covered years 1987–2011. As a comparison the dataseries used by Mäntyniemi *et al.* (2012) are also described. To obtain measures of *per capita* food availability for post-smolts, herring and sprat recruitments and SSB's were divided by the total number of post-smolts present/migrating through the sea area.

VARIABLE	NOTATION	MÄNTYNIEMI *ET AL.*
SSB of herring in Bothnian Bay (Subdivision 31) 1)	HER_SSB(31)	-
SSB of herring in Bothnian Sea (Subdivision 30) 2)	HER_SSB(30)	-
SSB of herring in Central Baltic 3)	HER_SSB(CB)	1987–2006
SSB of sprat in Central Baltic 3)	SPR_SSB(CB)	1987–2006
Recruitment of 1+ herring in Bothnian Bay (Subdivision 31) 1)	HER_recr(31)	1987–2006
Recruitment of 1+ herring in Bothnian Sea (Subdivision 30) 2)	HER_recr(30)	1987–2006
Recruitment of 1+ herring in Central Baltic 3)	HER_recr(CB)	-
Recruitment of 1+ sprat in Central Baltic 3)	SPR_recr(CB)	-
Abundance of greyseal in the Swedish coast of Baltic Sea	SEAL	1987–2007

1) Divided by number of wild and reared salmon smolts in SD31.

2) Divided by number of wild and reared salmon smolts in SD30–31.

3) Divided by number of wild and reared salmon smolts in SD24–32.

In general, the expanded analyses carried out within IBPSalmon give a more complex picture with more possible causal relationships than in previous analyses (Mäntyniemi *et al*., 2012). Relative probabilities for a total of 512 (all possible) combinations of the nine explanatory variables in Table 2.1 were estimated, and the results showed that models with highest posterior probabilities included both grey seal and herring (SSB) abundance per post-smolt in different areas of the Baltic Sea (Figure 2.9). Hence, as observed previously by Mäntyniemi *et al*. (2012), our expanded analyses indicate that the declining trend in post-smolt survival correlates well with the increased number of grey seals (see also Figure 2.10). It still remains unclear, however, whether or not this correlation arise from a direct causality.

The same concern regarding causality could be raised for SSB data, since the above initial analyses (Figures 2.7 and 2.8) indicated that the correlations between MPS and SSB data largely reflects coinciding trends rather than year-to-year covariation between variables. Furthermore, contacts during IBPSalmon with both Finnish and Swedish herring experts have revealed that SSB is not expected to be a good predictor of recruitment. This is also supported by a general lack of correlation between these variables for herring (not shown here).

As can be seen in Table 2.2, there are many variable combinations with a high coefficient of determination; also some excluding seal and/or SSB. As an example, the model with only herring recruitment in all areas (the model HER_recr(CB;30;31)) explains as much as 67% of the variation in post-smolt survival (Table 2.2). As can be seen in Figure 2.10 (right panel), this particular model also predicts MPS comparably well, both in terms of the downgoing trend and annual fluctuations.

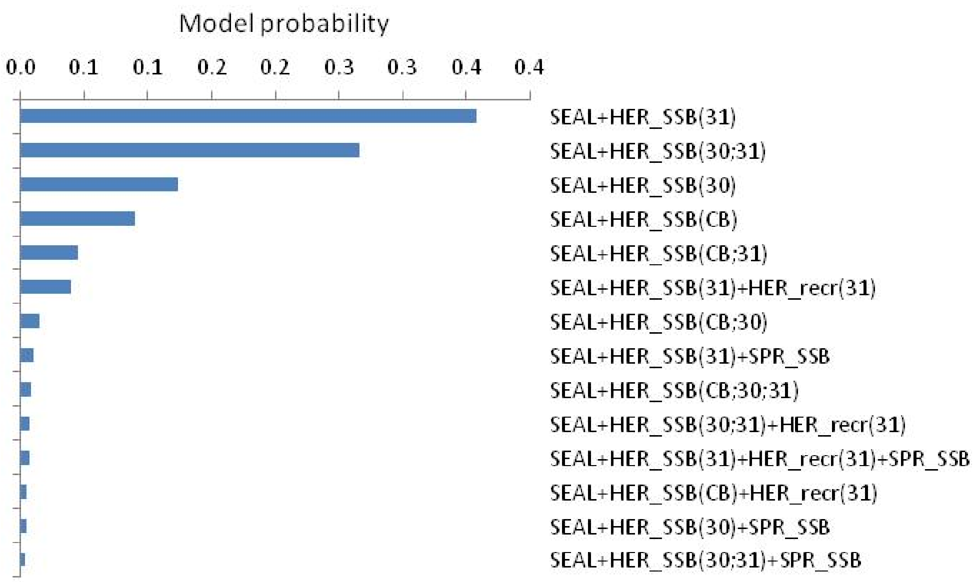

Figure 2.9. Posterior probabilities of the 14 most likely combinations of the nine explanatory variables.

Table 2.2. Coefficient of determination for the 14 most likely, and some additional selected, combinations of explanatory variables. The most likely combinations are listed in the order of their posterior probabilities (cf. Figure 2.9).

Model	r^2
SEAL+HER_SSB(31)	76%
SEAL+HER_SSB(30;31)	88%
SEAL+HER_SSB(30)	84%
SEAL+HER_SSB(CB)	83%
SEAL+HER_SSB(CB;31)	83%
SEAL+HER_SSB(31)+HER_recr(31)	87%
SEAL+HER_SSB(CB;30)	87%
SEAL+HER_SSB(31)+SPR_SSB	81%
SEAL+HER_SSB(CB;30;31)	88%
SEAL+HER_SSB(30;31)+HER_recr(31)	91%
SEAL+HER_SSB(31)+HER_recr(31)+SPR_SSI	89%
SEAL+HER_SSB(CB)+HER_recr(31)	88%
SEAL+HER_SSB(30)+SPR_SSB	87%
SEAL+HER_SSB(30;31)+SPR_SSB	87%
SEAL	38%
HER_SSB(CB;30;31)+SPR_SSB	72%
HER_recr(CB;30;31)	67%
SEAL+HER_SSB(CB;30;31)+SPR_SSB	88%
SEAL+HER_recr(CB;30;31)	51%
SEAL+HER_recr(CB;30;31)+SPR_recr	51%
HER_SSB(CB;30;31)	67%
SEAL+HER_SSB(CB;30;31)	88%
SEAL+SPR_SSB	58%
SEAL+HER_recr(30;31)	87%
HER_recr(31)	34%
HER_recr(30)	-13%
HER_recr(CB)	41%
SPR_recr	did not run
HER_SSB(31)	46%
HER_SSB(30)	18%
HER_SSB(CB)	57%
SPR_SSB	-7%

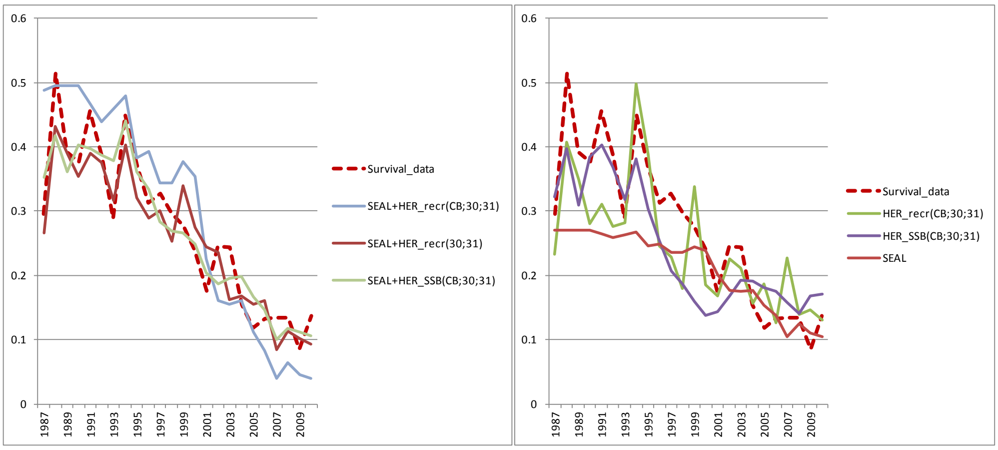

Figure 2.10. Posterior medians of post-smolt survival rates (based on data from 2012 assessment) and corresponding posterior medians of expected survival rates from selected model combinations (cf. Mäntyniemi *et al.*, 2012).

2.2.2 Conclusions and suggestion on which variables to use

Based on the above results from uni- and multivariate analyses, and independent biological information (salmon diet studies and contact with herring experts), it seems safe to presume a causal relationship between herring recruitment and post-smolt survival (MPS), whereas it still remains unclear to what extent data on seal abundance and herring/sprat SSB are directly related to variation in MPS. For the stock assessment of Baltic salmon, there is a need to improve estimates of MPS for the most recent years due to lack of data for the latest smolt cohorts occurring at sea.

Hence, it is of particular importance to find explanatory variables that explain short-term annual variation in MPS, and herring recruitment seems to fulfil this requirement.

One problem at the moment, however, is to get information on herring recruitment (0+) for the year preceding the salmon assessment year (i.e. herring recruitment which affects MPS for the smolt cohort that is expected to dominate among salmon accessible for exploitation in the year for which ICES gives advice). To get this information we would need data on 1+ herring abundance for the salmon assessment year. This information is not available at the time for the WGBAST meeting as the herring surveys take place late in the year. However, with respect to Bothnian Sea, a recruitment model was recently developed within WKPELA/ICES, from which it is possible to forecast the abundance of 1+ herring one year in advance based on zooplankton and temperature data for the preceding year. Such 1+ herring estimates could be used by WGBAST as a proxy for the real 1+ abundance (and thus as a proxy for the 0+ abundance in the year of interest for salmon assessment). However, there are no such models developed for the other basins in the Baltic Sea. Thus, it is currently not possible to include herring recruitment in multiple areas in the salmon assessment model. In addition, there will most likely be improvements in the Baltic herring assessment in the near future, especially for the Bothnian Sea stock, which also calls for postponing the inclusion of herring data in the salmon assessment model.

2.2.3 Fitting the herring data to the assessment model

As soon as necessary data are available, the aim is to fit the herring recruitment data to the assessment model with a similar model as in Mäntyniemi *et al*. (2012). Fitting the model with herring data simultaneously with all the other datasets enables us to investigate the covariation between different model parameters. It also makes it possible to estimate the distributions for parameters that describe the connection between salmon post-smolt survival and herring, and thus to estimate with higher precision the post-smolt survival in recent years which, in turn, will improve our estimates of current abundance of salmon at sea. The details how this modelling will be done and what are the exact explanatory variables remains an open question. However, finding a technical solution to add explanatory variable(s) as covariates in the model is not anticipated as a complicated task.

3 Inclusion of populations in assessment units 5 and 6 in the full life-history model

To date, the full life-history assessment model used by WGBAST is only applied to salmon populations in assessment units (AU) 1–4 (Gulf of Bothnia and populations in southern Sweden; see ICES 2012a, Section 5). Wild salmon populations in AU:s 5 (Estonia, Latvia and Lithuania) and 6 (Gulf of Finland) are treated in a much simpler way, and the assessment results are thus much more uncertain for these populations.

The current analysis of AU5 salmon is based on a simple simulation model of the life cycle of AU5 populations. It is used to assess current population status by comparing smolt production to the 50% and 75% level of the estimated natural production capacity on a river-by-river basis. The following input data are used in the model:

- Prior probability distributions for the smolt production capacity that are based on expert opinions. These estimates are not based on the Bayesian modelling of expert knowledge used for the northern rivers and are therefore considered to be less reliable. In particular there is concern that the probability distributions provided by experts, and which describes the uncertainty about our knowledge of production capacity, are unrealistically narrow.
- Smolt production estimates derived mainly from electrofishing data using various methods that are based on the relation between parr and smolt abundances in the same and/or other rivers. These estimates do not usually contain information about uncertainties. For some rivers, smolt production estimates are completely based on data derived from other (similar) rivers in the region.
- Estimates from the full life-history model on annual harvest rates for offshore fisheries (thus assuming the same at sea migration pattern as for Gulf of Bothnia salmon).
- Estimates from the full life-history model on adult natural mortality (fixed over time) and annual post-smolt mortalities (thus assuming the same at sea survival as for Gulf of Bothnia salmon).

For AU6, there is no analytical assessment model developed. The assessment of population status is based on a qualitative assessment taking into account trends in parr densities, smolt production and exploitation rates. Expert opinions on natural production capacities are available for AU6 rivers, but no analysis of the stock–recruit dynamics exist at the moment, precluding validation of these preliminary production values.

At the working group meeting in spring 2012, a plan for how to include AU5 was discussed and agreed upon (see ICES 2012a, Section 8.4). The initial idea was to complete this task during IBPSalmon, but because of failure in compiling relevant data it has not been possible to achieve this goal. Instead, we have chosen to focus this presentation on the data needed to be able to continue this work in future. The data needs for inclusion of AU6 populations are rather similar as the needs for AU5 populations. Information needed divide into already existing information and information/data that is currently not available from the countries in question.

3.1 Data available to the working group

- Stock–recruit information. The same assumptions as for AU4 will be used.
- Sex ratio, fecundity and smolt age. There is information available to estimate sex ratio, fecundity and most common smolt ages (including variation for these parameters).
- M74. Information about the eventual occurrence of M74 is available from AU5–6.
- Fishing: Coastal fisheries in AU5 occurs only in Gulf of Riga (to any substantial amount), and it was decided that an assumption of no coastal fishing for stocks outside Gulf of Riga should be used, whereas a separate coastal fishing for Gulf of Riga is assumed. Data on catches in the Gulf of Riga is available from Latvia and Lithuania, divided between coast (including river mouth) and river. Catch statistics is also available for AU6.
- Maturation rate. Data from River Salaca (AU5), and Rivers Vasalemma, Keila and Kunda (AU6) has been delivered to the working group. Data for River Mörrumsån (AU4) is available, which makes it possible to investigate if the maturation rate for AU5–6 is the same as for the other southern populations. If not, separate AU specific maturation rates will be used in the modelling.
- Reared salmon. Stocking statistics from AU5 and 6 are available. Stocking of reared salmon into some (so-called "mixed") rivers with wild production must perhaps be considered. If so, there is a possibility to use a similar procedure as for Tornionjoki and Simojoki; stocking of young juveniles (fry, parr) must then be assessed separately, i.e. the countries in question must deliver smolt production estimates related to the releases of younger stages.

3.2 Information still missing

- Reliable priors of the potential smolt production capacity (PSPC) with associated uncertainties.
- Time-series of reliable smolt abundance estimates. As long time-series as possible are needed, but the length of the time-series could vary between rivers. The time-series for each river should be checked and updated (if needed) by the countries in question.
- There is a need to evaluate if the amount of available electrofishing data is large enough to arrive at smolt production estimates with reasonable precision.
- Effort data for coastal fishing. It is proposed that the effort in Gulf of Riga trapnet fisheries has been rather stable over the years, but information from Latvia on the number of gears per year is needed to investigate this further. The WG has decided to assume no coastal effort for stocks outside Gulf of Riga. At the last working group meeting, it was also proposed to assume the same offshore and river harvest rates as for stocks in other assessment units. This is because AU5 salmon seems to use the same feeding areas as northern stocks, and expert opinions on river fishing indicate that also the river harvest rate in AU5 may be rather similar as for northern stocks. The assumption about river harvest rate is, however, a bit uncertain as poaching may be an issue in some rivers/regions.

- Index river data. Although not critical for the inclusion of AU5 and AU6 populations, the establishment of a full index river in both AU5 and AU6 would be very valuable to estimate sea survival and stock–recruitment dynamics for these populations, and for studying eventual differences compared to AU1–4 populations. Such information could be used to improve precision in analyses and also to evaluate the realism of assumptions about e.g. sea survival rates.

4 Updating correction factors for unreporting and discards

4.1 Background

Currently, the assessment model simultaneously models the tagged salmon population as well as the total salmon population (ICES 2012a, Sections 5.3.8 and 5.3.9). In case of the tagged salmon, the population equations account for tagging induced mortality, tag shedding and underreporting of recaptured tags. The model is also fitted to offshore, coastal and river catches. Fishery and country specific priors are given for underreporting of tag recaptures and catches, based on expert elicitations. Generally, underreporting has been assumed to stay constant over time.

However, underreporting of tags and catches due to losses of salmon mauled by seals (discarding) in coastal trapnets has been taken into account by a year specific parameter (factor) which is based on the annual amounts of mauled salmon reported by Finnish coastal fishermen. Here it is assumed that fishermen are not reporting mauled salmon as part of their catches and it is also assumed that any possible tags which have been attached to mauled salmon are lost. Another annually varying source of unreporting comes from recalculation of the total Polish salmon catch. The Polish catch has been calculated by multiplying Polish effort with combined Danish, Finnish, Swedish and Latvian catch per unit of effort, assuming 75% of the fishing efficiency for Polish fishermen compared to others (see ICES 2012a, Section 2.2.1 for more details).

Except for the annually varying factors described above, unreporting and discarding have been quantified by probability distributions. These distributions have been reported in the working group report section describing catch statistics (under Chapter 2, see also Annex 2). However, only point estimates (medians) from the distributions of unreporting have been used in the life-history model. Moreover, only discarding in the coastal fishery has been taken into account in the model.

In future projections of salmon populations and fisheries carried out by WGBAST, unreporting and discarding are not separately calculated but instead the projections calculate these removals as part of total catch. Therefore, different components of future catch estimates can only be reverted by separate calculations.

4.2 Achievements during IBPSalmon

Reporting rate and discard estimates were elicited for the first time in 2003 (Michielsens *et al*., 2004, see Annex 2). In IBP, the questionnaire form (Annex 3) was slightly amended from the 2003 study to focus on the reporting rates of catch and effort, proportions of discards, survival of released undersized salmon from longlines, and tag reporting rates. Estimates were asked separately for offshore, coastal and river fisheries for years 2004–2011. Offshore driftnet fishing was covered until 2007 since it was banned in 2008.

In the 2003 study only WG experts were elicited, which may partly explain the differences of the results between that and the present study. In the present study the aim was to collect from each country the best understanding of the fishery data based on expert opinions or, if available, on datasets. Persons working with fisheries inspection and in fisheries statistics departments and also some fishermen were interviewed. Members of the WG compiled the national data in the questionnaire and gave the country specific estimates so that they represented as good as possible the compound view of all the interviewed people in the country. Country specific estimates are thus the result of subjective considerations based on various views instead of pooled probabilities quantitatively computed from multiple priors. An estimate of catch and effort reporting rates are inevitably rough approximates that at best give the order of magnitude.

Expert evaluations were given from Poland, Denmark, Sweden and Finland, which covers the main fisheries and about 98% of catches in the Baltic Sea. For Polish fishery the estimates of catch reporting rate were given by assuming that estimated misreporting of salmon as trout was first added to reported catch. Elicited multiple priors and pooled probability distributions of the studied parameters (cf. Annex 2) were not constructed by the completion of IBP, but updated parameter values will be included in the working group report and used in 2013 assessment.

Preliminary results indicate changes in conversion factors for years 2004–2011, which consequently will potentially change assessment results for that period retrospectively. It was difficult for experts to evaluate if changes in reporting or discarding have taken place in any specific year within the above range of years. Therefore, in 2013 assessment we intend to use the old estimates for years 1987–2003 and the new updated estimates for years 2004–2011, and also in the short-term stock projections. In year 2012 the TAC restricted salmon fishing in all four countries mentioned above for the first time since the mid-1990s. The TAC will likely restrict the fishing also in the coming years. Therefore, experts considered it probable that reporting behaviour may change from 2012. This makes it necessary for the WG to follow the development in reporting rate in the coming few years.

As pointed out earlier, so far only the median values of the conversion factors for unreporting have been used when the assessment model has been fitted to catches, and discarding has only been taken into account for coastal fishery. Within IBP, we preliminary explore potential methods to include uncertainties in unreporting. Inclusion of discards (both in coastal and offshore fisheries) and their survival are also considered. If successfully applied, these changes would make the estimation process for the historical stock development more consistent with the future stock projections under different effort scenarios. However, it is too early to evaluate if inclusion of uncertainties could be successfully carried out and by which method. So far we can only conclude that various technical difficulties may prevent any progress made here. A special problem arises from the need to recalculate Polish offshore catches; so far we have not been able to quantify uncertainties connected to this recalculation process, although the recalculated Polish catch has made up a substantial proportion of the total offshore catch.

5 The effect of climate variability on maturation rate in Baltic salmon

5.1 Background

The effect of winter temperatures on spawning run strength has previously been analysed briefly by the working group (ICES 2011; 2012a, Section 5.6). These analyses were prompted by the fact that both coastal catches and spawner counts in rivers were considerably lower in 2010 and 2011 than expected by the assessment model. At the same time, temperatures for winters 2009/2010 and 2010/2011 were clearly lower than the average level. Analyses of the relation between spawning-run strength (spawner counts in rivers) and winter sea surface (0–10 m depth) temperatures in the Southern Baltic Sea revealed an interesting pattern; for the last decade, a clear positive relationship between annual spawning run strength and water temperatures in February was found. No such relationship existed between winter temperature and model predictions of run strength, however, which was expected as the present assessment model is not fitted to climate data.

In previous analyses carried out by the working group, it was also discovered that even if winter 2010–2011 was even more severe than the preceding one, several rivers displayed a somewhat larger spawning run 2011 than in 2010, in contrast to the model prediction that was about the same for 2010 and 2011. This observation suggested that delayed maturation following a cold winter (rather than elevated natural mortality) could be an important factor (cf. Friedland and Haas, 1996, Friedland *et al*., 2009), but that further studies on the possible effects on maturation/survival are needed. It was also concluded that the assessment model would most likely benefit from inclusion of environmental drivers, like climate information, in future. Despite the fact that climate data are not used in the present assessment model; however, there is a very good agreement between the model results and independent empirical information about stock status regarding the long-term trend in development of salmon populations, although it seems obvious that not all short-term variation is picked up by the model (Figure 5.1).

The hypothesis that winter temperature plays a significant role for the dynamics of salmon populations through its effect on maturation/survival became even more topical during 2012, when the spawning run size in many rivers was much higher compared to 2010 and 2011, and for some rivers clearly exceeded levels predicted by the assessment model. At the same time, temperature data from the southern Baltic Sea indicated that winter 2011/2012 was one of the warmest during the past 20 years. These somewhat extreme temperature fluctuations during the last three winters clearly enable a more careful look at how climate variation affects the salmon populations.

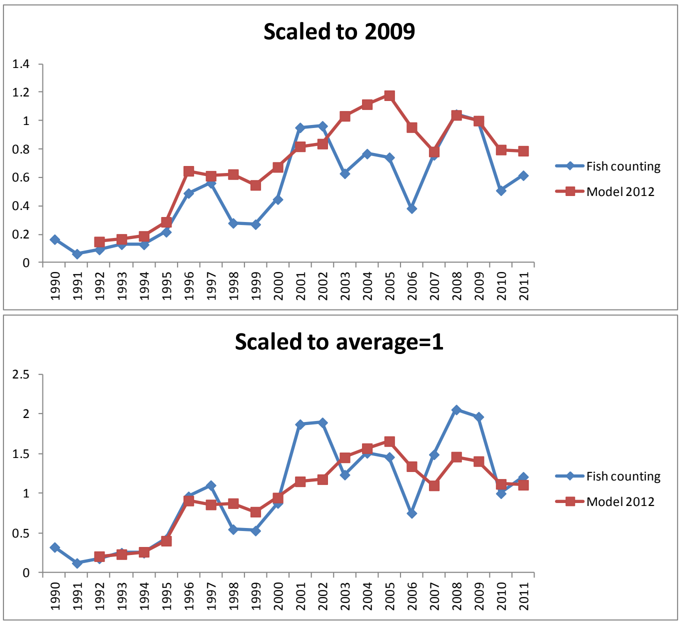

Figure 5.1. Upper panel: measure of the annual strength of the spawning run (calculated as the number of ascending spawners divided by the spawner count for 2009, averaged over seven rivers) in rivers with fish counting compared with corresponding model estimates (from the assessment in spring 2012) for the same rivers and years. Lower panel: annual strength of the spawning run calculated as above, but then scaled to an average of one to highlight the fact that fish counting data indicate more pronounced short-term variation in spawning run strength compared to model predictions.

5.2 Achievements during IBPSalmon

The assessment model currently used by WGBAST is fitted to various data from rivers. One important data source is information on the number of returning spawners, which in combination with smolt production estimates provides valuable information about survival rate at sea, including post-smolt survival rate which is one of the most important factors affecting estimates of pre-fishery abundance (ICES 2012a, Section 5.4.3). Maturation rate is currently assumed to be fixed over time, which makes the use of spawner counts in rivers rather critical for the estimation of salmon survival and abundance at sea. If there is a strong association between climate variation and maturation rate, which is not accounted for in the current model (assuming a fixed maturation rate over time), fitting the model to spawner counts in rivers introduces a risk that salmon survival and abundance become underestimated in years following cold winters and vice versa. The aim within IBPSalmon was to first carry out more in depth analyses of the association between winter temperatures and the spawning run size and maturation patterns. A second aim was to suggest a strategy for how to take into account in the assessment the fact that maturation rate may vary over time due to e.g. climate variation in southern Baltic Sea.

