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Report of the ICES/BSRP Workshop on Developing and Testing Environmentally-Sensitive Stock-Recruitment Relationships of Baltic Herring and Sprat Stocks (WKSSRB)

2–5 April 2008

Ponza, Italy

ICES
International Council for the Exploration of the Sea

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Contents

Executive summary

The direct and indirect effects of climate-induced hydrographic change and the effect of the parental stock on five Baltic herring stocks and Baltic sprat were investigated. Specifically, WKSSRB reviewed, updated and validated recruitment-environment relationships developed by WKRPBH (ICES 2007b) for five distinct Baltic Sea herring stocks: the Western Baltic (WBH), the Main Basin (MBH), the Gulf of Riga (GRH), the Bothnian Sea (BSH) and the Bothnian Bay (BBH). The predictors to be included in the final recruitment models were selected on the basis of the parsimonious principle and the ecological criterion fulfilled simultaneously (ICES 2007b). Data were also updated, including a revised time series of temperature, Baltic Sea Index and the inclusion of the Bottom Depth Anomalies for sprat recruitment modelling.

Temperature was detected to be an important predictor for all Baltic herring stocks. Spawning stock biomass (SSB) was the major factor explaining recruitment success (R_s) for MBH and recruitment for GRH. For MBH, food supply was also a significant predictor, suggesting that a part of the changes in climate and hydrographic conditions may affect herring indirectly via prey availability. Despite regional variability, our analyses showed that temperature was the main variable together with parental stock size, determining recruitment success of Baltic herring stocks. The effect of temperature on recruitment is likely to be in part indirect by changing the zooplankton food supply.

As during the WKSSRB meeting new potentially useful environmental and fisheries data series appeared, it was possible to construct a completely new model for sprat. Parental effect (SSB), predation mortality by cod on 0-group sprat (PM), Bottom Depth Anomalies (BDA), and August Sea Surface Temperature (NASA8) were identified as significant predictors of sprat recruitment. Unfortunately, predation mortality data might be not available for the most recent years as it is not an operational variable. Therefore, the alternative model with cod total biomass (Cod_TB) as a proxy of predation mortality was constructed. For both models, SSB and the newly introduced BDA were the most important predictors.

Generally, models developed in WKRPBH (ICES 2007b) were confirmed for herring stocks and predictions generated by those models were satisfactory. Short term projections were re-run using recruitment models predictions and compared to RCT3 estimates of recruitment.

1 Opening of the meeting and adoption of agenda

2007/2/BCC05 An ICES/BSRP Workshop on Developing and Testing Environmentally-Sensitive Stock-recruitment Relationships of Baltic Herring and Sprat stocks [WKSSRB] (Chair: M. Cardinale, Sweden and P. Margonski, Poland) met in Ponza, Italy from 2–5 April 2008 to:

a) review the work on environment-recruitment relationships for Baltic herring and sprat stocks, especially by WKHRPB;
b) construct stock-recruitment relationships including environmental variables;
c) evaluate the performance of environmentally-sensitive stock-recruitment relationships in stock projections.

WKSSRB should report by 30 April 2008 to the attention of the Baltic Committee.

The Co-Chairs Max Cardinale and Piotr Margoński welcomed the participants (Annex 1) and introduced the agenda (Annex 2) for the workshop. The main objectives were clearly identified by the Terms of Reference adopted by the Council.

The agenda proposed by the Co-Chairs was discussed and adopted by the participants. Basically the first day was devoted to presentations provided by participants and plenary discussions on statistical analyses. Four subgroups were created: statistical analyses and recruitment modelling of herring (follow-up and modifications of last year results), statistical analyses and recruitment modelling of sprat (new analyses), short-term predictions including environmental variables, and report compilation and writing.

During the following days participants were working in sub-groups. Plenary sessions were organised to present workshop progress and discuss achieved results.

2 Introduction

A number of abiotic and biotic predictors for herring recruitment modelling were selected a priori on the basis of known ecological, biological and physiological processes. The predictors to be included in the final model were subsequently selected on the basis of the parsimonious principle and the ecological criterion fulfilled simultaneously (ICES 2007b). The ecological criterion implies that the sign of the relationship between certain variables cannot be accepted although it is statistically significant when lacking a sound ecological basis (Dippner and Ottersen, 2001). For example, there is no ecological explanation for zooplankton species to negatively affect fish condition (i.e., that more zooplankton results in a lower condition) and therefore such a relationship was discarded. If some of the relationships found in the best model selected by generalized cross validation (GCV) were not fulfilling the ecological criterion, the variable was excluded and the backward selection was continued. This implies that we might obtain recruitment models in which SSB is excluded as the model without SSB is statistically the most parsimonious. However, the number of recruits (or the recruitment success) in a fish species is generally related to egg number or SSB, a proxy of egg production, and thus the SSB effect should always be included when investigating recruitment-environment relationships (Myers and Barrowman, 1996; Cardinale and Hjelm, 2006). In particular cases, as for the WBH stock, where the time series is relatively short and/or the contrast in SSB is small, we might run the risk to exclude SSB on the basis of the parsimonious principle. Moreover, the effect of the SSB might be less evident when the SSB time series do not include values close to the origin but obviously its effect will increase if the stock does approach the lower range of the SSB values. On that basis, we decided that SSB should always be included in the recruitment models to be used for short term predictions purposes even when, with available data, SSB was excluded from the final model.

As a first step the models provided by the ICES/BSRP Workshop on Recruitment Processes of Baltic Sea herring stocks (ICES 2007b) and by Cardinale *et al*. (2008) were tested with updated data series. Models were modified when new data influenced the old models' performance. For sprat completely new models were calculated using a new set of possible explanatory variables.

3 Review of the work on environment-recruitment relationships for Baltic herring and sprat stocks, especially by WKHRPB

Max Cardinale reviewed the results from last year's recruitment modelling. The Baltic Sea hosts a number of different herring populations with considerable economic importance for the bordering countries. These populations inhabit local ecosystems with different abiotic and biotic conditions. The salinity gradient across the Baltic Sea is pronounced, from almost marine conditions in the Western Baltic to near fresh water conditions in the northern areas of the Bothnian Sea and Bothnian Bay. There is also a marked temperature gradient from the southern to the northern areas of the Baltic. As a result of the variable abiotic conditions, local ecosystem structure is likewise changeable, with e.g., differently structured zooplankton communities (Cardinale *et al*. 2008). Here we investigated the direct and indirect effects of climate-induced hydrographic change and the effect of the parental stock on five Baltic herring stocks. Specifically, we analyzed recruitment-environment relationships for five distinct Baltic Sea herring stocks; the Western Baltic (WBH), the Main Basin (MBH), the Gulf of Riga (GRH), the Bothnian Sea (BSH) and the Bothnian Bay (BBH). A number of hydro-climatic and biological variables were tested for their effect on recruitment. We used two proxies for recruitment; total recruitment (R: in numbers) or recruitment success (R_s: log (R/spawner biomass)), selected depending on the functional relationship between stock and recruitment. Temperature was detected to be an important predictor for all Baltic herring stocks, except for BBH. Spawning stock biomass (SSB) was the major factor explaining R_s for MBH and GRH, while for the other stocks SSB either did not affect R_s or the relationship between stock and recruitment could not be distinguished from a random process. Significant parental effects were found for MBH and GRH. For stocks for which complete zooplankton data were available, food supply was also a significant predictor, suggesting that a part of the changes in climate and hydrographic conditions may affect herring indirectly via prey availability. Despite regional variability, our analyses showed that temperature was the main variable together with parental stock size, determining Baltic herring recruitment success. The effect of temperature on recruitment is likely to be indirect by changing the zooplankton food supply.

For review of recruitment processes and detailed description of preformed analyses see the Report of the ICES/BSRP Workshop on Recruitment Processes of Baltic Sea herring stocks (ICES 2007b).

4 Presentations given by participants

The presentations given during the first day of the meeting covered (i) a report from the Ex Fish project on incorporating extrinsic drivers into fisheries management of the Baltic Sea, (ii) a review of last year's recruitment modelling results (see Section 3), (iii) an update of the time series from the Eastern Baltic and the Gulf of Riga, (iv) new recruitment-models, developed by Hannes Baumann, with respect to their further development and potential incorporation into operational models to be developed by WKSSRB, (v) a plan of the statistical analysis (see Section 6), and (vi) a review of processes affecting recruitment of open-sea and gulf Baltic herring stocks. A summary of the Rügen herring larvae survey was given during the 3rd day of the meeting.

Piotr Margoński presented the 'Incorporating extrinsic drivers into fisheries management (IN EX FISH) project experience'. The main aim of the project is to increase the responsiveness of fisheries management to a range of anthropogenic and non-anthropogenic forcing factors. Therefore, the potential explanatory variables influencing fish stock dynamics were reviewed and tested in stock-recruitment relationships. Project is dealing with various fish stocks of he North East Atlantic, the Baltic Sea , the West Iberian Sea, and the Mediterranean Sea RACs. In the Baltic Sea RAC area models were prepared for sprat, Gulf of Riga and Central Baltic herring, and Eastern Baltic cod stock. Central Baltic herring stock was used in the presentation as an example of carried out analyses. It was agreed within the project that the common procedure would be followed regarding data exploration: years (records) with missing values were removed, data were transformed to cope with outlier problem, correlation between explanatory variables was check by VIF and finally only those variables which presented the scientifically justified relation with recruitment were left in the model. The best model for the Central Baltic herring stock(s) included: SSB and sea surface temperature recorded in August.

George Kornilovs presented an update of the 2006 zooplankton and hydrological data for the Eastern Baltic and the Gulf of Riga. The data were submitted by the Latvian Fish Resources Agency which performs regular seasonal surveys in February, May, August and October. The winter of 2006 was the second coldest in the last 10 years, resulting in relatively low water temperatures in the winter and partly also in the spring. The summer water temperature of the upper layer in the eastern Baltic was relatively high, while in the Gulf of Riga it was rather low compared to the long-term average. In autumn the water temperature was high in both basins. The salinity in the Gotland Basin remained low in the upper 0–50 m level, while it remained at the same high level in the 50–100 m layer as the last four years, compared to the previous 15 years. The zooplankton data for the Eastern Baltic and the Gulf of Riga were updated for year 2006. The data were submitted by Latvian Fish Resources Agency which performs regular seasonal surveys in February, May, August and October. In 2006 the spring zooplankton abundance in the Gulf of Riga was comparatively low for the main Copepoda species *Eurytemora affinis* and *Acartia* spp., which is a characteristic pattern after cold winters. In summer the zooplankton biomass remained on a low level in comparison with long term average both for Copepoda and Cladocera species. In the Eastern Baltic in spring the zooplankton abundance was on an average level due to rather high level of *Pseudocalanus elongatus*, while the abundance of *Acartia* spp. was low. In summer the zooplankton abundance was on a low level for all Copepoda species as well as for Cladocera.

Daniel Stepputtis presented new recruitment-models, developed by Hannes Baumann, with respect to their further development and potential incorporation into operational models to be developed by WKSSRB. Baumann *et al*. 2006 investigated possible relationships between year class strength and sea-temperature, drift pattern of eggs and larvae and SSB. Whereby, two new models were developed. This work was reviewed (see Baumann *et al*. 2006) and their use for models to be developed by WKSSRB was discussed. In that way, recent development to establish an operational available drift index for sprat early life stages was presented. For more details, refer to Section 5.3.

Tiit Raid discussed processes affecting recruitment of the gulf and open-sea Baltic herring stocks and potential causes for the different recruitment patterns observed for these stocks. While the Gulf herrings spend the whole year within the big gulfs, open sea stocks perform annual migrations to and from spawning grounds located along the open-sea coasts of the Baltic Proper and also in the gulfs. In the open sea populations, abundant year classes appear in the periods of intense water exchange between the Baltic and the North Sea and consequently higher salinity waters. Intense water exchange favours vertical mixing of water layers and up-mixing of nutrients to support high biological production, including abundant stock of copepod *naupli,* in herring spawning and larval retention areas in the period of transfer of herring larvae to exogenous feeding (e.g. Rannak, 1974). In the gulf populations, strong year-classes (in the North-eastern Baltic) are formed mainly in warm springs with dominating westerly winds promoting rich biological production in the period of larval development and favouring their high survival (Rannak, 1971; Ojaveer, 1988; Raid, 1997; Grygiel, 1999). The positive correlation between zooplankton abundance and herring recruitment abundance has been revealed in several areas, including in the Gulf of Riga (ICES, 2005) and in the Gdansk (Grygiel, 1999; Parmanne and Sjöblom; 1982). The gulf and open-sea stocks showed different, often opposite recruitment pattern over the recent 30 years. Recruitment was generally high in the Central Baltic (mostly open sea stocks) in 1970–1980s, while it was mostly average or below average in the 1990–2000s. At the same time, the recruitment of the gulf stocks (Gulf of Riga herring and the Bothnian Sea herring) showed increasing trends from the historical lows in the 1970–1980s. The differences in recruitment dynamics probably indicate different responses by the open sea and gulf herring on recruitment formation conditions. There are also similarities in the recruitment pattern of gulf and open sea stocks however. Analyses of recruitment dynamics indicated that in both cases recruitment variability was different at different stock levels. When stock biomass was low, the recruitment variability was low, while at periods of high stock biomass, recruitment variability was higher. This may indicate that stock-related effects (stock size, condition, individual mean fecundity etc) were the dominating processes influencing recruitments at low stock levels. High variability of recruitment at high stock levels on the other hand may indicate the domination of other, particularly environmentally driven effects (e.g. survival at different stages of development). The domination of different recruitment formation factors at different stock levels may have implications when modelling the recruitment of a given stock. Consequently, the position of a stock on its historical trajectory of abundance or biomass should be considered in the recruitment model.

Christine Assmuth provided an overview of Rügen herring larvae survey (RHLS): A new recruitment index for WB-Herring and further works exploiting dynamics in larvae amount and activity. The RHLS started surveying up to 35 fixed stations in the Greifswalder Bodden, Strelasund and along the cost of Rügen and Usedom Island, since 1977. This area is the main spawning area of WB-Herring. The RHLS data series were judged as one of the highest temporally and spatially resolved survey datasets in the world – with a huge potential value in investigating processes of life history of herring – by external reviewers (from IMARES and IMR) and experts from the Institute for Baltic Sea Fisheries in Rostock. The total number of larvae per m^2, their stationary length distribution and hydrographic information were collected weekly from mid March to early July (around 10-14 weeks) every year on an annual basis. For every station the total number of larvae for each length interval is estimated by the fraction of mean length interval of 3 sub-samples (larvae length up to 1 mm below) and the total counted sample number. Corrected by volume of filtered water of the Bongo-gear and depth the result is the ratio of larvae for each length class per m^2. With these data series Oeberst *et al*. 2008 developed a new year-class index of spring spawning herring in ICES subdivisions 22–24, which is going to be used in the stock assessment of WB-Herring. The N20-Index defines the total number of larvae per m^2, which will reach a maximum length of 20 mm with high probability. The estimation of this new index takes into account the influence of water temperature on mean daily larvae growth by including the water temperature increase dependent on cruise begin and sampling time of every cruise itself. A varied number of realized cruises and sampled stations yield a bias mean length frequency in the total spawning area. Hence, a stratified mean method is used, based on five defined strata. The N20-Index is the sum of the estimated mean length distribution overall cruises – presupposing the larvae will actually reach a length of 20mm during the duration of every cruise till the next cruise – based on stratified mean surface temperature. So the growth of larvae between the subsequent cruises is taken into account and the N20-Index can be used as unbiased indicator for the year class. A second important step to get a deeper insight into WB-Herring stock-activities in relation to climatic changes was done by Stürmer *et al*. 2007. They investigated the spawning behaviour by estimating the first significant hatch date. For every year the timing of hatching onset was recalculated for the first cohort of larvae, which survived with a length of 10 mm (i.e. started to feed). Moreover, an estimated last hatch date, where a certain amount of freshly hatched larvae dominate, is investigated. Regarding time trend, it is apparent, that the first successful hatch date shifts backwards in time and the last hatch time-point stays constant. Both generated time series were put into relation to different climatologic parameters. A closer, relationship could be uncovered with frost- and ice-air-temperatures, and the estimated hatch date of WB-Herring. An increasing amount of averaged frost- or ice-days influences a later hatch time point.

