8.3.3.1 Multi-annual management of pelagic fish stocks in the Baltic

Request

The European Commission (EC) requested ICES to identify options for multi-annual management of the Baltic pelagic stocks.

Specifically, ICES is requested to:

a. *Identify multi-annual management options for each of the Baltic herring stocks and the Baltic sprat stock (herring and sprat management units are given in the background) based on the following form of Harvest Control Rule (HCR):*
   i. *The sum of the regulated catches for the stock of ("the stock") shall be set according to a fishing mortality of **[A]**.*
   ii. *Notwithstanding paragraph i above, the sum of the regulated catches shall not be altered by more than **[B]** % with respect to the sum of the regulated catches for the previous year.*
   iii. *Notwithstanding paragraphs i and ii, in the event that the spawning stock size for the stock is estimated at less than **[C tonnes / appropriate model-specific units]**, the sum of the regulated catches for the stock shall be adapted to assure rebuilding of the spawning stock size to above **[C]** without incurring the restriction referred to in paragraph ii. ICES should propose a TAC-setting calculation in such cases.*

   ICES is asked to identify combinations of values for A, B and C that would assure management of the stock that would conform to the precautionary approach; i.e. a low risk of stock depletion, stable catches and sustained high yield.

   ICES should explore other relevant scenarios on its own initiative, but should include at least scenarios where A: F = S.Q. or MSY or below MSY (appropriate level to be selected by ICES) and B: limit on TAC changes = 15% or no limits.

   Multi-species considerations such as the implications from an increased cod stock should be taken into account.

   For WBSS herring advice provided in 2008 on the request EC-DG FISH 27.03.2007-02 should be updated as necessary. Following recommendations in this advice, results from the benchmark assessment carried out in March 2008 should be taken into account and advice management options be developed in light of the multi-fleet fisheries on this stock. In addition, mixing with the North Sea Autumn Spawning herring in IIIa should be taken into account and advice be provided for a fixed allocation of catch options between Division IIIa and SD 22-24.

b. *Evaluate the potential impact of stock density on growth parameters in the Bothnian Sea.*
c. *Evaluate the efficiency of existing area management approaches in relation to the overall objective to ensure highest sustainable yields in the long-term for each of the stocks concerned (division Central Baltic and Gulf of Riga, joint management of Herring stocks in Subdivisions 30-31 and the 50-50 split of the TAC for Western Herring between SD 22-24 and IIIa).*
d. *Evaluate the ecosystem effects (including the size of the cod stock) of a reduction of the size of the sprat stock through an increased fishing mortality for sprat.*
e. *Provide proposals on how the industry can contribute to an improvement of the assessment of the pelagic stocks (quality of data).*

After consultation with the EC it was agreed that ICES would respond to ToR a, except for the last paragraph, by 1 April 2009. ICES will respond to the remaining ToRs by 29 May 2009.

ICES Response

Below please find answers to the request for each ToR above in sections 8.3.3.1a-e.

8.3.3.1a Answer to ToR (a) on *multi-annual management options*

ICES identified combinations of [A], [B], and [C] for Western Baltic herring, Central Baltic herring, Gulf of Riga herring and sprat that are generally consistent with the objectives of a low risk of stock depletion, stable catches, and sustainable high yields. The formulation considered by ICES applied a constraint on the percentage change in TAC of [B] relative to the previous year for a spawning-stock biomass (SSB) below [C] (contrary to paragraph a.iii), as well as for an SSB equal to or greater than [C]. If the constraint is not applied for an SSB below [C] (per paragraph a.iii), the SSB will recover quicker than indicated in the analyses performed by ICES for SSB falling below [C]. Multi-annual management options analyses could not be performed for the Bothnian Sea herring (SD 30) or the Bothnian Bay herring (SD 31) because there is no agreed stock assessment for these stocks.

The management options identified by ICES, along with some of their characteristics, are given in Table 8.3.3.1a.1

Table 8.3.3.1a.1 Management options identified by ICES.