5.2.1 Analyses of the association between climate and spawning run size

During IBPSalmon, associations between climate and spawning run size have been analysed in more detail. Focusing just on the size of the spawning run according to spawner counts in rivers, analyses indicate a clear relationship with winter temperatures during the last ten years (Figure 5.2), and it seems as if winter temperatures in February and March are most important, although also April and May temperatures show a positive correlation with spawning run strength. However, the relationship between winter temperatures and spawning run size disappears when looking at a longer time-series (Figure 5.3). This probably reflects the fact that other factors than winter temperature were relatively more important during the 1990s, such as M74 outbreaks and changes in the exploitation rate. Indeed, if effects of year-class strength (including effects of M74) and exploitation patterns are taken into account by looking at the relationship between winter temperature and the deviation between spawning run size derived from spawner counts and model predictions (model predictions accounts for year-class strength and changes in exploitation patterns but not winter temperatures), there is a clear positive relationship for the whole time period (Figure 5.4). Again it seems that sea surface temperatures in February to May have the highest impact on spawning run size. This lends considerable support to the hypothesis that winter temperatures affect the size of the spawning run. It still remains unclear, however, if this correlation is due to changes in the maturation rate and/or the survival rate.

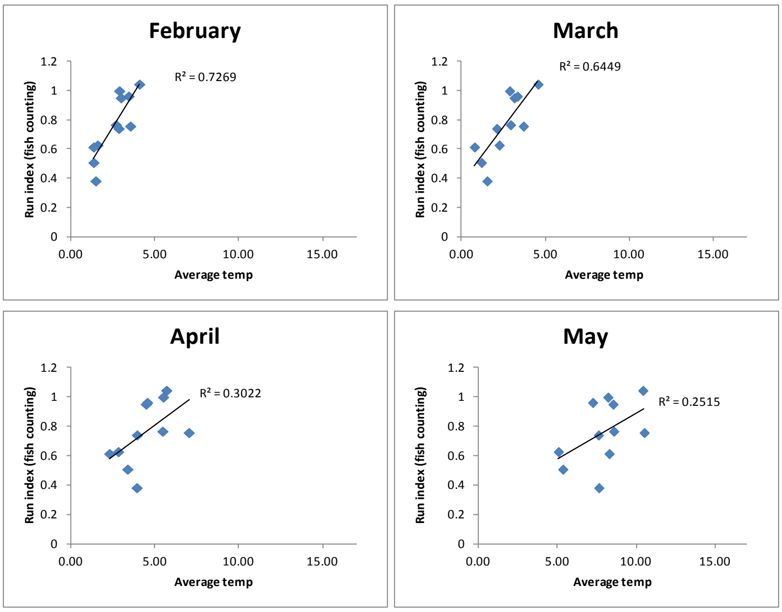

Figure 5.2. Correlations between spawning run strength based on fish counting (cf. Figure 5.1 upper panel) for years 2001–2011, and winter sea surface temperature (SST) in the Main Basin (average for a large number of stations at 0–10 m depth).

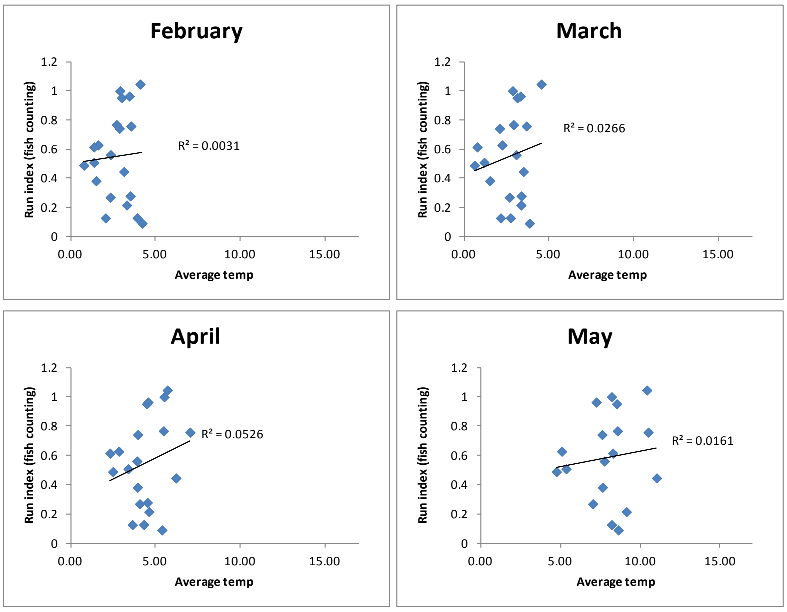

Figure 5.3. Correlations between spawning run strength based on fish counting (cf. Figure 5.1 upper panel) for years 1992–2011, and winter sea surface temperature (SST) in the Main Basin (average for a large number of stations at 0–10 m depth).

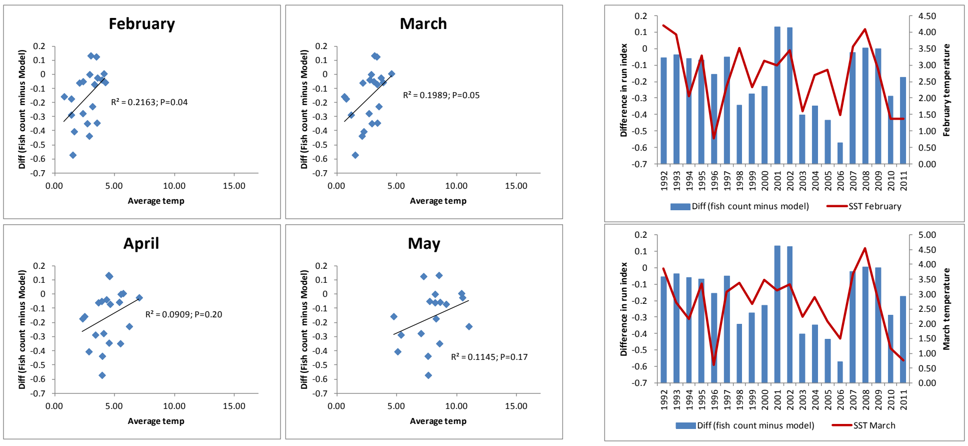

Figure 5.4. Correlations between winter sea surface temperature (SST) (SST) in the Main Basin and the deviation between spawning run size derived from spawner counts (cf. Figure 5.1 upper panel) and corresponding model predictions (model predictions accounts for year-class strength and changes in exploitation patterns but not winter temperatures) for years 1992–2011. The right-most panels indicate the development in the deviation between spawning run size derived from spawner counts and corresponding model predictions, and in sea surface temperature (SST)s in February and March.

To be able to focus on the potential effects on maturation rate only, a dataset from River Tornionjoki on age composition among spawners has been utilized. Catch samples from the river fishery for age determination (scale reading) have been taken every year since 1973. Here, the information on sea age (number of years spent at sea) was used from the year 1990 onwards to estimate the proportion within a smolt cohort that returned to spawn after one, two or three sea winters (SW). Individuals that have spent four years or more at sea are very rare and were therefore pooled with 3SW salmon.

The proportion of a smolt cohort that returned as 1SW salmon was positively correlated with sea surface temperatures in winter/spring preceding the spawning migration (Figure 5.5). This relationship was strongest for average temperatures in March and April. When focusing on multi-sea winter salmon of the same smolt cohort (i.e. 1SW salmon were removed from calculations), the proportion that returned after two winters (2SW) was also highly correlated with average sea surface temperatures during winter/spring months (especially April and May temperatures) preceding the spawning migration (Figure 5.6). Finally, Figure 5.7 shows the level of explanatory power in linear regressions for the proportion of salmon that returned to spawn after one and two years at sea, respectively, as a function of average sea surface temperatures for different months preceding the spawning run. It seems from these analyses that temperature during spring months (especially April) have the largest effect on maturation rate. It should be noted, however, that temperatures during winter and spring months are correlated to some extent and that the strong signal for April may simply indicate an accumulated effect of temperature conditions during a longer time period also covering winter (accumulation of degree days).

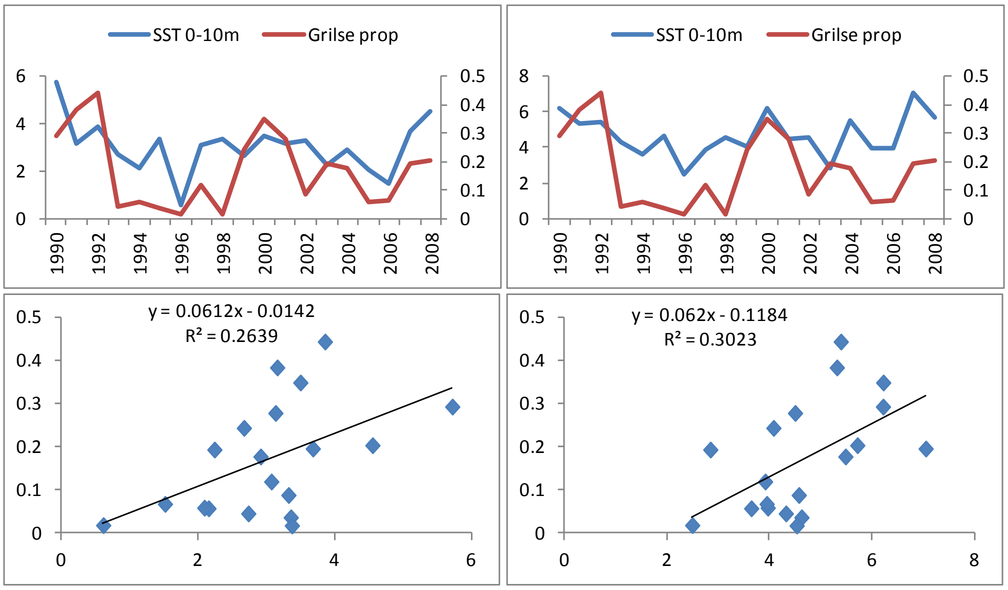

Figure 5.5. Upper panel: proportion of grilse (1SW salmon) in smolt cohorts and average temperature in Main Basin in March (left) and April (right). The lower panel shows the correlation between the variables.

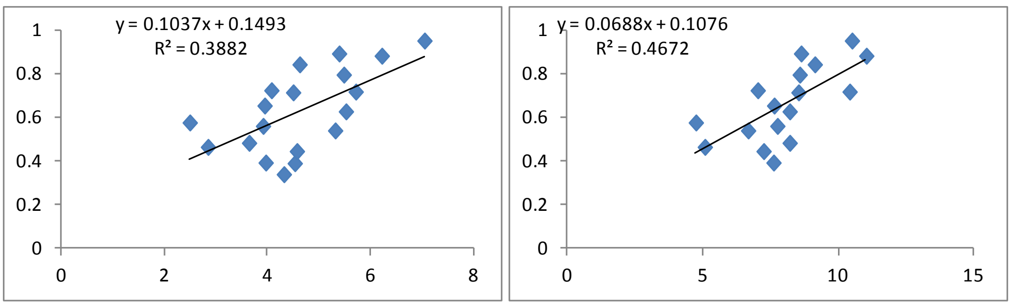

Figure 5.6. Correlation between proportion of a smolt cohort that migrate back after two winters at sea (2SW salmon) and average temperature in Main Basin in April (left) and May (right).

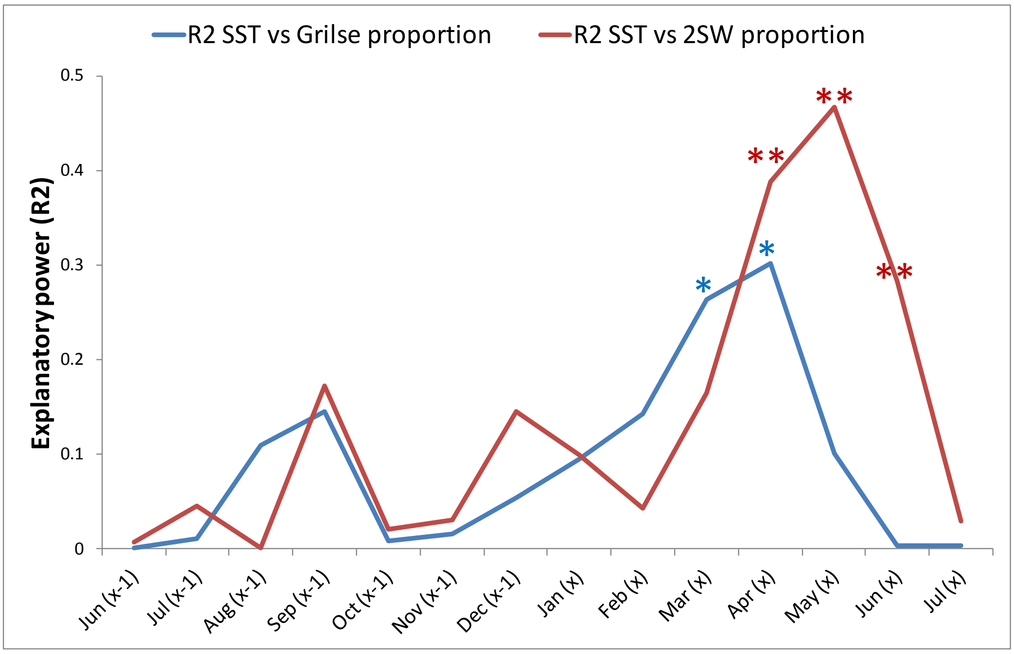

Figure 5.7. Results (R^2) from linear regressions between monthly average temperatures in the same (x) or the year preceding the spawning run (x-1), and the proportion of a smolt cohort that returned to spawn (blue line=grilse proportion; red line=proportion of 2SW salmon among multi-sea winter salmon (i.e. grilse excluded)). These analyses indicate statistically significant positive associations between temperature in spring months and return rate of grilse and 2SW salmon. *P<0.05; **P<0.01.

In conclusion, these analyses strongly indicate that climate induced variation in maturation rate seems to be an important factor behind much of the annual variation in run strength.

5.2.2 Accounting for variation in maturation rate

From the above findings it was considered within the IBPSalmon that the assumption about fixed maturation rates over time needs to be released, although it is too early to build an explanatory model for maturation with environmental covariates. However, there is plenty of information already included within the full life-history model about changes of maturation rates over time. We present here an outline of how to model maturation parameters in a way that allows variation over time.

Our aim is to minimize the required number of independent parameters to prevent this change from taking too much computational power. The mean of the maturation rate of wild salmon (muLW) is assumed to depend on the age class (parameter b[j] where j is the age) and the smolt cohort (parameter c[i] where i is the smolt cohort) specific terms. Furthermore, parameter tau[j] describes the variation around the expected values of maturation rate of age class j. The logit-transformation enables us to use age and smolt cohort as explanatory variables for maturation. The variation between different smolt cohorts is defined with parameters muc and tauc.

The maturation of reared salmon is assumed to differ from wild with a parameter LReffect which can have only positive values. This reflects the prior idea that at any given age the maturation rate of reared salmon is at least as high as the maturation rate of wild salmon. In this version the reared effect term is constant over time and does not depend on the age of the fish, but it could also be set separately for different age classes.

```
# Annually varying maturation rates
# ##############################
for (i in 1:m){ # number of years
  for (j in 1:4){ # age classes
    # lw: maturation rate for wild salmon on logit scale
    lw[i,j]~dnorm(muLW[i,j],tau[j])
    muLW[i,j]<-c[i]+b[j]
    # LW: maturation rate for wild salmon on scale [0,1]
    logit(LW[i,j])<-lw[i,j]

    # lr: maturation rate for reared salmon on logit scale
    lr[i,j]~dnorm(muLR[i,j],tau[j])
    muLR[i,j]<-c[i]+b[j]+LReffect
    # LR: maturation rate for reared salmon on scale [0,1]
    logit(LR[i,j])<-lr[i,j]
  }
  c[i]~dnorm(muc,tauc)

  LW[i,5]<-1 # all remaining salmon mature after 5 sea winters
  LR[i,5]<-1
}

# Prior distributions

# smolt cohort specific components for maturationmuc~dnorm(,)  # mean
tauc~dlnorm(,) # variation across cohorts

# age class specific components for maturation
b[1]~dnorm(,)
b[2]~dnorm(,)
b[3]~dnorm(,)
b[4]~dnorm(,)

# positive effect term for maturation of reared salmon compared to wild
LReffect~dlnorm(,)

# age class specific precision terms
tau[1]~dlnorm(,)
tau[2]~dlnorm(,)
tau[3]~dlnorm(,)
tau[4]~dlnorm(,)
```

The prior distributions for the parameters of maturation have not yet been fully elicited from the experts, and because of that the values are left out from this presentation. However, a preliminary set of priors has been combined and successfully included to the full life-history model. The aim is to implement this change fully in the 2013 assessment.

6 Update the hierarchical stock–recruit model by new parameterization of the Beverton–Holt SR function

The current submodel that is used for building the priors for the stock–recruit relationship of Baltic salmon is based on steepness parameter (the long-term unfished recruitment obtained when the stock abundance is reduced to 20% of the virgin level; Michielsens and McAllister, 2004). However, estimating steepness requires making assumptions about life-history parameters outside the riverine phase, such as (adult) natural mortalities, growth and maturation rates. Thus, such assumptions have been made for the Atlantic salmon stocks for the purposes of this hierarchical meta-analysis, and are transferred to the life-history model of the Baltic salmon in the form of prior distribution of steepness. This creates a contradiction since in the full life-history model those life-history parameters are being estimated by the Baltic data.

It is possible, however, to model the stock–recruitment dynamics without need to do these assumptions by utilizing slightly different parameterization for the Beverton–Holt SR function. In this alternative, parameter that describes the maximum survival of eggs is transferred from the meta-analysis into the full life-history model instead of steepness. This means in practice that the meta-analysis concentrates only on the riverine phase but not on the latter (marine) life phases.

Pulkkinen and Mäntyniemi (2013) discuss these issues and explain in further detail why the steepness is not a suitable parameter to be transferred from a meta-analysis into a life-history model. The aim is that the parameterization of the S–R relationship of the assessment model of Baltic salmon will be changed accordingly in the near future, including the new prior distributions formulated with methods specified by Pulkkinen and Mäntyniemi (2013).

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Annex 2: ICES WGBAST 2004 Working paper No. 11

Evaluation of the quality of the data estimates used for the assessment of Baltic salmon

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Introduction

Within the WGBAST working group report, most dataseries such as catch data and fishing effort data are presented as point estimates. In reality these dataseries should be considered estimates since they are derived dataseries and have undergone various manipulations by fisheries statisticians. Fisheries statisticians have to deal with nonreporting, missing data, discrepancies in logbooks and uncertainties regarding the actual observations. Within the working group we tried to assess the quality of these point estimates i.e. how well they represent to actual catches, fishing effort, etc. This has resulted in the establishment of conversion factors which can be used in combination with the point estimates reported within the data tables to obtain estimates for the actual catches, fishing efforts or tag recoveries.

This document explains the process of eliciting and summarizing the uncertainty associated with the different data estimates used within the assessment methodology for Baltic salmon. The resulting probability distributions for the uncertainty of catch estimates, fishing effort estimates and tagging data estimates can subsequently be used within the assessment methodology as prior probability distributions. In order to obtain general support, prior probability distributions need to have some evidence or consensus in support (Spiegelhalter, 2004). For several of the parameters needed within the assessment methodology, data are limited (e.g. tag reporting rates) or not available (e.g. underreporting of catches). In such cases expert opinion is important. This paper documents how expert opinions have been elicited to formulate prior probability distributions for the uncertainty associated to the data estimates used for the assessment model.

Methodology

Eliciting prior probability distributions from expert can however result in biases (Kadane and Wolfson, 1997). Chaloner (1996) provided a thorough review of methods for prior elicitation and concluded that fairly simple methods work best, i.e. using interactive feedback, providing experts with a systematic literature review, basing elicitation on 2.5th and 97.5th percentiles and using as many experts as possible. For the working group's stock assessment, expert opinions about the quality associated with different data estimates (i.e. how well they are likely to correspond to the true values) have been elicited from working group members during a workshop at Bornholm (ICES, 2003). The parameters on which the experts were asked to give their opinion have been thoroughly explained and the participants of the workshop presented the available information (previous studies or literature) about these parameters (Annex Table 1 and Table 2). For each parameter, the experts have been asked to provide a most likely value and a minimum and maximum value. This information could be based on data obtained from previous studies done (if available), could come from the literature, could be based on their experience or could be a subjective expert estimation in case no information is available. Twelve experts in total have been asked their expert opinion. The information was asked for each country, but these country specific estimates are kept in the database of the WG. Some of the information elicited from the experts was seen to be politically sensitive, and therefore within the working group report the results from individual experts/countries are not reported. The working group decided to use simulation models to expand the given country specific probability distributions to the whole fishery, i.e. to use combined estimates of uncertainties and bias in the assessment model applied.

More specifically, the information has been analysed within @RISK, an add-in to Excel, which allows for the use of probability distribution to describe and present uncertain values. The prior probability distributions are triangular (using the minimum, maximum and most likely value to describe the distribution) and Monte Carlo sampling is used to sample from the different triangular prior probability distributions.

The use of multiple experts resulted in multiple priors for the different model parameters. In order to combine the knowledge from all the experts, arithmetic pooling (Genest and Zidek, 1986; Spiegelhalter *et al.*, 2004) has been applied by taking the average of the height of the prior distributions for each parameter value θ so that:

$$p(\theta) = \sum_k p_k(\theta) \Big/ K$$

The resulting prior has the property that the pooled probabilities for certain events are the average of the individual events.

Because the expert opinion about the quality of the catch estimates, fishing effort estimates and tag recovery estimates are country specific, the probability distributions for each country are weighted by the country's contribution to catches. The countries' contributions to catches have been calculated as point estimates obtained by calculating average catches over the last five years for each country, and the corresponding contribution of each country to the total catch in the different fisheries. This method requires one probability distribution for the parameter values for each country. For some countries, more than one expert had been available. In this case, the diversity of opinions about the parameter values for that country has been considered most important. Therefore the lowest and highest values over the different expert opinions for that country have been used in combination with the average for the most likely value. In case no expert opinion had been given for certain parameters, the lowest and highest values over the expert opinions of the other country had been taken in combination with the average for their most likely values. The resulting distributions have been approximated by parametric distributions.

When developing priors to be used in subsequent analyses, care should be taken not to use the same data to construct the prior probability distribution as to fit the model to. Using the same data for the prior as within the likelihood function would result in too informative posterior probability distributions. In this case, we use the estimated contribution of different countries to the catches and to the salmon production to weight the experts' opinions about the quality of the data provided by each country. The resulting probability distributions can be used as prior probability distributions within the assessment methodology unless the contributions of the different countries to the catches are also used are used a second time within the assessment methodology. The current methodology does not use this information.

Results

The uncertainty associated to the different dataseries has been summarized through graphs showing the histograms of the original probability distributions together with their parametric approximations. Table 1 summarizes all the uncertainties and provides their distributions, the median and CV of the distribution and the kind of information sources on which the prior probability distributions of the individual experts have been based (data or subjective expert opinion). The probability distributions for the different parameters are the result subjective expert opinion based on the available and partial data. All parametric distributions have been truncated at the lowest and highest possible values indicated by the experts.

Tag reporting rates

A summary of the available data on tag reporting rates can be found in the Bornholm report (ICES, 2003). Figure 1 summarizes the results for the tag reporting rates in the river, coastal, offshore driftnet and offshore longline fisheries in the Baltic. It is estimated that the reporting rates of tags by river fishermen (the probability of the river fishermen reporting a captured tag) are the highest and the associated uncertainty is the lowest (Table 1). Also the return rate for tags from the longline fishery is estimated to be relatively high but there is more uncertainty associated to this figure. The coastal fishermen are estimated to return the smallest proportion of tags. The return rates of both the coastal fishery and the offshore driftnet fishery are quite uncertain. All probability distributions for the return rates could be approximated fairly well by beta distributions.

Conversion factors for catch estimates

The Bornholm report (2003) contains a qualitative assessment of the quality of the catch data estimates. The probability distributions for the conversion factors of catches have been primarily based on this information. These conversion factors present the belief of experts in the catch estimates. A conversion value of 1.1 for example means that the expert's belief that the real catches are 10% higher than the reported catches. The conversion factors can be used in combination with the reported point estimates for the catches in order to obtain a probabilistic estimate of the true catches. Again, underreporting is assumed to be highest for the coastal catches where it is estimated that the actual catches are on average 25% higher than the reported catches and the uncertainty regarding this figure is large (Figure 2; Table 1). The CVs of the probability distributions for the conversion factors of river catches, offshore catches and average catches are half the CV of the probability distribution for the conversion factor for coastal catches. The underreporting of offshore catches is assumed to be lowest. All probability distributions have been approximated by lognormal distributions. Especially the conversion factor for coastal catches has a heavy tail to the right, stating that it is possible that the actual number of salmon caught in the coastal fisheries could be more than double what is currently reported. Although the best-fitted parametric lognormal distribution does not show such a heavy tail, the parametric probability distribution does not rule out high values of underreporting by the coastal fisheries.

Conversion factors for fishing effort estimates

The conversion factors for the fishing effort estimates indicate that the uncertainty regard fishing effort estimates is much larger for the coastal fishing effort by gillnets than for the other fisheries (Figure 3 and Table 1). The coastal gillnet fisheries consists predominantly of fishermen who fish for consumption within the household. The extent to which the fishing behaviour of these fishermen is recorded in the fisheries statistics, differs from country to country. This has resulted in a very wide and bi-modal probability distribution for the conversion factor for fishing effort by the coastal gillnet fishery.