5 Overview on data for statistical analyses

5.1 New Sea Surface Temperature Data Series from Remote Sensing

As in some cases the monthly average values of sea surface temperature calculated on the basis of data downloaded from the ICES Data Centre was problematic due to unbalanced spatial and temporal coverage of different Baltic Sea areas, it was decided to test possibility of including NASA satellite sources (http://www.cdc.noaa.gov/cdc/data.noaa.ersst.html, 2x2 deg. grid, file: sst.mnmean.nc) in our analyses.

NASA data were used for Central Baltic Herring (CBH) and sprat stocks.

Monthly averages of SST calculated of points 1–15 and 4–15 were used for sprat and CBH analyses, respectively (Figure 5.1.1).

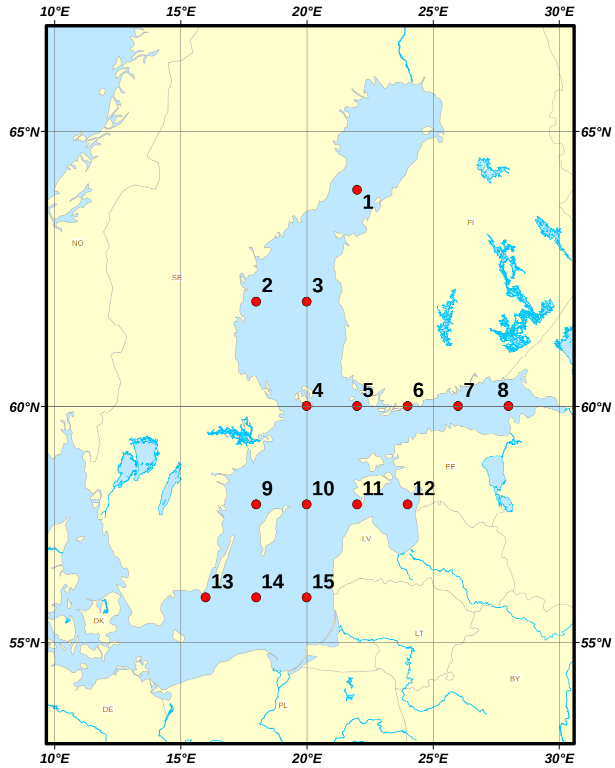

Figure 5.1.1. Central points of 2x2 degree grid of NASA SST measurements used for sprat and CBH analyses. (http://www.cdc.noaa.gov/cdc/data.noaa.ersst.html, file: sst.mnmean.nc)

5.2 Qualitative measures for age/size structure of the sprat spawning stock

Usually (or at least for other stocks), spawner abundance is not directly proportional to egg production. Moreover, the relative fecundity of fish usually increases with size/age. Hence the size/age structure of a stock and its development over time could be a useful link between SSB and recruitment. Therefore one goal of the recent workshop was to investigate whether the stock structure has an influence on the recruitment success for Baltic sprat.

Two different measures were calculated to give a qualitative measure for the stock structure of Baltic sprat.

a) Mean weight of spawning stock weighted by the spawning proportion per age-classes and year:

During the WKHRPB workshop a mean weight was used as an explanatory variable. In this case, a simple average of weight at age of year class 3 and older was calculated based on the sprat WECA (weight in catch)/WEST(weight in stock) table of the WGBFAS 2006 report (ICES 2006). This index did not include the abundance of particular age groups.

During current workshop a new index was developed taking into account the different numbers in each age group. Additionally, when looking at the effect of stock structure, only spawning individuals should be relevant. Therefore, number of spawning stock per age was calculated using the total stock number at age (output from XSA) and MATPROP table (proportion per age of mature at spawning time) (ICES 2007a). The relative proportion of each age group for a given year was used to weight the mean individual weight of this age group.

This procedure was done for all age groups older than two and three years, respectively:

- mean weight of spawning stock over all ages (1 to 8+)
- mean weight of spawning stock over all ages > 2 (2 to 8+)
- mean weight of spawning stock over all ages > 3 (3 to 8+)

b) Mean age of spawning stock weighted by the spawning proportion per age-class and year:

In a similar way, as mentioned above, the mean age per year was calculated.

5.3 Bottom Depth Anomaly

Previous work by Baumann *et al*. has shown that recruitment variability was highly depending on the drift of sprat larvae (Baumann *et al*. 2004, Baumann *et al*. 2006). Hereby, the survival of larvae (and the recruitment) was higher in, so called, retention years (Figure 5.3.1. left) – years where drifters stay in deeper areas. In, so-called, dispersion years (Figure 5.3.1. right), recruitment was found to be relatively low. Consequently, Baumann *et al*. (2006) developed an index, which captures the state of larvae drift. This Bottom Depth Anomaly (BDA) takes into account the change of bottom depth under modelled drifters over a given simulation period (see Hinrichsen *et al*. 2005 for a detailed introduction of the hydrodynamical model and the Lagrangian particle tracking method).

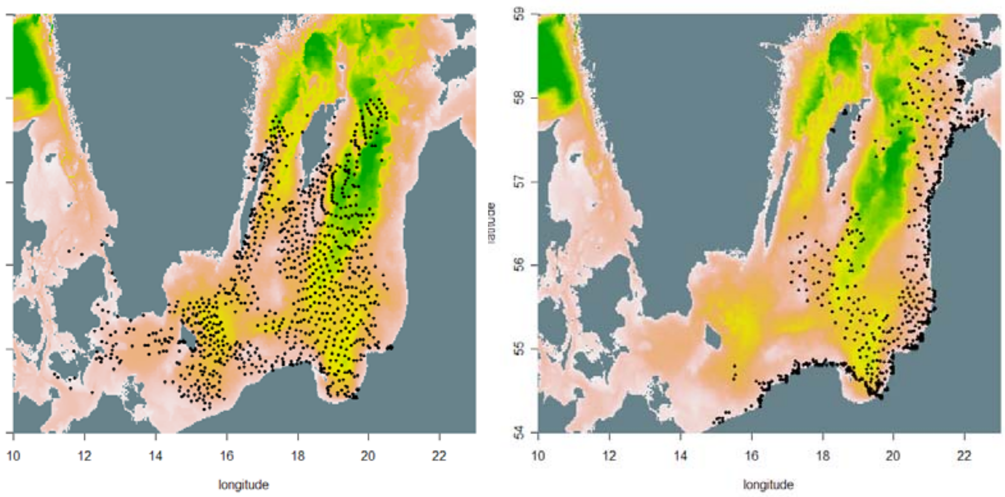

Figure 5.3.1. Two different scenarios of particle drift. Left: retention (2003 data), Right: dispersion (2005 data).

The dataset presented by Baumann *et al*. covers a time period from 1979-2003. This BDA time series was an excellent predictor for sprat recruitment (in a model with SSB). Therefore, the BDA should be included in environmental sensitive stock-recruitment relationships.

However, using the BDA by Baumann (2006) is limited since the time series is only available until 2003. Nevertheless, the underlying hydrodynamical model is calculated for a given year with driving data (atmospheric and river run-off data) available earliest in May of the following year, which means after the meeting of the Baltic Fisheries Assessment Working Group.

Therefore, a new data series (1999-2007) was calculated using a operational hydrodynamical model operated by the Bundesamt für Seeschifffahrt und Hydrographie (www.bsh.de). This model is calculated in real time and therefore, drift date and calculated BDA will be available each year at a time of WGBFAS meeting for the year prior to the meeting.

It was shown by Baumann *et al*. that simulations starting at day 190 each year (and lasting 50 days) have the highest correlation to recruitment. Therefore, the same settings were used for calculations of the new data series.

Since, the underlying model changed, some changes in particle tracking had to be implemented. The most important one was the need to reduce the number of drifters released into the model domain (see Figure 5.3.2.).

For the new data series, 1000 particles (compared to 2671 in the simulation by Baumann *et al*. (2006)) were distributed over all areas with water depth deeper than 40m and south of 58.12°N.

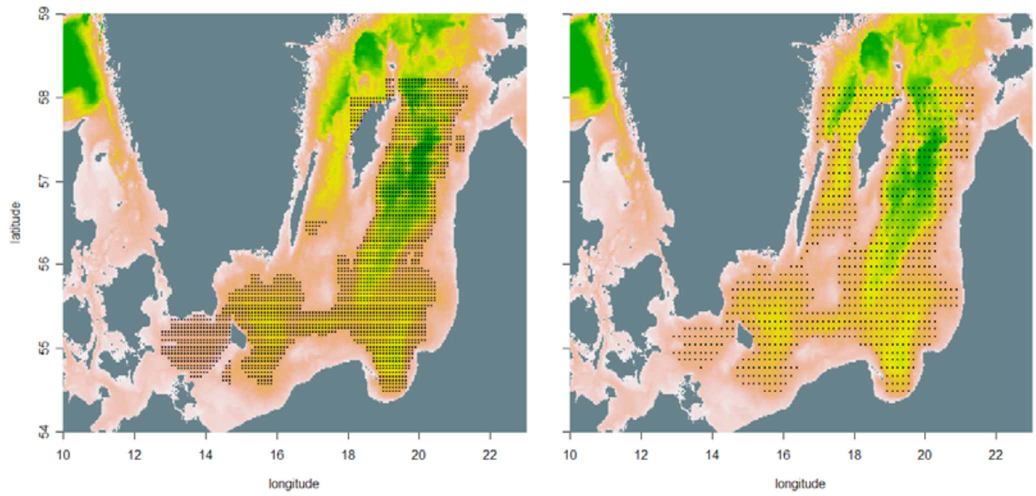

Figure 5.3.2. Comparison of release grid as used by Baumann *et al*. 2006 (left) and the new drift simulations (right).

Slight problems occurred, since the BDA is calculated as index over all model years, which might be somehow tricky when combining two different data series. Nevertheless, both data series were combined successfully by averaging results (mean bottom depth per day of the simulation) of overlapping years prior to the calculation of the BDA.

Since no reference for this new BDA-time series is available so far, please contact Daniel Stepputtis (daniel.stepputtis@vti.bund.de) for further information.

5.4 Gulf of Riga Herring

There was a shift of Gulf of Riga herring recruitment in late 1980s and SSB increased sharply during that time. The biomass of ages 5+ increased as well (Figure 5.4.1.). In contrast weight-at-age 3+ dropped in the same time. Positive values of Baltic Sea Index prevailed starting from late 1980s. It caused an increase of an average spring sea surface temperature. From the beginning of 1990s feeding conditions improved on average however a considerable year to year variability was observed during this period.

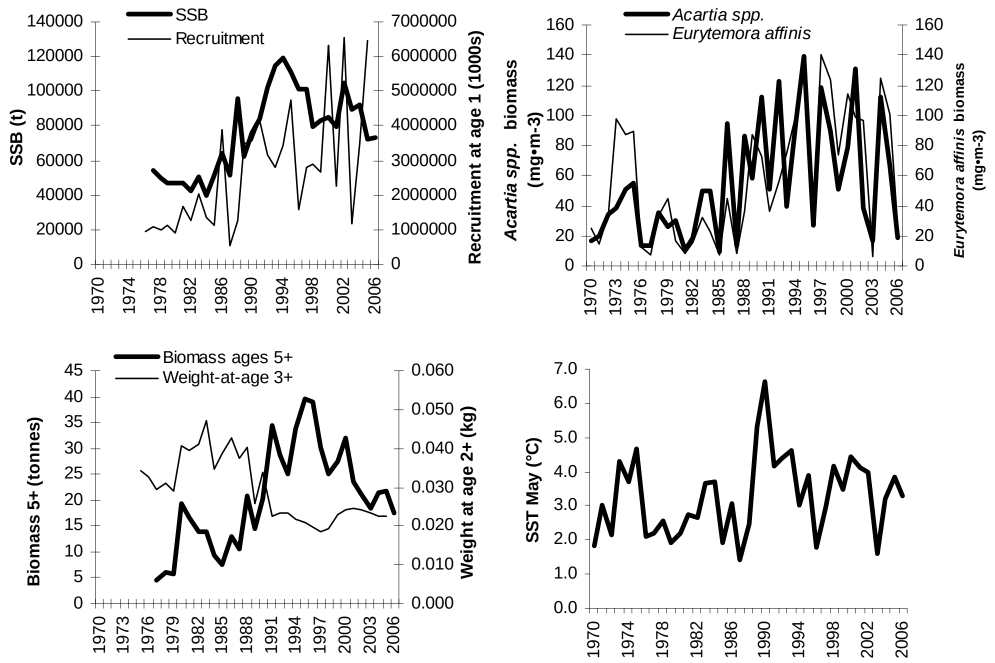

Figure 5.4.1. Biotic and abiotic time-series used for the Gulf of Riga herring analyses.

5.5 Central Baltic Herring (SD25-29&32 exl. Gulf of Riga)

Spawning Stock Biomass (SSB) and recruitment presented decreasing trends since the mid 1970s, with a slight increase during the last few years (Figure 5.5.1.). A similar pattern might be observed for the weight-at-age 3 and the biomass of ages 5+. Spring biomass of the copepods *Acartia* spp. and *Temora longicornis* increased strongly after the end of 1980s, whereas the biomass of the copepod *Pseudocalanus acuspes* declined. The August sea surface temperature (NASA 8) increased significantly over the last 20 years.

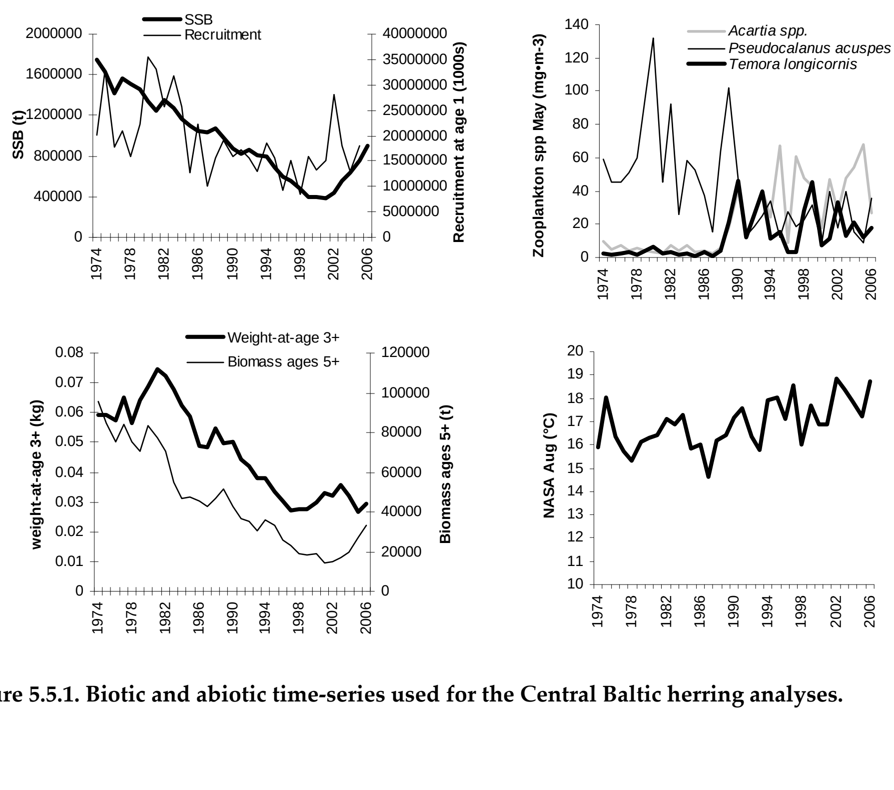

Figure 5.5.1. Biotic and abiotic time-series used for the Central Baltic herring analyses.

5.6 Baltic sprat (SD 22-32)

Sprat SSB started to increase dramatically since the beginning of 1990s (Figure 5.6.1.). Also recruitment was observed at much higher level during that period however a pronounced year to year variability appeared. Obviously predation mortality (calculated by MSVPA) caused by cod dropped with the decrease of cod biomass. Both summer sea surface temperatures revealed a significant increase since the late 1980s. No clear pattern may be found in BDA. Positive values of Baltic Sea Index prevailed starting from late 1980s.