	Western Baltic herring (*)	**Central Baltic herring**	**Gulf of Riga herring**		**Sprat**
Fishing mortality **[A]** (year^{-1})	< 0.25	0.22	0.26	0.35	0.40
Annual TAC variation **[B]** (± percentage)	15	15	15	20	20
Spawning-stock biomass **trigger [C]** ('000 t)	None	800	60		400
Probability of SSB_{2015}<**[C]**	< 5% (**)	< 5%	< 5%		< 5%
B_{lim} ('000 t)	110 (***)	385	40		200
When SSB<B_{lim}	F = 0	F = 0	F = 0		F = 0
F when B_{lim}<SSB_y<[C]	Not Applicable	0.22*[(SSB_y-385)/(800–385)]	0.26*[(SSB_y-40)/(60–40)]	0.35*[(SSB_y-40)/(60–40)]	0.40*[(SSB_y-200)/(400–200)]
Spawning-stock biomass in 2015 SSB_{2015} ('000 t)	(*)	1 056	117	101	962
Yield in 2015 Y_{2015} ('000 t)	(*)	190	24	29	256

(*) WKHMP (ICES 2008) provided preliminary recommendations of the values for [A], [B], and [C]. The end results should be regarded only as indicative of what a management plan for Western Baltic herring should include; no quantitative results are therefore calculated for SSB and Yield in 2015.
(**) probability of SSB < 110 000 t (as suggested by WKHMP 2008).
(***) no value for [C] or B_{lim} available, 110 000 t is used (as suggested by WKHMP 2008).

ICES used multispecies models to investigate the implications of cod predation on management of Baltic Sea pelagic stocks. Herring of the Central Baltic Sea and the Gulf of Riga (combined) were considered, as were sprat. The target F for cod was set according to the agreed management plan (F = 0.3).

If cod recruitment continues to fluctuate around the average level observed over the most recent 15 years, the herring and sprat HCR options given above perform reasonably well. The probability of the pelagic stocks declining below B_{lim} is less than 5%, although the probability of the herring stock falling below the trigger values of SSB [C] is greater than 5%. If cod recruitment is higher than in recent years (by a factor of 2.25, which is still much lower than in the 1980s), the target Fs [A] for herring and sprat are too high to maintain the stock above the trigger SSB levels with confidence. However, an increase in the mean weight of herring to the level of the 1980s could compensate for the higher level of cod recruitment. This analysis illustrates the importance of keeping HCRs under review so that they can be modified to take account of the dynamic nature of marine ecosystems.

The options given above satisfy the objectives given in the EC's request, but there are likely to be multiple sets of options that merit consideration. For complex situations like this one (with multispecies, potential effects of ecosystem dynamics and multiple objectives), ICES favors a management plan development process that involves an interactive dialogue among scientists, managers, and stakeholders to explore options.

Background

The current stock assessment and management areas for Baltic Sea pelagic resources are given in Table 8.3.3.1.2a.

Table 8.3.3.1a.2 Baltic Sea pelagic resources.

Stock	Assessment area	Management area (EC waters)
Western Baltic herring	Division IIIa and Subdivisions 22–24	Division IIIa Subdivision 22–24
Central Baltic herring	Subdivisions 25–27, 28.2, 29, and 32	Subdivisions 25–27, 28.2, 29, and 32
Gulf of Riga herring	Subdivision 28.1	Subdivision 28.1
Bothnian Sea herring	Subdivisions 30 (part of management unit 3)	Subdivisions 30–31
Bothnian Bay herring	Subdivisions 31 (part of management unit 3)	Subdivisions 30–31
Baltic sprat	Subdivisions 22–32	Subdivisions 22–32

The evaluation of HCRs for multi-annual management plans were conducted using the age-structured multispecies assessment model SMS (Stochastic Multi Species model). Simulations were performed for each stock, using as starting conditions the population parameter estimates from the 2008 stock assessment and recruitment predicted from a segmented regression S–R model with breakpoint at [C]. The recruitment at higher spawning biomass than [C] was taken as the geometric mean R of the whole assessment period for Central Baltic Sea herring and of the period of favorable R, i. e. after 1988–1989 for Gulf of Riga herring and Baltic sprat. The evaluation of the Western Baltic Sea herring stock was based on previous analyses conducted by the ICES Workshop on Herring Management Plans (WKHMP) (ICES, 2008) in February 2008.

The range of analyzed fishing mortality options **[A]** included values encompassing $F_{0.1}$ (a proxy for F_{msy}), F <F_{msy} proxy, F_{pa}, and F_{sq} (F_{max} is not well defined for these stocks).

Simulations were carried out without limits in TAC changes **[B]** and for a wide range of interannual variation of TAC, from ±5% to ±40%.

Setting of trigger SSB [C] was based on the historical development of the stocks and the environment (further explained below in each stock paragraph).

ICES tested the following HCR structure for Central Baltic and Gulf of Riga herring and the sprat stocks:

1. If SSB is at or above [C] the target F [A] is kept constant;
2. If SSB falls below [C] the target F [A] is linearly reduced to 0.0 at B_{lim};
3. If SSB falls below B_{lim} no catches should be allowed (F = 0).