Adjustment factor for catches to accounted for unreported discarded catches

Within the catch tables only the discarded catches, which have been reported in log-books, are recorded. Therefore an adjustment factor based on the experts' belief of the unreported discarded catches has been developed. This conversion factor can be multiplied with the estimates catches from the tables to obtain probabilistic estimates for the total number of salmon caught, including discarded catches.

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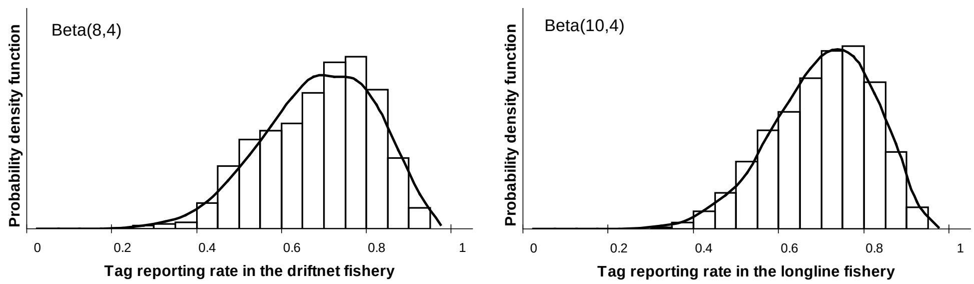

Figure 1. Estimated tag reporting rates in the river, coastal and offshore fisheries obtained through arithmetic pooling of expert opinions, weighted according to the contribution of the experts' country to the catches in the different fisheries (histogram) and the corresponding approximate parametric probability distributions.

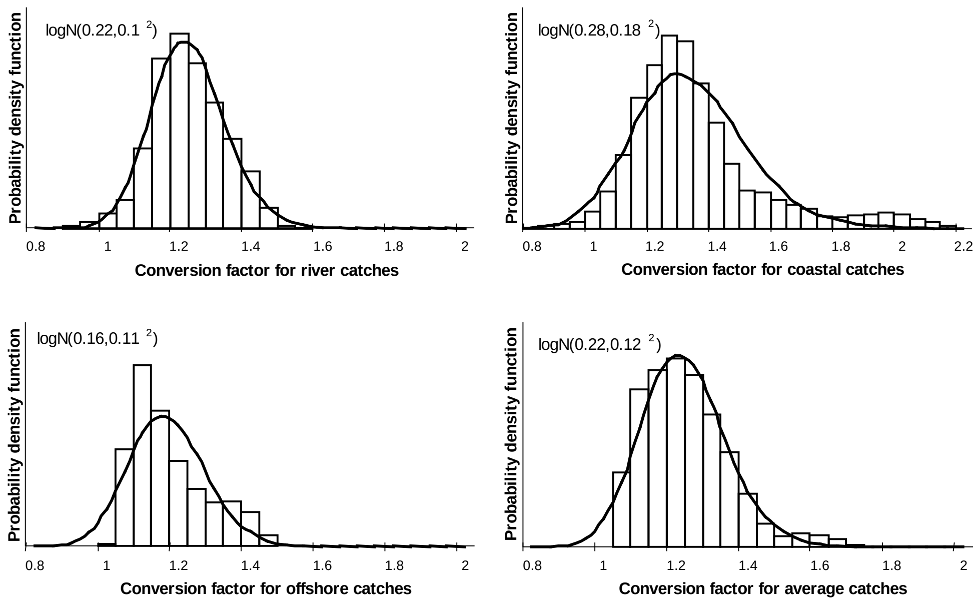

Figure 2. Conversion factors for catches in the river, coastal and offshore fisheries obtained through arithmetic pooling of expert opinions, weighted according to the contribution of the experts' country to the catches in the different fisheries (histogram) and the corresponding approximate parametric probability distributions. The conversion factors reflect the uncertainty of the catch estimates and can be multiplied with the catch point estimates in order to obtain probabilistic estimates for the true catches by the different fisheries.

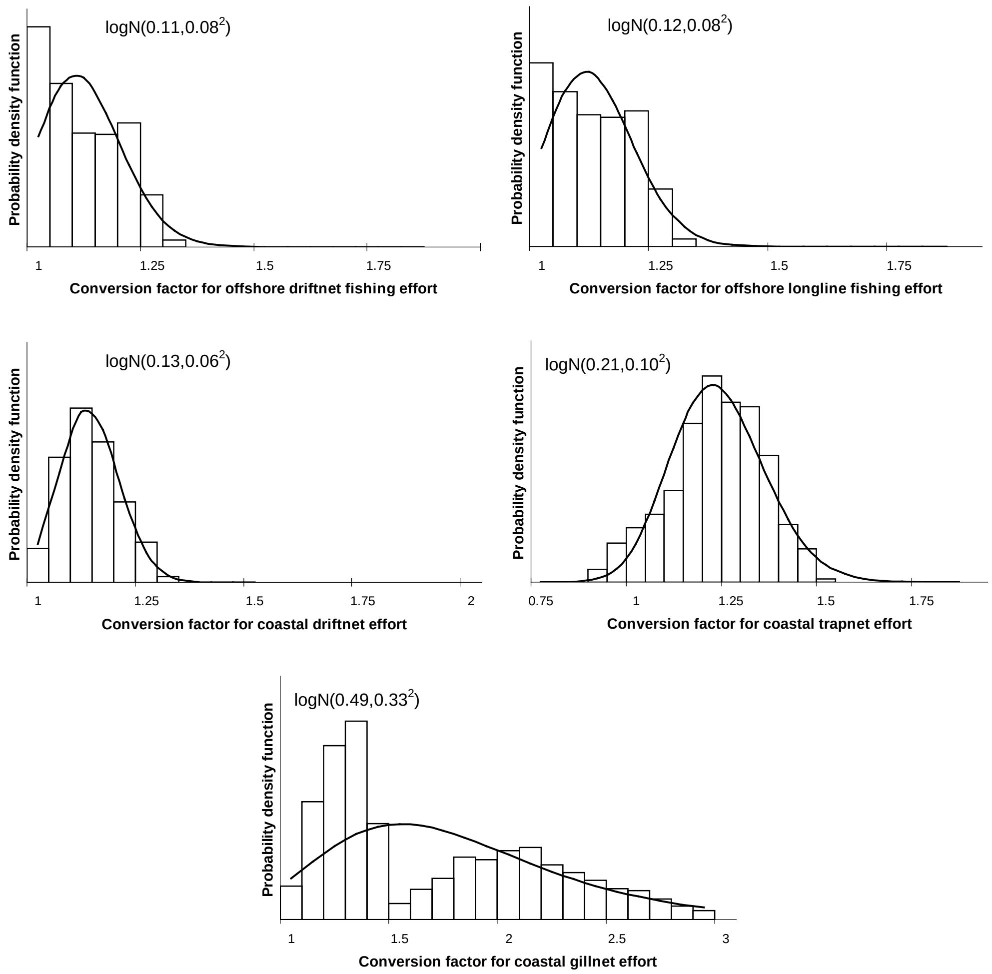

Figure 3. Conversion factors for fishing efforts by the offshore driftnet, offshore longline, coastal driftnet, coastal trapnet and coastal gillnet fisheries, obtained through arithmetic pooling of expert opinions, weighted according to the contribution of the experts' country to the catches in the different fisheries (histogram) and the corresponding approximate parametric probability distributions. The conversion factors reflect the uncertainty of the data and can be multiplied with the point estimates for the fishing effort in order to obtain probabilistic estimates for the true fishing effort by the different fisheries.

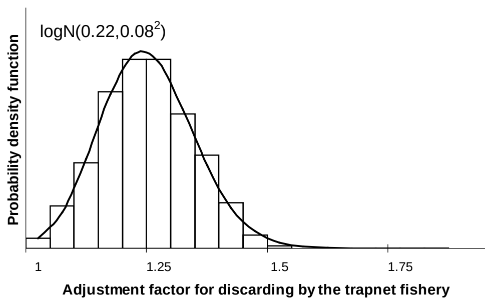

Figure 4. Adjustment factor for unreported discarding of catches by the offshore driftnet fishery, the offshore longline fishery and the coastal trapnet fishery, obtained through arithmetic pooling of expert opinions, weighted according to the contribution of the experts' country to the catches in the different fisheries (histogram) and the corresponding approximate parametric probability distributions. The adjustment factor for unreported discards can be multiplied with the catch estimates in order to obtain probabilistic estimates for the total catches, including discarding. The adjustment factor does not take into account discarded catches that have been reported in the logbooks and have been reported in the catch tables.

Table 1. Summary of the uncertainty associated to different dataseries according to the expert opinions of Baltic salmon working group members backed by data (D) or based on subjective expert estimation (EE). The conversion factors can be multiplied with the observed data in order to obtain estimates for the true catches, cpue or smolt production.

PARAMETERS	DISTRIBUTION	MEDIAN	CV	SOURCE
Tag reporting rate in the river fishery	Beta(16,6)I(0.3,0.95)	0.73	0.13	D, EE
Tag reporting rate in the coastal fishery	Beta(11,9)I(0.3,0.8)	0.55	0.19	D, EE
Tag reporting rate in the driftnet fishery	Beta(8,4)I(0.2,0.95)	0.68	0.20	D, EE
Tag reporting rate in the longline fishery	Beta(10,4)I(0.3,0.95)	0.72	0.16	D, EE
Conversion factor for river catches	logN(0.22,98)I(0.9,1.6)	1.24	0.10	D, EE
Conversion factor for coastal catches	logN(0.28, 31)I(0.8,2.2)	1.33	0.18	D, EE
Conversion factor for offshore catches	logN(0.16, 90)I(1,1.5)	1.18	0.09	D, EE
Conversion factor for average catches	logN(0.22, 74)I(1.05,1.75)	1.26	0.10	D, EE
Conversion factor for the offshore driftnet effort	logN(0.11,150)I(1,1.3)	1.13	0.06	EE
Conversion factor for the offshore longline effort	logN(0.12,155)I(1,1.3)	1.13	0.06	EE
Conversion factor for the coastal driftnet effort	logN(0.13,288)I(1,1.3)	1.14	0.05	EE
Conversion factor for the coastal trapnet effort	logN(0.21,103)I(0.9,1.5)	1.23	0.09	EE
Conversion factor for the coastal gillnet effort	logN(0.49,9)I(0.9,3)	1.72	0.27	EE
Adjustment factor for discarding by coastal fishery	logN(0.22,168)I(1,1.5)	1.24	0.07	EE
Adjustment factor for discarding by driftnet fishery	logN(0.075,822)I(1,1.3)	1.08	0.03	D, EE
Adjustment factor for discarding by longline fishery	logN(0.2,413)I(1.1,1.5)	1.22	0.05	D, EE

Annex 3: Questionnaire form for expert elicitation of information on discards and underreporting of tag recaptures, catches and effort

Model parameters associated to fishery and tagging data and their minimum, most likely and maximum values. Salmon.

If reporting rates have changed after 2003 Bornholm meeting, give the year when the change occured. If several changes/periods give separate estimates for each range of years (multiplicate the table section concerned).

If discards have varied in periods of years, give separate estimates for each period of years (multiplicate the table section). If discards vary along the fishing season give separate estimates e.g. for autumn and spring.

All values should be country-specific. Therefore, the estimates given should only concern the fishery in your country.

LLD= long line, GND=drift net, TN=trap net

Fishery data	Updated values				
	Minimum value	Most likely value	Maximum value	Based on data (D) or subjective expert estimate (EE)	Range of years
Total catches in the off shore fishery (1.2 means that you believe that real catches are 20 % higher than reported catches)					
Total catches in the coastal fishery					
Total catches in the rivers					
Total effort in off shore LLD fishery					
Total effort in off shore GND fishery (by the end of 2007)					
Total effort in coastal TN fishery					

Tagging data	Minimum value	Most likely value	Maximum value	Based on data (D) or subjective expert estimate (EE)	Range of years
Tag reporting rate in off shore fishery					
Tag reporting rate in coastal fishery					
Tag reporting rate in river fishery					

Discards	Minimum value	Most likely value	Maximum value	Based on data (D) or subjective expert estimate (EE)	Range of years
Proportion of undersized salmon in the catch of off shore LLD fishery					
Survival rate of undersized salmon that are released from LLD hooks					
Proportion of seal damaged salmon in LLD catch					
Proportion of undersized salmon in the catch of off shore GND fishery (before 2008)					
Survival rate of undersized salmon that are released from GND (before 2008)					
Proportion of seal damaged salmon in GND catch (before 2008)					
Proportion of undersized salmon in the catch of coastal TN fishery					
Survival rate of undersized salmon that are released from TN					
Proportion of seal damaged salmon in TN catch					

Annex 4: External review and response from the working group

Two external reviewers have scrutinized the IBP report and their comments are presented in this Annex. The reviews include many relevant comments which have been taken into account/will be taken into account in future work by the working group. A response from the working group is given after each reviewer comment. The aim of the working group response is to facilitate an efficient use of the constructive criticism presented in the reviews, as well as to inform readers how the advice has been used/will be used to improve the assessment.

Review by Rebecca Whitlock

Prioritizing the proposed updates

Of the issues I have reviewed (Sections 1, 4, 5 of the IBP report), dealing with nonreporting of tags and catches and adding an observation model for trap catches of spawning salmon might be regarded as priorities as they seem likely to have the greatest effect on the estimated stock status and estimated probability of meeting the PSPC target. Overall the updates proposed in the report for the Inter-Benchmark Protocol for Baltic salmon are commended and all of them should contribute to improving the assessment for Baltic salmon. Specific comments follow below.

Review of the proposed updates

Section 1. Relative abundances of wild and reared salmon

It would be helpful/facilitate the review process if more descriptive text was added to the BUGs code to explain what the various lines of code are. It would also have been useful to know when, from where and at what age the tagged fish were released in the summary on page 3.

- The model assumes that both mark–recapture experiments within each year have the same catchability; it is stated that this is a simplification on page 4 but it would be useful to see some justification of the assumptions made here (how far apart in time were the two experiments in each year, and would there have been exploitation in between them?).
- Is there a summer closure affecting river fisheries? If yes, is there the possibility for a seasonal effect caused by the timing of the spawning run in a particular year? I.e. because of the fixed closed season, the catch might represent different proportions of the total run size from year to year, which could warrant inclusion of some variable to account for run timing in the model.
- The priors etaL and muL in the second code extract ("Luleälven trap") are different from the ones about a third of the way down the page, are they somehow scaled to the annual level?

  WG response. All mark–recapture experiments were carried out quite late in the season (August–September), when all salmon were assumed to have ascended the river and most of the exploitation had taken place. Thus, experiments within years were targeting the same population of salmon. Therefore, the catchability did not vary much between the experiments (as indicated by the number of returns per day). In a similar manner, variation in exploitation between years (due to e.g. variation in run timing) would not affect the results because the experiments were carried out late in *the season when all exploitation had taken place, and year specific coastal and river fishing is accounted for within the full life-history model.*

Regarding the priors etaL and muL in the code extract, this was an error and has been corrected.

Section 4. Updating correction factors for unreporting and discards

- An alternative way to account for the misreporting of salmon as trout in the Polish fishery (instead of using Polish effort, combined cpue of other countries and a fixed correction factor) could be to place a beta prior (possibly bounded away from 0 using the T() construct in BUGs) on the proportion of salmon in the Polish catches (ideally an informative prior, either empirical or based on expert opinion). The model predicted salmon catch could then be divided by this proportion to obtain the model predicted catch of salmon. The predicted salmon catch would then be divided by 1 minus the proportion of sea trout in Polish catches (again, an informative prior) to get the estimated combined catch of salmon and sea trout which could be fitted to the observed combined Polish catches of salmon and sea trout. This might be a more process-based way of representing the misreporting which would also account for the uncertainty in the proportion of salmon that is misreported as trout.

  WG response. If Polish total reported catches (both sea trout and salmon) is assumed to be reliable information, this kind of procedure could be conducted. It would, however, require a slightly more complex approach for the model fit with the observed catches compared to the current methodology, since the reported catch would need to be considered random (instead of known, as currently). Also, acknowledging the fact that the prior for the proportion of salmon out of the total catch would be very close to one based on catch samples, this alternative procedure would most likely not change the conclusions to any significant extent. One difference with this alternative approach, however, would be that the assumption of Poland having 75% of the cpue compared to other countries could be removed; instead, we would consider the salmon proportion in Polish catches to be around 97–99% of the total catch (combined salmon and sea trout catch) as for other countries.

- Paragraph 3, page 16; it is slightly unclear whether the statement that only medians from the distributions for non-reporting have been used refers to reporting of tags or catches. It would be preferable to use distributions for nonreporting here to account for the full range of uncertainty; was this done for technical reasons? One option to incorporate the elicited information about catch conversion factors in the model (if the assumption that the minimum conversion factor is 1 would be valid/there is no overreporting of catches) would be to take the reciprocal of the elicited distribution for the catch conversion factor e.g. approximating it with a beta distribution. The model predicted catch (before accounting for nonreporting) could then be multiplied by this beta distribution to get the predicted catch after accounting for nonreporting, which would be fitted to the observed catch (analogous to the use of tag reporting rates).

  WG response. Medians are used instead of the total distributions for technical reasons. The problem is that if we approximate the elicited distribution with, say, a beta distribution and include it in the model as a prior distribution for the reporting rate, it will be updated with the other sources of information and the resulting posterior will *not have values that are satisfactory. Instead, we could use the likelihood approximation (so called pseudo-observation method) in inclusion of this information, but it requires some studies to find out if it is correct to use such a method together with expert elicited information.*

- It would be desirable to include discarding in fisheries other than the coastal fishery if possible (the reason for this omission was not clear in the IBP report).

  WG response. In the IBP report it should now be clear that also the discard in offshore fishery is intended to be included in the model. The reason why it has not been included earlier is a consequence of historical development of the assessment. At the beginning, only tag recovery data with the corresponding unreporting estimates were used. Fitting the model to catches was done later and at that point discards in the offshore were seen insignificant because the major fishery at that time was carried out by driftnets, and those catches contained insignificant amounts of undersized salmon. Starting from year 2008, longline effort has increased gradually to a significant level in the last few years. According to recent studies, the proportion of undersized salmon in the longline catch is around 2–15%.

- For consistency, it might be preferable to elicit the reporting rates for 1987–2003 using the amended questionnaire and more diverse pool of experts consulted in the recent study, to try to ensure that differences in the elicited distributions for the two time periods reflect expert opinion that the reporting rates have changed, rather than changes in the elicitation protocol. If beta distributions are used for catch reporting, similarly as for tag reporting rates this change could be made to the formulation of priors using elicitation of expert opinion going forward.

  WG response. This is a very relevant comment and will be considered by the working group.

- Comment on Annex 3; in order to get a clear picture of temporal changes in reporting rates, it might be better to change the table so that it already contains replication for different time periods, e.g. the whole time period could be split into two or three sections and the elicitation exercise repeated for each (asking experts to replicate their answers if they believe no change has occurred). Although this places a slightly greater workload on the experts, it could focus experts more clearly on temporal changes by making them state reporting rates for each period.

  WG response. See comment above.

Section 5. The effect of climate variability on maturation rate in Baltic salmon

Figure 5.6 in this section lacks axis labels.

The possibility of a causal link between water temperature in winter/spring and the size of a spawning run is an interesting one and the proposed model for maturation would allow incorporation of environmental covariates for maturation (e.g. where some measure of temperature in the months preceding the spawning migration could be added as an explanatory variable for the proportion of fish in a given cohort and of a given age that mature in a particular year). There might be a possibility to include prior information for the effect of temperature on maturation based on other studies for salmonid fish (e.g. Morita *et al.*, 2009). Including temperature as a covariate could be desirable for forecasting run size (and potentially timing) if continued monitoring/investigations support a causal link.

The assumption that all fish die after spawning (WGBAST report, page 174) is quite a strong one, particularly when estimated smolt production in relation to potential smolt production capacity is used to assess the status of Baltic salmon stocks. Although the current population may contain a low percentage of repeat spawners, this might not reflect the natural/unfished age structure in the population as exploitation truncates the age structure e.g. a smaller proportion of repeat spawners as a result of exploitation is suggested by Karlsson and Karlström (1994). Repeat spawners could contribute disproportionately to recruitment in natural populations because of their larger size and fecundity, in addition to possible maternal effects. I came across a PhD thesis (Halttunen, 2011) that may contain some material relevant to this point. It would be useful to see more discussion of this assumption (and whether it is justified) in the report. Assuming that all salmon die after spawning in the model could lead to bias in estimates of steepness and may also affect the results of evaluations of alternative management option via projections with the full life-history model.

If it is assumed that fish can repeat spawn (iteroparity) in the full life-history model, it would be necessary to modify the new maturation model to account for the numbers or proportions of fish at different sea ages from a given cohort that are immature and have matured in previous years to predict the number of spawning fish in a given year (repeat spawners plus first time/maturing spawners).

WG response. This comment is relevant and inclusion of repeat spawning is one important task for the future development of the model. The task has been too demanding to be tabled in the current IBP and it is also uncertain if repeat spawning could be added into the current model in the first place. Historic catch samples from the Baltic salmon fisheries (e.g. Alm, 1934; Järvi, 1938) indicate rather low (typically 5–10%) occurrence of repeat spawners during the era when fishing pressure on the feeding ground was lower than more recently. Levontin (2008) concluded that ignoring iteroparity has minor implications for Baltic salmon management. On the other hand, a study in the River Alta (Halttunen, 2011) indicates that the proportion of repeat spawners taking part in reproduction may be higher than what e.g. catch samples indicate, which underlines the need to take repeat spawners into account. Inclusion of repeat spawners in the life cycle model would not only require structural changes in the modelled life cycle, but also the use of some datasets (most importantly tagging data) would need to be revised.

Other points

The assumptions that fishing mortality is proportional to effort and that catchabilities have been constant through time may warrant further investigation. In particular, catchability of some of the gears used, particularly set gears in coastal areas (e.g. trapnets) and river fisheries may be density-dependent, so that catchability increases at low population density.

Given the very long time needed for convergence of the current model, testing alternative model structure will be unfeasible. It is therefore suggested that a smaller submodel (e.g. that uses data from only one river) is developed with the same assumptions/basic structure as the assessment model, to provide a testing ground for the effect of various model assumptions/analysing the model and for use in model development.

Is there any plan to re-elicit the expert priors for potential smolt production capacity? These distributions could plausibly change over time if there are changes in river morphology, quality of rearing habitat, etc.

WG response. The above comments will be discussed within the working group.

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Review by Kevin Friedland

Section 2. Improving survival estimates and stock projections

Background. The concern over declining post-smolt survival is framed in the context of limits placed on fishing opportunities and the pragmatic need to develop mechanistic forecast models to predict survival and provide fisheries advice. The WG has adopted a general mechanistic framework of model design based on the paper by Mäntyniemi (Mantyniemi *et al*., 2012), which attributes survival to herring recruitment and possibly related to seal predation as well. It is reasonable to suspect that prey items may affect salmon survival through size related predation; however, the methods and meaning of these results raise questions and concerns. Herring recruitment does not appear to be related to salmon survival (see Figure 2a from Mäntyniemi), the recruitment variable shows little contrast over the time-series suggesting that the post-smolts would have encountered a herring prey field with similar herring larval densities in years with good and poor survival.

To achieve a measure of association between the herring recruitment index and post-smolt survival, the herring recruitment variable is transformed by dividing it by the number of post-smolts in the ecosystem to yield a per capita herring density. This creates a herring recruitment index that shows contrast over time and declines with post-smolt survival. First, an immediate concern is that this represents a spurious self-regression since now the number of post-smolts is in both the herring index and the salmon survival rate (Kenney, 1982). That concern aside, the hypothesis supported by these data would appear to be density related mortality. For the herring index to decline over time, greater numbers of post-smolts would have to be in the system; greater numbers of post-smolts associated with lower post-smolt survival? If that is truly the case, competition would have to have increased to the point that the system is oversaturated and the Baltic salmon is now showing a strong Ricker type recruitment pattern, or mortality has increased with some other factor related to salmon density like disease (Krkošek *et al*., 2012, in press). This is not the interpretation the WG is using, so the relationship raises more questions than it answers. In regard to the seal variable, it is reasonable to assume that by some means aggregate predation on post-smolts has increased, but is this single predator the main driver of this mortality rate? For seals to be the main driver, there would have to be some level of independence between survival and other factors like post-smolt growth (Friedland *et al.*, 2009b; Hogan and Friedland, 2010). The main focus of smolt growth studies have been the effect of size of marine entry and maturation rate. I am not aware of any study of post-smolt growth related to marine survivorship in the Baltic area.

Achievements during IBPSalmon. Herring, sprat and seal variables are updated and first related to post-smolt survival via a residual analysis. Fundamentally this analysis is flawed since it is incorrect to take the residual of the salmon survival rate. Residual analyses are used in recruitment studies to correct for stock size effects by fitting recruitment to stock size with some SR curve. In that way, an alternative is provided to a ratio estimator of recruits per spawner. The survival rate already accounts for stock (assumed to be based on smolt numbers) thus taking the residuals removes the information content of the data. In other words, residuals associated with high and low recruitment will be all over the data space make the correlate meaningless (or fortuitous at best). The information content here is not the high frequency signal of the year-to-year fluctuation it is the decadal scale low frequency signal which this analysis eliminates. As a general note, the modelled variable is usually plotted as the ordinate not the abscissa.