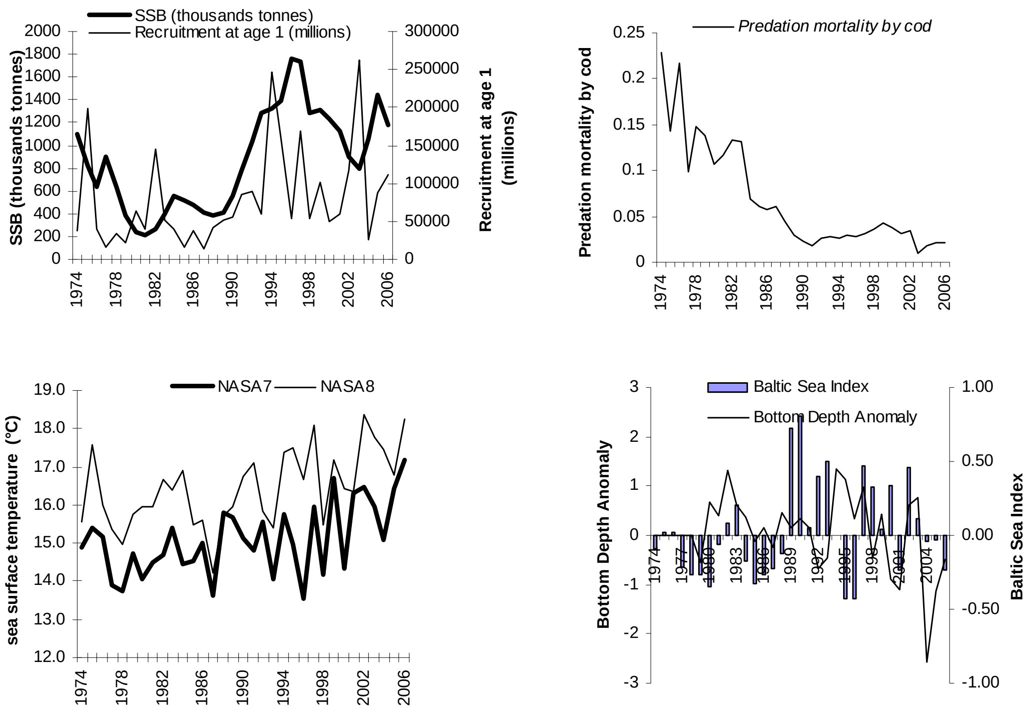

Figure 5.6.1. Biotic and abiotic time-series used for sprat analyses.

6 Environmentally-sensitive stock-recruitment relationships

6.1 Introduction and Results Overview

As described by Stige *et al*. (2006) and by Cardinale and Hjelm (2006), the logarithm of the ratio between the annual numbers of recruits (R) and spawning stock biomass (SSB), is defined as recruitment success (R_s; see also Beverton 2002). According to the models by Ricker (1954) and Beverton and Holt (1995), this ratio is a linear function of SSB:

(1) $$R_s = \ln (R \bullet SSB\text{-}1) = a + b \bullet SSB + f(1) + f(2)$$

The other effects can be modelled as predictors (f) in equation (1). The point here is that the number of recruits in a fish species is generally related to egg number or SSB, a proxy of egg production and thus the SSB effect should always be scaled out when investigating recruitment-environment relationships (Myers and Barrowman, 1996; Cardinale and Hjelm; 2006). However, since SSB appears both as dependent and independent variable, this would run the risk to detect spurious correlations instead of the actual relation between SSB and recruitment success. In order to avoid this, we investigated the relationship between SSB and recruitment for a random effect. This tested the probability that the relationship between stock and number of recruits is equivalent to a random process. The test was performed dividing the scatter plots of the SSB-R relationship in 4 quadrants and testing if the frequency of observations in the quadrants is different from random (i.e. not statistically different frequency of observation between the different quadrants) using a t-test. For stocks where the frequency in the different quadrants was different from a random process, R_s was used as response in (1). Otherwise, R_s was considered to be not related to SSB or the relationship between SSB and R could not be distinguished from a random process (in the range of available data) and thus the number of recruits should be used as response. This will give:

(2) $R = a + b \bullet SSB + f(1) + f(2)$

The other effects can be modelled as predictors (f) in equation (2).

New or updated stock-recruitment models including environmental explanatory factors were calculated for Central Baltic and Gulf of Riga Herring stocks and for sprat (for detail see Sections 6.4–6.6). Those models were used to estimate recruitment for short term predictions. There were many different reasons that we decided not to update models and not to provide recruitment estimates for Western Baltic, Bothnian Sea, and Bothnian Bay Herring stocks. Details are presented in Sections 6.2. and 6.3. Final recruitment models are summarized in Table 6.1.1.

For the **Central Baltic Herring stock,** the last year best model (ICES 2007b) was used as a starting point. This model included SSB, Weight at Age 3+, Baltic Sea Index, August Sea Surface Temperature, and spring *Pseudocalanaus* biomass. The same model was fitted with the new assessment data for SSB and R_s and with revised explanatory variables (more accurate WAA3pl, August sea surface temperatures (NASA8), and a new BSI). Using the satellite SST data improved model fitting. As alternative, a simpler model was constructed as the effect of *Pseudocalanus* and BSI was weak. This model was not only simpler but also presented lower GCV score and it was still explaining almost 80% of deviance. Analysis of residuals confirmed no violations of normality and constancy of variance assumptions.

A similar approach was used for the **Gulf of Riga Herring stock**: the best 2007 model was run using new estimations for SSB, number of recruits, and May Sea Surface Temperature. The general model performance remained almost unchanged (Dev.expl. = 78.3%). The estimations of both the updated and the last year models were compared and their fit is very similar. The updated model shows less extreme values during early 1990s and in 2001 following the lower values produced by the most recent assessment. Both models are not able to follow the very high number of recruits observed since 2000.

In the case of **Sprat stock** the 2007 model (ICES 2007b) including SSB, Baltic Sea Index, spring *Pseudocalanus* biomass, and Predation Mortality by cod, running with updated data series was not valid any more. As during the WKSSRB meeting new potentially useful environmental and fisheries data series appeared it was possible to construct a completely new model for sprat (for details see the Section 6.6. and Annexes 4 & 5). Model which included predation mortality by cod (PM) was tested at first. The analysis of residuals indicated no violations of assumptions and the new model was relatively well following the high recruitment success values. Taking into account a considerable increase of deviance explained (possible overfitting) and much better fit to data, this model was regarded as the best model. The main problem with this model is that predation mortality data (PM) might be not available for the most recent years as it is not an operational variable. Therefore, the alternative model with cod total biomass (Cod_TB) as a proxy of predation mortality was constructed. The alternative best model is explaining over 80% of deviance. Recruitment success relation with SSB and NASA7 is linear and with BSI almost linear. Only in the case of BDA the pattern is more complicated (edf close to 3). However, a slight violation of normality and constancy of variance assumptions is observed at low sprat SSB values. This model has some problems with high recruitment success values.

Table 6.1.1. Results of the recruitment analysis for the Central Baltic (CBH), Gulf of Riga (GRH) herring and sprat stocks: Generalized cross validation (GCV) for models developed in 2007 and updated models, total deviance explained by each model, time interval covered and the variables explaining the largest proportion of the model deviance (LED).

Stock	Response	Model	Deviance explained	GCV	time interval	LED
CBH	Rs	Rs ~ SSB + WAA3pl + BSI + SST8 + PSE	81.4%		1974-2004	WAA3+, SSB
CBH	Rs	Rs ~ SSB + wWAA3pl + BSI_new + NASA8 + PSE	80.5%	0.0062	1974-2005	SST, SSB
CBH	Rs	Rs ~ SSB + wWAA3pl + NASA8	76.9%	0.0058	1974-2005	SST, WAA3+
GRH	R	R ~ SSB + SST5	78.5%		1977-2004	SSB
GRH	R	R ~ SSB + SST5	78.3%		1977-2005	SSB
sprat	Rs	Rs ~ SSB + BSI + PSE + PM	69.5%	0.3559	1974-2004	
sprat	Rs	Rs ~ SSB + PM + BDA + NASA8	91.6%	0.0057	1974-2005	BDA, SSB, NASA8
sprat	Rs	Rs ~ SSB + BSI + BDA + NASA7	80.7%	0.0072	1974-2005	BDA, SSB

6.2 Western Baltic herring (D IIIa & SD22-24)

According to Cardinale *et al*. (2008) the only predictor of recruitment dynamic in the final WBH model was the BSI. Following the benchmark assessment carried out during HAWG in 2008, spawning stock biomass and recruitment of WBH were re-estimated as well as an estimate of the larval abundance was provided and used as recruitment index for the WBH stock (ICES 2008). After the benchmark assessment, the perception of the stock trend was slightly changed as the stock showed a decrease of both SSB and R in the last years (ICES 2008) compared to the latest assessment estimates (ICES 2008). In order to account for the newly estimated stock trends and larvae index availability, the analysis of recruitment process was re-made using both XSA age 0 and larval abundance estimates as response variable in the recruitment model. In both cases, no satisfactory model was found. A reason for that might be (i) the shortness of the time series and (ii) the lack of zooplankton estimates for the Western Baltic. Thus it was decided that no recruitment estimates for short-term predictions will be calculated.

6.3 Bothnian Sea herring (SD30) and Bothnian Bay herring (SD31)

SSB did not affect R_s for either the BBH or the BSH stocks and recruitment (as number of individuals; R) was used as response for modelling recruitment processes (Cardinale *et al*. 2008). Temperature (SST_{June}) was selected as an important predictor for the BSH stock explaining 62.3% of the deviance in the final model. No satisfactory model was found for the BBH stock. Potential reasons for the failure to find a significant model for the BBH stock and for the decision made not to conduct short term prediction for either stocks are that i) complete time series of potentially important variables, such as, zooplankton are missing for these areas, and ii) the assessment data are currently unreliable, as they are based solely on commercial CPUE, with no fishery independent tuning series available.

6.4 Gulf of Riga Herring

The last year best model (ICES 2007b) as presented below was used as a starting point for the analyses on the herring stock in the Gulf of Riga that were carried out during the workshop.

```
Family: Gamma         Link function: log

Formula:       RECR ~ s(SSB, k = 4) + s(SST5, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 14.64810    0.06098   240.2   <2e-16 ***

Approximate significance of smooth terms:
          edf Est.rank     F  p-value
s(SSB)  1.000        1 26.15 3.11e-05 ***
s(SST5) 1.989        3 15.07 1.00e-05 ***

R-sq.(adj) =   0.58   Deviance explained = 78.5%
GCV score = 0.12141   Scale est. = 0.10411   n = 28
```

As updated versions of the explanatory variables WAA3pl and BSI were available, their effects were tested for the Gulf of Riga recruitment model, but the model defined the last year was found to be robust and still valid (results not presented).

Thus, the model was run using new estimations for SSB and number of recruits. The effect the parental component (SSB) and sea temperature in May (SST5) were still statistically significant ($p<0.01$). The effect of SST5 is confirmed as an asymptotic curve. On the contrary, the functional response of recruitment to increased SSB is changed from a simple positive linear relationship to a more classical Beverton and Holt R-S relationship. The asymptotic level is reached for SSB values >75-80 * 10^3 tons (Figure 6.4.1).

General model performances remained almost unchanged (R-sq = 0.54; Dev.expl. = 78.3%).

```
Formula:       RECR ~ s(SSB, k = 4) + s(SST5, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 14.65749    0.06074   241.3   <2e-16 ***

Approximate significance of smooth terms:
          edf Est.rank      F  p-value
s(SSB)  2.266        3  6.293  0.00273 **
s(SST5) 2.263        3 14.941 1.19e-05 ***

R-sq.(adj) =   0.54   Deviance explained = 78.3%
GCV score = 0.13219   Scale est. = 0.10699   n = 29
```

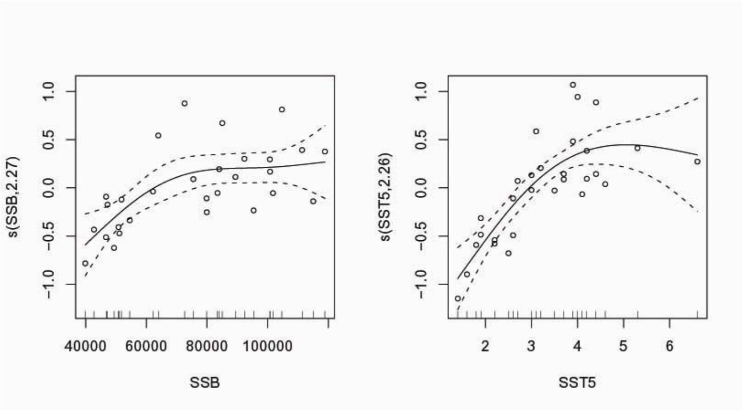

Figure 6.4.1. Effects of SSB and SST5 on the number of herring recruits in the Gulf of Riga.

The estimations from the updated model (red line) were compared with the last year estimations (black line) and with observations (dots) (Figure 6.4.2.). The patterns described by the two models were very similar, with an evident increase in the recruitment level and variation from 1989. The revised model shows less extreme values during early 1990s and in 2001 following the lower values produced by the most recent assessment. As expected on the basis of the last year results, the Gulf of Riga model of herring recruitment was not able to catch the very high number of recruits observed since 2000.

The 2006 forward projection from the GAM model was compared with estimation from RCT3 and it was found only 25% higher (Figure 6.4.2. right panel).

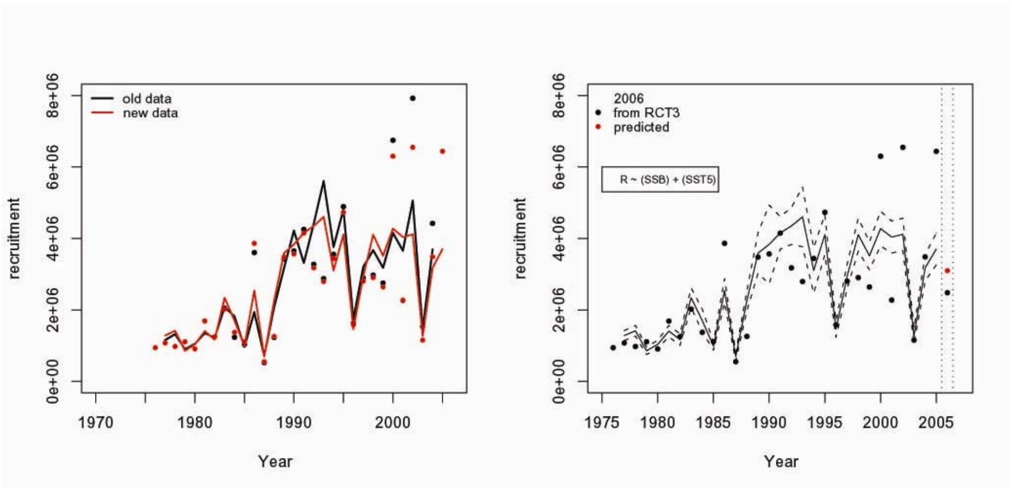

Figure 6.4.2. Comparison of performance of 2007 model with the updated one (left). Updated model (+/- SE intervals) and its 2006 prediction (right).

6.5 Central Baltic Herring (SD25-29&32 exl. Gulf of Riga)

The last year best model (ICES 2007b) as presented below was used as a starting point for the analyses carried out in 2008.

```
Family: Gamma          Link function: identity

Rs ~ s(SSB, k = 3) + s(WAA3pl, k = 3) + s(PSE, k = 4) + s(SST8,
    k = 4) + s(BSI, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
```

```
(Intercept)  3.00048    0.03588   83.62   <2e-16 ***

Approximate significance of smooth terms:
            edf Est.rank      F  p-value
s(SSB)    1.822        2 13.272 0.000180 ***
s(WAA3pl) 1.174        2  8.462 0.001972 **
s(PSE)    1.955        3  2.772 0.066451 .
s(SST8)   1.740        3  2.637 0.075890 .
s(BSI)    1.998        3  6.538 0.002635 **

R-sq.(adj) =   0.76   Deviance explained = 81.4%
GCV score = 0.0064026   Scale est. = 0.0044014  n = 31
```

The last year model was fitted with the new assessment data for SSB and R_s and with an additional point from the last year estimation (2005). Revised explanatory variables were available (more accurate WAA3pl, August sea surface temperatures (NASA8) and a new BSI). They were used running the updated model.

In the updated version of the CBH model for the recruitment success the deviance explained remained at comparably high level, but the biomass of *Pseudocalanus* (PSE) and the Baltic Index (BSI) still presented quite weak effects and their statistical significance in the last year model was even weaker.

```
Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(PSE, k = 4) + s(NASA8,
    k = 4) + s(BSI_new, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01124    0.03677    81.9   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB)     1.872        2 11.168 0.000366 ***
s(wWAA3pl) 1.000        1 10.715 0.003188 **
s(PSE)     1.905        3  1.469 0.247901
s(NASA8)   1.000        1 24.479 4.63e-05 ***
s(BSI_new) 1.000        1  0.648 0.428685

R-sq.(adj) =  0.748   Deviance explained = 80.3%
GCV score = 0.0062272   Scale est. = 0.0047138  n = 32
```

Thus, we tested alternative reduced models that did not include one or both PSE and BSI.