Western Baltic herring

Simulations for Western Baltic herring were conducted for combinations of target F [A], trigger biomass [C] and constraint on year-to-year change in TAC [B]. For F less than or equal to 0.25, the risk of SSB falling below 110 000 tonnes (a threshold level used by WKHMP to designate a level below which there should be zero catch) is low (a few percent), regardless of the value of [B] or [C]. Therefore, the HCR given in Table 8.3.3.1a.1 does not include a trigger biomass. However, it may be desirable to have a trigger biomass to avoid a sudden reduction in F (from 0.25 to 0.0) if SSB does decline to 110 000 tonnes.

Simulations were used to examine the effect of the selectivity of the fishery shifting to catch a higher proportion of small/young fish. The result was an increase in the probability of SSB declining below 110 000 tonnes. However, with the selectivity of 0- to 2-year-old herring at double the current selectivity, the probability of SSB declining below 110 000 tonnes remains less than 5%.

Central Baltic herring

For Central Baltic herring the trigger SSB [C] of 800 000 tonnes based on observations after 1989 was adopted to account for changes in the weight-at-age of herring since 1989. This value of [C] corresponds to a breakpoint in the stock–recruitment data. The analysis (Figure 8.3.3.1a.1) showed that for target Fs [A] up to 0.22, the probability of SSB falling below the trigger SSB [C] is lower than 5%. At target Fs of 0.16 (= $F_{status\ quo}$) and 0.19 (F <F_{msy} proxy), the SSBs in 2015 will be 14% and 6% higher and the yields will be 14% and 6% lower, respectively, than for a target F of 0.22. At catch constraints [B] above or below 15% the yield was slightly lower.

Gulf of Riga herring

For Gulf of Riga herring the adopted [C] of 60 000 tonnes is the lowest observed SSB after 1989, during a period of favorable R. The proxy for F_{msy} for the stock is $F_{0.1}$ = 0.26. However, for a target F [A] up to 0.35, the probability of SSB falling below trigger SSB [C] is lower than 5%. Therefore, 2 options for a target F [A] are presented. At a target level of F = 0.26, a stable yield and high probability of SSB remaining above trigger SSB [C] is obtained (Figure 8.3.3.1a.2). At a target level of F = 0.35, yields are higher but SSB is closer to the trigger SSB level [C]. However, in order to maintain the probability of SSB falling below the trigger SSB [C] at 5% or less, the TAC constraint [B] must be 17% or more.

Sprat

The trigger SSB [C] for the HCR was determined by examining SSB data. The trigger SSB [C] of 400 000 tonnes is the lowest observed SSB in the period after 1989, corresponding to a period of high sprat recruitment and lower mean weight-at-age. For target fishing mortality up to 0.50, the SSB has a lower than 5% probability of falling below the trigger SSB [C], and equilibrium catches are similar. At target Fs of 0.45 ($F_{status\ quo}$) and 0.30 (F <F_{msy} proxy) the SSB_{2015} and Y_{2015} will be 6% lower and 5% higher and 11% higher and 14% lower, respectively, than those observed at target F of 0.40. However, for a TAC constraint [B] up to 16%, the probability of the SSB falling below the trigger SSB [C] was greater than 5% for some scenarios. Therefore, a higher value of [B], i. e. 20%, is indicated (Figure 8.3.3.1a.3).

Multispecies simulation

Multispecies simulations were carried out to evaluate the implications from an increased cod (SD 25–29, 32) stock on herring (SD 25–29, 32 but including Gulf of Riga catches) and sprat (SD 25–32) stocks. The simulations were undertaken using a multispecies model where predation mortality is variable and estimated on the basis of sizes of the predator (cod) and prey (cod, herring, and sprat). Forecast scenarios were made using the target F [A], trigger SSB [C], and TAC constraints [B] advised for the Central Baltic herring and sprat stocks (Figures 8.3.3.1a.4–6). A trigger SSB of 860 000 tonnes in total [C] was used for herring (800 000 tonnes for the Central Baltic and 60 000 tonnes for the Gulf of Riga herring). For cod the agreed management plan (EU Council regulation 1098/2007) was implemented.