The analysis then turns to relating post-smolt survival to herring SSB. Here the variables are first examined without residual transforms and strong relationships emerge. The focus up to this point has been on measures of herring recruitment based on the assessment estimates of older herring, not the direct measure of 0-group herring abundances, which could be argued to be better represented by SSB levels then recruitment estimates at age 1 if there is significant mortality between age 0 and 1. The herring assessment experts raise concerns over this interpretation, the nature of these arguments are not laid out. The lack of fit in Figure 2.8 makes sense in that the residual analysis is not appropriate here.

Of the suite of models reported, models using the recruitment are confusing, which recruitment treatment is being used, is it the per capita index, the residual index or raw recruitment estimates? The underlying basis of using the first two does not support their use and no evidence was provided support the use of raw recruitment estimates. There are many models using herring SSB, which would be more supportable and would fit into assessment requirements since SSB could more easily be projected for use in salmon assessments.

The focus on herring and seal likely hit upon elements of the recruitment dynamics of Baltic salmon, but do they represent the drivers? Can and should Baltic salmon recruitment be related to aspects of the physical environment? Attempts to relate salmon survival to SST have been made in the Baltic (Kallio-Nyberg *et al.*, 2006), but I am not aware of a comprehensive examination of SST throughout the Baltic over the post-smolt year.

To address this need, the association between post-smolt survival and SST was tested by Pearson product-moment correlation. The significance test requires that the data be distributed as a bivariate normal distribution (Sokal and Rohlf, 1981). The distributions of stock abundances were tested for normality (Shapiro-Wilk W statistic) and by inspection of frequency distributions and normal probability plots. The survival rate was log-transformed. Trends in Baltic SST were characterized using the extended reconstructed SST dataset (ERSST, version 3b; monthly data, 2° grid resolution). This dataset is based on the SST compilation of the International Comprehensive Ocean-Atmosphere Dataset (ICOADS) and represents interpolation procedures that reconstruct SST fields in regions with sparse data (Smith *et al.*, 2008). The SST data were not transformed.

The time-series compared here displayed varying degrees of autocorrelation. Autocorrelation was corrected by adjusting the effective degrees of freedoms of each test according to Pyper and Peterman (Pyper and Peterman, 1998). The effective degrees of freedom (N*) of a correlation between two time-series, in notation series X and Y, was estimated by:

$$\frac{1}{N^*} \approx \frac{1}{N} + \frac{2}{N}\sum_{j=1}^{N/5} \frac{(N-j)}{N} \rho_{xx}(j)\rho_{yy}(j)$$

Where N is the number of time-series values and are the autocorrelations of X and Y at lag j. Following Garrett and Petrie (Garrett and Petrie, 1981), we took the autocorrelation at lag j of the cross-products of standardized time-series of X and Y. The probability associated with a correlation coefficient using the corrected degrees of freedom is designated p*.

Salmon survival was found to be negatively correlated with SST. The correlations were weak during the early segments of the post-smolt year (Figure 1 below) at generally r=-0.3 during the first months at sea. Correlations became more negative during later summer into fall with the highest magnitude correlation fields being observed during November, over much of the area near r=0.7. The corrected correlation probabilities suggest that the only meaningful correlations are those from fall October through December. This pattern is very similar to the SST correlates observed for European Atlantic salmon (Friedland *et al.*, 2009a), which for the European stock complex was interpreted as a change in the physical environment that shifted ecosystem conditions and impacted salmon post-smolt growth and thus changed their vulnerability to predation via size related mortality factors. This may be, in part or wholly, extended to Baltic salmon, which would not be incompatible to the observed relationship to herring and seals.

To summarize

- There are some fundamental problems in how some variable are being used, including the per capita transform approach to herring recruits and the deviations approach to marine survival. This has led to a set of contradictory and confusing results being used to support the basis of variable inclusion in the forecast models.
- Herring SSB, though criticized by the herring assessment experts as an indicator of age 0 herring, may be a better indicator of herring 0 group abundance than the back calculated number based on age 1 recruitment. It is puzzling that herring SSB has declined while recruitment based on the numbers of older ages fish has not (see Figure 2a from Mäntyniemi *et al.*). For the salmon assessment to use herring recruitment they have to grab the most recent assessment for the age 1 estimate; this is the most poorly estimated value in the assessment, which in turn is being used as the basis of the salmon assessment. At this stage and with my understanding from the review document, I am more comfortable with the use of the SSB variable.
- The seal variable is valid but is a concern for the reasons mentioned above.

- A time-series of post-smolt growth would be a helpful piece of information. If survival correlated with post-smolt growth then certain mechanisms and variables would have a firmer basis for inclusion in the model.
- The attached SST analysis could be of use by the WG in that it provides a physical forcing variable that suggests a shift in ecosystem conditions and provides an explanatory variable that would be easily accessible to the WG for year ahead forecasting. Unlike the herring recruitment estimate, its error would be unchanged over time.

  WG response. Many relevant comments regarding the way the association between post-smolt survival and potential explanatory variables has been analysed in the IBP are presented in the review. Within the IBP, there was no time to use the results of analyses to update the assessment model. Instead, the aim was to look at potential explanatory variables that could be used in future modelling to improve estimates of post-smolt survival and thereby also the stock projections. The comments included in the review will be very valuable in the continuation of this work. Especially the results provided in the review which indicate that sea surface temperature (SST) seems to be correlated with variation in post-smolt survival are interesting, because this opens up the possibility to include SST in the assessment model to improve salmon abundance estimates. As pointed out in the review, one advantage with SST is that the error is assumed to be unchanged over time while the uncertainty for e.g. herring recruitment estimates is higher for the very recent years. The WG is planning to bring up this issue for discussion at their next meeting in April 2013.

Section 5. The effect of climate variability on maturation rate in Baltic salmon

Background. What is annual spawning run strength; it is not clear what this quantity is? Is it a measure of how much more or less the spawning run was in respect to the model estimates? So is it saying that over time, as winter temperature have warmed, more fish are returning than the model would predict, and you are attributing it to maturation rate?

WG response. Annual spawning run strength is a measure of the number of salmon that return to rivers to reproduce. Spawner counts (by fish counters in fishladders and by DIDSON echosounders in natural river channels) are combined into one aggregate measure of the run strength. This measure is compared to model predictions of how many salmon are expected to return to different rivers. In the background section, we are summarizing some previous analyses of spawner counts in rivers indicating that following a warm winter, a larger number of salmon return to the rivers and vice versa, indicating that winter temperatures affect the maturation rate and/or sea survival of the salmon. This association with winter temperatures is, however, not evident when using model predictions instead of spawner counts, which is believed to be due to the fact that the model is not fed with temperature data. After some reformulations of the text, we hope that this section now reads better.

Analyses of the association between climate and spawning run size. Is the run index the same as annual spawning run strength, not sure what this index means? The idea of winter conditions affecting maturation can be found in growth analyses for salmon in North America (Friedland and Haas, 1996; Friedland *et al.*, 2009b). What is not clear is that for both 1SW and 2SW fish, increasing temperature has resulted in increased proportion of fish for the respective age group, why aren't these rates reciprocal?

WG response. The run index is the same as the spawning run strength (based on spawner counts). We have reformulated parts of this section so that the term "spawning run strength" *is used throughout the section. Regarding analyses of the relationship between winter temperature and proportion of 1SW and 2SW salmon that return to spawn, we have included all salmon when calculating proportion of 1SW, but only MSW salmon, i.e. excluded the 1SW salmon, when calculating proportion of 2SW salmon. This explains the fact that both proportion of 1SW and 2SW salmon increases following a warm winter/spring and vice versa. Further, one must keep in mind that 3SW and even 4SW salmon are common in the Baltic Sea, so, salmon do not have only the two youngest sea ages as alternatives to mature, but instead many salmon postpone maturation to older ages.*

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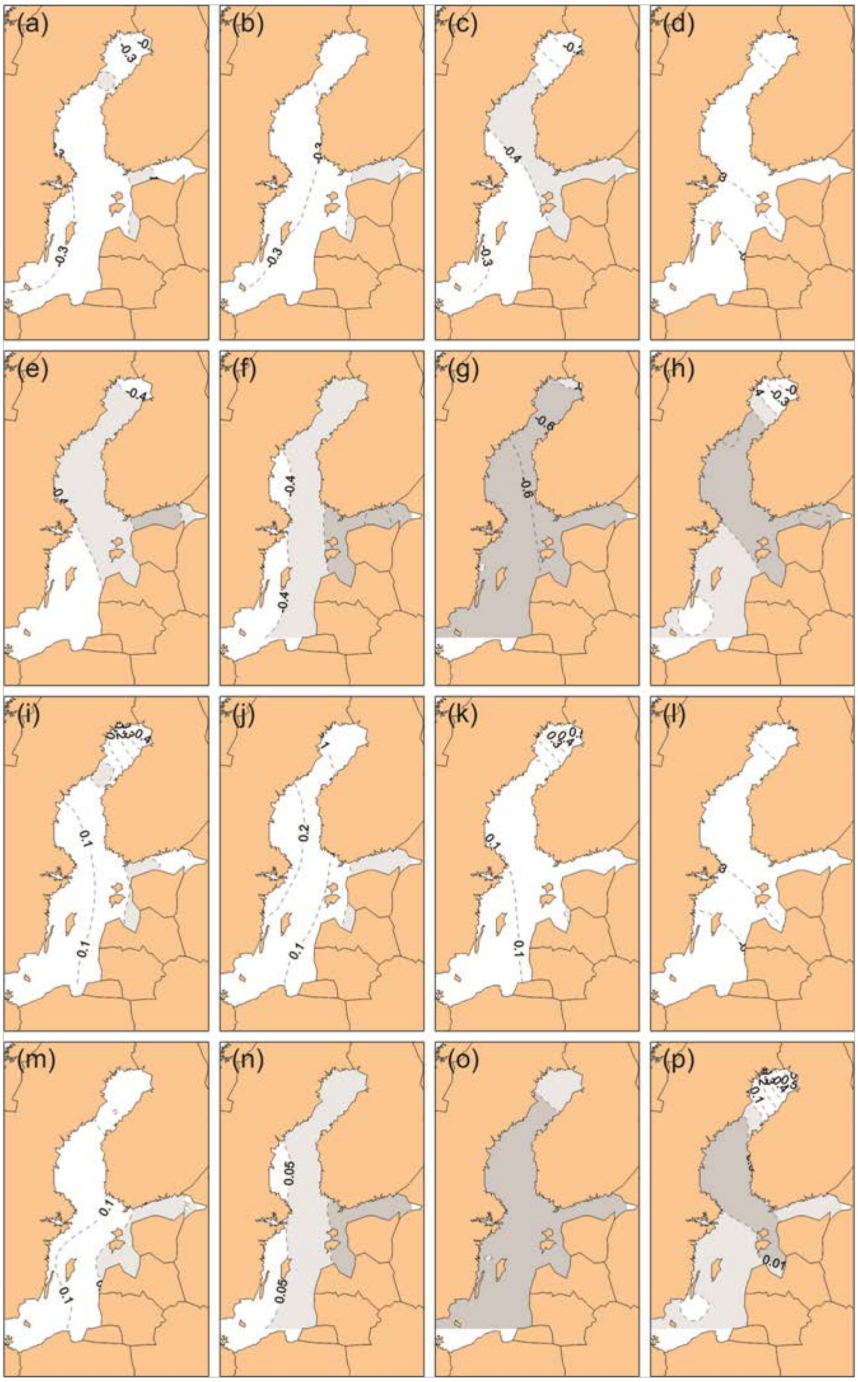

Figure 1. Pearson product-moment correlation between Baltic salmon survival and May through December SST (panels a–h, respectively). For these panels light grey denotes correlation significant at p=0.05, dark grey at p=0.01, for correlations not corrected for time-series autocorrelation. Time-series autocorrelation corrected probabilities for correlation between Baltic salmon survival and May through December SST (panels i–p, respectively). For these panels light grey denotes p=0.05, dark grey p=0.01.

Annex 5: Stock Annex for salmon in SD 22–32

Stock	Salmon in SD 22–31 (Main Basin and Gulf of Bothnia) and SD 32 (Gulf of Finland)
Working Group	WGBAST Baltic Salmon and Trout Assessment Working Group
Date	31 January 2013
Revised by	WGBAST during the IBPSalmon

A. General

A.1. Stock definition

The Baltic salmon is characterized by a marked population genetic structure. Previous studies indicate clear genetic differences both between salmon from different rivers located within restricted geographical areas and between groups of rivers on a larger geographical scale. According to the results of Säisä *et al*. (2005), there are three main groups of salmon populations in the Baltic Sea: 1) Gulf of Bothnia populations, 2) populations in southern Sweden, and 3) eastern populations (Gulf of Finland and eastern Main Basin). These groups or lineages are assumed to mirror three distinct post-glacial colonization events. About 5% of the total genetic diversity of the Baltic salmon is explained by differences between rivers within groups, whereas 6% is explained by differences between the lineages (Säisä *et al.*, 2005).

Because of the pronounced population genetic structure, the Baltic salmon could not be regarded as one single assessment or management unit. Instead, the assessment is focused on restricted assessment units and rivers, and management objectives are evaluated both on an assessment unit level and on a river-by-river basis. Throughout this document, we are using the term "river stock" for salmon that belongs to a particular river. In most cases, river stocks most likely correspond to biological populations which lend support for this level of division from a conservation genetic perspective. However, it should be noted that some larger rivers may harbour several salmon subpopulations that are genetically separated spatially and/or temporally. There may also be cases where several smaller, closely situated rivers together constitute one single biological population because of significant gene flow.

A.1.1. Definition of assessment units within the Baltic Sea area

Within the Baltic Sea area, currently six different assessment units (AUs) have been established (Figure A.1.1.1). The grouping of rivers within an assessment unit is based on management objectives and biological and genetic characteristics of the river stocks contained in a unit. The partition of rivers into assessment units needs to make sense from a management perspective. River stocks of a particular unit are believed to exhibit similar migration patterns at sea. It can therefore be assumed that they are subjected to the same sea fisheries, experience the same exploitation rates and are affected by management of sea fisheries in the same way. In addition, the genetic variability between river stocks of an assessment unit is smaller than the genetic variability between river stocks of different units (see above). Although the rivers of assessment units 5 and 6 are relatively small in terms of their production capacity in comparison to rivers of the other assessment units, they are very important from a conservation perspective because of their unique genetic background.

The six assessment units in the Baltic Sea consist of:

1) Northeastern Bothnian Bay river stocks, starting at Perhonjoki up till the river Råneälven.
2) Western Bothnian Bay river stocks, starting at Lögdeälven up to Luleälven.
3) Bothnian Sea river stocks, from Dalälven up to Gideälven and from Paimionjoki up till Kyrönjoki.
4) Western Main Basin river stocks.
5) Eastern Main Basin river stocks, i.e. rivers in Estonia, Latvia and Lithuania.
6) Gulf of Finland river stocks.

Wild river stocks belonging to each assessment unit are listed in the next section.

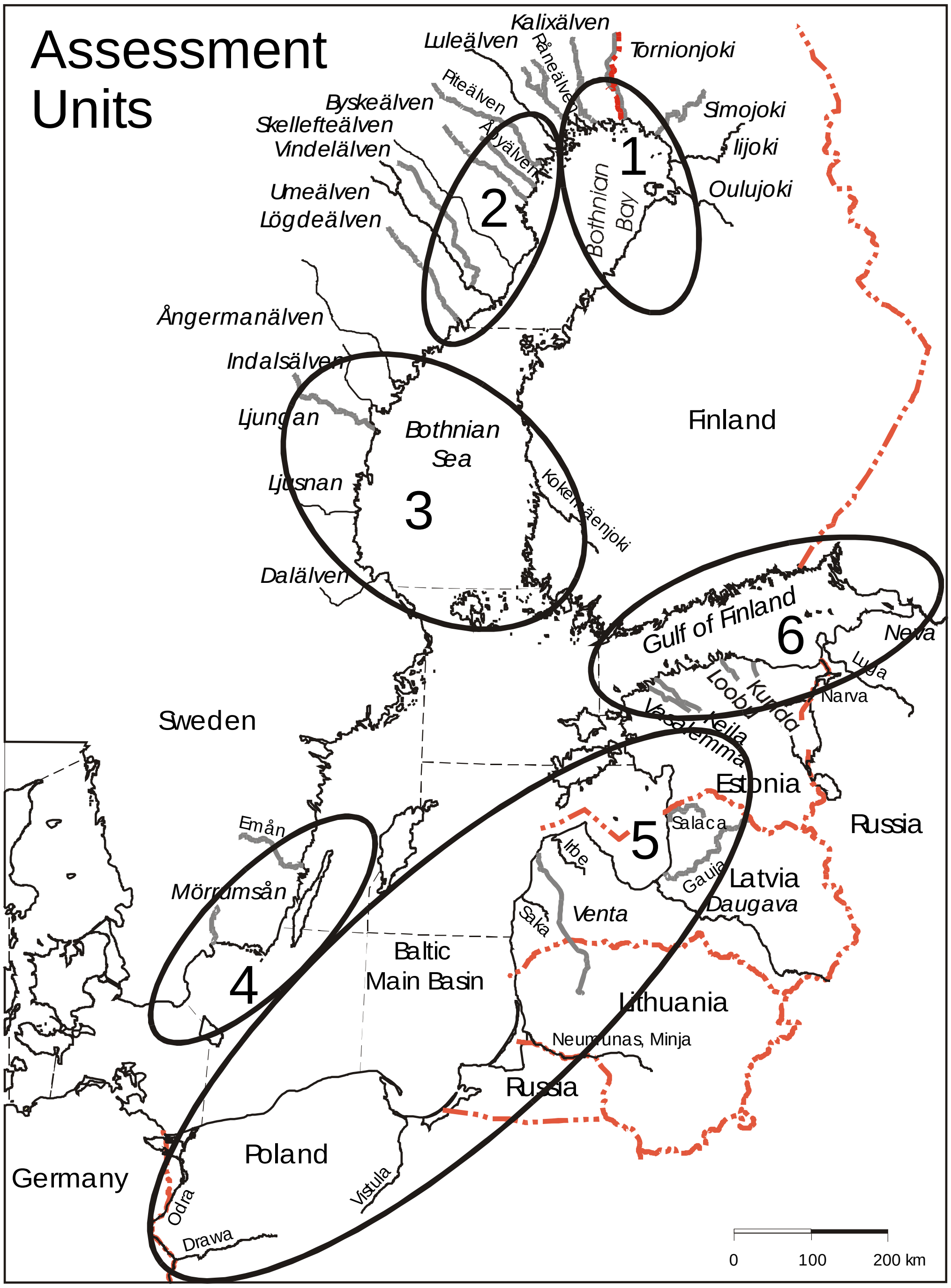

Figure A.1.1.1. Grouping of salmon river stocks in six assessment units in the Baltic Sea. The genetic variability between river stocks of an assessment unit is smaller than the genetic variability between river stocks of different units. In addition, the river stocks of a particular unit exhibit similar migration patterns. Note that not all rivers are indicated in the map.

A.1.2. Division of rivers into wild, mixed, reared and potential

The Baltic salmon rivers may be divided into four main categories: those holding either wild, mixed or reared river stocks and those owing potential to hold (but which currently do not hold) a wild or mixed river stock. This categorization scheme (see Table A.1.2.1) is used when discussing data from particular rivers, and it has been defined and discussed in earlier reports from ICES (e.g. ICES 2008b). The same scheme has also been used for determining which wild rivers should be included in the yearly assessments of stock status performed by the working group.

Briefly, wild salmon rivers (i.e. rivers holding wild river stocks) should be self-sustainable with no or very limited releases of reared fish; mixed rivers have some wild production but are subject to considerable stocking and it is often unclear if they could become self-sustainable (however, in some larger river systems regarded as mixed, individual tributaries like Zeimena in Nemunas river basin have self-sustainable wild populations); reared rivers currently have no possibility of holding self-sustaining river stocks and thus are entirely dependent on stocking; river stocks in potential rivers are currently not regarded as self-sustainable but are believed to have a fair chance of becoming so in future (Table A.1.2.1). It should be noted that during the re-establishment process, a potential river may first become a mixed river before it finally fulfils the criteria for becoming a wild river. In the total Baltic Sea (AU 1–6), there are currently 56 salmon rivers out of which 26, 12 and 18 are considered as wild, mixed and reared, respectively. In addition to these, a relatively large number of potential rivers (several with ongoing reintroduction programmes or occasional reproduction) exist.

Table A.1.2.1. Classification criteria for wild, mixed, reared and potential salmon rivers in the Baltic Sea.

Category of salmon river	Management plan for salmon stock in the river	Releases	Criteria for wild smolt production
Wild	Self-sustaining	No continuous releases	>90% of total smolt prod.
Mixed	Not self-sustaining at these production levels	Releases occur	10–90% of total smolt prod.
Reared	Not self-sustaining	Releases occur	<10% of total smolt prod.
Potential leading to category wild	Lead to self-sustaining river stock	Releases occur during re-establishment	Long-term >90% wild smolt prod.
Potential leading to category mixed	Not self-sustaining river stock	Releases occur	Long-term 10–90% of total smolt prod.

Wild and mixed salmon rivers in the Baltic Sea

Current wild salmon rivers in the Baltic Sea are listed below per country and assessment unit (AU). Several of the rivers were also listed in the former IBSFC Salmon Action Plan.

- Finland: Simojoki (AU 1)
- Finland/Sweden: Tornionjoki/Torneälven (AU 1)
- Sweden: Kalixälven (AU 1), Råneälven (AU 1), Piteälven (AU 2), Åbyälven (AU 2), Byskeälven (AU 2), Rickleån (AU 2), Sävarån (AU 2), Ume/Vindelälven (AU 2), Öreälven (AU 2), Lögdeälven (AU 2), Ljungan (AU 3), Emån (AU 4), Mörrumsån (AU 4)
- Estonia: Kunda (AU 6), Keila (AU 6),Vasalemma (AU 6), Pärnu (AU 5)
- Latvia: Salaca (AU 5), Vitrupe (AU 5), Peterupe (AU 5), Irbe (AU 5), Uzava(AU 5), Saka (AU 5)
- Latvia/Lithuania: Barta/Bartuva (AU 5)

Current mixed salmon rivers in the Baltic Sea are listed below per country and assessment unit (AU). Some of these may in future become wild rivers.

- Latvia: Gauja (AU 5), Daugava (AU 5), Venta (AU 5)
- Lithuania: Nemunas river basin (AU 5)
- Estonia: Purtse (AU 6), Selja (AU 6), Loobu (AU 6), Valgejõgi (AU 6), Jägala (AU 6), Pirita (AU 6), Vääna (AU 6)
- Russia: Luga (AU 6)
- Finland: Kymijoki (AU 6)

More information about wild, mixed and reared rivers could be found in Tables C.1.2.1, C.2.1 and C.3.1.

Potential rivers

Several countries have officially appointed potential salmon rivers as suggested in the former IBSFC Salmon Action Plan. Mostly, these rivers are old salmon rivers that have lost their salmon population. Restoration in potential salmon rivers was started in some countries in different ways and with varying efforts. The goal of the restoration is to re-establish natural reproduction of salmon.

Apparent increase in wild reproduction has been documented in at least one or two of the rivers in Gulf of Bothnia, but most of the potential rivers show only low and irregular wild reproduction despite even massive stocking programmes and other rebuilding efforts. Several problems in various phases of salmon's life cycle may adversely affect restoration measures, but their relative importance is difficult to assess. A more thorough analysis, e.g. comparing more and less successful cases of restoration is needed. The rivers Kågeälven and Testeboån show increasing densities of parr, indicating that self-sustainable river stocks may have been established in these rivers and both are under consideration by the working group to be included into the categorization of wild salmon rivers. More detailed information on the development and most updated status of salmon stocks in potential rivers could be found in the WGBAST report.

A.2. Fishery

A description of gears used in different fisheries, including extensive descriptions of gears in Sweden, Finland, Estonia, Latvia, Poland and Denmark, as well as historical gear development in the Baltic salmon fisheries, can be found in ICES 2003.

In the commercial offshore fishery, only longlines are used today for directed fishery on salmon. Driftnets, which were previously the most common gear in the Baltic fishery for salmon, was banned in the Baltic area 1 January 2008 according to Regulation (EC) 812/2004. From 1 January 2013, Sweden and Finland will phase out their longline fishery in the Main Basin. In the commercial coastal fishery, trapnets dominate today but also anchored floating gillnets are used to some extent (in Sweden anchored floating gillnets will be prohibited from 1 January 2013). The main fishing season for longlines is January and February, but some fishing takes place also during November, December, March and April. The main fishing season for the coastal fishery is June and July.

With continued problems from seals predating on salmon captured in fishing gears, the use of trapnets that protect the salmon from seal predation has increased. In Gulf of Bothnia and Gulf of Finland, trapnet fisheries have been developed using new netting material that the seal cannot bite through. Also fixed fences at the entrance of the traps, preventing the seal from entering the traps, has been developed. In Sweden a new type of trap has been developed in recent years, the so called 'push-up trap', with fixed walls that protect the catch from seals. An inventory of the number of both traditional and seal-safe traps was carried out in 2007. It showed that the total number of seal-safe traps in Gulf of Bothnia decreased from 703 in 2003 to 666 in 2007, being 35% of all trapnets. In Finland the government has been giving support to coastal fishermen to change from traditional traps to seal-safe traps, which currently constitute almost all traps.