Excluding BSI only:

```
Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(PSE, k = 4) + s(NASA8,
    k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01138    0.03652   82.45   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB)     1.868        2 11.232 0.000325 ***
s(wWAA3pl) 1.000        1 10.621 0.003192 **
s(PSE)     1.923        3  1.466 0.247532
s(NASA8)   1.000        1 27.291 2.04e-05 ***

R-sq.(adj) =  0.749   Deviance explained = 79.8%
GCV score = 0.0059038   Scale est. = 0.004651  n = 32
```

Excluding only PSE :

```
Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(NASA8, k = 4) + s(BSI_new,
    k = 4)

Parametric coefficients:
```

```
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01163    0.03779    79.7   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB)     1.793        2 11.236 0.000304 ***
s(wWAA3pl) 1.174        2  7.474 0.002723 **
s(NASA8)   1.000        1 23.609 4.86e-05 ***
s(BSI_new) 1.000        1  0.538 0.469728

R-sq.(adj) =  0.734   Deviance explained = 77.7%
GCV score = 0.0061207   Scale est. = 0.0049793  n = 32
```

Excluding both PSE and BSI (best model):

```
Formula:
Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(NASA8, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01206    0.03763   80.05   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank     F  p-value
s(SSB)     1.829        2 11.71 0.000214 ***
s(wWAA3pl) 1.000        1 13.58 0.001005 **
s(NASA8)   1.000        1 26.27 2.14e-05 ***

R-sq.(adj) =  0.735   Deviance explained = 76.9%
GCV score = 0.0058104   Scale est. = 0.0049335  n = 32
```

The last model was not only the most parsimonious including only three response variables, but also the best one on the basis of the GCV criteria (lowest GCV). At the same time it maintained elevated capabilities to fit the data and explain the temporal variability in recruitment success (R-sq = 0.735; Dev.expl = 76.9%).

Evaluation of the covariate effects substantially confirmed the same functional relationships observed in the last year model. The main difference was a more evident positive effect of sea temperature in August (NASA8) that changed to a linear relationship (Figure 6.5.1.). The SST8 effect in the previous year model was strongly affected by the occurrence of an extremely low value in 1995 (12.08°C). The use of the remote sensing data time series did not confirm this outlier in the sea surface temperature, with a consequent improved fitting of the variable effect.

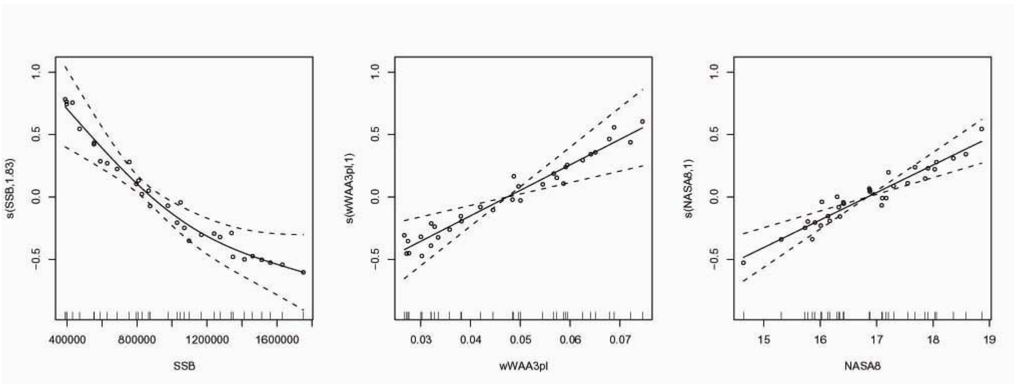

Figure 6.5.1. Effects of SSB, wWAA3pl, and NASA8 on recruitment success of CBH (*best model*).

Also the model residuals were appropriately distributed according to the main assumptions of normality and constancy of variance (Figure 6.5.2.).

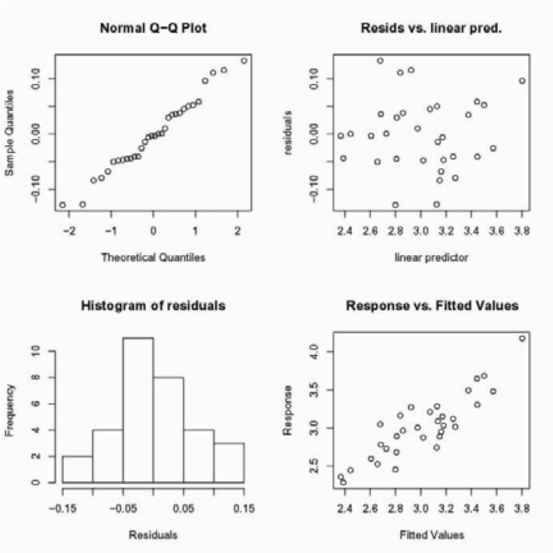

Figure 6.5.2. Analysis of residuals for the selected *best model*.

Finally the estimations from the *best model* (red line) were compared with the last year estimations (black line) and with observations (dots). As expected the two models behaved in a very similar way, following the same pattern throughout the 31 years of the time series (1975–2004). Slight but negligible differences were found in mid 90s. Thus, the current *best model* was run one year forward to estimate recruitment success in 2006 and the value was compared with the RCT3 estimation, even if they cannot be considered completely independent because both based on summer sea surface temperature. As shown in Figure 6.5.3. the value of 3.03 predicted by the *best model* is well comparable with the RCT3 estimation of 2.79.

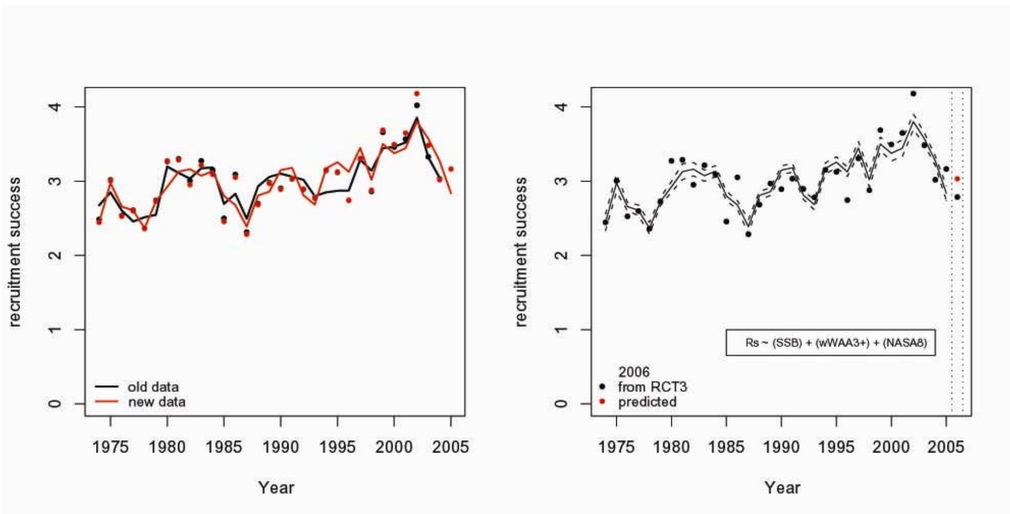

Figure 6.5.3. Comparison of performance of 2007 model with the updated one (left). Updated model (+/- SE intervals) and its 2006 prediction (right).

6.6 Baltic sprat (SD 22-32)

We run the 2007 sprat model (ICES 2007b) with updated data series and changed to Gamma distributed:

```
Family: Gamma  Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4) + s(BSI_newCM, k = 4) + s(PSE, k = 4) +
    s(PM, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)    4.387      0.126   34.81   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Est.rank     F p-value
s(SSB_new)   1.000        1 0.980   0.331
s(BSI_newCM) 1.625        3 1.624   0.207
s(PSE)       1.000        1 2.339   0.138
s(PM)        1.000        1 1.539   0.225

R-sq.(adj) =  0.173   Deviance explained =   27%
GCV score = 0.032672   Scale est. = 0.027103  n = 33
```

Unfortunately, the 2007 model with new data was not valid any more.

Fortunately, during the WKSSRB meeting new potentially useful environmental and fisheries data series appeared (Table. 6.6.1). Therefore, a sprat model revision was possible.

Table. 6.6.1. Complete list of data available for the 2007 sprat model revision. Correlation with Sprat Recruitment Success is also presented. Data marked with asterix are presenting R>0.15. Data shadowed were used for construction of the best sprat model in 2007. Right panel presents data selected for further 2008 analyses; for variable codes, see Annex 3.

Correlations of the variables

	Rs_new	
NASA1	-0.147	
NASA2	-0.060	
NASA3	0.070	
NASA4	0.110	
NASA5	0.085	
NASA6	0.167	*
NASA7	0.277	*
NASA8	0.326	*
NASA9	0.224	*
NASA10	0.026	
NASA11	-0.137	
NASA12	0.016	
SI	-0.148	
BSI_new	0.139	
IC	-0.101	
ACA	-0.124	
TEM	-0.072	
PSE	0.454	
CLA	-0.136	
SSB_new	-0.380	
PM	0.314	
MWSS	0.286	*
MWSS2pl	0.332	*
MWSS3pl	0.349	*
BDA	0.704	*
MASS	0.186	*
Cod_TB	0.335	*

selected for further analyses

SSB_new	those of 2007 model (after revision and updating)
BSI_new	
PSE	
PM	
NASA6	plus others which seem do be promissing
NASA7	
NASA8	
NASA9	
MWSS	
MWSS2pl	
MWSS3pl	
BDA	
MASS	
Cod_TB	

Furthermore, the cross correlation between potentially useful parameters (see Table 6.6.1) was checked using Variance inflation factor-test (VIF) and parameters with VIF>5.0 were excluded. Remaining parameters are listed in table. 6.6.2.

Table. 6.6.2. List of variables successfully verified by VIF test (VIF<5.0). As predation mortality (PM) is not operational data series the other initial combination of variables with cod total biomass (Cod_TB) was tested as well (right panel)

Variance inflation factors

	GVIF
NASA6	2.94
NASA7	3.56
NASA8	3.63
NASA9	4.62
BSI_newCM	1.84
BDA	1.59
MASS	1.85
MWSS3pl	3.93
SSB_new	4.45
PSE	2.33
PM	2.24

Variance inflation factors

	GVIF
NASA6	2.99
NASA7	3.4
NASA8	2.37
BSI_new	2.14
BDA	1.69
MASS	1.79
MWSS3pl	3.64
SSB_new	4.97
PSE	2.61
Cod_TB	4.47

Model including PM was tested at first.

As four SST times series were identified, four models each of them including one SST variable were constructed and the model presenting the lowest GCV score was selected (model with August temperature):

```
Family: Gamma          Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_newCM, k = 4, bs = "cs") +
    s(PM, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") + s(MWSS3pl,
    k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") + s(BDA, k = 4,
    bs = "cs") + s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.44897    0.05208   85.43   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                   edf Est.rank      F  p-value
s(SSB_new)   2.889e+00        3 11.847  0.00019 ***
s(BSI_newCM) 1.720e+00        3  1.708  0.20271
s(PM)        1.927e+00        3  5.451  0.00811 **
s(PSE)       4.961e-01        1  2.110  0.16438
s(MWSS3pl)   4.787e-06        1  0.019  0.89305
s(MASS)      2.381e-06        1  0.086  0.77325
s(BDA)       1.006e+00        3 22.809 3.18e-06 ***
s(NASA8)     7.762e-01        2  6.237  0.00919 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.885   Deviance explained = 91.6%
GCV score = 0.0057261   Scale est. = 0.0036449  n = 27
```

Due to very low values of smoothers edfs of mean weight of spawning stock age 3 plus (MWSS3pl) and mean age of spawning stock (MASS) it is possible to construct simpler model and remove those variables:

```
Family: Gamma         Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_newCM, k = 4, bs = "cs") +
    s(PM, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") + s(BDA,
    k = 4, bs = "cs") + s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.44897    0.05208   85.43   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                edf Est.rank      F  p-value
s(SSB_new)   2.8886        3 11.847  0.00019 ***
s(BSI_newCM) 1.7196        3  1.708  0.20271
s(PM)        1.9270        3  5.451  0.00811 **
s(PSE)       0.4960        1  2.110  0.16438
s(BDA)       1.0058        3 22.809 3.18e-06 ***
s(NASA8)     0.7762        2  6.237  0.00919 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.885   Deviance explained = 91.6%
GCV score = 0.0057261   Scale est. = 0.0036449  n = 27
```

Removing insignificant variables (BSI and PSE) one at the time enabled to create a simpler model with lower GCV score:

```
Family: Gamma         Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(PM, k = 4, bs = "cs") +
    s(BDA, k = 4, bs = "cs") + s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45438    0.05161   86.32   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Est.rank      F  p-value
s(SSB_new) 2.9384        3 18.212 1.19e-05 ***
s(PM)      2.0124        3  6.136  0.00474 **
s(BDA)     2.3293        3 25.290 1.25e-06 ***
s(NASA8)   0.9832        2  7.195  0.00515 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.878   Deviance explained = 91.6%
GCV score = 0.0054041   Scale est. = 0.00355   n = 27
```

The same model was calculated without bs='cs' parameter (*the best model*):

```
Family: Gamma         Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4) + s(PM, k = 4) + s(BDA, k = 4) + s(NASA8,
    k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   4.4537     0.0522   85.32   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB_new) 2.846        3 15.760 3.44e-05 ***
s(PM)      2.368        3  6.431  0.00404 **
```

```
s(BDA)     2.533        3 24.661 1.81e-06 ***
s(NASA8)   1.000        1 11.083  0.00391 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.874   Deviance explained = 91.6%
GCV score = 0.0056897   Scale est. = 0.0036359  n = 27
```

Figure 6.6.1. presents the response of sprat recruitment to changes of identified explanatory variables. Effect of August sea surface temperature is linear but the relation with the rest of variables is more complicated. Increasing predatory mortality causes a decrease of recruitment success at relatively low PM values. Further PM increase will not cause additional reduction of R_s but this part of relation is based on very few data points.

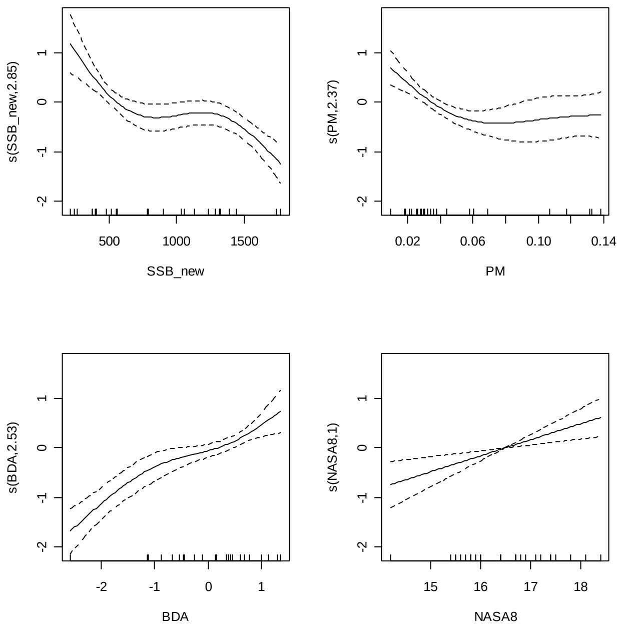

Figure 6.6.1. Effects of SSB, PM, BDA, and NASA8 on recruitment success of sprat (*best model*).

Comparison of the *best model* of 2008 with the 2007 one is presented in Figure 6.6.2. The current model is relatively well covering high recruitment values (at least much better than the 2007 one).