Three forecast scenarios were evaluated, assuming: (i) cod recruitment at a low level representing the most recent period (SSB–recruitment derived from a “hockey stick” model with a breakpoint at 90 000 tonnes fitted to the period 1989–2007) and mean weights-at-age for all species derived from the period 2005–2007; (ii) cod recruitment at a higher level representing the recruitment for the period 1975–2007 (SSB–recruitment derived from a “hockey stick” model with a breakpoint at 160 000 tonnes fitted to the period 1975–2007. For a cod stock size above 160 000 tonnes, the recruitment is approximately a factor 2.25 higher than in the low recruitment scenario) and mean weights-at-age for all species as in i); and (iii) cod recruitment as in ii) but with higher herring mean weights, derived from the period 1980–1989, representing a period with lower population size and higher mean weight, and with mean weight for cod and sprat as in i). The results from these three scenarios are discussed in the ICES Response section of this document.

Western Baltic Spring Spawning herring advice (ToR (a) last paragraph)

Answer to be found under the Section on Western Baltic Herring (8.4.3).

Sources of information

ICES. 2008. Report of the Workshop on Herring Management Plans (WKHMP), 4–8 February 2008, ICES Headquarters. ICES CM 2008/ACOM: 27.

ICES. 2009. Report of the Workshop on Multi-annual Management of Pelagic Fish Stocks in the Baltic (WKMAMPEL), 23–27 February 2009, ICES Headquarters. ICES CM 2009/ACOM: 38.

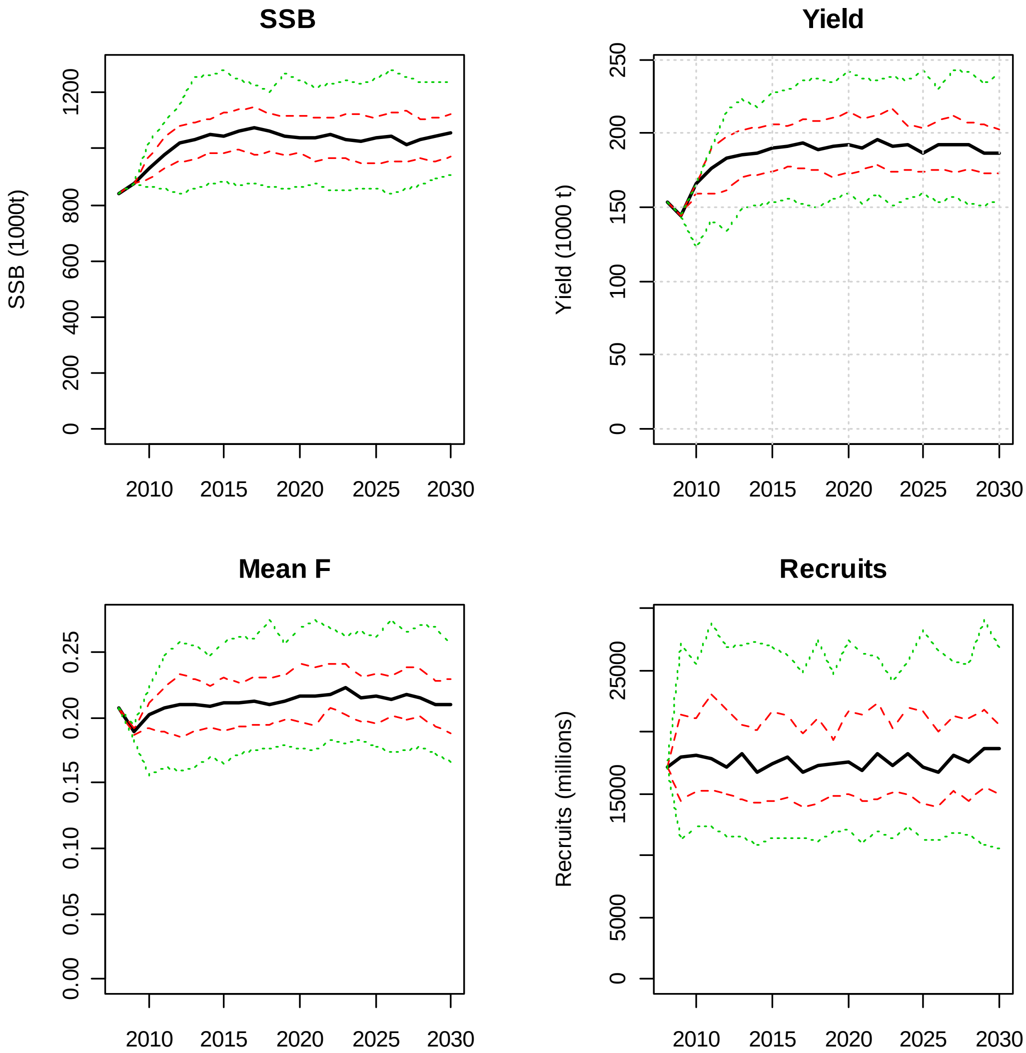

Figure 8.3.3.1a.1 Central Baltic herring. Percentiles (5% and 95% – dotted lines, 25% and 75% – dashed lines, 50% – solid line) of SSB, yield, mean F, and recruitment distribution for HCR with a target F of 0.22 [A] and constraints in yearly TAC changes at ±15% [B].