Recreational fishing targeting salmon takes place in offshore, coastal and river areas. Landings from recreational fishing are not included in the TAC (see below) and no obligation to report catches exist. Catches are therefore estimated annually country by country through different surveys. Recreational fishing in offshore areas is practised by trolling, mainly located to the Main Basin. Studies to estimate catches outside Sweden has been performed in 2003, 2007 and 2011, and those are indicating an increase in both effort and total catch. In 2011, landings of salmon in Swedish trolling were estimated to be 21% of that in the Swedish longline fishery.

Recreational fishing along coastal areas mainly occurs in SD 30 and 31 by use of traditional trapnets. Inventories of non-commercial traps along the Swedish coast show continuous decrease in numbers from 264 to 102 between 1999 and 2011. Proportion of non-commercial traps in comparison to total numbers of traps in Sweden has decreased from 34% to 17% between 1999 and 2011.

Recreational river fisheries take place in wild, mixed and reared rivers, where angling by use of rod and line dominates. Traditional gears like seinenets, gillnets and trapnets are still used in some rivers. Due to stocking objectives, broodstock fishery occurs in some reared rivers. In these reared rivers broodstock fishery usually makes up a substantial part of the total catch.

International regulatory measures

The salmon fishery is regulated by both international and national management measures. International management measures adopted by IBSFC have regulated the salmon fishery in the convention area of IBSFC until the end of 2005. However, since the IBSFC was superseded by bilateral cooperation between the European Community and the Russian Federation new technical measures are developed for the Baltic salmon fishing by EU. These do not always follow strictly the recommendations made by the IBSFC but their purpose is rather to contribute to a comprehensive and consistent system of technical measures for Community waters, based on existing rules. Council Regulation (EC) No 2187/2005 laid down certain measures for the conservation of fishery resources in the waters of the Baltic Sea, the Belts and the Sound. Regulatory measures to be used in the Russian federation waters are not available.

<u>TAC</u>. IBSFC implemented a TAC system for Baltic salmon fishery management for the first time in 1993. There are two separate management areas; one consists of the Baltic Main Basin and Gulf of Bothnia (Subdivisions 22–31) and the second of Gulf of Finland (Subdivision 32). TACs have not been agreed between EC and Russian federation. The salmon TAC agreed for Main Basin and Gulf of Bothnia, and Gulf of Finland is divided between EC countries as indicated in Table A.2.1 (Council regulation (EC) 2010/0247 (NLE)). Catch quotas have not been regulating the fishing pressure before year 2012, because quotas have not been fulfilled. In early and mid-1990s, however, the quotas apparently decreased offshore fishing. This decrease together

with strict national regulations set for the Gulf of Bothnian coastal fisheries was the impetus to the recovery of the northern Baltic salmon stocks (Romakkaniemi *et al*., 2003). The substantial decrease in the TAC for 2012 and consequent actions taken in the national regulations restricted salmon fishing in some countries in Subdivisions 22–31 in year 2012.

Table A.2.1. Allocation of TAC between EC countries.

COUNTRY	ALLOCATION KEY (%)
Management area: Main Basin and Gulf of Bothnia (Subdivisions 22–31):	
Estonia	2.0660
Denmark	20.3287
Finland	25.3485
Germany	2.2617
Latvia	12.9300
Lithuania	1.5200
Poland	6.1670
Sweden	27.4783
Russian Federation	1.9000
Total	100
Management area: Gulf of Finland (Subdivision 32):	
Estonia	9.3000
Finland	81.4000
Russian Federation*	9.3000
Total	100

***) No agreed TAC.**

Minimum landing size. Minimum landing size of salmon is 60 cm in Subdivisions 22–30 and 32, and 50 cm in Subdivision 31. Minimum landing size is restrictive and important in the offshore fishery, but a size limit is of little or no importance in river and coastal fishery as long as smolts are protected from being captured in rivers. On the contrary, in river and coastal fisheries, this measure may decrease exploitation of the least valuable parts of the stock.

Summer closure. In EC Community waters there are no longer gear based summer closures. They have been replaced by restrictions on fishing for salmon and sea trout (Article 17 of the Council Regulation (EC) No 2187/2005) and they are as follows;

- The retention on board of salmon (*Salmo salar*) or sea trout (*Salmo trutta*) shall be prohibited;
  - From 1 June to 15 September in waters of Subdivisions 22 to 31;
  - From 15 June to 30 September in waters of Subdivision 32.
- The area of prohibition during the closed season shall be beyond four nautical miles measured from the baselines.
- By way of derogation from paragraph 1, the retention on board of salmon (*Salmo salar*) or sea trout (*Salmo trutta*) caught with trapnets shall be permitted.

Driftnet ban. According to Council regulation (EC) No. 812/2004 of 26.4.2004 the use of driftnets in the fishery was banned from 1 January 2008. As a consequence, the harvest rate of feeding salmon decreased to about one third from 2007 to 2008. Since then the longline fishing has increased so that the harvest rate in offshore fishing in 2011 was probably as high as the combined harvest rate for driftnets and longlines in 2005. The share of discarded minimum size salmon is most likely higher in the present offshore longline fishery than in the past driftnet focused fishery.

The salmon fishery is also to a large extent regulated through national management measures. National regulatory measures and annual updates of these are described in detail in the WGBAST report. Also other factors influencing the salmon fishery, such as dioxin regulations, fishery economics and changes in natural mortality are described in the WGBAST report.

A.3. Ecosystem aspects

The salmon (*Salmo salar*) reproduce in rivers across the whole Baltic Sea, but the most productive rivers are found in the northern parts (Gulf of Bothnia). Juvenile salmon stay in freshwater for one to four years and then spend from one to several years at sea on a feeding migration before they return to spawn in the natal river. Salmon from different rivers (populations) are mixed in the southern Baltic during the feeding migration, but they become gradually segregated on their migration routes back to the home rivers. The Baltic salmon feed mainly on herring and sprat during the sea migration.

Environmental conditions in both the freshwater and marine ecosystem have a marked effect on the status of salmon stocks. In many rivers, hydropower exploitation has eradicated the wild salmon populations, and the production in many of these rivers is today maintained solely by breeding and releasing hatchery reared salmon. In many rivers in the southern Baltic, a range of problems in the freshwater environment may largely explain the current poor status of wild stocks. In many cases river damming and habitat deterioration have had devastating effects on freshwater environmental conditions.

The survival of Baltic salmon during the first year at sea (post-smolt stage) has decreased from around 30% in the mid-1990s to around 10% in recent years. The reasons for the decline in post-smolt survival are still unclear, but the post-smolt survival has been found to be negatively correlated with seal and smolt abundance, and positively correlated with herring recruitment in the Gulf of Bothnia (Mäntyniemi *et al*., 2012). The decline in survival seems also to be associated with changes in climatic conditions (ICES 2012b; cf Friedland *et al*., 2009).

The thiamine deficiency syndrome M74 is a reproductive disorder which causes mortality among yolk-sac fry of Baltic salmon. M74 related mortality among salmon fry was extremely high at the beginning of the 1990s (around 80%), but has thereafter declined to lower levels (5–15%) in recent years. The development of M74 is believed to be coupled to a diet which is characterized by an unbalanced composition between fatty acids (energy) and thiamine (Keinänen *et al*., 2012). Especially young sprat, which is a common prey for Baltic salmon, seems to provide low concentrations of thiamine in relation to the supply of unsaturated fatty acids (Keinänen *et al*., 2012).

Studies on Baltic salmon have found a correlation between spawning run size and spring sea surface temperatures in the Main Basin; following a cold winter and late spring, the salmon tend to arrive in smaller numbers and vice versa, a phenomena believed to be due to climate induced variation in maturation rate rather than climate effects on mortality (e.g. ICES 2012b). Cold winters have also been shown to delay the timing of the spawning run in the subsequent summer. Thus, climate variation has a rather strong impact on the population dynamics of the Baltic salmon.

The current salmon fishery in the Baltic Sea probably has no or minor influence on the marine ecosystem. However, the exploitation rate on salmon may affect the riverine ecosystem through changes in species compositions. There is limited knowledge of these effects and their magnitude.

Because the Baltic salmon is affected by both commercial and recreational fishing, as well as the marine ecosystem state, the Helsinki Commission (Helcom) has pointed out Baltic salmon as a candidate core indicator reflecting the status of the marine environment (Helcom 2012a,b). Suggested parameters of this core indicator include smolt production in rivers, post-smolt survival and trend in number of rivers with self-reproducing salmon populations.

B. Data

The main sources of information currently used for the assessment of the wild salmon stocks can be categorized into three groups according to the place where the actual data collection is carried out:

River surveys: parr density estimates, smolt trapping, monitoring of spawning runs and river catches;

Sea surveys: catch data, fishing effort data and catch composition estimates;

Joint river and sea surveys: tagging data (tagging in rivers, recaptures from sea and river fishery).

Section C gives an overview of all the riverine and tagging data collected and used for assessment on regular basis for the different river stocks within the Baltic Sea area.

B.1. Commercial and non-commercial catch

Description of basic collection of catch data

Countries participating in the Baltic salmon fishery are asked to deliver catch data of salmon and sea trout. Catches are given by economic zone, ICES subdivision, as well as type of fishery separated by offshore, coastal and river. Catches are further classified as commercial, recreational, discard, and seal damage. Catch per unit of effort is given as weight and number of caught individuals in different gears (longline, trapnet, non-commercial catches or other). Effort is given in terms of number of fishing days each gear was deployed.

Logbooks provide only preliminary information taken on board the vessels, where real count and weight estimates are normally difficult to obtain. The catch statistics in different countries are obtained by combination of data included in logbooks, landing declarations, first sales notes and fisheries companies catch reports. From 2005 EU type logbooks were implemented in the new member states Latvia, Estonia, Poland and Lithuania.

The catch statistics provided for WGBAST are mainly based on logbooks and/or sales notes (Table B.1.1). Non-commercial catches are mainly estimated by questionnaires or special issues. Area specific non-commercial catch estimates are, however, rather uncertain. In particular, estimates of catches and fishing efforts in (each) river are needed in order to better model the potential trends/changes in river fishing. In total, logbook information on catches represented approximately 67% of the total salmon catch (Table B.1.1). Extrapolated and estimated catch (partly based on solid information) provides approximately 32% of the total salmon catch.

Table B.1.1. Catch statistics provided for WGBAST.

Fishery type	Logbook [1)]	Extrapolated	Estimated	Guestimated	Total	%
Commercial	112 053	18 064	3116	1845	135 078	78.32
Discard	142				142	0.08
Non-commercial			34 560		34 560	20.04
Seal Damage	2696				2696	1.56
Total	114 891	18 064	37 676		172 476	100.0
%	66.61	10.47	21.85	1.07	100.0	

[1)] **Includes all fisheries documentation, sales notes, logbooks, and landing declarations.**

Catch tables presented in the annual WGBAST report are constructed by extracts from the resulting WGBAST salmon catch database. Because of a delay in the delivery of data from some countries, part of the catch information is preliminary. These data are corrected the following year. Effort data are calculated separately for stocks of assessment units 1–3. Basic data for these calculations are found in the catch database, but needs to be divided into assessment units before calculations are made.

Collection of catch statistics by country

Denmark: The catch statistics are based on official landing reports and logbooks, combined with additional information from logbooks (e.g. type of gear for all catches and from 2007 effort for 100% of the catches), and are collected in a database at DTU Aqua. From this total catches and effort is estimated. As no Danish salmon rivers discharge into the Baltic Sea, sports fishing for salmon is only possible by offshore trolling. The estimates of recreational catches are calculated by information from competitions, sports fishermen, and from boat rental companies.

Estonia: The catch statistics are based on logbooks from the offshore and coastal fisheries. Data on river catches are from broodstock fishery and anglers questionnaires.

Finland: Catch statistics in the commercial fishery has been collected in logbooks from the offshore and coastal fishery. Estimates of recreational salmon catches in sea are based on the results of the Finnish Recreational Fishing 2010 survey. Recreational river catches are estimated by annual surveys and by interviews and voluntary riverside catch statistics. To obtain more accurate estimates on catches in rivers Tornionjoki and Simojoki, extensive inquiries are conducted every year among fishermen who have bought a fishing licence.

Latvia: The Latvian salmon catch and landing statistics are based on the logbooks and landing declarations from the offshore and logbooks from coastal and inland fisheries. Catch data from a small-scale recreational fishing in the River Salaca and River Venta is based on questionnaires. These data are not included in catch statistics.

Lithuania: Catch statistics are based on logbook data. All data storing and processing are provided by the Fisheries Department of Ministry of Agriculture.

Poland: Commercial offshore and coastal catch statistics are based on logbooks of vessels over 8 m and on monthly reports of vessels smaller than 8 m. All raw data are sent through Regional Fisheries Inspectorates for input to the database, which is run by the VMS centre of the Ministry of Agriculture and Rural Development. Estimated catch data from rivers is obtained from Polish Anglers Union and cooperatives having rights to fish salmon in rivers.

Russia: The catch statistics are based on landing reports, logbooks and direct observation from the offshore and coastal commercial fisheries and broodstock fisheries in the rivers. Catches could be grossly underestimated.

Sweden: Swedish commercial catch data are mainly reported by logbooks from offshore fisheries and journals from coastal and river fisheries. Catches at sea are collected and stored by the Swedish Agency for Marine and Water Management while river catches are collected by responsible counties.

Recreational fishery takes place in offshore areas by trolling, in coastal areas by trapnets and in rivers by rod angling as well as use of nets, seine nets and other gears. As no obligations to report recreational catch exist, total recreational catch derives from estimates from different surveys.

Estimates of total trolling catch in offshore areas are based on surveys carried out in the Main Basin (SD 25–29) about every fourth year. Total nominal catch in the recreational trapnet fishery is estimated by comparing number of recreational gears to catches in the commercial trapnet fishery. An inventory of recreational trapnets distributed along the Swedish coast (SD 29–31) is carried out every fourth year. River catches are yearly collected from all Swedish salmon rivers through catch reports and questionnaires. Data quality highly depends on local interest, size of the river and on how the river fishery is organized.

Discards and unreporting

In general, data on discards, misreporting and unreporting of salmon from different fisheries in the Baltic Sea are incomplete and fragmentary. Main reasons for discard of salmon in the Baltic fisheries are seal damages on adults and bycatch of undersized young salmon. Salmon discard due to seal damages occurs predominantly in the northern part of Baltic Sea, in the main distribution area of the grey seal; Gulf of Riga, Gulf of Finland and Gulf of Bothnia. Bycatch of young salmon occurs in the whole Baltic Sea and in different types of fisheries, but probably mainly within pelagic sprat and herring trawling where it is likely to often remain unnoticed (e.g. ICES 2011) and in longline salmon fisheries, in terms of mortality among undersized individuals that are released back into the sea.

To account for presence of unreported discarded catches, a conversion factor based on experts' opinions of these catches has been developed (ICES 2003; ICES 2004b). These opinions are based on the reported knowledge presented in this stock annex and in the WGBAST report, and other background information available for each country. Expert opinions were updated in 2012 (ICES 2012b). The conversion factors are applied to obtain probabilistic estimates for the total number of salmon caught, including discarded catches. According to expert judgements the magnitude of discards has been 1.5% to 15% and reporting rate of catches 70% to 100% in the different fisheries in the last ten years. Conversion factors for catch, effort and discards are presented in the WGBAST report.

The magnitude of the present discard and unreported salmon catch is presumed to vary between regions and to generally account for 25–50% of the total commercial salmon catch in numbers. Some of these conversion factors may be too low, especially considering the high potential for bycatch of small salmon in the large-scale pelagic trawling fishery (ICES 2011). So far, however, too little is known regarding the magnitude of that discard to motivate changes in the corresponding adjustment factors.

Unreporting of salmon catches is also expected to occur in many types of fisheries. One type of unreporting is associated with traditional small-scale commercial fisheries, where it may occur as self-consumption, traditional direct selling from the boat, unreported discards of dead fish, etc. Unreporting may also occur in offshore fisheries for salmon or other species, including bycatch of larger salmon in large-scale trawling fisheries.

Misreporting of salmon catches to varying extent probably occurs in all types of fisheries, fishery zones and countries. Typically salmon may be reported as sea trout, rainbow trout or even marine rainbow trout. Different reasons for misreporting salmon can be identified, including mistakes due, e.g. to difficulties to separate species, and deliberate actions aimed at obtaining a higher market price or to avoid fishery regulations (e.g. minimum landing size or TAC). Misreporting is included in the conversion factor for unreporting of catches. However, assumed misreporting in the Polish offshore salmon fishery is handled separately (see below), and estimates of the additional Polish salmon catch are included on top of the catch estimates generated by the general conversion factor for the offshore fishery.

In recent years' assessment, WGBAST has estimated Polish offshore salmon catches based on Polish reported effort and catch per unit of effort (cpue) of other countries fishing in the same part of the Baltic Sea. The reason behind the use of this estimation procedure is that reported Polish data on effort and catches of salmon and sea trout have deviated markedly from corresponding data delivered by other countries fishing with the same gears in the southern Main Basin, indicating that salmon have been misreported as sea trout in the Polish offshore fishery. To be able to fit the assessment model to fairly realistic offshore catches of salmon, the working group has agreed on an estimation procedure which is based on Polish reported (trout) offshore effort times cpue of salmon among Swedish, Finnish and Danish fishermen times a correction factor of 0.75. By applying a correction factor of 0.75, the estimated Polish catch of salmon becomes close to the total number of salmon and trout reported by Poland for most years in the time-series. This was considered realistic as offshore catches of other countries are strongly dominated by salmon and the proportion of sea trout usually falls well below 5%. This correction procedure has been applied for the fishing years 1992 to 2011 and updates the Polish salmon catches substantially; misreported catch has accounted for about 10% to 50% of the total salmon catch in the Main Basin. The misreporting is expected to decrease from 2012 because of the EFCA JDP campaigns that have included salmon fishing from autumn 2012.

More information on discards and unreporting on a country-by-country basis is presented in the WGBAST report.

B.2. Biological

Since 2004–2005, all EU Baltic sea countries follow the EU data collection framework (DCF) which includes collection of fishery associated data such as salmon age, length and weight composition in catches. Sampling of salmon catches under the DCF has been dealt with in the WGBAST 2005 report (ICES 2005). The rationale of salmon sampling was described there and also in the various national programmes under the DCF. The national data collection programmes mostly include different fisheries regions (offshore, coastal, river), different fisheries (commercial, angling, broodstock), different origin (wild, reared) of fish. Only Russia provides data collection according to a state research programme.

The number of sampled and analysed fish varies between countries; mostly the national sampling programmes exceed the precision requirements of EC 1639/2001. Annually at least 3–4 thousand salmon are sampled from different fisheries. Available data on age, length and weight composition of salmon catches are presented in Table B.2.1.

Table B.2.1. Data on age, length and weight composition of salmon catches. Data available from the year indicated and onwards.

COUNTRY	FISHERIES	PARAMETERS			
		Length	Weight	Age	Sex
Denmark [1, 2]	Offshore	2002	1973	1973	-
Estonia	Coastal	2005	2005	2005	2005
Finland	Offshore [3]	1986	1986	1986	
	Coastal	1986	1986	1986	
	River	1974	1974	1974	1974
Latvia	Offshore [2]	1974	1974	1974	-
	Coastal	1978	1978	1978	1978
Lithuania	Coastal	1999	1999	1999	1999
Russia	River	Na	Na	Na	Na
Sweden [2]	Offshore [3]	2002	2002	2002	2006
	Coastal	1990	1990	1990	1990
	River	1991	1991	1991	1991
Poland	Offshore	2003	2003	2003	2003

1) no sampling in 2007.

2) no sampling in 2008.

3) no sampling from 2013 and onwards due to phasing out of the offshore fishery.

Also other data on salmon, besides fishery associated data, is collected within the DCF. This includes for example data collection in salmon index rivers. In 1999, in its 25th session, the former International Baltic Sea Fishery Commission (IBSFC) adopted a list of index rivers to be established as part of the IBSFC Salmon Action Plan. The status of wild salmon in these rivers would according to IBSFC be considered the basis for monitoring the status of wild salmon stocks. In total twelve index rivers were appointed, four in Gulf of Bothnia, five in the Main Basin and three in the Gulf of Finland. The monitoring in these rivers should consist of electrofishing, smolt trapping and counting of spawners (see Section B.3 for a description of these surveys). However, despite several attempts, in 2012 only four rivers (Simojoki, Tornionjoki, Vindelälven and Mörrumsån) with both smolt trapping and counting of spawners have so far been possible to establish.

The Working Group has repeatedly stressed the importance of establishment of index rivers in all parts (assessment units) of the Baltic as it is otherwise difficult to monitor the actual importance of the fishery for the future development of river stocks in these areas, estimate properly the at-sea survival, as well as create stock–recruit functions to be able to calculate the actual potential smolt production capacity of the rivers and estimate future development of the river stocks under different exploitation scenarios.

In the already established index rivers, electrofishing, smolt counting and counting of returning adults is carried out (see Section B.3 below). Part of these data is used in the assessment model (see Section C for more details), and the working group has the ambition to include additional data when it becomes available. Electrofishing data are also collected and used for assessment in all non-index rivers which are listed as wild. Table B.2.2 provides an outline of the data requirements by the Working Group and to what extent such data are provided by the DCF. It also gives an overview of whether these data are used or not.

The amount of information available from individual rivers differs significantly by river and assessment unit. Because of the discrepancies between the amounts of information available on wild salmon in different assessment units, the uncertainties in the assessment of stock status differ significantly between assessment units.

A detailed presentation, country by country, of the data collection during the last year can be found in the WGBAST report. Also updated schemes for data collection, and future needs of inclusion of additional data collection under the DCF, are presented in the annual WGBAST report.

Table B.2.2. Overview of the compatibility of data collected under the DCF with the data needed for stock assessment.

Type of data	Collected under DCF	Available to WG	Reviewed and evaluated by WG	Used in current assessment	Future plans	Notes
Fleet capacity	yes	yes	no	no	n	Incompatible with current assessment model
Fuel consumption	yes	no *)	no	no	n	Incompatible with current assessment model
Fishing effort	yes	yes	yes	yes	n	-
Landings	yes	yes	yes	yes	n	-
Discards	yes	yes	yes	yes	n	-
Recreational fisheries	yes	yes	yes	yes	n	-
CPUE data series	yes	yes	yes	yes	n	-
Age composition	yes	yes	yes	partly used	Increased use	Not incorporated in current assessment model, river samples used
Wild/reared origin (scale reading)	yes	yes	yes	partly used	Increased use	
Length & weight at age	yes	yes	yes	no	n	Not incorporated in current assessment model
Sex ratios	yes	yes	no	partly used	n	Not incorporated in current assessment model, river samples used
Maturity	yes***)	no ***)	no	no	n	
Economic data	yes	no *)	partly used	no	n	Incompatible with current assessment model
Data processing industry	yes	no *)	no	no	n	Incompatible with current assessment model
Electrofishing data	yes **)	yes	yes	yes	n	-
Smolt trapping data	yes **)	yes	yes	yes	n	-
Tagging data	no	yes	yes	yes	n	-
Fish ladder data	yes **)	yes	yes	yes****)	Increased use	-
Genetic data	yes **)	yes	yes	no	Will be used	Not incorporated in current assessment model

*) Not asked for by the working group.
**) Not mandatory under current DCR.
***) DCF requires collection but only a few of the countries are doing it.
****) Partial use.
n. No change.

B.3. Surveys

ICES salmon assessment is not based on sea surveys commonly used for other species. Instead, the assessment of salmon is based mainly on surveys in rivers (counting of spawners and smolts, and electrofishing surveys).

Monitoring of parr densities in rivers are carried out by standardized electrofishing surveys in all assessment units. Fish densities are estimated by using removal fishing. The electrofishing procedure is the same today as at the beginning of the time-series. The choice of electrofishing sites in almost all rivers was done at the beginning of the time-series (mostly during the 1980s) when densities of parr were extremely low. In order to have a reasonable possibility to detect salmon parr in those years, 'best' rapids and sites were often selected. When number of sites has increased to better cover whole river systems, the selection of sites has usually been made the same way as earlier. Because of this non-random selection of monitoring sites the calculated density estimates cannot be considered as fully representative and unbiased estimates of the average parr density in a river. Instead, the density estimates serve as relative abundance indices and the possibility that the relationship between density index and smolt production varies from river to river must be taken into account (see Section C.1.5).

Salmon spawning runs into rivers are usually monitored in fishladders. The control of fish migration is carried out by electronic counters (usually an infrared fish counter, "Riverwatcher", Vaki Aquaculture System Ltd, Iceland), in combination with cameras which makes detection of individual species possible. DIDSON (Dual frequency IDentification SONar, http://www.soundmetrics.com/) is used in two rivers to monitor spawning run in natural river channels. DIDSON uses sound to produce video images of underwater areas. Identification of species is basically based on the length of the detected individuals and this sets certain limits to successful use of DIDSON to monitor salmon runs. In all fishladders and in one of the two DIDSON monitoring sites, the resulting count represents only a proportion of the total number of spawners ascending the river. This is because either the monitoring site is located in the middle- or upstream part of the river, or some fish may be able to pass the migration obstacle without using the fishladder (partial obstacle), or fish may not find the fishladder. One must take this into account when utilizing the data in the assessment (see Section C.1.9).