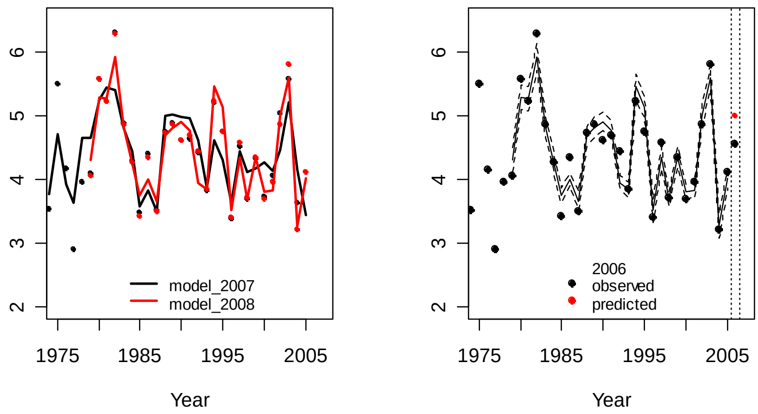

Figure 6.6.2. Comparison of performance of the 2007 model with the updated one (left). Updated model (+/- SE intervals) and its 2006 prediction (right).

Prediction for 2006 equals R_s=5.002258.

The main problem with this model is that predation mortality data (PM) might be not available for the most recent years as it is not an operational variable.

Therefore, the alternative model with cod total biomass (Cod_TB) as a proxy of predation mortality was constructed. List of potential explanatory variables has been presented in Table. 6.6.2.

As three summer SST times series were identified (Table. 6.6.2), three models each of them including one SST variable were constructed and the model with July temperature was selected as it presented the lowest GCV score:

```
Family: Gamma          Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_newCM, k = 4, bs = "cs") +
    s(Cod_TB, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") +
    s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
    s(BDA, k = 4, bs = "cs") + s(NASA7, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45258    0.03522   126.4   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                  edf Est.rank      F  p-value
s(SSB_new)    2.907e+00        3 14.295 0.000144 ***
s(BSI_newCM)  8.854e-01        2  1.563 0.243591
s(Cod_TB)     2.185e+00        3 14.090 0.000155 ***
s(PSE)        3.691e-05        1  1.081 0.315893
s(MWSS3pl)    1.040e-05        1  0.200 0.661337
s(MASS)       2.686e+00        3  4.141 0.026575 *
s(BDA)        1.085e+00        3 57.621 3.44e-08 ***
s(NASA7)      2.056e+00        3 12.663 0.000268 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.929   Deviance explained = 96.9%
GCV score = 0.0031502   Scale est. = 0.0016562   n = 27
```

The following explanatory variables might be removed due to very low edf for smoothers: PSE and MWSS3pl (no change of GCV score):

```
Family: Gamma          Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_newCM, k = 4, bs = "cs") +
    s(Cod_TB, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
    s(BDA, k = 4, bs = "cs") + s(NASA7, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45258    0.03522   126.4   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                edf Est.rank      F  p-value
s(SSB_new)   2.9067        3 14.295 0.000144 ***
s(BSI_newCM) 0.8854        2  1.563 0.243596
s(Cod_TB)    2.1852        3 14.090 0.000155 ***
s(MASS)      2.6857        3  4.141 0.026575 *
s(BDA)       1.0854        3 57.621 3.44e-08 ***
s(NASA7)     2.0562        3 12.663 0.000268 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.929   Deviance explained = 96.9%
GCV score = 0.0031502   Scale est. = 0.0016562  n = 27
```

As GCV score increased after BSI removal it was decided to include this variable in the *alternative model*. However a difficult to justify Rs response to Cod Total Biomass and Mean Age of Sprat Spawning Stock was observed (Figure 6.6.3.).

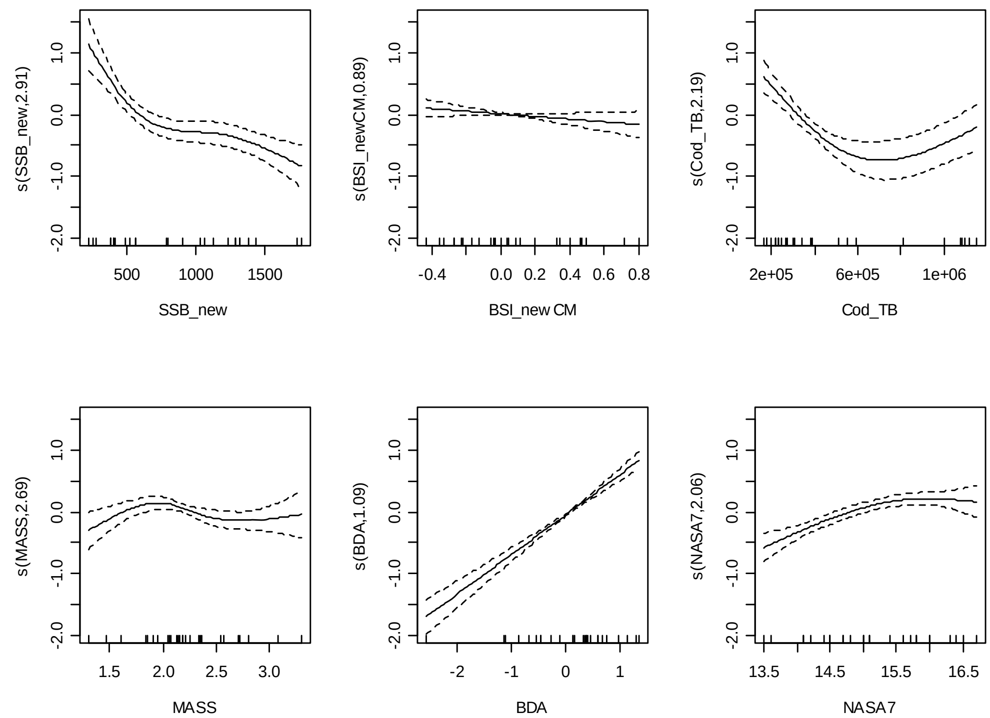

Figure 6.6.3. Effects of SSB, BSI, Cod_TB, MASS, BDA, and NASA7 on recruitment success of sprat.

Therefore, the next model was calculated without Cod_TB and MASS and without bs='cs' parameter (*alternative best model*).

```
Family: Gamma          Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4) + s(BSI_newCM, k = 4) + s(BDA, k = 4) +
    s(NASA7, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45532    0.07334   60.75   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Est.rank      F  p-value
s(SSB_new)   1.000        1 15.798 0.000739 ***
s(BSI_newCM) 1.186        3  1.368 0.281191
s(BDA)       2.681        3 16.574 1.16e-05 ***
s(NASA7)     1.000        1  6.281 0.020893 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.739   Deviance explained = 80.7%
GCV score = 0.0096322   Scale est. = 0.0071823  n = 27
```

The alternative best model is explaining over 80% of deviance. Recruitment success relation with SSB and NASA7 is linear and with BSI almost linear. Only in the case of BDA the pattern is more complicated (edf close to 3) (Figure 6.6.4.).

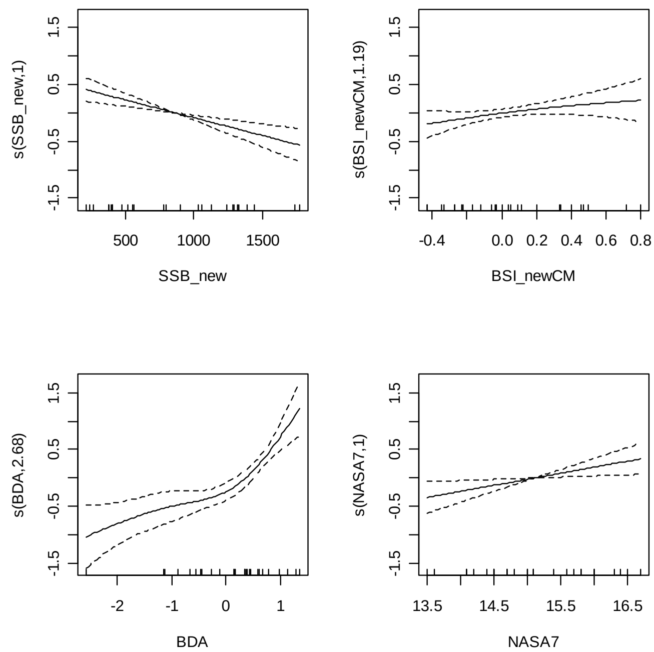

Figure 6.6.4. Effects of SSB, BSI, BDA, and NASA7 on recruitment success of sprat.

Even a slight violation of normality and constancy of variance assumptions is observed at low sprat SSB values (Figure 6.6.5.) it was decided to predict 2006 recruitment using this model.

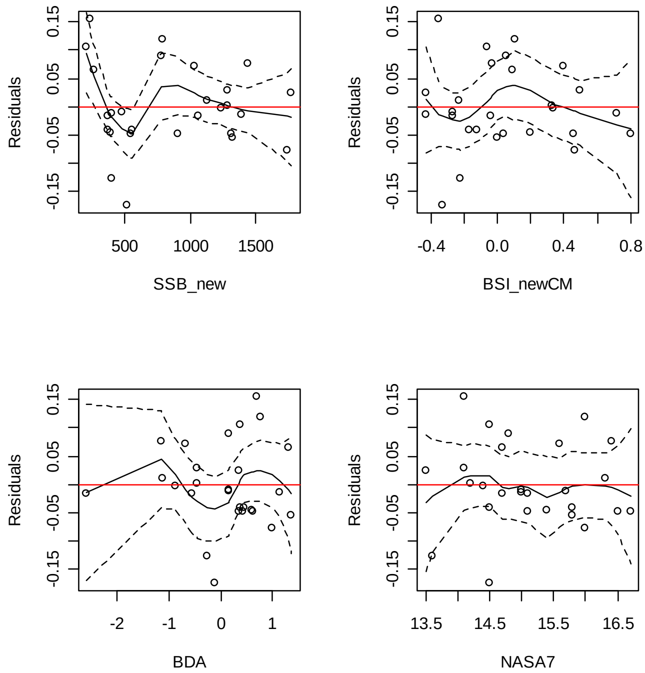

Figure 6.6.5. Analysis of residuals for the selected *alternative best model*.

Comparison of the *alternative best model* with the 2007 one is presented in Figure 6.6.6. This model has some problems with high recruitment values. The 2006 prediction (4.199018) is relatively close to RCT3 estimation but this time it is lower than observed.

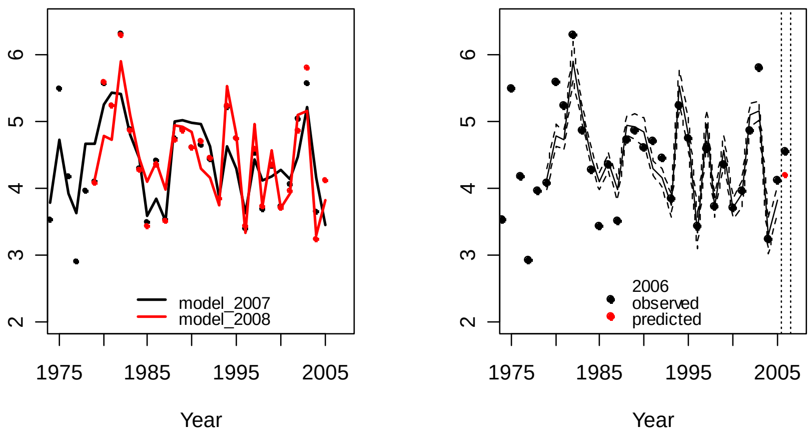

Figure 6.6.6. Comparison of performance of 2007 model with the updated one (left). Updated model (+/- SE intervals) and its 2006 prediction (right).

7 Short-term predictions

7.1 Introduction

The short-term preditions forecast stock parameters for next 2 years is using the output from stock assessment models (XSA, ICA) and the recruitment estimates as an input. The estimates of most recent recruitment are derived from different sources for different stocks. In the short term forecast the recruitment estimates of the two last years are long-term geometric means.

For the **Gulf of Riga** herring the year class abundance is predicted from the relationship between year-class abundance of herring, average water temperature of 0–20 m layer in May and the biomass of *Eurytemora affinis* in spring.

To estimate the most recent **Central Baltic herring** year-class abundance at age 1, in RCT3 analysis, the number of 0 group herring from the Baltic International Acoustic Survey is used (since 1991).

The estimates of most recent recruitment of s**prat in Sub-divisions 22-32** are derived from Latvian/Russian acoustic estimates of age 0 sprat abundance in Subdivisions 26 + 28.

In order to provide additional sources for recruitment estimations incorporating the new knowledge on ecosystem interactions the Workshop performed a number of trial runs of short term predictions with new recruitment estimates

7.2 Results

Short-term forecast for the **Baltic herring in Sub-divisions 25-29 & 32** was rerun with the new obtained recruitment value (n=18808682) for age group one in 2007 (Table 7.2.1.). The recruitment value used by WGBFAS in 2007 was n=14706000 and was obtained from RCT3. At $F_{status\ quo}$ the new forecast produced slightly higher landings in 2007 (120.1 thou t compared to 118.7 thou t) and in 2008 (130.1 thou t compared to 127.6 thou t). The SSB in 2009 would be 1082.3 thou t in comparison with 1039.3 thou t of the forecast of the WGBFAS.

Short-term forecast for the **Gulf of Riga herring** was rerun with the new obtained recruitment value (n=3099135) for age group one in 2007 (Table 7.2.2.). The recruitment value used by WGBFAS in 2007 was n=2481575 and was obtained from RCT3. At $F_{status\ quo}$ the new forecast produced slightly higher landings in 2007 (38.5 thou t compared to 37.7 thou t) and in 2008 (36.1 thou t compared to 34.7 thou t). The SSB in 2009 would be 79.2 thou t in comparison with 75.5 thou t of the forecast of the WGBFAS.

Short-term forecast for the **sprat** in Sub-divisions 22-32 was rerun with the new obtained recruitment value (n=174 928) for age group one in 2007 (Table 7.2.3.). The recruitment value used by WGBFAS in 2007 was n=111145 and was obtained from RCT3. At $F_{status\ quo}$ the new forecast produced higher landings in 2007 (349 thou t compared to 325 thou t) and in 2008 (371 thou t compared to 330 thou t). The SSB in 2009 would be 1383 thou t in comparison to 1198 thou t of the WGBFAS forecast.

7.3 Consequence of using the new model for TAC

The obtained SSB and landing estimates of the short-term forecasts in the next three years are depending very much on the recruitment value which is used for the first year of the prediction. This value is usually calculated in RCT3 using estimates of the

0 group in surveys. Usually higher recruitment estimate will result in increase of SSB and landings while lower recruitment values will result in opposite development of the stock. For the management of the fish stocks the underestimation of recruitment would mean utilization of resources on lower level than possible, while the overestimation would mean possible overfishing and decrease of the fish stock.

The main advantage of the model constructed during the workshop is that they are providing the additional source of recruitment estimates based on better understanding of ecological processes influencing the recruitment changes.

The new recruitment values produced at the workshop for all three stocks were higher than those used by WGBFAS in 2007. Consequently higher estimates of SSB and possible landings were obtained for the predicted years in 2007-2009. Actually it would be necessary to determine which recruitment estimate is more correct and closer to the recruitment estimate of the assessment (XSA). The year-class 2006 (age group 1 in 2007) will be best estimated by the assessment of 2009 which will include catch and survey data up to 2008. In the further work it would be desirable to produce recruitment estimates not only for the last year but several estimates of the recent period which could be then compared with recruitment estimates which have been used by WGBFAS and recruitment estimates from the assessments.

Table. 7.2.1. Short term predictions for Central Baltic Herring.