Smolt production is monitored by partial smolt trapping and mark–recapture experiments in 1–2 rivers per assessment unit. The traps are either specially designed fykenets or so-called rotatory screw traps (EG Solutions, Oregon, USA). A smolt trap is set up in a river as early as possible in spring and trapping continues to the end of the smolt migration season. In some years, high and late spring floods prevent early enough start of the surveys and the results from such years are not normally used in assessment. The smolt trap is emptied once or twice a day, a proportion of the catch is marked by an individual or group mark and the marked fish are then released some distance upstream the trap site. Recaptures of marked smolts are monitored at the trap. Catch and recapture data are stratified according to different time intervals, like days, or presented as annual totals. Daily water level and water temperature are also monitored as potential covariates affecting e.g. recapture rate of marked smolts. Based on this material, the catchability of the trap is estimated and the total run is assessed (see Section C.1.4).

B.4. Commercial cpue

In the same way as biological sampling of salmon, the EU member states fisheries data collection programmes include cpue data. The seasonal average cpue information has been collected since 1980/1981 for Danish, Finnish, Latvian and Swedish fisheries in various combinations of subdivisions in the Main Basin, the Gulf of Bothnia and the Gulf of Finland (Table B.4.1).

Table B.4.1. Available information on cpue for countries, fisheries and subdivisions (LL: longlines, DN: driftnets, GN: gillnets, TN: traps).

Country	Subdivision	Offshore fisheries, gear		Coastal fisheries, gear		Period from
		LL	DN (stopped in 2008)	GN/DN	TN	
Denmark	22–25; 26–29	X	X			1983
Estonia	28–29; 32		X			1980–1988
Finland	22–31; 32	X	X		X*	1980
Latvia	26, 28		X		X*	1980
Poland	24	X	X	X		2004
	25/26	X	X	X		2000
Russia	26		X			2000
Sweden	22–29	X	X			1985

*** Dataseries from 2000.**

The cpue is presented as number of salmon per 100 nets (driftnet), as number of salmon per 1000 hooks (longline) and number of salmon per trapnet day in coastal fisheries. From year 2000, all information available on cpue is obtained from the WGBAST salmon catch database (see Section B.1).

B.5. Other relevant data

Tagging data

Tagging data are currently used for many purposes by the Working Group. Carlin tagging data have been an important information source in the assessment models for the Main Basin and the Gulf of Bothnia. Tagging data in combination with tag reporting rate have been used within the assessment of Baltic salmon in order to estimate river stock parameters as well as the exploitation rates by different fisheries (see Section C for more information). Tagging data are almost exclusively from reared salmon. Tagging of wild salmon smolts has taken place only in assessment unit 1.

Swedish tagging data constituted a major part of the data when the initial models were established in the late 1990s, but since 2001 the power companies have been responsible for most Carlin tagging, and there have been periods when the data have not been available to the WGBAST. When the database finally became available from the power companies in 2007, it turned out that the database suffered from quality problems that had arisen in the period when it had been unavailable. The Swedish University of Agricultural Sciences has rectified the database, and the data are now again used in the assessment model.

The number of tag returns has become so sparse in the last few years that they update the catchability estimates little. There are various reasons for the drop in number of tag returns. Apart from the decrease in post-smolt survival during the last 20 years, reasons include also a decrease in recapture rate due to a decline in exploitation, and the reduction in number of tagged salmon in the last few years. Another factor is the reporting rate. Some studies to estimate the reporting rate have been carried out in the Baltic Sea and their results indicate an obvious unreporting. In the assessment model, a conversion factor (which is based on expert opinions and empirical information) is used to take into account unreporting of tags (see the WGBAST report for more information). A more problematic issue is the possible decline in reporting rate over time. Increasing evidence suggests that the tag reporting rate of Swedish fishermen has decreased considerably but to an uncertain extent in the last decade, also for tags from other countries. The reason for the decline is not clear.

The small number of tag returns is not highly critical so far in estimation of catchability values since the estimates are not year specific (each fishery based estimate covers the range of years 1987–2011). In addition the catchability of each fishery is assumed to stay rather stable through the years. However, the tag return data influence also to the annual post-smolt survival estimates, which is a key parameter in the Baltic salmon assessment framework. As the quality of the tagging data seems to have decreased considerably for the reasons mentioned above (a main problem being an assumed decline in reporting rate), development of an alternative tagging system that could replace the current Carlin tagging programme has been discussed (ICES 2010).

Analyses of catch samples

Combined DNA- and smolt-age-data has been used by the group to estimate river stock and stock group proportions in salmon catches in the Baltic Sea since year 2000. The baseline data currently includes data for 17 microsatellite loci for 33 river stocks. Catch samples are also analysed using scale reading, which gives direct information on the composition of wild vs. reared salmon. The relative abundance of wild vs. reared salmon in the Main Basin, as determined by scale reading, is used in the assessment model (see Section C). Genetic data on catch composition, on the other hand, has not been used so far in salmon stock assessment. However, information generated from genetic mixed-stock analyses has been used as independent information to evaluate model predictions on e.g. relative abundance-at-sea of salmon of different river origin. The scale reading work is shared between Poland, Sweden and Finland. The DNA analysis is carried out in Finland.

C. Assessment: data and method

Salmon populations in Gulf of Bothnia and southern Sweden (AUs 1–4), eastern Main Basin (AU5) and Gulf of Finland (AU6) are assessed separately following different methodologies which are described under different subheadings below.

C.1. Salmon in assessment units 1–4

Model used: A Bayesian state–space model fed by multiple Bayesian data analyses

Software used: WinBUGS (Bayesian inference using Gibbs sampling) software, versions 1.4 and newer (http://www.mrc-bsu.cam.ac.uk/bugs).

Model Options chosen: See later details

General introduction to Bayesian inference: description of the modelling approach

A Bayesian approach to statistical inference (Gelman *et al.*, 1995) has been used for the assessment of Baltic salmon in assessment units (AUs) 1–4. This approach permits a probabilistic approach to fisheries stock assessment in which uncertainties about unobserved quantities are formulated as probability distributions (McAllister and Kirkwood, 1998). It also allows a diverse range of data and expertise to be incorporated probabilistically into the stock assessment and the input to be specified in a formal and probabilistic manner.

The key idea of the Bayesian approach is to express the prior knowledge of parameters of interest (population parameters, catchability, tag reporting rate, etc.) in the form of probability distributions, and then update the knowledge of the parameters by using empirical observations. The distribution which describes the degree of knowledge before obtaining empirical observations is called the prior (probability) distribution. The distribution updated by empirical observations is called the posterior (probability) distribution which is seen as a formal compromise between the prior knowledge and information contained in observations. Generally, small amounts of data result in small updates of the prior knowledge and large amounts of data results in more substantial updates of knowledge. Posterior distributions obtained from the analysis of one dataset can be used as prior distributions in the analysis of another dataset. This way the Bayesian approach serves as a formal tool for scientific learning as the information from multiple datasets accumulates to the posterior distribution.

The probability distributions are analysed using Monte Carlo simulation methods such as Markov Chain Monte Carlo (MCMC) methods and specialized software such as WinBUGS and Hugin have been used to calculate the probability distributions of interest based on the statistical models and prior probability distributions. The statistics most frequently used to describe a probability distribution (i.e. mode, median, mean, 95% probability interval) are illustrated by Figure C.1.1.

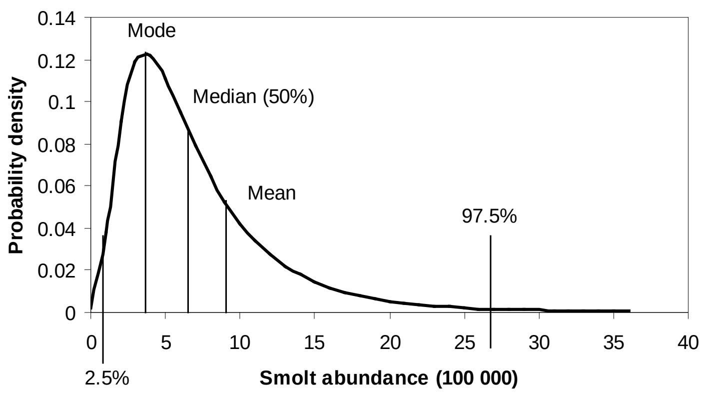

Figure C.1.1. Example of a posterior distribution for smolt abundance. The location of different statistics which are used to describe posterior distributions in the report are indicated by vertical lines in the figure. Most of the posterior distributions calculated by assessment models have shapes similar to the one presented here, which means that the order of mean, median and mode is the same as here: the median value lies between the most likely value (mode) and the expected value (mean).

C.1.2. Overview of the assessment method

An overview of the entire assessment model with the different submodels, data or information used within the submodels and their outputs, can be found in Figure C.1.2.1. The use of a Bayesian estimation procedure allows this type of systematic and integrative modelling approach which is able to utilize most of the information sources available.

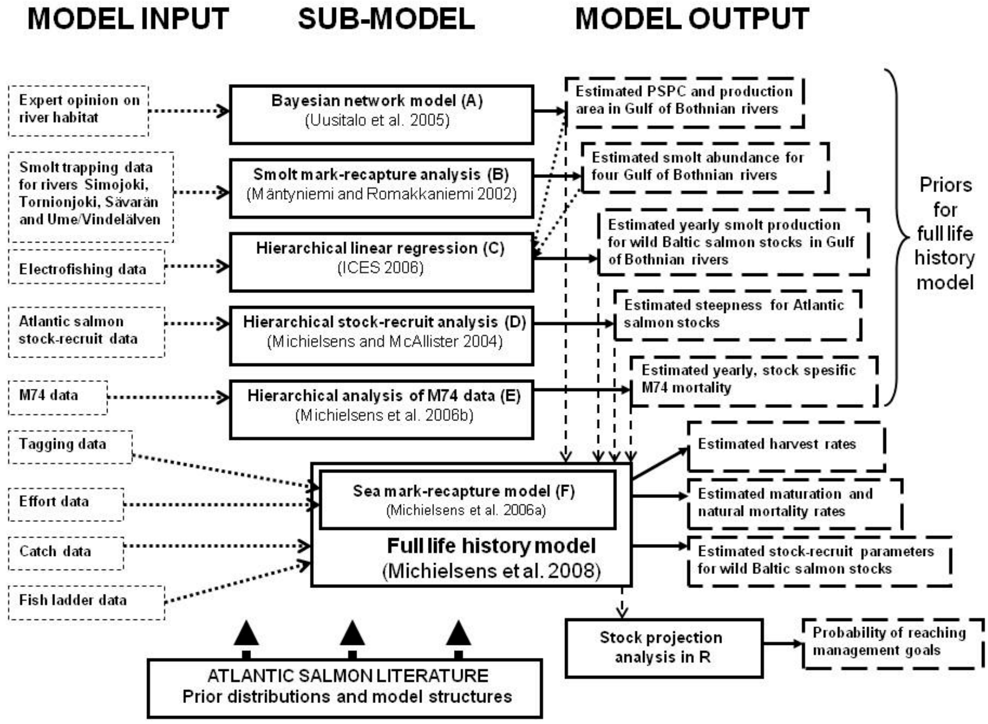

Figure C.1.2.1. Overview of the assessment methodology for Baltic salmon stocks. The results from five uppermost analyses provide informative prior probability distributions for the full life-history model. These priors become automatically updated by the information contained in the data and by the biological knowledge of the Baltic salmon life cycle used to build a full life-history model. PSPC=Potential Smolt Production Capacity.

In order to assess the status of the salmon stocks with respect to the reference points, the first requirement is to obtain estimates of the Potential Smolt Production Capacity (PSPC). A Bayesian network model (Uusitalo *et al*., 2005) has been used to obtain the prior distribution for the PSPC of different Baltic salmon rivers. The model is based on expert opinions or judgements of the characteristics of the river environments and the corresponding salmon stocks. The resulting PSPC estimates are used as prior probability distributions when estimating the stock–recruit relationships.

In addition to the PSPC, the full life-history model also requires yearly smolt production estimates in order to assess the smolt production in relationship to the PSPC. For the rivers Tornionjoki/Torneälven, Simojoki, Ume/Vindelälven and Sävarån, smolt trapping data are available that can be analysed using a mark–recapture model in order to obtain yearly smolt production estimates for these four rivers (Mäntyniemi and Romakkaniemi, 2002). For most rivers, however, only electrofishing data are available. In order to be able to estimate the smolt production based on electrofishing data, the results for the rivers Tornionjoki/Torneälven, Simojoki, Ume/Vindelälven and Sävarån (for which both electrofishing and smolt trapping data are available), can be used within an hierarchical linear regression analysis to estimate the smolt abundance of different rivers based on parr density estimates obtained from electrofishing data (ICES 2004, Annex 2).

In order to be able to update the historic smolt abundance estimates and predict future smolt abundances, information regarding the relationship between the number of eggs and the resulting number of smolts is needed. Within the Baltic Sea, no stock–

recruit data (egg and smolt counts) as such are available. Therefore a hierarchical analysis of Atlantic salmon stock–recruit data has been undertaken in order to estimate the likely form and parameters of the stock–recruit function (Michielsens and McAllister, 2004).

In order to be able to use the stock–recruit function and predict future smolt abundances, a full life-history model is needed that can predict the number of spawners given a certain level of exploitation. A full life-history model requires the estimation of life-history parameters such as maturation rates, natural mortality rates and exploitation rates. In order to be able to estimate these parameters, tagging data are analysed using a mark–recapture model (Michielsens *et al.*, 2006). The results of this model are used together with the smolt abundance estimates and the priors for the stock–recruit function within a full life-history model of individual Baltic salmon stocks in order to be able to estimate the stock–recruit function parameters for individual salmon stocks, and update the smolt production and PSPC estimates of the individual salmon stocks (Michielsens *et al.*, 2008).

The results of the assessment models are used to calculate the probability that 50% or 75% of the PSPC will be exceeded in a given year and to assess future probabilities of reaching this objective under different assumptions about future exploitation and states of nature. The probabilistic projection of the stocks beyond 2010 has been executed using R.

An overview of the different types of data available for the different Baltic salmon stocks can be found in Table C.1.2.1. The table indicates for which rivers the current assessment methodology is able to predict future smolt abundance to be compared to the PSPC. This estimation is based on smolt abundance estimates, spawner abundance estimates and associated stock–recruit relationships.

The following subsections discuss more in detail each of the different submodels within the assessment methodology.

Table C.1.2.1. Overview of the different types of data available for the different Baltic salmon stocks. The table also indicates for which stocks the current assessment methodology is estimating smolt abundance, spawner abundance and associated stock–recruit function. River categories: W=wild, M=mixed, R=reared.

River identification				Data										Estimates		
River			Country	IBSFC index river	M74 data	Electrofishing survey	smolt trap data	tagging data	fish ladder/counter	broodstock fishery	river catches	age structure	Genetic baseline	smolt estimates	spawner estimates	S/R parameters
Assessment group 1: North-eastern Bothnian														x	x	x
Tornionjoki;Torneälven	31	W	FI/SE	x	x	x	x	x	x		x	x	x	x	x	x
Kalixälven	31	W	SE			x			x		x	x	x	x	x	x
Råneälven	31	W	SE			x							x	x	x	x
Simojoki	31	W	FI	x	x	x	x	x	x		x	x	x	x	x	x
Kemijoki	31	R	FI		x			x					x			
Iijoki	31	R	FI					x					x			
Oulujoki	31	R	FI					x					x			
Assessment group 2: North-western Bothn														x	x	x
Piteälven	31	W	SE			x			x					x	x	x
Åbyälven	31	W	SE			x			x			x	x	x	x	x
Byskeälven	31	W	SE			x			x		x		x	x	x	x
Rickleån	31	W	SE			x			x					x	x	x
Sävarån	31	W	SE	x		x	x				x	x		x	x	x
Ume/Vindelälven	31	W	SE	x	x	x	x	x	x	x	x	x	x	x	x	x
Öreälven	31	W	SE			x			x				x	x	x	x
Lögdeälven	31	W	SE			x							x	x	x	x
Luleälven	31	R	SE		x			x		x			x			
Skellefteälven	31	R	SE		x			x		x			x			
Assessment group 3: Bothnian Sea														x	x	x
Ljungan	30	W	SE		x	x		x					x	x	x	x
Gideälven	30	R	SE					x								
Ångermanälven	30	R	SE		x			x		x			x			
Indalsälven	30	R	SE		x			x		x			x			
Dalälven	30	R	SE		x			x		x			x			
Ljunsnan	30	R	SE		x			x		x			x			
Kokemäenjoki	30	R	FI					x								
Aurajoki	29	R	FI													
Paimionjoki	29	R	FI													
Assessment group 4: Western Main Basin														x	x	x
Emån	27	W	SE			x							x	x	x	x
Mörrumsån	25	W	SE	x	x	x	x				x	x	x	x	x	x

C.1.3. Prior probability distributions for Potential Smolt Production Capacity (PSPC)

A Bayesian network model (Jensen, 2001) is used for the construction of the prior distribution for the PSPC of each river. The idea is to express the knowledge of salmon scientists about the PSPC in the form of probability distribution. In particular, the knowledge of the PSPC before obtaining any recent smolt abundance data is intended to be expressed here. Each expert is asked to provide their knowledge of different factors affecting the PSPC, like area suitable for production, habitat quality and mortality of smolts during downstream migration. Prior probability distributions for the PSPC are then calculated as the product of all these factors. The final prior distributions are an average over priors of all experts, which means that the diversity of different expert opinions is taken into account. Detailed description of this method can be found from Uusitalo *et al*. (2005).

Data

No measurement data are directly used in this model. Experts are asked to not to take into account measurement data that will be used explicitly in the Bayesian stock assessment model. For example, experts are asked to ignore any smolt counts that will be used in the assessment, since these data will be used later to update the prior probability distribution for the PSPC. However, before giving their opinion the experts look at existing additional material from the different rivers that contain information useful for the evaluation of the river areas suitable for production, the habitat quality of each river and information on mortality of smolts during downstream migration.

The data have been obtained from five salmon experts (Lars Karlsson, Ingemar Perä, Ulf Carlsson, Eero Jutila and Atso Romakkaniemi) from the northern Baltic Sea area. The experts represented different views in the controversy over the smolt production capacity. Clemen and Winkler (1999) noted that experts who are very similar in philosophy and opinions tend to provide redundant information, and heterogeneity among experts is thus desirable. The marginal utility of information decreases as the number of experts increases, and using 3–5 experts is generally suggested (Makridakis and Winkler, 1983; Ferrell, 1985).

Eliciting the expert information has been done in three stages:

1) First the experts discussed the model structure and assumptions and any differences in definitions of the parameters were ironed out. Clemen and Winkler (1999) pointed out that great effort may be required to reach this goal. For successful combination of the estimates it is vital that experts agree on what is to be estimated and on the definitions regarding the model.

2) Secondly the experts conducted a ''warm up-exercise'', going through the estimation using as an example a southern Swedish salmon river not included in the analysis. This was intended to help the experts become familiar with the practice of probabilistic estimation in this specific context (Morgan and Henrion, 1990). The probability distributions and conditional distributions were also explained in detail to ensure that they were understood in the same way by all experts.

3) Finally, the experts estimated the probability distributions of the river-specific variables and conditional distributions that link these environmental factors to salmon reproduction. Each expert did this alone via a questionnaire form, with the possibility to hold discussions with the analyst, if desired. This arrangement was made to ensure that nobody's opinions and interpretations would affect the judgements of others, but that every expert would give the estimates in accordance with his own judgement. Hints also exist that interaction between experts at this stage may increase overconfidence and thus produce poorer results (Morgan and Henrion, 1990).

Methodology

The network model summarizes the current expert knowledge of PSPC of northern Baltic salmon rivers. The model was constructed in cooperation with salmon experts and aims to be compatible with experts' lines of reasoning rather than to describe the actual relationships of the nature in a detailed manner. Thus it describes a probabilistic justification for the expert views of salmon smolt production.

The model consists of ten variables (Figure C.1.3.1), five of which describe or reflect the external factors, physical and biological, to which salmon reproduction is exposed in the reproduction rivers (*chance of successful spawning*, *habitat quality of parr area*, *smoltification age*, *mortality during migration*, and *size of production areas*). Three variables (*parr density capacity*, *pre-smolt density capacity*, and *smolt production capacity*) describe the juvenile salmon stocks' response to the external factors. The remaining variables, *expert* and *river*, are auxiliary variables that enable handling of all the estimates in the same model. The first two variables have five discrete classes. The lowest class (i.e. very poor) is fixed to describe the situation in the poorest river in the northern Baltic Sea area, and the highest class (i.e. very good) the best salmon production river in the northern Baltic Sea. This relative scale is based on the fact that some part of the required knowledge is related to the intuitive understanding of experts who have spent most of their careers in studying these populations.

Current knowledge is based on several small pieces of information, and the model here permits the experts to quantify this knowledge as probabilities. The variable smoltification age does not aim to reflect a distribution for the smoltification age, i.e. the percentage of parr that smoltify at each age, but the modal smoltification age and uncertainty connected with it. The minimum age of wild smolts in the rivers concerned is two years, which means that all salmon juveniles contribute to the densities of older parr (age 1+ and older) prior to smoltification. Dependencies between the variables (Figure C.1.3.1) are described by conditional probabilities. For example, there is a table that contains the probability distribution of *parr density capacity* as a function of *chance of successful spawning*, *habitat quality of parr area*, and *expert*. It states the probability distribution, i.e. the probabilities of every possible value, of *parr density capacity*, given that e.g. the value of *chance of successful spawning* is ''very good'' and the value of *habitat quality of parr area* is ''good'' and *expert* is ''Expert 1''. A probability distribution exists stating the probabilities of different values of *parr density capacity* for every combination of values of the parent variables, in this case *chance of successful spawning*, *habitat quality of parr area*, and *expert*. Standard probability calculus has been used to obtain the probability distributions for carrying capacity, giving the results from the different experts an equal weight. Hugin-software package has been used for calculation of probabilities.

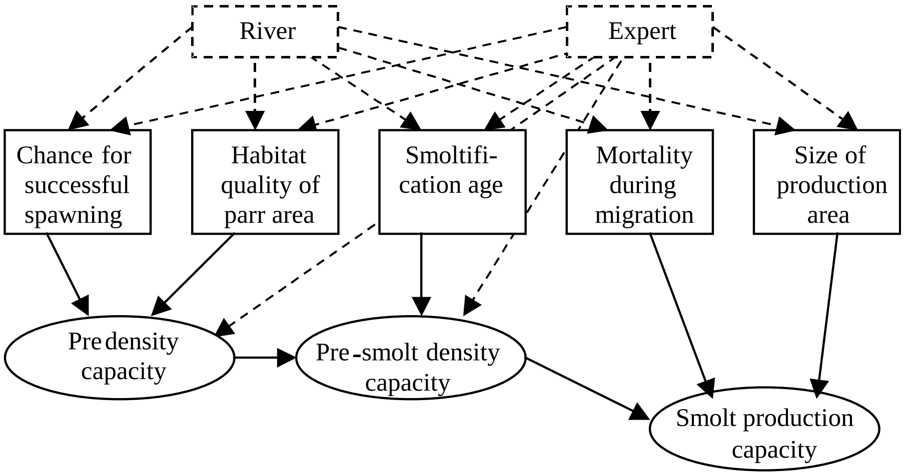

Figure C.1.3.1. Model structure. The solid rectangular nodes denote river-specific characteristics which are estimated for each river separately by each expert; the elliptical nodes denote conditional estimates on related input arcs, e.g. smolt production capacity depends on pre-smolt density capacity, mortality during migration, and the size of production area. The dashed nodes denote the auxiliary variables. The variables that are children of river are estimated separately for each river; the variables that are children of ''expert'' include separate estimates from each expert (Uusitalo *et al.*, 2005).

The model outputs are discrete prior distributions for the PSPC. Discrete distributions obtained directly from the model are difficult to use as such in further analysis. Therefore suitable continuous parametric distributions have been used to approximate the shape of the exact distributions obtained from this model. Lognormal distributions with median and coefficient of variation matching with the ones of exact distributions have been used for approximation. Multiple experts were used to come up with the priors for the set of rivers creates dependence between river-specific prior distributions. In other words, having new information about the PSPC in one river will also change the perception of the PSPC of other rivers. This can be also seen as automatic evaluation of experts: experts whose prior coincides well with the information implied by observations from a particular river will be given more weight in the prior distribution of other rivers. This inherent correlation between river-specific PSPC priors has been taken into account by approximating the prior distribution of each expert separately by a lognormal distribution. The resulting probability distributions for the PSPC can be found in Table C.1.3.1. PSPCs of the unit 4 rivers (Mörrumsån, Emån) are based on less structured expert judgements.

It is important to note that these probability distributions based on expert opinions only form the prior probability distributions for the PSPC. These priors will be updated when fitting stock–recruit models (C.1.7) to the available stock–recruit data (C.1.9), obtained by combining the smolt production estimates (C.1.4 and C.1.5) with the estimates of the marine survival (C.1.8). If the egg-to-smolt stock–recruit estimates for the Baltic salmon stocks appear to be informative, the probability density functions for the PSPC will then be substantially updated. Such an update can be expected in each assessment year as new data accumulates. The amount of annual change will depend on the amount of new data and the amount of information contained in the data.

Table C.1.3.1. Prior probability distributions for the smolt production capacity (* 1000) in different Baltic salmon rivers. The prior distributions are described in terms of their mode or most likely value, the 95% probability interval (PI) and the method on how this prior probability distribution has been obtained. These priors will be updated when fitting the Beverton–Holt stock–recruit function to the available stock–recruit data (Section C.1.9).