MFDP version 1a
Run: CBH-Ponza2 **New forecast**
Herring in Sd 25-32 (excl. GOR).
Time and date: 15:52 04/04/2008
Fbar age range: 3-6

2007				
Biomass	SSB	FMult	FBar	Landings
1379314	980695	1	0.1205	120117

2008					2009	
Biomass	SSB	FMult	FBar	Landings	Biomass	SSB
1429834	1101061	0	0	0	1585195	1257044
.	1096410	0.1	0.012	13740	1570601	1238172
.	1091780	0.2	0.0241	27312	1556187	1219626
.	1087172	0.3	0.0361	40719	1541950	1201399
.	1082586	0.4	0.0482	53963	1527888	1183486
.	1078021	0.5	0.0602	67046	1513999	1165880
.	1073477	0.6	0.0723	79970	1500280	1148576
.	1068954	0.7	0.0843	92738	1486729	1131568
.	1064452	0.8	0.0964	105351	1473344	1114850
.	1059971	0.9	0.1084	117812	1460122	1098418
.	1055511	1	0.1205	130122	1447061	1082266
.	1051072	1.1	0.1325	142285	1434159	1066388
.	1046654	1.2	0.1446	154301	1421414	1050780
.	1042256	1.3	0.1566	166172	1408824	1035437
.	1037878	1.4	0.1687	177902	1396386	1020353
.	1033521	1.5	0.1807	189491	1384099	1005525
.	1029184	1.6	0.1928	200942	1371961	990946
.	1024867	1.7	0.2048	212256	1359969	976613
.	1020570	1.8	0.2169	223435	1348121	962522
.	1016293	1.9	0.2289	234481	1336416	948666
.	1012036	2	0.241	245396	1324852	935043

Input units are thousands and kg - output in tonnes

MFDP version 1a
Run: CB Herring_1
Herring in Sd 25-32 (excl. GOR).
Time and date: 10:16 21/04/2007
Fbar age range: 3-6

2007				
Biomass	SSB	FMult	FBar	Landings
1334458	980695	1	0.1205	118748

2008					2009	
Biomass	SSB	FMult	FBar	Landings	Biomass	SSB
1377188	1066593	0	0	0	1529848	1210359
.	1062009	0.1	0.012	13478	1515562	1191878
.	1057446	0.2	0.0241	26790	1501453	1173719
.	1052905	0.3	0.0361	39937	1487520	1155876
.	1048385	0.4	0.0482	52923	1473760	1138343
.	1043886	0.5	0.0602	65750	1460172	1121115
.	1039409	0.6	0.0723	78419	1446752	1104185
.	1034952	0.7	0.0843	90933	1433498	1087548
.	1030517	0.8	0.0964	103293	1420408	1071199
.	1026102	0.9	0.1084	115503	1407480	1055132
.	1021708	1	0.1205	127564	1394711	1039342
.	1017335	1.1	0.1325	139478	1382100	1023823
.	1012982	1.2	0.1446	151247	1369644	1008571
.	1008649	1.3	0.1566	162873	1357341	993581
.	1004337	1.4	0.1687	174358	1345190	978848
.	1000045	1.5	0.1807	185704	1333187	964366
.	995773	1.6	0.1928	196913	1321331	950132
.	991521	1.7	0.2048	207987	1309620	936140
.	987289	1.8	0.2169	218927	1298052	922387
.	983077	1.9	0.2289	229735	1286625	908868
.	978885	2	0.241	240413	1275337	895578

Input units are thousands and kg - output in tonnes

Table. 7.2.2. Short term predictions for Gulf of Riga Herring.

MFDP version 1a
Run: GoR-Ponza **New forecast**
Herring Gulf of Riga,2008,ANON,COMBSEX,PLUSGROUP
Time and date: 16:22 04/04/2008
Fbar age range: 3-7

2007				
Biomass	SSB	FMult	FBar	Landings
146099	96760	1	0.4741	38482

2008					2009	
Biomass	SSB	FMult	FBar	Landings	Biomass	SSB
133482	97825	0	0	0	160024	122553
.	97022	0.1	0.0474	4262	155391	117219
.	96226	0.2	0.0948	8363	150936	112137
.	95436	0.3	0.1422	12310	146653	107294
.	94653	0.4	0.1897	16110	142534	102678
.	93877	0.5	0.2371	19767	138573	98278
.	93107	0.6	0.2845	23289	134762	94084
.	92344	0.7	0.3319	26679	131097	90085
.	91587	0.8	0.3793	29945	127570	86272
.	90836	0.9	0.4267	33090	124177	82635
.	90091	1	0.4741	36119	120913	79167
.	89353	1.1	0.5216	39038	117771	75858
.	88621	1.2	0.569	41850	114747	72701
.	87896	1.3	0.6164	44560	111836	69688
.	87176	1.4	0.6638	47171	109034	66813
.	86462	1.5	0.7112	49688	106336	64069
.	85754	1.6	0.7586	52115	103738	61449
.	85053	1.7	0.806	54455	101237	58948
.	84357	1.8	0.8535	56711	98827	56559
.	83667	1.9	0.9009	58886	96507	54278
.	82982	2	0.9483	60985	94271	52099

Input units are thousands and kg - output in tonnes

MFDP version 1a
Run: new07 **Forecast with the same input as in 2007**
Herring Gulf of Riga,2008,ANON,COMBSEX,PLUSGROUP
Time and date: 11:46 28/03/2008
Fbar age range: 3-7

2007				
Biomass	SSB	FMult	FBar	Landings
140089	96760	1	0.4741	37723

2008					2009	
Biomass	SSB	FMult	FBar	Landings	Biomass	SSB
128069	93084	0	0	0	154071	117059
.	92313	0.1	0.0474	4101	149633	111947
.	91548	0.2	0.0948	8047	145366	107077
.	90789	0.3	0.1422	11844	141265	102438
.	90037	0.4	0.1897	15498	137322	98018
.	89291	0.5	0.2371	19015	133531	93806
.	88551	0.6	0.2845	22399	129885	89792
.	87818	0.7	0.3319	25658	126379	85966
.	87091	0.8	0.3793	28795	123006	82319
.	86370	0.9	0.4267	31816	119763	78842
.	85655	1	0.4741	34725	116642	75526
.	84946	1.1	0.5216	37527	113639	72364
.	84244	1.2	0.569	40227	110750	69347
.	83547	1.3	0.6164	42827	107970	66470
.	82856	1.4	0.6638	45333	105294	63725
.	82171	1.5	0.7112	47748	102718	61105
.	81491	1.6	0.7586	50075	100239	58605
.	80818	1.7	0.806	52319	97851	56218
.	80150	1.8	0.8535	54482	95553	53940
.	79488	1.9	0.9009	56567	93339	51764
.	78831	2	0.9483	58578	91207	49686

Input units are thousands and kg - output in tonnes

Table. 7.2.3. Short term predictions for sprat.

MFDP version 1a
Run: sprat2 **New forecast**
Sprat
Time and date: 21:25 13/05/2008
Fbar age range: 3-5

2007				
Biomass	SSB	FMult	FBar	Landings
2220	1238	1	0.2933	349

2008					2009	
Biomass	SSB	FMult	FBar	Landings	Biomass	SSB
2186	1613	0	0	0	2421	1853
.	1597	0.1	0.0293	41	2380	1798
.	1582	0.2	0.0587	82	2339	1745
.	1567	0.3	0.088	121	2300	1695
.	1552	0.4	0.1173	159	2262	1645
.	1537	0.5	0.1466	197	2224	1598
.	1522	0.6	0.176	233	2187	1552
.	1508	0.7	0.2053	269	2152	1507
.	1493	0.8	0.2346	304	2117	1464
.	1479	0.9	0.2639	338	2083	1423
.	1465	1	0.2933	371	2050	1383
.	1451	1.1	0.3226	404	2017	1344
.	1438	1.2	0.3519	436	1985	1306
.	1424	1.3	0.3812	467	1954	1270
.	1410	1.4	0.4106	497	1924	1234
.	1397	1.5	0.4399	527	1895	1200
.	1384	1.6	0.4692	556	1866	1167
.	1371	1.7	0.4986	584	1838	1135
.	1358	1.8	0.5279	611	1810	1105
.	1345	1.9	0.5572	638	1783	1075
.	1333	2	0.5865	665	1757	1046

Input units are thousands and kg - output in tonnes

Sprat
Short-term forecast produced by WGBAS in 2007
Fbar age range: 3-5

2007				
Biomass	SSB	FMult	FBar	Landings
1922	1196	1	0.2933	325

2008					2009	
Biomass	SSB	FMult	FBar	Landings	Biomass	SSB
1885	1363	0	0	0	2152	1611
.	1349	0.1	0.029	37	2115	1563
.	1335	0.2	0.059	73	2080	1516
.	1322	0.3	0.088	108	2045	1471
.	1309	0.4	0.117	142	2011	1428
.	1295	0.5	0.147	175	1978	1386
.	1282	0.6	0.176	208	1945	1346
.	1270	0.7	0.205	239	1914	1307
.	1257	0.8	0.235	270	1883	1269
.	1244	0.9	0.264	300	1853	1233
.	1232	1	0.293	330	1824	1198
.	1220	1.1	0.323	358	1795	1164
.	1207	1.2	0.352	386	1767	1131
.	1195	1.3	0.381	414	1740	1099
.	1183	1.4	0.411	440	1714	1068
.	1172	1.5	0.44	466	1688	1039
.	1160	1.6	0.469	492	1662	1010
.	1149	1.7	0.499	516	1638	982
.	1137	1.8	0.528	541	1614	955
.	1126	1.9	0.557	564	1590	929
.	1115	2	0.587	587	1567	904

Input units are thousands and kg - output in tonnes

8 Conclusions and Recommendations

1) Workshop participants recommend verification of presented results (model predictions) by the ICES WGBFAS

2) Analysis for herring stocks in the Bothnian Sea and Bothnian Bay will be possible when existing fisheries assessment for those areas is verified by independent data.

3) Additional environmental datasets (e.g. zooplankton time series) are required to construct successful model(s) for the Western Baltic Herring stock.

4) Participants of the Workshop recommend to continue the work and to explore the possibility to calculate medium-term recruitment predictions including climatic scenarios.

9 References

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Annex 1: List of participants

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Annex 2: Agenda

ICES Workshop on Developing and Testing Environmentally-Sensitive Stock-recruitment Relationships of Baltic Herring and Sprat stocks [WKSSRB] Ponza, Italy, 2 April to 5 April 2008.

AGENDA

Tuesday, 1 April 2008

Arrival and arrangements in the Hotel Ortensia, dinner at Maurizio Restaurant

Wednesday, 2 April 2008

09:30 – 10:45	Practical information, Introduction to the Workshop and Discussion of the Agenda (Piotr Margonski & Max Cardinale)
10:45 – 11:15	Coffee & Tea (At the bar da Pippo)
11:15 – 13:00	Presentations: 1) Incorporating extrinsic drivers into fisheries management of the Baltic Sea: an In Ex Fish project experience (Piotr Margoński) 2) Review of the work on environment-recruitment relationships for Baltic herring and sprat stocks, especially by WKHRPB (Max Cardinale) 3) Updating of the time series from the Eastern Baltic and Gulf of Riga (George Kornilovs) 4) New recruitment-models, developed by Hannes Baumann, with respect to their further development and potential incorporation into operational models to be developed by WKSSRB (Daniel Stepputtis)
13:00 – 14:30	Lunch
14:30 – 15:30	Presentations cont.: 5) Plan of the statistical analysis (Max Cardinale)
15:30 – 16:00	Coffee & Tea
16:00 – 16:30	Presentations cont.: 6) Baltic herring recruitment: process and results (Tiit Raid)
16:00 – 17:00	Discussion of group work and forming of sub-groups Sub-groups: 1) Statistical analyses and recruitment modelling of herring 2) Short term prediction with environmental variables 3) Statistical analyses and recruitment modelling of sprat 4) Report compilation and writing
19:00 -	Dinner

Thursday, 3 April 08

09:00 – 10:45	Work in subgroups
10:45 – 11:00	Coffee & Tea
11:00 – 13:00	Work in subgroups cont.
13:00 – 14:15	Lunch
14:15 – 15:30	Plenary: 1st summary of the state of the sub-groups
15:30 – 16:00	Coffee & Tea
16:00 – 17:00	Work in subgroups cont.

Friday, 4 April 2008

09:00 – 10:00	Plenary: Review of the statistical analyses and the recruitment modelling
10:00 – 10:45	Presentations cont.:
	Ruegen herring larvae survey – A new recruitment index for WB-herring (Christine Assmuth)
10:45 – 11:00	Coffee & Tea
11:00 – 13:00	Work in subgroups cont
13:00 – 14:15	Lunch
14:15 – 15:30	Plenary: Summarizing results of subgroups; decision on structure and contents of the report
15:30 – 16:00	Coffee & Tea
16:00 – 17:00	report writing and (if needed) additional work in subgroups

Saturday, 5 April 2008

09:00 – 10:45	Plenary: Wash-up
10:45 – 11:00	Coffee & Tea
11:00 – 13:00	Report writing
13:00	Closure of workshop

Annex 3: Overview table on data series used in statistical analyses of environment-recruitment relationships

Stock area	Stock acronymous	Variable	Variable acronymus	Source
Div. IIIa & ICES SD 22-24	WBH	Sea Surface Salinity February	SAL2	www.smhi.se
Div. IIIa & ICES SD 22-24	WBH	Sea Surface Temperature February	SST2	www.smhi.se
ICES SD 25-29 & 32 exl.GOR	MBH	Sea Surface Temperature August	SST8	LatFRA
ICES SD 25-29 & 32 exl.GOR	MBH	Sea Surface Temperature August	NASA8	www.cdc.noaa.gov
SD 22-32	BS	Sea Surface Temperature January-December	NASA1-NASA12	www.cdc.noaa.gov
Gulf of Riga ICES SD 28.1	GRH	Sea Surface Temperature May	SST5	LatFRA
SD 22-32	BS	Baltic Depth Anomaly	BDA	Baumann et al. 2004 & 2006
Whole Baltic Sea	All stocks	Baltic Sea Index	BSI	Lehmann et al. 2002
SD 22-32	BS	Winter Severity Index	SI	LatFRA
SD 22-32	BS	Maximum Ice Cover	IC	FIMR
SD 22-32	BS	*Pseudocalanus acuspes* spring biomass	PSE	LatFRA
SD 22-32	BS	*Temora longicornis spring* biomass	TEM	LatFRA
SD 22-32	BS	*Acartia spp.* spring biomass	ACA	LatFRA
SD 22-32	BS	Cladocera summer biomass	CLA	LatFRA
ICES SD 25-29 & 32 exl.GOR	MBH	*Pseudocalanus acuspes* biomass	PSE	LatFRA
Gulf of Riga ICES SD 28.1	GRH	*Eurytemora affinis* biomass	EUR	LatFRA
Div. IIIa & ICES SD 22-24	WBH	Spawning stock biomass	SSB	ICES 2008
SD 25-29 & 32 exl.GOR	MBH	Spawning stock biomass	SSB	ICES 2007a
Gulf of Riga ICES SD 28.1	GRH	Spawning stock biomass	SSB	ICES 2007a
ICES SD 30	BSH	Spawning stock biomass	SSB	ICES 2007a
ICES SD 31	BBH	Spawning stock biomass	SSB	ICES 2007a
SD 22-32	BS	Spawning stock biomass	SSB	ICES 2007a
Div. IIIa & ICES SD 22-24	WBH	Recruitment at age 0	R0	ICES 2008
ICES SD 25-29 & 32 exl.GOR	MBH	Recruitment age at 1	R1	ICES 2007a
Gulf of Riga ICES SD 28.1	GRH	Recruitment age at 1	R1	ICES 2007a
ICES SD 30	BSH	Recruitment age at 1	R1	ICES 2007a
ICES SD 31	BBH	Recruitment age at 1	R1	ICES 2007a
SD 22-32	BS	Recruitment age at 1	R1	ICES 2007a
Div. IIIa & ICES SD 22-24	WBH	Biomass ages 5+	$BIOM_{5+}$	ICES 2008
ICES SD 25-29 & 32 exl.GOR	MBH	Biomass ages 5+	$BIOM_{5+}$	ICES 2007a
Div. IIIa & ICES SD 22-24	WBH	Weight at age 3+	WAA_{3+}	ICES 2008
ICES SD 25-29 & 32 exl.GOR	MBH	Weight at age 3+	WAA_{3+}	ICES 2007a
ICES SD 25-29 & 32 exl.GOR	MBH	Weight at age 3+	$wWAA_{3+}$	ICES 2007a
SD 22-32	BS	Mean Weight of Sprat Spawning Stock (all age classes)	MWSS	this report (see chapter 5.2.)
SD 22-32	BS	Mean Weight of Sprat Spawning Stock (at age 2 plus)	MWSS2pl	this report (see chapter 5.2.)
SD 22-32	BS	Mean Weight of Sprat Spawning Stock (at age 3 plus)	MWSS3pl	this report (see chapter 5.2.)
SD 22-32	BS	Mean Age of Spawning Stock	MASS	this report (see chapter 5.2.)
SD 22-32	BS	Cod Total Biomass	Cod_TB	ICES 2007a
SD 22-32	BS	Predation mortality by cod at age 0	PM	ICES 2007b

LatFRA = Latvian Fisheries Research Agency
FIMR = Finnish Institute of Marine Research

Annex 4: Output of statistical modelling of environment-recruitment relationships

For codes of the variables see Annex 3.