		Smolt production capacity (thousand)		Method of
		Mode	95% PI	estimation
Assessment unit 1				
1	Tornionjoki	690	246-6819	1
2	Simojoki	39	15-384	1
3	Kalixälven	240	143-2779	1
4	Råneälven	26	10-294	1
Total assessment unit 1		1598	589-8255	
Assessment unit 2				
5	Piteälven	30	7-369	3
6	Åbyälven	6	3-119	1
7	Byskeälven	75	31-879	1
8	Rickleån	3	1.0-31	1
9	Sävarån	2	0.6-30	1
10	Ume/Vindelälven	95	86-1330	2
11	Öreälven	5	4-160	1
12	Lögdeälven	17	7-289	1
Total assessment unit 2		492	238-2221	
Assessment unit 3				
13	Ljungan	2	0.8-27	1
Total assessment unit 3		2	0.8-27	
Assessment unit 4				
14	Emån	15	11-21.	3
15	Mörrumsån	90	66-128	3
Total assessment unit 4		105	79-145	

Method of estimation of smolt production capacity
1 Bayesian modelling of expert knowledge (Uusitalo et al. 2005)
2 Bayesian hierarchical stock-recruit analysis of Atlantic salmon stocks (Michielsens and McAllister 2004)
3 Expert opinion with associated uncertainty

C.1.4. Mark–recapture analysis of smolt trapping data

Mark–recapture experiments combined with smolt trapping have been used in four rivers (Tornionjoki, Simojoki, Ume/Vindelälven and Sävarån). Bayesian mark–recapture model proposed by Mäntyniemi and Romakkaniemi (2002) have been used to analyse the datasets. Simplified versions of the mark–recapture model (Bayesian Petersen method) are used in cases when data have not allowed incorporation of daily variation in parameters affecting trapping success.

Data

Mark–recapture data comprises of the number of untagged fish caught by the smolt trap, the number of tagged smolts released upstream from the trap, and the number of recaptured tagged smolts. These data are stratified according to different time intervals, like days, or presented as annual totals. Environmental covariates (daily water level and water temperature data) are also included into the analysis.

Methodology

The model structure is based on biological knowledge of the behaviour of salmon smolts during their migration. For example, their tendency to form shoals is taken into account by allowing catches to be more variable than in the case of independent behaviour. Knowledge of the sampling design is also utilized in the model structure. For example, the fact that it may take several days for a tagged smolt to pass the smolt trap again after the release is accounted for by modelling the mean and variance of the swimming speed of each marking group. A vague prior distribution is used for population size when analysing smolt trapping datasets. Posterior distributions for model parameters are calculated with the help of MCMC simulation.

Key assumptions behind the model structure:

- Smolts migrate in schools (shoals) rather than independently;
- Tagged and untagged smolts have equal capture probability when passing the smolt trap.

The output of the mark–recapture analysis is a posterior probability distribution, which formally includes all the information about the smolt abundance contained in the mark–recapture data. The smolt abundance estimates will be used in combination with parr density estimates in Section C.1.5.

C.1.5. Hierarchical linear regression analysis to estimate wild smolt production of different salmon stocks

A hierarchical Bayesian model is used to describe the relationship between relative densities of salmon parr and absolute abundance of salmon smolts. Parr populations are regularly monitored and a relative index of annual parr density has been calculated in most of the Baltic salmon rivers. For a few rivers (currently Tornionjoki, Simojoki, Ume/Vindelälven and Sävarån in the units 1–4) also smolt abundance estimates are available, which makes it possible for these rivers to look at and learn about the relationship between parr density and corresponding wild smolt production. By using a hierarchical structure based on assumed exchangeability of stock-specific parameters, the smolt abundance for stocks for which only parr density estimates are available is then estimated.

The core of the model is a latent dynamic linear regression model which connects relative densities of parr to smolt abundances. Information about parameter values between different rivers is transferred through hyperparameters, which are common to all rivers. Needed model inputs are prior distributions of model parameters and independent estimates of relative parr density and smolt abundance in a form of statistics of posterior distributions calculated separately from electrofishing and smolt trapping data.

Data

This model requires time-series of parr abundance indices for all rivers considered, and time-series of smolt abundance estimates for as many rivers as possible. More specifically, the annual number of sampling sites electrofished and the corresponding estimated density of age 0+, 1+ and >1+ parr are needed. The number of sampling sites is used as a measure of precision of the parr density. Medians of the posterior distributions from mark–recapture analysis for smolt abundance are used as observations, and CVs of the posteriors are used as their measurement errors. In order to be able to assume that the parameters of the linear model are exchangeable between rivers, the smolt abundance of each river must be scaled down by the assumed production area of the river. The prior distributions for the smolt production area of each river are obtained from the domain experts by using the network model provided by Uusitalo *et al*. (2005). Currently, parr density data from twelve rivers are used together with smolt abundance estimates from Simojoki, Tornionjoki, Ume/Vindelälven and Sävarån.

Methodology

It is assumed that a linear model can characterize the relationship between the parr density index and the smolt abundance based on the assumption that no density-dependent survival takes place in rivers of the Baltic Sea after the first summer (Figure C.1.5.1). The parameters of this linear relationship can be learned or estimated for rivers for which time-series of both parr abundance indices and smolt abundance estimates are available. It is assumed that the parameters of the linear model are not equal in all rivers, but instead they are assumed to be random draws from a distribution that characterizes the variation between rivers. In addition, mean discharge of the river is used as an explanatory variable for the slope of the linear model in each river. The residual variance can be learned from the variance of the parameters between rivers that have the necessary data. For rivers which have only parr abundance indices, the parameters of the linear model are given prior distributions which include the between river variability of the parameters and has the expected value predicted by the mean discharge of the river. This reflects the assumption that the parameters of the linear model are partially exchangeable between rivers. The model is described in detail in ICES (2004), Annex 2.

Key assumptions of the model:

- Parr density estimates are proportional to the true parr density.
- Survival and smoltification rates are not density-dependent after the fry stage.
- Relative selectivity of electrofishing is equal in all rivers.
- Knowing the name of the river would not help in the estimation of river-specific survival rate. This means that rivers cannot be ordered based on survival parameters by using prior information. This is the assumption of exchangeability which in turn leads to the assumption that river-specific parameters are random draws from a probability distribution describing the variation in survival between rivers.

This model produces posterior probability distributions for the annual smolt output of each river, as well as estimates of relative parr abundances, survival parameters and variation of survival parameters across rivers. The results of this analysis include all the information about smolt abundance contained in the electrofishing and smolt trapping data.

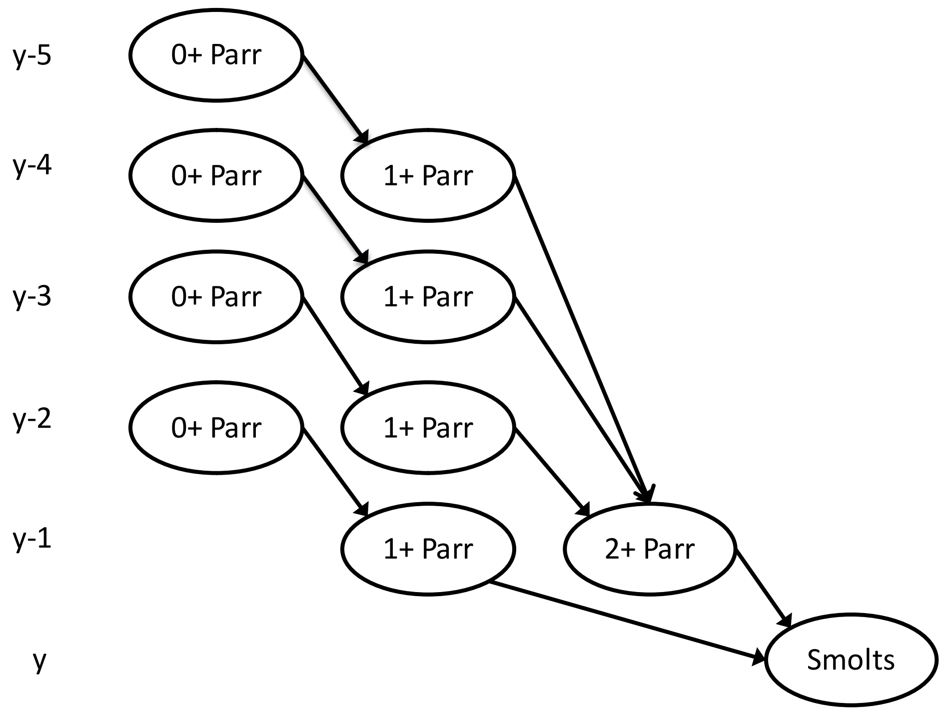

Figure C.1.5.1. A schematic diagramme illustrating the assumed dependencies when assessing the smolt abundance of year y (modified from ICES 2004).

Smolt production estimates in rivers not included in hierarchical linear regression analysis

For Piteälven, Emån and Mörrumsån, the smolt production estimates have been obtained differently. In Piteälven the number of eggs is estimated based on the number and size of the females passing the fishladder at the power plant station. Using an egg-to-smolt survival rate of 1%, it is possible to estimate the corresponding smolt production four and five years later:

Piteälven smolt forecast: = (0.01 * ((eggSY-4 * 0.62) + (eggSY-5*0.38)))

In Emån and Mörrumsån the smolt production is predicted using densities of 0+ and 1+ parr in combination with survival rates from one-summer old parr to two-summer old parr to smolts.

C.1.6. Estimating M74 mortality for different wild salmon stocks

Each year, the working group updates time-series on the percentage of females (at hatcheries) affected by M74 and the percentage of total yolk-sac-fry mortality. For assessment purposes, however, we need to know the percentage of annual mortality caused by M74 among the salmon offspring. These estimates allow us to integrate M74 mortality within the population dynamics of the stock.

Data

Two different datasets have been used to calculate the mortality among alevins due to M74 mortality. The first dataset consists of data for females from the river Simojoki, Kemijoki and Tornionjoki/Torneälven stocks. For each female it is indicated if the female suffered from the M74 syndrome and the percentage of yolk-sac-fry mortality by its offspring, calculated on the basis of the proportion of alevins from each female that die. A second dataset consists of M74 information for nine Swedish salmon stocks. The dataseries indicate the number of females sampled and the number of females affected by the M74 syndrome for each year and for each stock. Updated time-series on the data mentioned above can be found in the annual WGBAST report.

Methodology

The data are analysed using the same Bayesian hierarchical model as described by Michielsens *et al.*, 2006b. The probability of eggs surviving the alevin stage depends on the probability of females being affected by M74. In case the females are not affected by M74, it is assumed that the probability of the eggs surviving the alevin stage is dependent on the 'normal' level of yolk-sac-fry mortality (M). If the females are affected by M74 then either all offspring die or only part of the offspring die (Figure C.1.6.1).

Because the degree of M74 mortality is assumed to differ across years and across stocks, the model calculates the average survival from M74 mortality for each stock for each year. By separating the M74 induced yolk-sac-fry mortality from the 'normal' yolk-sac-fry mortality (YSFM), the model also removes the effect of the rearing environment on the M74 mortality estimates. It is assumed that the 'normal' YSFM can differ between offspring from different females but that the variation between the 'normal' YSFM from offspring of females of the river Simojoki, Kemijoki and Tornionjoki is the same as the variation in 'normal' YSFM between different years and between different stocks. Based on this assumption it is possible to implement an hierarchical model structure and use the estimated mean 'normal' YSFM and the associated variance among females to predict the 'normal' YSFM for years and stocks for which no data exist which would allow to estimate the 'normal' YSFM. Similarly for the M74 mortality it is assumed that this mortality can differ for each female and that there is a mean M74 mortality across the different stocks for each year and a constant variation across stocks over the years. This assumption allows to use a hierarchical structure across stocks and to predict the M74 mortality for stocks for which there is no information on M74. Because the average M74 mortality across stocks is year-dependent, this methodology does not allow the prediction of future M74 mortalities.

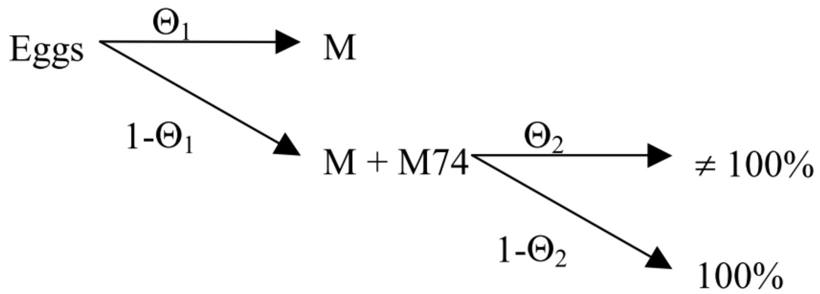

Figure C.1.6.1. Schematic illustration of the M74-model. M represents the normal yolk-sac-fry mortality (YSFM), M74 represents the mortality due to the occurrence of M74, Θ_1 is the probability that the offspring of a female will not show M74 related mortality and Θ_2 is the probability of a female of not having 100% mortality among its offspring.

C.1.7. Hierarchical analysis of Atlantic salmon stock–recruit data

A hierarchical analysis of Atlantic salmon stock–recruit data has been undertaken to come up with prior distributions for the steepness parameter of the stock–recruit function for Baltic salmon stocks (Michielsens and McAllister, 2004).

Data

Until year 2008 assessment, data from river Ume/Vindel was used in the hierarchical stock–recruit analysis together with the data from other Atlantic salmon stocks (ICES 2008). This reflected the idea that by incorporating the stock–recruit data of at least one Baltic salmon stock, the resulting probability distribution for steepness could be used for any unsampled stock, including Baltic salmon stocks which may in certain aspects differ from Atlantic salmon stocks from outside the Baltic Sea area. However, because of this the stock–recruit parameters of river Ume/Vindel were not updated in the full life-history model and it resulted in major problems with some posterior estimates of Ume/Vindel stock–recruit parameters. As a solution to this problem, Ume/Vindel was removed from the stock–recruit analysis and it was treated similarly in the full life-history model as all the other Baltic stocks.

Consequently, the stock–recruit analysis to obtain priors for the Baltic stocks is now based on data only from Atlantic salmon stocks outside the Baltic Sea. This is deemed justified since the stock–recruit parameter values of Ume/Vindel were not extreme compared to other Atlantic salmon stocks (ICES 2008). It is an indication that the range of values of stock–recruit parameters obtained from outside Baltic may well cover also the range of parameter values prevailing among Baltic stocks.

Methodology

A detailed description of the model used for the hierarchical analysis of stock–recruit data can be found in Michielsens and McAllister, 2004. Because the Beverton–Holt stock–recruit function has a much higher probability of being more suitable for Atlantic salmon than the Ricker function (Michielsens and McAllister, 2004), the current analysis will only be using this stock–recruit relationship.

The results for the steepness parameter are presented in Table C.1.7.1. For the Atlantic salmon stocks within the Northern Baltic Sea area (assessment units 1 to 3), it is assumed that the mean steepness across all Atlantic salmon stocks can be regarded as the prior distribution for the mean steepness and that the variance of the steepness among Atlantic salmon stocks can be used as the variance of the steepness of Northern Baltic salmon stocks. It is assumed that the mean steepness across the Southern Baltic salmon stocks (assessment unit 4) is lower than the mean steepness across the Northern Baltic salmon stocks but the variance in steepness across the southern stocks is given the same prior probability distribution as for the northern stocks (Prévost *et al*., 2003).

Table C.1.7.1. Mean and CV for the posterior probability distribution of the steepness for the Beverton–Holt stock–recruit function for Atlantic salmon. The posterior predictive distribution for an unsampled Atlantic salmon stock is used as a prior probability distribution for any unsampled Atlantic salmon stock in the Baltic Sea area.

	Posterior distributions	
Stock	mean	CV
Little Codroy river	0.79	0.13
Margaree river	0.66	0.19
Pollett river	0.74	0.14
Trinite river	0.79	0.13
Western Arm Brook	0.64	0.23
river Bush	0.70	0.19
river Ellidaar	0.72	0.19
river Oir	0.70	0.19
river Bec-Scie	0.67	0.19
Unknown Atlantic salmon river	0.71	0.20

C.1.8. Sea mark-recapture model for assessing the exploitation of Baltic salmon

Based on various data from fisheries and the sea and spawning migration of salmon it is possible to estimate population dynamics and harvesting of salmon from smolt to spawner. This is dealt with under this section.

Data

For the mark–recapture model, fishing effort data and tagging data have been used. The fishing effort data have been divided in separate coastal fishing efforts for stocks of assessment unit 1 to 3. The Swedish trapnet effort in Subdivision 31 has been divided between assessment units 1 and 2 with respective proportions of 45% and 55%. An overview of the number of tagged hatchery-reared and wild salmon released in rivers of assessment units 1, 2 and 3 can be found in the WGBAST report. Wild salmon have been tagged only in assessment unit 1.

For several of the parameters needed within the assessment model, basic data are fragmented and limited (e.g. tag reporting rates) or not simply not available (e.g. underreporting of catches). Instead of using the common approach of relying on expert opinions as such to extrapolate the data into parameter estimates, a more formalized approach has been used. For each parameter within the assessment model, twelve experts have been asked to provide a most likely value and a minimum and maximum value during a meeting at Bornholm in 2003 (ICES 2003). These expert opinions were based on data obtained from previous studies done, on literature, on the experts' experience or were subjective expert estimations in case no other information was available. Preliminary analyses, used for the formulation of prior probability distributions, included among others information from the broodstock fisheries, double tagging experiments, etc. Care has been taken to assure that the prior distributions were not based on data used within the mark–recapture model in order to avoid using the same data twice and thus rendering the results too informative. In general, these preliminary analyses gave often only a first indication of the model parameters but expert opinion needed to be used for example to extrapolate it to the entire Baltic Sea, or to other fisheries, etc.

The use of multiple experts resulted in multiple priors for the different model parameters. Model parameters such as the reporting rates of tags are dependent on the country. As such, the probabilities distributions for each country have been weighted by the country's contribution to catches of salmon and arithmetic pooling of the priors has been applied (Genest and Zidek, 1986; Spiegelhalter *et al.*, 2004). For other priors each expert is assumed to have equal expertise, arithmetic pooling without weighting of the priors has been applied. A description of the different model parameters and their prior probability distribution has been provided by ICES 2005.

The expert elicitation was carried out for the first time in 2003 (ICES 2003). At that time the elicited experts were mainly the members of the WGBAST. The resulting reporting rates have been used in the Baltic salmon assessments in years 2003–2012. However, because of the changes in the Baltic salmon fishery the WG saw appropriate to repeat the expert judgement in autumn 2012. The biological parameters were excluded and the focus was solely on tag reporting, unreporting of catch and effort and rate of discards in different fisheries. This time wider group of people including persons working with fisheries inspection and in fisheries statistics departments and also some fishermen were interviewed. The expert judgements from 2012 cover years 2004–2012 and resulting conversion factors replace the old estimates in 2013 assessment for the years concerned. The results from 2003 elicitation are used for years 1987–2003. Summary of the uncertainties associated to tag reporting and fishery can be found in the WGBAST report.

Methodology

The mark–recapture model is run within the full life-history model (Section C.1.9 below) and therefore separation of the descriptions of these two models is somewhat artificial. A state–space formulation is adopted to account for uncertainties in system dynamics and the observation process. The population dynamics model used within the mark–recapture analysis is age-structured and different fisheries are assumed to take place sequentially over time (Figure C.1.8.1). A detailed description of the model can be found in Michielsens *et al.*, 2006. The main difference between the model used by WGBAST and the one presented in this paper is that for the working group the model has been expanded to include assessment units 1 to 4 instead of only assessment unit 1. The main assumptions about the salmon stocks in the model are:

- The maturation rate for wild grilse is lower than that of the hatchery-reared grilse (Kallio-Nyberg and Koljonen, 1997; Jutila *et al.*, 2003).
- The post-smolt mortality rate of hatchery-reared fish is considered to be higher than that of wild fish (Olla *et al.*, 1998; Brown and Laland, 2001). The difference in post-smolt mortality rates between wild and reared salmon is modelled with an effect term which states that the instantaneous post-smolt mortality for reared salmon is the mortality of wild salmon times the effect term. The year specific effect terms are sampled from a distribution with common hyper parameters.
- The instantaneous natural mortality rate for adult salmon is allowed to differ between wild and reared salmon, but within both groups it is assumed to be constant over the years (except the mortality caused by seals along the coast, see below).
- On the coastal spawning migration of the Gulf of Bothnia seals are assumed to capture salmon at the entrance or outside the trapnets; this extra source of natural mortality is assumed to have increased proportionally to the increase of the Baltic seal population since 1989. This increase is incor-

porated by a coefficient which is given value=1 for year 1989 and which increases proportionally to the development of seal abundance.

- It is assumed that all adults die after spawning.

The main assumptions about the fishery in the mark–recapture model are:

- Stocks belonging to the same assessment unit experience the same harvest rates.
- Harvest rates between salmon stocks of assessment unit 1 to 4 mainly differ in the coastal fisheries and it is assumed that no coastal fishery exploits the salmon of assessment unit 4.
- The catchability coefficients for the different offshore and coastal fisheries are assumed constant over the years.

For each year, the model estimates different fishing mortality rates depending on the fishery (offshore driftnet, offshore longline, coastal driftnet, trapnet and gillnet and river fishery), depending on the age of the fish, and depending on whether it is a wild or hatchery-reared fish.

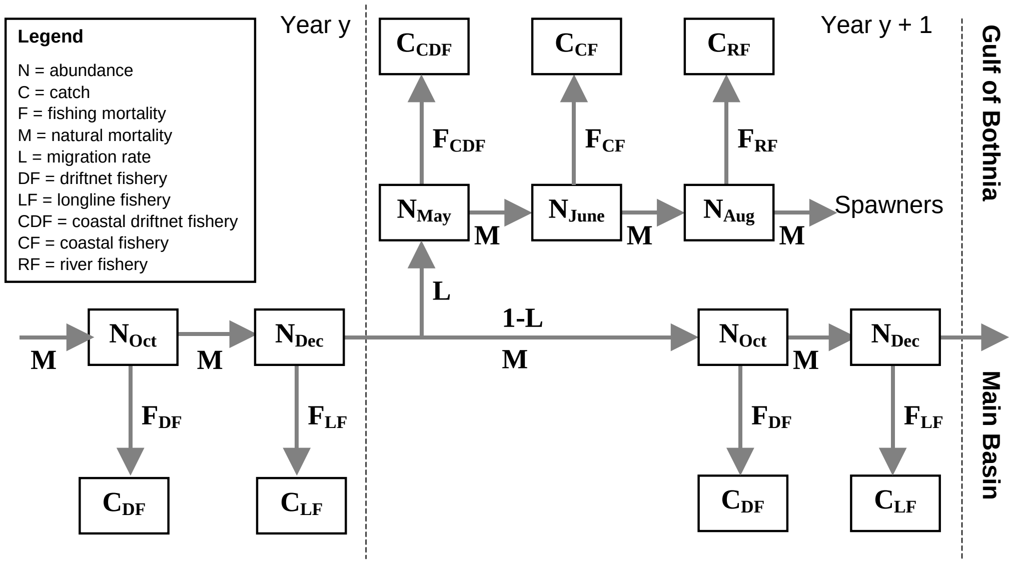

Figure C.1.8.1. Schematic presentation of the mark–recapture model for Baltic salmon. The offshore driftnet and longline fisheries in the Baltic Main Basin are assumed to take place in October and December, respectively. During the migration to the spawning grounds, the salmon can be intercepted by the coastal driftnet fishery in May, the trapnet and gillnet fisheries in June and the river fishery in August (Michielsens *et al.*, 2006).

C.1.9. Full life-history model of different wild Baltic salmon stocks

Spawner abundance estimates has been obtained by using the wild smolt abundance estimates of different rivers (Section C.1.5) with similar population dynamics as within the mark–recapture model (Section C.1.8; Michielsens *et al.*, 2006; Michielsens *et al.*, 2008). By linking the derived egg abundance estimates with the wild smolt abundance four years (in the case of Gulf of Bothnia stocks, assessment units 1–3) or three years (in case of assessment unit 4 stocks) later, it is possible to estimate stock–recruit parameters. The resulting stock–recruit function makes the loop between salmon generations and the estimates of abundance and survival parameters become updated across the time-series. The resulting posterior distributions are then used to assess the stock status and to predict abundance into the future.

Data

Both total number of wild smolts and number of released hatchery-reared smolts are used as inputs into the model. The model is also fitted to offshore, coastal and river catches. The Polish catch has been calculated by multiplying Polish effort with combined Danish, Finnish, Swedish and Latvian catch per unit of effort, assuming 75% of the fishing efficiency for Polish fishermen compared to others (see Section B). The Swedish trapnetting effort has been approximated by using Swedish catch data and Finnish catch per unit of effort for trapnetting, assuming 80% fishing efficiency for Swedish fishermen compared to the Finnish ones. Also, Swedish recreational trapnet fishery is assumed to have 80% of the efficiency of the Swedish commercial trapnet fishery. The number of salmon mauled by seals (discards) in coastal trapnets of the Gulf of Bothnia is calculated based on reports of Finnish fishermen.