Gulf of Riga Herring

```
Family: Gamma     Link function: log

RECR ~ s(SSB, k = 4) + s(SST5, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 14.64810    0.06098   240.2   <2e-16 ***

Approximate significance of smooth terms:
          edf Est.rank     F  p-value
s(SSB)  1.000        1 26.15 3.11e-05 ***
s(SST5) 1.989        3 15.07 1.00e-05 ***

R-sq.(adj) =   0.58   Deviance explained = 78.5%
GCV score = 0.12141   Scale est. = 0.10411   n = 28
-----

1) Family: Gamma  Link function: log

RECR ~ s(SSB, k = 4) + s(SST5, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 14.65749    0.06074   241.3   <2e-16 ***

Approximate significance of smooth terms:
          edf Est.rank      F  p-value
s(SSB)  2.266        3  6.293  0.00273 **
s(SST5) 2.263        3 14.941 1.19e-05 ***

R-sq.(adj) =   0.54   Deviance explained = 78.3%
GCV score = 0.13219   Scale est. = 0.10699   n = 29
```

Central Baltic Herring (SD25-29&32 exl. Gulf of Riga)

```
Family: Gamma     Link function: identity

Rs ~ s(SSB, k = 3) + s(WAA3pl, k = 3) + s(PSE, k = 4) + s(SST8,
    k = 4) + s(BSI, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.00048    0.03588   83.62   <2e-16 ***

Approximate significance of smooth terms:
            edf Est.rank      F  p-value
s(SSB)    1.822        2 13.272 0.000180 ***
s(WAA3pl) 1.174        2  8.462 0.001972 **
s(PSE)    1.955        3  2.772 0.066451 .
s(SST8)   1.740        3  2.637 0.075890 .
s(BSI)    1.998        3  6.538 0.002635 **

R-sq.(adj) =   0.76   Deviance explained = 81.4%
GCV score = 0.0064026   Scale est. = 0.0044014  n = 31
-----

1) Family: Gamma  Link function: identity

Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(PSE, k = 4) +
s(NASA8, k = 4) + s(BSI_new, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01124    0.03677    81.9   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB)     1.872        2 11.168 0.000366 ***
s(wWAA3pl) 1.000        1 10.715 0.003188 **
s(PSE)     1.905        3  1.469 0.247901
s(NASA8)   1.000        1 24.479 4.63e-05 ***
s(BSI_new) 1.000        1  0.648 0.428685

R-sq.(adj) =  0.748   Deviance explained = 80.3%
GCV score = 0.0062272   Scale est. = 0.0047138  n = 32
------

2) Family: Gamma  Link function: identity

Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(PSE, k = 4) +
s(NASA8, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01138    0.03652   82.45   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB)     1.868        2 11.232 0.000325 ***
s(wWAA3pl) 1.000        1 10.621 0.003192 **
s(PSE)     1.923        3  1.466 0.247532
s(NASA8)   1.000        1 27.291 2.04e-05 ***
```

```
R-sq.(adj) =  0.749   Deviance explained = 79.8%
GCV score = 0.0059038   Scale est. = 0.004651  n = 32
-----

3) Family: Gamma  Link function: identity

Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(NASA8, k = 4) +
s(BSI_new, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01163    0.03779    79.7   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB)     1.793        2 11.236 0.000304 ***
s(wWAA3pl) 1.174        2  7.474 0.002723 **
s(NASA8)   1.000        1 23.609 4.86e-05 ***
s(BSI_new) 1.000        1  0.538 0.469728

R-sq.(adj) =  0.734   Deviance explained = 77.7%
GCV score = 0.0061207   Scale est. = 0.0049793  n = 32
------

4) Family: Gamma  Link function: identity

Rs ~ s(SSB, k = 3) + s(wWAA3pl, k = 3) + s(NASA8, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.01206    0.03763   80.05   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank     F  p-value
s(SSB)     1.829        2 11.71 0.000214 ***
s(wWAA3pl) 1.000        1 13.58 0.001005 **
s(NASA8)   1.000        1 26.27 2.14e-05 ***

R-sq.(adj) =  0.735   Deviance explained = 76.9%
GCV score = 0.0058104   Scale est. = 0.0049335  n = 32
```

Sprat (SD 22-32)

```
Family: Gamma     Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4) + s(BSI_new, k = 4) + s(PSE, k = 4)
+ s(PM, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)    4.387      0.126   34.81   <2e-16 ***

Approximate significance of smooth terms:
               edf Est.rank     F p-value
s(SSB_new)   1.000        1 0.980   0.331
s(BSI_new) 1.625        3 1.624   0.207
s(PSE)       1.000        1 2.339   0.138
s(PM)        1.000        1 1.539   0.225

R-sq.(adj) =  0.173   Deviance explained =   27%
GCV score = 0.032672   Scale est. = 0.027103  n = 33
```

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```
1) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(PM, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") +
s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA6, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.44735    0.05046   88.14   <2e-16 ***

Approximate significance of smooth terms:
                edf Est.rank      F  p-value
s(SSB_new)   0.9117        2  3.172  0.07409 .
s(BSI_new) 2.1327        3  6.373  0.00636 **
s(PM)        1.7473        3  4.936  0.01585 *
s(PSE)       2.0092        3  4.265  0.02539 *
s(MWSS3pl)   2.4263        3  2.548  0.09915 .
s(MASS)      0.1919        1  1.503  0.24108
s(BDA)       1.0777        3 33.792 1.49e-06 ***
s(NASA6)     1.9436        3  5.106  0.01414 *

R-sq.(adj) =  0.877   Deviance explained = 93.8%
GCV score = 0.0068188   Scale est. = 0.0034245  n = 27
```

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```
2) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(PM, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") +
s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA7, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.44941    0.05254    84.7   <2e-16 ***
```

```
Approximate significance of smooth terms:
                   edf Est.rank      F  p-value
s(SSB_new)   9.548e-06        1  1.684  0.21441
s(BSI_new) 1.902e+00          3  2.549  0.09559 .
s(PM)        2.642e+00        3  4.046  0.02764 *
s(PSE)       1.836e+00        3  2.914  0.06945 .
s(MWSS3pl)   7.095e-01        1  4.398  0.05371 .
s(MASS)      1.722e+00        3  2.547  0.09581 .
s(BDA)       1.013e+00        3 24.103 6.23e-06 ***
s(NASA7)     1.471e+00        3  6.754  0.00437 **

R-sq.(adj) =  0.856   Deviance explained = 92.7%
GCV score = 0.0067963   Scale est. = 0.0037017  n = 27
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```
3) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(PM, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") +
s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.44897    0.05208   85.43   <2e-16 ***

Approximate significance of smooth terms:
                   edf Est.rank      F  p-value
s(SSB_new)   2.889e+00        3 11.847  0.00019 ***
s(BSI_new) 1.720e+00        3  1.708  0.20271
s(PM)        1.927e+00        3  5.451  0.00811 **
s(PSE)       4.961e-01        1  2.110  0.16438
s(MWSS3pl)   4.787e-06        1  0.019  0.89305
s(MASS)      2.381e-06        1  0.086  0.77325
s(BDA)       1.006e+00        3 22.809 3.18e-06 ***
s(NASA8)     7.762e-01        2  6.237  0.00919 **

R-sq.(adj) =  0.885   Deviance explained = 91.6%
GCV score = 0.0057261   Scale est. = 0.0036449  n = 27
```

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```
4) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(PM, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") +
s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA9, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.44637    0.06629   67.08   <2e-16 ***

Approximate significance of smooth terms:
                   edf Est.rank      F  p-value
s(SSB_new)   8.804e-01        2  3.184   0.0644 .
s(BSI_new) 2.001e+00        3  3.340   0.0414 *
s(PM)        1.939e+00        3  4.318   0.0177 *
s(PSE)       7.811e-01        2  3.007   0.0736 .
```

```
s(MWSS3pl)   1.688e-05        1  0.132   0.7205
s(MASS)      1.103e-04        1  1.231   0.2812
s(BDA)       1.106e+00        3 19.288 5.76e-06 ***
s(NASA9)     4.719e-01        1  3.354   0.0829 .

R-sq.(adj) =  0.808   Deviance explained = 85.1%
GCV score = 0.0085115   Scale est. = 0.0059329  n = 27
```

```
5) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(PM, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.44897    0.05208   85.43   <2e-16 ***

Approximate significance of smooth terms:
                edf Est.rank      F  p-value
s(SSB_new)   2.8886        3 11.847  0.00019 ***
s(BSI_new) 1.7196        3  1.708  0.20271
s(PM)        1.9270        3  5.451  0.00811 **
s(PSE)       0.4960        1  2.110  0.16438
s(BDA)       1.0058        3 22.809 3.18e-06 ***
s(NASA8)     0.7762        2  6.237  0.00919 **

R-sq.(adj) =  0.885   Deviance explained = 91.6%
GCV score = 0.0057261   Scale est. = 0.0036449  n = 27
```

```
6) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(PM, k = 4, bs = "cs")
+ s(PSE, k = 4, bs = "cs") + s(BDA, k = 4, bs = "cs") +
s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   4.4517     0.0539    82.6   <2e-16 ***

Approximate significance of smooth terms:
                 edf Est.rank      F  p-value
s(SSB_new) 2.952e+00        3 15.685 2.14e-05 ***
s(PM)      1.996e+00        3  6.192  0.00402 **
s(PSE)     2.368e-05        1  0.507  0.48493
s(BDA)     1.019e+00        3 23.148 1.37e-06 ***
s(NASA8)   8.390e-01        2  6.602  0.00658 **

R-sq.(adj) =  0.872   Deviance explained =   90%
GCV score = 0.0054745   Scale est. = 0.0038916  n = 27
```

```
7) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(PM, k = 4, bs = "cs")
+ s(BDA, k = 4, bs = "cs") + s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45438    0.05161   86.32   <2e-16 ***

Approximate significance of smooth terms:
              edf Est.rank      F  p-value
s(SSB_new) 2.9384        3 18.212 1.19e-05 ***
s(PM)      2.0124        3  6.136  0.00474 **
s(BDA)     2.3293        3 25.290 1.25e-06 ***
s(NASA8)   0.9832        2  7.195  0.00515 **

R-sq.(adj) =  0.878   Deviance explained = 91.6%
GCV score = 0.0054041   Scale est. = 0.00355   n = 27
```

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```
8) Family: Gamma        Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4) + s(PM, k = 4) + s(BDA, k = 4) +
s(NASA8, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   4.4537     0.0522   85.32   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB_new) 2.846        3 15.760 3.44e-05 ***
s(PM)      2.368        3  6.431  0.00404 **
s(BDA)     2.533        3 24.661 1.81e-06 ***
s(NASA8)   1.000        1 11.083  0.00391 **

R-sq.(adj) =  0.874   Deviance explained = 91.6%
GCV score = 0.0056897   Scale est. = 0.0036359  n = 27
```

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```
11) Family: Gamma             Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(Cod_TB, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs")
+ s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA6, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45504    0.03068   145.2   <2e-16 ***

Approximate significance of smooth terms:
                   edf Est.rank      F  p-value
s(SSB_new)   2.399e+00        3 29.336 2.12e-05 ***
s(BSI_new) 1.965e+00        3  6.927 0.007648 **
s(Cod_TB)    2.603e+00        3 23.400 5.97e-05 ***
s(PSE)       1.777e+00        3  1.699 0.227288
s(MWSS3pl)   5.388e-06        1  0.714 0.417146
```

```
s(MASS)      1.455e+00        3  3.052 0.076374 .
s(BDA)       2.902e+00        3 87.042 1.08e-07 ***
s(NASA6)     2.437e+00        3 12.566 0.000848 ***

R-sq.(adj) =  0.959   Deviance explained = 98.2%
GCV score = 0.0032273   Scale est. = 0.0012506  n = 27
```

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```
12) Family: Gamma            Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(Cod_TB, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs")
+ s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA7, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45258    0.03522   126.4   <2e-16 ***

Approximate significance of smooth terms:
                   edf Est.rank      F  p-value
s(SSB_new)   2.907e+00        3 14.295 0.000144 ***
s(BSI_new) 8.854e-01        2  1.563 0.243591
s(Cod_TB)    2.185e+00        3 14.090 0.000155 ***
s(PSE)       3.691e-05        1  1.081 0.315893
s(MWSS3pl)   1.040e-05        1  0.200 0.661337
s(MASS)      2.686e+00        3  4.141 0.026575 *
s(BDA)       1.085e+00        3 57.621 3.44e-08 ***
s(NASA7)     2.056e+00        3 12.663 0.000268 ***

R-sq.(adj) =  0.929   Deviance explained = 96.9%
GCV score = 0.0031502   Scale est. = 0.0016562  n = 27
```

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```
13) Family: Gamma            Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(Cod_TB, k = 4, bs = "cs") + s(PSE, k = 4, bs = "cs")
+ s(MWSS3pl, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs") +
s(BDA, k = 4, bs = "cs") + s(NASA8, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45770    0.03705   120.3   <2e-16 ***

Approximate significance of smooth terms:
                   edf Est.rank      F  p-value
s(SSB_new)   2.883e+00        3 30.571 1.39e-06 ***
s(BSI_new) 1.212e-06          1  0.163  0.69212
s(Cod_TB)    2.974e+00        3 16.647 5.25e-05 ***
s(PSE)       1.481e-06        1  0.014  0.90818
s(MWSS3pl)   1.763e-06        1  0.114  0.74089
s(MASS)      1.490e-06        1  0.004  0.95058
s(BDA)       2.924e+00        3 47.343 8.15e-08 ***
s(NASA8)     2.446e+00        3  8.071  0.00203 **

R-sq.(adj) =  0.939   Deviance explained = 96.4%
GCV score = 0.0033247   Scale est. = 0.0018191  n = 27
```

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```
14) Family: Gamma             Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(BSI_new, k = 4, bs =
"cs") + s(Cod_TB, k = 4, bs = "cs") + s(MASS, k = 4, bs = "cs")
+ s(BDA, k = 4, bs = "cs") + s(NASA7, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45258    0.03522   126.4   <2e-16 ***

Approximate significance of smooth terms:
                edf Est.rank      F  p-value
s(SSB_new)   2.9067        3 14.295 0.000144 ***
s(BSI_new) 0.8854        2  1.563 0.243596
s(Cod_TB)    2.1852        3 14.090 0.000155 ***
s(MASS)      2.6857        3  4.141 0.026575 *
s(BDA)       1.0854        3 57.621 3.44e-08 ***
s(NASA7)     2.0562        3 12.663 0.000268 ***

R-sq.(adj) =  0.929   Deviance explained = 96.9%
GCV score = 0.0031502   Scale est. = 0.0016562  n = 27
```

____

```
15) Family: Gamma             Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4, bs = "cs") + s(Cod_TB, k = 4, bs =
"cs") + s(MASS, k = 4, bs = "cs") + s(BDA, k = 4, bs = "cs") +
s(NASA7, k = 4, bs = "cs")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45247    0.03833   116.2   <2e-16 ***

Approximate significance of smooth terms:
             edf Est.rank      F  p-value
s(SSB_new) 2.842        3 11.815 0.000298 ***
s(Cod_TB)  2.193        3 11.695 0.000315 ***
s(MASS)    2.652        3  3.745 0.034059 *
s(BDA)     1.193        3 51.100 3.62e-08 ***
s(NASA7)   1.931        3 10.392 0.000573 ***

R-sq.(adj) =  0.916   Deviance explained =   96%
GCV score = 0.003487   Scale est. = 0.0019617  n = 27
```

______

```
16) Family: Gamma             Link function: identity

Formula:
Rs_new ~ s(SSB_new, k = 4) + s(BSI_new, k = 4) + s(BDA, k = 4)
+ s(NASA7, k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.45532    0.07334   60.75   <2e-16 ***
```

```
Approximate significance of smooth terms:
               edf Est.rank      F  p-value    
s(SSB_new)   1.000        1 15.798 0.000739 ***
s(BSI_new) 1.186        3  1.368 0.281191    
s(BDA)       2.681        3 16.574 1.16e-05 ***
s(NASA7)     1.000        1  6.281 0.020893 *  

R-sq.(adj) =  0.739   Deviance explained = 80.7%
GCV score = 0.0096322   Scale est. = 0.0071823  n = 27
```