Because assessment units 5 and 6 have not yet been included in the model, the catches have been raised by the proportions of smolts produced in these assessment units in comparison to the total smolt production of all units. In addition, the model also uses the data on the spawner counts in the rivers Ume/Vindelälven, Kalixälven, Tornionjoki/Torneälven, Simojoki, and the data on proportion of MSW (multi-sea-winter) spawners encountered in the rivers Tornionjoki, Kalixälven, Byskeälven, Ume/Vindelälven and Öreälven. The model also utilizes trap catches and the associated mark–recapture experiments of reared spawners in the rivers Dalälven in 2004–2011 and Luleälven in 1996, 1997 and 2001.

Data available about the relative occurrence of wild vs. reared salmon in catches is utilized from the river Tornionjoki (all years) and from offshore fishery (years 1996, 1998, 2001–). The data from the offshore fishery consists of the samples used for the genetic and scale reading analyses (see Section B), supplemented with some samples left outside the current genetic analyses.

By linking the wild spawner abundance produced from the yearly smolt production, with the smolt production four years (three years for AU4) after the year of spawning, it is possible to obtain stock–recruit information for wild salmon stocks. For each stock, the estimated abundances of spawners of different ages are multiplied with corresponding sex ratios and fecundity values (eggs/female) in order to estimate the total number of eggs deposited in each river in each year. The resulting number of eggs has been corrected for the effect of M74 by multiplying the estimated number of eggs with the percentage of yolk-sac-fry mortality due to the occurrence of M74 (Section C.1.6). In case no M74 data have been available for certain river stocks, the predictions of M74 related yolk-sac-fry mortality for unknown stocks are used.

Methodology

The population dynamics for the total abundance of salmon is expressed by similar equations as the population dynamics for the abundance of tagged salmon (Michielsens *et al.*, 2006). In order to estimate salmon catches, the tag reporting rates within the catch equation for tagged salmon have been replaced by the catch reporting rates. The main model outputs are the estimated stock–recruit parameters, i.e. the steepness parameter and the PSPCs.

The model simultaneously models the tagged salmon population and the total salmon population. For tagged salmon, the population equations account for tagging induced mortality, tag shedding and underreporting of tagged salmon catches. Based on the tagging data, the model is able to estimate maturation rates, natural mortality rates, and harvest rates. These estimates are then used to model the total salmon population based on the number of wild and released hatchery-reared salmon smolts. In order to estimate the coastal and river catches, the corresponding equations account for possible underreporting of the salmon catches. The probability distributions for the wild smolt abundance will be used as priors until the year 1992 for which the model is able to calculate the smolt abundance using the estimated number of spawners and the stock–recruit parameters. From that year onwards, the model can be fitted to the smolt abundance estimates instead of using them as priors. The entire model has thus been fitted to tagging data, catch data, catch composition data, data on the composition and counts of the spawning run, and data on smolt and parr abundance.

The prior probability distributions of the smolt production capacity for the different river stocks have been obtained by Uusitalo *et al.*, 2005 (Section C.1.3), based on expert opinions. The prior distribution for the steepness in each river has been derived by the hierarchical model described in Section C.1.7. These priors become updated by the full life-history model taking into account all available data.

Fishladder counts of spawners in rivers Kalixälven, Tornionjoki/Torneälven and Simojoki have been fitted with the amount of spawners ascending to the river. Probability for a spawner to be observed in the counter has been allowed to vary between years around a common mean. The model has been fitted also to the fishladder counts of spawners for river Ume/Vindelälven. Here, the ladder counts are assumed to indicate the maximum limit for the number of spawners in Ume/Vindelälven, because river fishing harvests salmon that pass the ladder. A separate parameter defines the success of ascending fish to find the fishladder. This parameter is given a prior distribution based on the results of tagging studies carried out in the river. The Ume/Vindelälven data are only used until 2009. A new fishladder in 2010 and a change in the flow regime in the fishladder area in 2011 makes older tagging studies less representative of the current situation.

In the river Luleälven, it is assumed that all salmon had reached the uppermost part of the river by the time of mark–recapture experiments. It is further assumed that the salmon are moving around randomly in the area and that all individuals have the same probability to enter the trap. However, the experiment period differs from year to year, and thus the data needs to be standardized with the period length (in days) since the possibility for a fish to enter the trap increases as the number of experiment days increases. A small observation model is fitted for the standardized mark–recapture experiment data to estimate the catchability of the trap. The data on total number of salmon caught by the trap is also standardized, and together with the mark–recapture data it provides an estimate of the total number of salmon surviving to the uppermost part of the river. This information is fitted with the model predicted abundances of reared fish in the Luleälven within the full life-history model.

Data on river Dalälven surviving salmon is modelled similarly as in Luleälven case, but in Dalälven there is no need to standardize the data with the number of experiment days. In the river Dalälven case, the prior distribution is given for the mean catchability of the trap and its variation over the years based on the information from continuous mark–recapture studies. This means that for river Dalälven, the original mark–recapture data are not included to the model (as is the case for Luleälven) since the prior distribution is informative enough in itself.

The model is fitted to time-series on the proportion of wild vs. hatchery-reared spawners in river catches from Tornionjoki/Torneälven. The model is also fitted to time-series of wild/reared proportions in catch samples from the offshore fishery. Because the offshore catch samples clearly consist of separate samples in time and space within each year, the wild/reared proportions were first analysed on annual basis using a hierarchical Bayesian model which allows estimation of true proportions from samples (Samu Mäntyniemi, unpublished). The results of this submodel were fed in the full life-history model as priors.

Estimation of post-smolt mortality. The first year at sea (post-smolt stage) is known to be critical for salmon because a large proportion of the marine mortality occurs within this period. Virtually no data exist about this stage of salmon's life, and therefore it is largely unknown what the exact processes are in this period and how they affect survival of salmon. Instead, data exist just before the period (smolt production estimates for wild salmon and stocking statistics for reared salmon) and also right after the period when salmon recruit to the fisheries and grilse mature. The post-smolt survival is year (i.e. smolt cohort) specific and the parameter aggregates all information about the total mortality within the post-smolt period. The parameter estimate is basically directly calculated from the difference in abundance estimates just before and right after the period. It should be noted that the abundance estimate after the post-smolt stage is derived from and strongly affected by all the accumulating information about the cohort specific abundance at later ages (as discussed above; catches, tag recaptures, spawner counts, etc.).

C.1.10. Uncertainties affecting the assessment results

Data deficiencies

The main information on the exploitation of wild salmon in the Baltic comes from mark–recapture data. The problem with these data is that they are geographically biased. All tag recapture data are representing salmon from AU 1–3, and wild salmon have been tagged only in AU1.

The fishing effort of the Swedish coastal fisheries by trapnet and other gears (predominantly gillnet fisheries) for the entire time-series have been based on the cpue of Finnish coastal fisheries. Also, the proportion salmon which is mauled by seals in the entire trapnet fishing is based on reports of the Finnish fishermen.

Uncertainties expressed by the prior probability distributions of the model parameters

For rivers with a lot of data such as Tornionjoki, the prior probability distributions for the smolt production capacity has been updated substantially, limiting the influence of the expert based prior probability distribution for the smolt production capacity. Other rivers such as the river Öreälven, for which not many data are available, the smolt production capacity is primarily updated due to the correlation between the smolt production capacity estimates of different rivers.

Prior probability distributions for the parameters of the sea mark–recapture model have been provided by twelve experts based on previous studies, on literature, on the experts' experience or were subjective expert estimations in case no other information was available. A table with all prior probability distributions are described in Michielsens *et al.*, 2006. With exception of the prior probability distributions of the catchability coefficients, the prior probability distributions for the model parameters have been given rather informative distributions. Sensitivity analyses have indicated, as could be expected, that results are to a large extent dependent on the prior probability distributions for the reporting rate and biological model parameters and to a very limited extent on the prior probability distributions for exploitation rates (Michielsens *et al*., 2006).

Uncertainties regarding the model assumptions and model structures of the estimation model

Given the large number of different methodologies used for the assessment of Baltic salmon stock, the model assumptions are described in the sections relating to the different methodologies.

Walters and Korman, 2001, have pointed out that for depleted stocks when the spawning stocks increase rapidly after long periods of low abundance, this may result in locally intense competition within those reproduction areas that are still being used. This patchy habitat use may impose local density-dependent effects, which may diminish in the longer run (after several generations) once spawners have dispersed to fully re-establish the natural or most productive structure of habitat use (Walters and Korman, 2001). If this phenomenon is valid for the Baltic salmon populations, our analysis of the recent stock–recruit information underestimates long-term (full) carrying capacity of the Baltic rivers.

Tag shedding and mortality

Possible sources of error in application of results from tagging experiments include the question of differential mortality between tagged and untagged fish and when this (possible) mortality occurs, also tag shedding (loss of tags) and whether this is related to the size of the fish. Possible difference in growth rate of tagged and untagged fish could be a problem. Reporting rate (proportion) of the tags caught in different fisheries are also important pieces of information to be able to use tagging data.

A considerable mix-up of these different factors is likely and in most cases it is difficult to keep the different factors apart.

It is vital for the tagging studies to have at least an overall estimate for tag shedding rate. Some information on salmon can be found in the data from Swedish broodstock fisheries in Gulf of Bothnia based on numbers of fish released in each year in 1987–1998 and the number of fish recovered in year 1990–1999. It is assumed that all tags in these fisheries are reported and therefore they can be used to elucidate the combined effect of tag shedding and difference in mortality between tagged and untagged. If the recovery rate in broodstock fisheries is compared with tag recoveries in rivers and river mouth areas, data on reporting rates can be calculated.

It is assumed that the best dataset is available from River Dalälven, which has a meticulous control of the number of the fish caught in the broodstock fishery. There is also a very good organization of the angling in this river and the catch statistics in this river is therefore assumed to be of particularly high class. The data from this river suggests that the tag shedding/mortality remove about 30% of the number of tags.

Comparison between model predictions and results from mixed-stock analyses

Previous comparisons between stock proportion estimates in catches (based on mixed-stock analyses) and model predictions of the stock composition in the Main Basin indicate that there is a good overall agreement between the two methods in the proportion of both wild and reared salmon. Not only the overall proportions of wild and reared salmon are in agreement, but also AU specific and even stock-specific catch proportions are in fair agreement between the model results and the results of genetic analyses of catches. Apparently, previous changes in the model structure and the expanded use of available data (fitting the model to proportion of wild vs. reared salmon in catch samples from offshore fishing, and to spawner counts in Dalälven, Luleälven, Tornionjoki/Torneälven and Simojoki) has greatly improved the performance of the model.

Nevertheless, there is a possibility that the present offshore fishing occur in areas where some stocks may be partly missing. For example the reared Daugava salmon has been observed in unexpected small proportions in the offshore catch samples which are taken from the Subdivisions 25 and 26 in the southern Main Basin. Neva salmon has been stocked in the Finnish Bothnian Sea; salmon of this strain has been shown to migrate shorter distances at sea than the strains of the Gulf of Bothnia salmon. Moreover, reared large smolts stocked in the Gulf of Bothnia are shown to stay on more northern feeding areas than smaller smolts. This together with the most recent spatial aggregation of offshore fishing to the southwesternmost part of the Baltic Sea may lead to stock/origin/strain specific differences in the offshore harvesting, which is not taken into account in the current model assumptions. Therefore it would also be important to further explore the distribution pattern of the feeding salmon vs. the distribution of the fishery.

Misreporting in the Polish longline fishery

Polish salmon catches has been corrected for the fact that a large proportion of the catches is misreported as being trout. The Polish longline catch of salmon was calculated from data on Polish effort and combined Finnish, Swedish and Danish cpue times a correction factor of 0,75. High-quality inspections are needed to give a reasonably precise estimate of the salmon catch in the Polish longline fishery, and to evaluate if the deviations from the corrected values are large enough to affect the assessment results. In 2012 European Fisheries Control Agency (EFCA) has included Baltic salmon fishery in the Joint Deployment Plan (JDP), which probably will gradually diminish the occurrence of misreporting. This would decrease the uncertainties of assessment result that are caused by this inaccessible catch component.

C.2. Assessment of salmon in eastern Main Basin (AU 5)

An overview of the different types of data available for salmon in AU 5 can be found in Table C.2.1.

Table C.2.1. Overview of the different types of data available for salmon in AU 5. The table also indicates for which stocks the current assessment methodology is estimating smolt abundance, spawner abundance and associated stock–recruit function. River categories: W=wild, M=mixed, R=reared.

River identification					Data										Estimates		
River	ICES subdiv	Category	Country	IBSFC index river	M74 data	Electrofishing survey	smolt trapping	tagging data	fish ladder/counter data	broodstock fishery	river catches	age structure	Genetic baseline	smolt estimates	spawner estimates	S/R parameters
Assessment group 5: Eastern Main Basin														x	x	x
Pärnu	28	W	EE	x		x							x	x	x	x
Salaca	28	W	LV	x		x	x	x				x		x	x	x
Vitrupe	28	W	LV											x	x	x
Peterupe	28	W	LV			x								x	x	x
Irbe	28	W	LV											x	x	x
Uzava	28	W	LV											x	x	x
Saka	28	W	LV											x	x	x
Barta	28	W	LV/LT											x	x	x
Gauja	28	M	LV			x		x					x	x	x	x
Daugava	28	M	LV					x					x	x	x	x
Venta	28	M	LV			x							x	x	x	x
Nemunas	26	M	LT	x		x							x	x	x	x
Minija	26	R	LT	x												
Lielupe	28	R	LV					x								

For AU 5, the full life-history model described in Section C.1.9 is run separately from AU 1–4. The model relies on several simplifying assumptions about salmon in this area (see below), and is used to assess current population status by comparing smolt production to the 50% and 75% level of the estimated natural production capacity on a river-by-river basis. Because of the limited amount of data available from AU 5, the estimates obtained for these rivers are not as reliable as for the other AUs. The following input data are used in the model:

- Prior probability distributions for the smolt production capacity that are mainly based on expert opinions (Table C.2.2). These estimates are not based on the Bayesian modelling of expert knowledge applied for northern rivers and are therefore considered to be less reliable. There is a concern that the probability distributions provided by experts, and which describes the uncertainty about our knowledge of production capacity, may be unrealistically narrow.
- Smolt production estimates derived mainly from electrofishing data using various methods that are based on the relation between parr and smolt abundances in the same and/or other rivers. These estimates do not usually contain information about uncertainties. For some rivers, smolt production estimates are completely based on data derived from other (similar) rivers in the region.
- Estimates from the full life-history model on annual harvest rates for offshore fisheries (thus assuming the same at sea migration pattern as for Gulf of Bothnia salmon).
- Estimates from the full life-history model on adult natural mortality (fixed over time) and annual post-smolt mortalities (thus assuming the same at sea survival as for Gulf of Bothnia salmon).

Table C.2.2. Prior probability distributions for the smolt production capacity (* 1000) in Baltic salmon rivers in assessment unit 5. The prior distributions are described in terms of their mode or most likely value, the 95% probability interval (PI) and the method on how this prior probability distribution has been obtained. These priors will be updated when fitting the Beverton–Holt stock–recruit function to the available stock–recruit data (see text and Section C.1.9).

		Smolt production capacity (thousand)		Method of
		Mode	95% PI	estimation
Assessment unit 5				
16	Pärnu	3.5	2.2-6.2	1
17	Salaca	30	26-35	2
18	Vitrupe	4	2.6-7.2	2
19	Peterupe	5	3.2-9.	2
20	Gauja	28	18-51	2
21	Daugava	10	6.-18	2
22	Irbe	4	2.6-7.2	2
23	Venta	15	10.-27	2
24	Saka	8	5.-14	2
25	Uzava	4	2.6-7.2	2
26	Barta	4	2.6-7.2	2
27	Nemunas river basin	150	96-269	2
Total assessment unit 5		291	218-395	

Method of estimation of smolt production capacity

1 Accessible linear stream length and production capacity per area

2 Expert opinion with associated uncertainty

In a similar way as for salmon in AUs 1–4 (Section C.1.9), stock–recruit parameters for AU 5 rivers are estimated by linking the derived egg abundance estimates with the wild smolt abundance two years later. The resulting stock–recruit function makes the loop between salmon generations and the estimates of abundance and survival parameters become updated across the time-series. The resulting posterior distributions are then used to assess the stock status.

C.3. Assessment of salmon in Gulf of Finland (AU 6)

For AU 6 salmon, there is no analytical assessment model developed. The assessment of population status is based on a qualitative assessment taking into account trends in parr densities, smolt production and exploitation rates. Expert opinions on natural production capacities are available for AU6 rivers, but no analysis of the stock–recruit dynamics exist at the moment, precluding validation of these preliminary production values.

An overview of the different types of data available for salmon in AU 6 can be found in Table C.3.1.

Table C.3.1. Overview of the different types of data available for salmon in AU 6. As can be seen, there is no analytical assessment model developed which could estimate smolt and spawner abundances, and associated stock–recruit functions. River categories: W=wild, M=mixed, R=reared.

River identification					Data									Estimates		
River	ICES subdiv	Category	Country	IBSFC index river	M74 data	Electrofishing survey	smolt trapping	tagging data	fish ladder/counter data	broodstock fishery	river catches	age structure	Genetic baseline	smolt estimates	spawner estimates	S/R parameters
Assessment group 6: Gulf of Finland																
Kunda	32	W	EE	x		x							x			
Keila	32	W	EE	x		x							x			
Vasalemma	32	W	EE			x										
Purtse	32	M	EE			x					x					
Selja	32	M	EE			x					x					
Loobu	32	M	EE			x										
Valgejõgi	32	M	EE			x					x					
Jägala	32	M	EE			x					x					
Pirita	32	M	EE			x	x				x	x				
Vääna	32	M	EE			x					x					
Luga	32	M	RU	x			x						x			
Neva	32	R	RU		x								x			
Karjaanjoki	32	R	FI													
Narva	32	R	RU/EE										x			

D. Short-term and long-term projections

Salmon in AU 1–4

Model used: Simulations based on full life-history model

Software used: R

Initial stock size: Stock and year specific numbers of smolts. Stock and year-specific numbers of fish by sea age group at sea in the first of May. Uncertainty included.

Maturity: Age-specific maturation rates estimated by full life-history model. Uncertainty included.

F and M: M is divided between post-smolt stage and 'adult' ages. M for post-smolt stage ('Mps') is assumed to hold the autocorrelation structure observed in the past, and the median value of it is assumed to return to a chosen value in the long term. M for 'adult' ages is same as estimated by the full life-history model. M74 mortality is assumed to vary within the limits of the observed range of values, but assuming the same autocorrelation structure as observed in the past. Fishery specific F's are dependent on assumed future effort through catchabilities which are estimated in the full life-history model.

Weight-at-age in the stock: Not used.

Weight-at-age in the catch: Not used.

Exploitation pattern: Same as in the last observed year.

Intermediate year assumptions: Same exploitation pattern as in the last observed year. Offshore fishing effort in the first months of the year are assumed known (no uncertainty) based on observed effort in the last months of the last observed year and by assuming similar division of effort between winter as observed one year before. Coastal fishing effort is based on expert opinions (uncertainty included).

Stock–recruitment model used: Stock-specific Beverton–Holt models estimated by the full life-history model. Uncertainty included.

Procedures used for splitting projected catches: Projections provide predictions of total removals with a given effort level. Splitting catches is based on the last observed year. The relative proportions of reporting, unreporting and discarding are assumed to stay the same as in the last year with observations.

Salmon in AU 5–6

No stock projections are made.

D.1. Description of stock projections

Projections are carried out for all rivers in assessment units 1–4. Due to the length of the life cycle of salmon and the chosen reference points (see G) projections are extended to at least six years into the future. There are no separate short-, medium- and long-term projections with different approaches.

The effects of various TAC decisions are screened stepwise by decreasing/increasing the last observed effort and by applying these alternative effort levels into the future. The stock projections are also based on scenarios for future post-smolt survival and M74 mortality.

Methods

In order to make forward projections, the salmon life cycle with the most relevant life-history parameters are copied from the full life-history model into a separate calculation platform. Joint posterior distributions describing the latest knowledge of the number of smolts and population parameters are also derived from the full life-history model (see Section C.1.9) and stored in the form of indexed MCMC chains. The estimates are stored up to the last year with observations about the parameter in concern. Scenarios are run by using R software (R Development Core Team, 2009).

Assumptions regarding biological parameters

The population dynamics for the stock projection analysis is similar to the full life-history model but lacks the process errors in the different survival parameters. In addition, only average annual M74 mortality is included in the stock projections instead of river-specific mortalities.

The two annually varying key parameters determining the natural survival of the salmon, i.e. post-smolt survival (Mps) and survival from M74 mortality are assumed to vary within the limits of the observed range of values, but assuming the same autocorrelation structure as observed in the past. The forward projection for Mps begins already from the assessment year -1 because of the absence of data containing information about the survival in that year. For M74, the projections start from the assessment year. Simulations are typically run for only one scenario about Mps: the median of which is expected to return to the lowest value in the historic time-series. Alternative scenarios can be executed if e.g. there are reasons to believe that Mps may improve in future. Survival from M74 mortality is expected to return to the median survival observed in the historic time-series.

Assumptions regarding development of fisheries

Scenarios for fisheries are implemented by making different scenarios for future development in effort. As an example, the key assumptions underlying the stock projections used by WGBAST in 2012 (ICES 2012a):

Scenario	Fishing effort for year 2013 and onwards
1	2011 level excluding Swedish longlining
2	-20% from level in scenario 1
3	-40% from level in scenario 1
4	-60% from level in scenario 1
5	-80% from level in scenario 1
	Post-smolt survival of wild salmon
	Projection starts from the 2010 survival estimate and is expected to approach the 2009 survival (7.5%) in the long run
	Post-smolt survival of reared salmon
	Same relative difference to wild salmon as on average in history
	M74 survival
	Projection starts from the 2011 survival estimate and is expected to approach the historical median (92%) in the long run

Survival values shown in the table represent the medians to which Mps and M74 are expected to return as explained above. Decisions which change management between the historic and future time-series can be taken into account if made before assessment. In the above example, the decision to ban longlining from 2013 onwards was made in Sweden before the 2012 assessment. The other fisheries would fish equally to their 2011 effort (scenario 1), or there would be either a 20% (scenario 2), 40% (scenario 3), 60% (scenario 4), or 80% (scenario 5) reduction in their effort compared to scenario 1. Also expert opinions about the country-specific development of the effort (with uncertainty) can be derived and applied in an alternative scenario. Expert opinions about the development of effort are needed anyway for coastal fisheries in the interim year.

European Commission has proposed to set TAC based on harvest rule F=0.1 (European Commission 2011). TAC based on this harvest rule can in principle be calculated directly from the stock abundance estimate. However, guidelines would be required to specifying how uncertainties in estimates should be taken into account and what would need to be assumed about the development of fisheries which is not controlled by TAC.

Evaluation of management alternatives

The future development of smolt production under different scenarios is evaluated in two ways:

1) River-specific probabilities to meet the 75% target is calculated for each future year, with a special emphasis on the smolt production of the years mostly affected by management measures in the year the advice is given for.

2) Changes in the river-specific probabilities to meet the 75% target from the current situation compared to one full generation into the future. The length of a salmon generation is on average seven years for AU 1–3 and six years for AU 4 river stocks. By comparing the current status with the status one generation ahead, the effect of a cyclic fluctuation in population abundance can be removed and the effects of different effort scenarios on the future development of stocks can be better evaluated.

Uncertainties regarding the stock projections

There are two differences between assumptions of the full life-history model and the population dynamics model which is used in projections.

1) Process error is lacking in all other survival processes except in recruitment (S/R dynamics). Excluding process error from the predictive model leads to results that are less variable than they would be if process errors in survival were included. Deterministic survival process in forward projections may underestimate the variation in probabilities to reach management targets in predictions.
2) Average values for M74 are used in the projection model instead of river-specific values used in the estimation model. River-specific differences in M74 mortality are therefore lost, which may lead to generally more uncertain river-specific projections.

Assuming a known offshore fishing effort in the interim year underestimates the uncertainties in stock size at the beginning of the year for which advice is given.

G. Biological reference points

There are no objectives with corresponding reference points agreed for the current management of Baltic salmon.

The working group evaluate the probability to reach 50% and 75% of the **Potential Smolt Production Capacity** (PSPC) in each river. Reaching at least 50% of the PSPC by 2010 in each river has been the objective of the Salmon Action Plan (SAP), defined by the former IBSFC. Reaching at least 75% of the PSPC has been suggested by ICES if the plan is to recover salmon river stocks to the MSY level (ICES 2008b and ICES 2008c). The objective of reaching at least 75% of the PSPC is also adopted in the Commission's proposal for establishing a multiannual plan for the Baltic salmon stock (European Commission, 2011), and is also used as a basis for ICES advice on fishing possibilities. The PSPC estimates therefore form the basis of the current reference points for the assessment of the Baltic salmon stocks.

There is a considerable amount of uncertainty associated to these reference points. All the model parameters including PSPC are updated every year when new data become available, and comparisons of the assessment year's and the previous year's PSPC estimates are provided in the annual WGBAST report.

For salmon in AU 6 (Gulf of Finland), no analytical assessment model has been developed (see Section C.3 above). Preliminary Potential Smolt Production Capacity (PSPC) values have been proposed based on expert opinions but no stock–recruit data exist at the moment, precluding validation of these preliminary PSPC values. Thus, it is currently not possible to evaluate the management objectives for rivers in AU 6. Determination of status of rivers in AU 6 is instead based on a qualitative assessment taking into account trends in parr densities, smolt production and exploitation rates.

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