Annex 5: Diagnostic plots of the finally selected environment-recruitment models

Gulf of Riga Herring

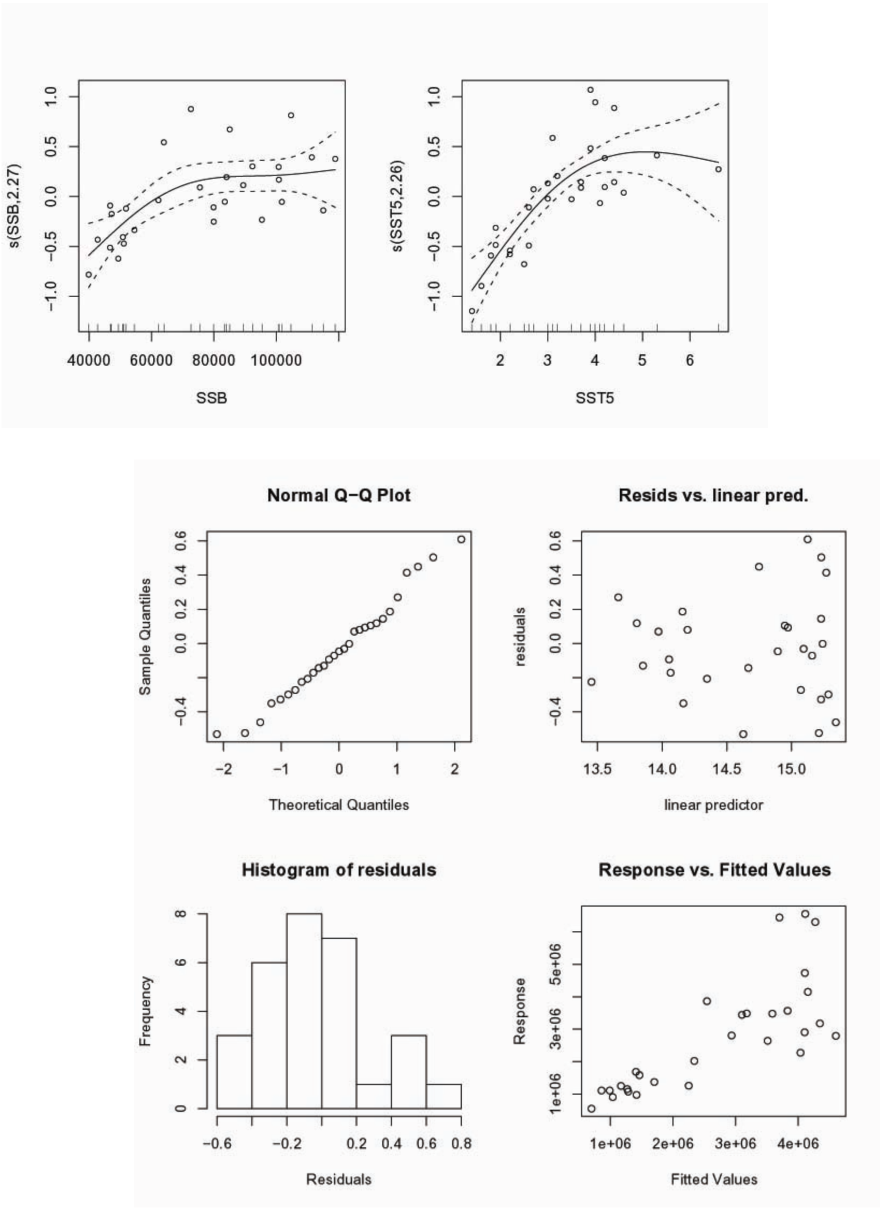

Figure 1. Diagnostic plots of the finally selected environment-recruitment models using R (model 1, see Section 6.4. and Annex 4):

- **Effects of spawning stock biomass (SSB) and May sea surface temperature (SST5);**
- **Analyses of model residuals.**

Central Baltic Herring (SD25-29&32 exl. Gulf of Riga)

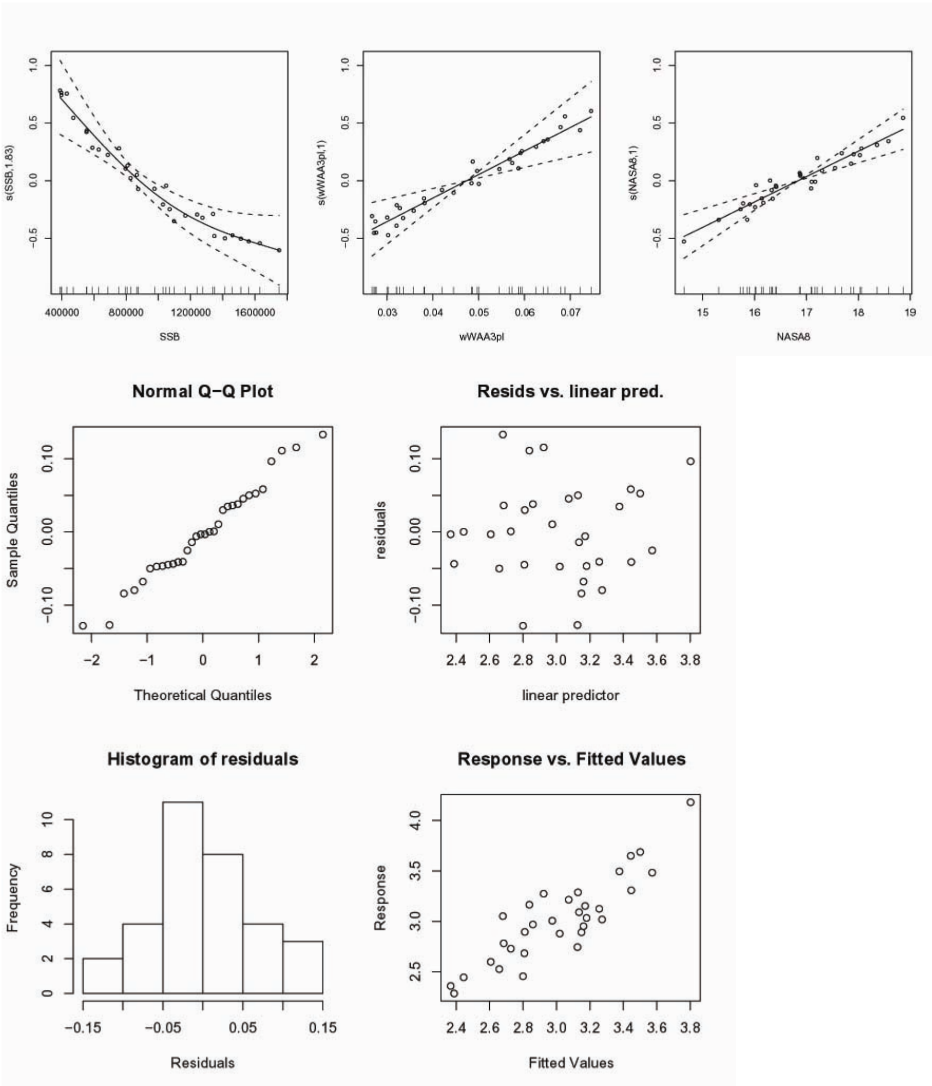

Figure 2. Diagnostic plots of the finally selected environment-recruitment models using Rs (model 4, see Section 6.5. and Annex 4):

- **effects of spawning stock biomass (SSB), weight at age 3+ (wWAA3pl), and August sea surface temperature (NASA8);**
- **analyses of model residuals.**

Sprat (SD 22-32)

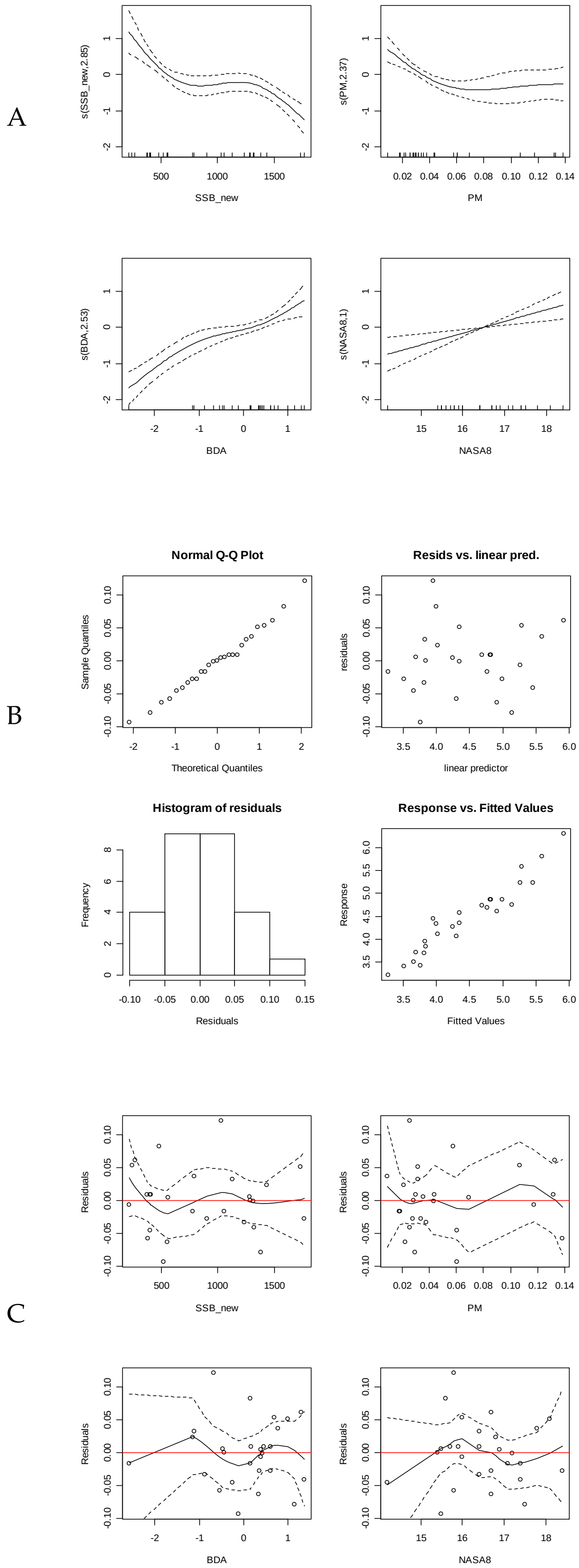

Figure 3. Diagnostic plots of the finally selected environment-recruitment models using R_s (see Section 6.6. and Annex 4: model 8): A) effects of spawning stock biomass (SSB), predation mortality (PM), Baltic Depth Anomaly (BDA), and August sea surface temperature (NASA8); B) analyses of model residuals; C) analyses of residuals' distribution vs. selected explanatory variables.

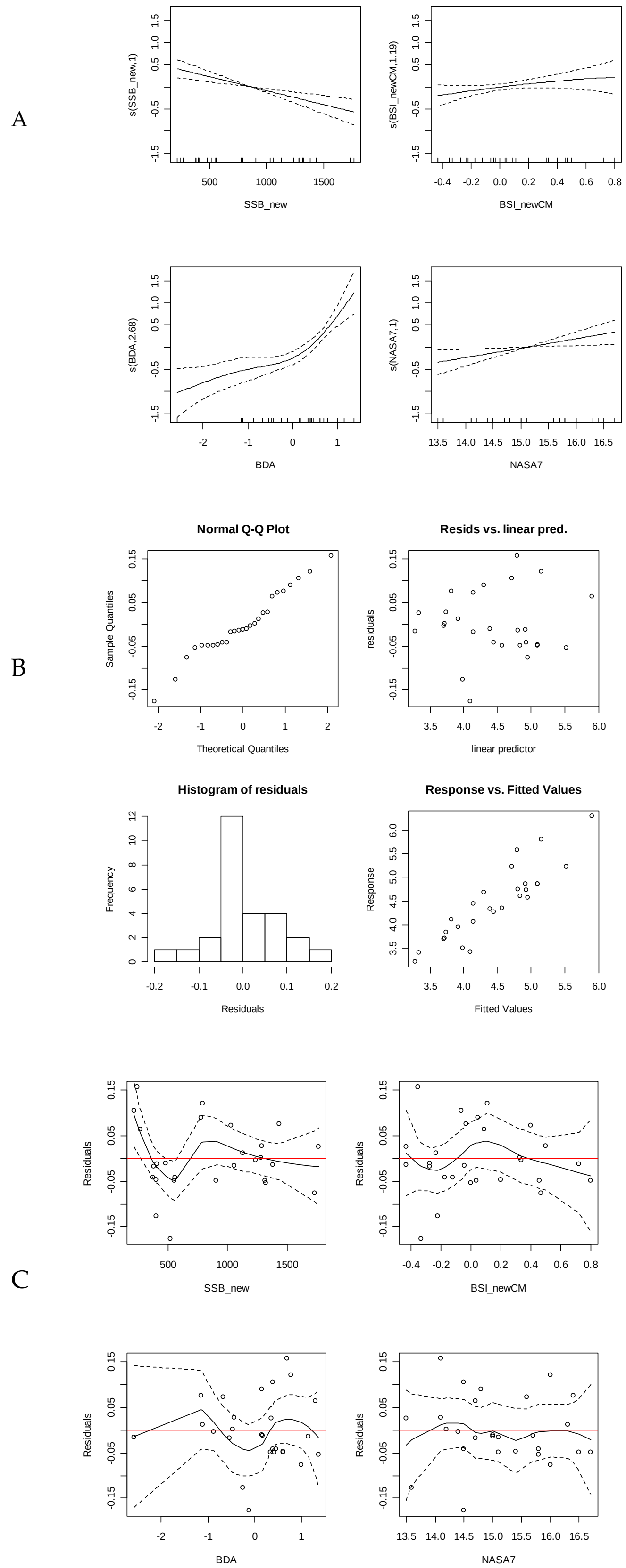

Figure 4. Diagnostic plots of the finally selected environment-recruitment models using Rs (see Section 6.6. and Annex 4: model 16): A) effects of spawning stock biomass (SSB), Baltic Sea Index (BSI), Baltic Depth Anomaly (BDA), and July sea surface temperature (NASA7); B) analyses of model residuals; C) analyses of residuals' distribution vs. selected explanatory variables

Annex 6: WKSSRB terms of reference for the next meeting

An ICES Workshop on Combining Climatic Scenarios and Medium-Term Predictions for Baltic Herring and Sprat stocks [WKCSMPB] (Chair: M. Cardinale, Sweden and Piotr Margonski, Poland) will meet in Ponza, Italy from 21–24 April 2009 to:

a) reviewing and validating the developed recruitment models using sensitivity analyses;

b) test different climatic scenarios in the medium-term predictions;

c) explore combining of medium-term predictions of clupeids with density dependent effects and climate scenarios.

WKCSSPB will report by 22 May 2009 for the attention of the Baltic Committee.

PRIORITY:	This Workshop will explore the possibility of combining the medium-term predictions of clupeids in the Baltic Sea with density dependent effects and different climate scenarios.
SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:	The Workshop contributes to Actions 1.2, 1.3, 1.6, 1.7, 1.12, 3.2, 3.5, 3.15, 4.11, 4.15, 5.3, 5.6. of the ICES Action Plan.Herring is an essential component of the Baltic ecosystem, being a food item for cod and exerting predation pressure on zooplankton populations. The different populations are of considerable commercial value for the countries bordering the Baltic. While growth of herring has been intensively studied, studies on recruitment processes of Baltic fish stocks have in recent decades been exclusively directed to cod and sprat. However, recruitment trends drive a large proportion of the dynamics of the different stocks, which are partly of opposite direction. The work of WKHRPB and WKSSRB has shown that these trends in recruitment are due to direct (e.g. temperature) and indirect effects (e.g. food availability) of climate. Reliably predicting recruitment is essential for proper stock management and environmentally-sensitive stock recruitment relationships are essential for implementing precautionary and ecosystem approaches. The workshop will thus built on the result of WKHRPB and WKSSRB and test different climatic scenarios in the medium-term predictions that are based on recruitment models developed in WKCSSP and includes density dependent effects on clupeid growth. Also, the workshop will develop stock-specific strategies for including environmental information into the work of WGBFAS.
RESOURCE REQUIREMENTS:	Assistance of the secretariat in maintaining and exchanging information and data to potential participants.
PARTICIPANTS:	This Workshop is expected to attract 10-15 participants working on Baltic herring and sprat stocks, contributing data and expertise. Further, experts from other areas should be encouraged to participate. SMS model expert should also be encouraged to participate,
SECRETARIAT FACILITIES:	None
FINANCIAL:	No financial implications.
LINKAGES TO ADVISORY COMMITTEES:	ACFM
LINKAGES TO OTHER COMMITTEES OR GROUPS:	BCC, LRC, SG/WGs related to Baltic Sea issues, HAWG, WGIAB
LINKAGES TO OTHER ORGANIZATIONS:	HELCOM