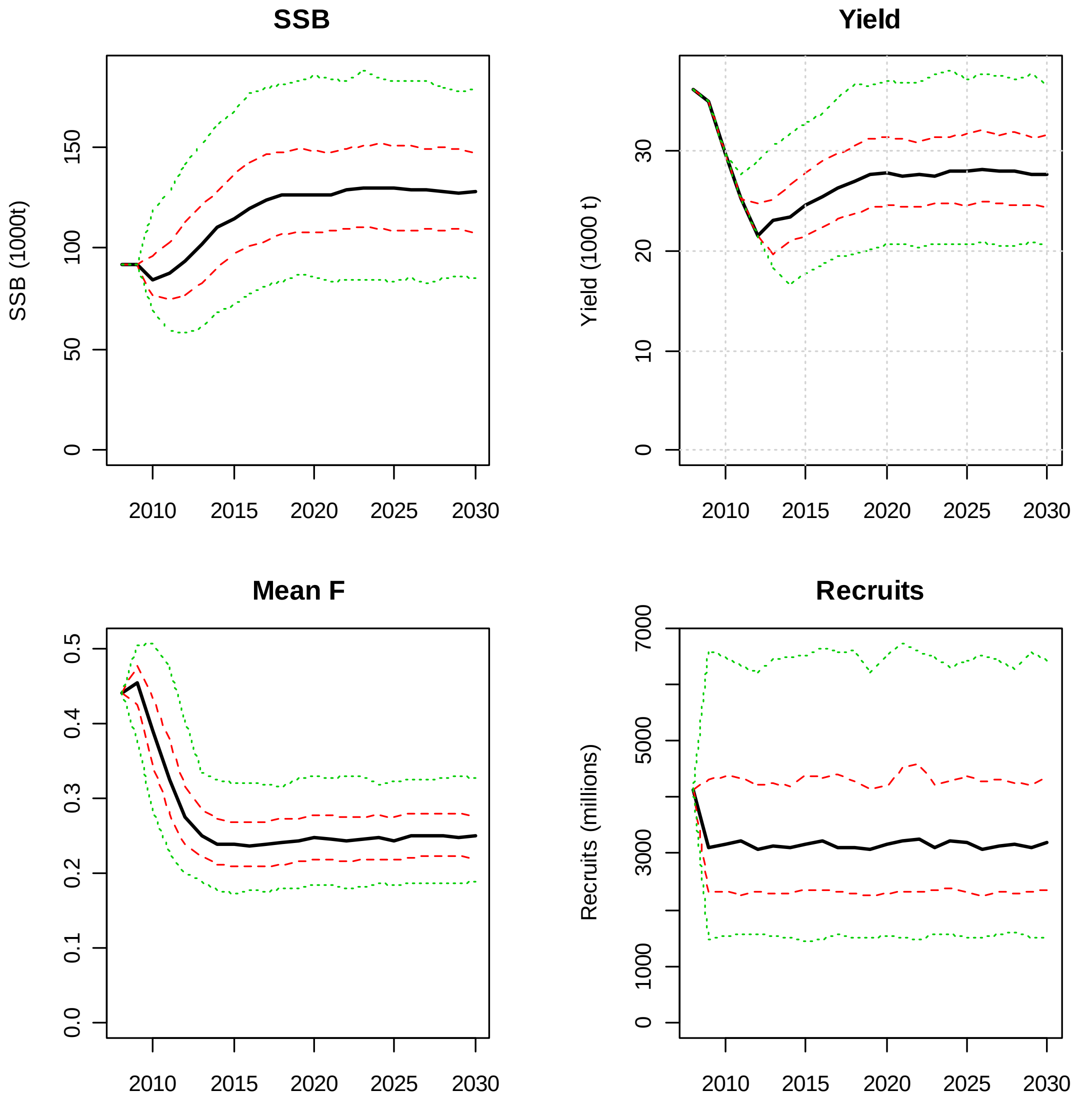

Figure 8.3.3.1a.2 Gulf of Riga herring. Percentiles (5% and 95% – dotted lines, 25% and 75% – dashed lines, 50% – solid line) of SSB, yield, mean F, and recruitment distribution for HCR with a target F of 0.26 [A] and constraints in yearly TAC changes at ±15% [B].

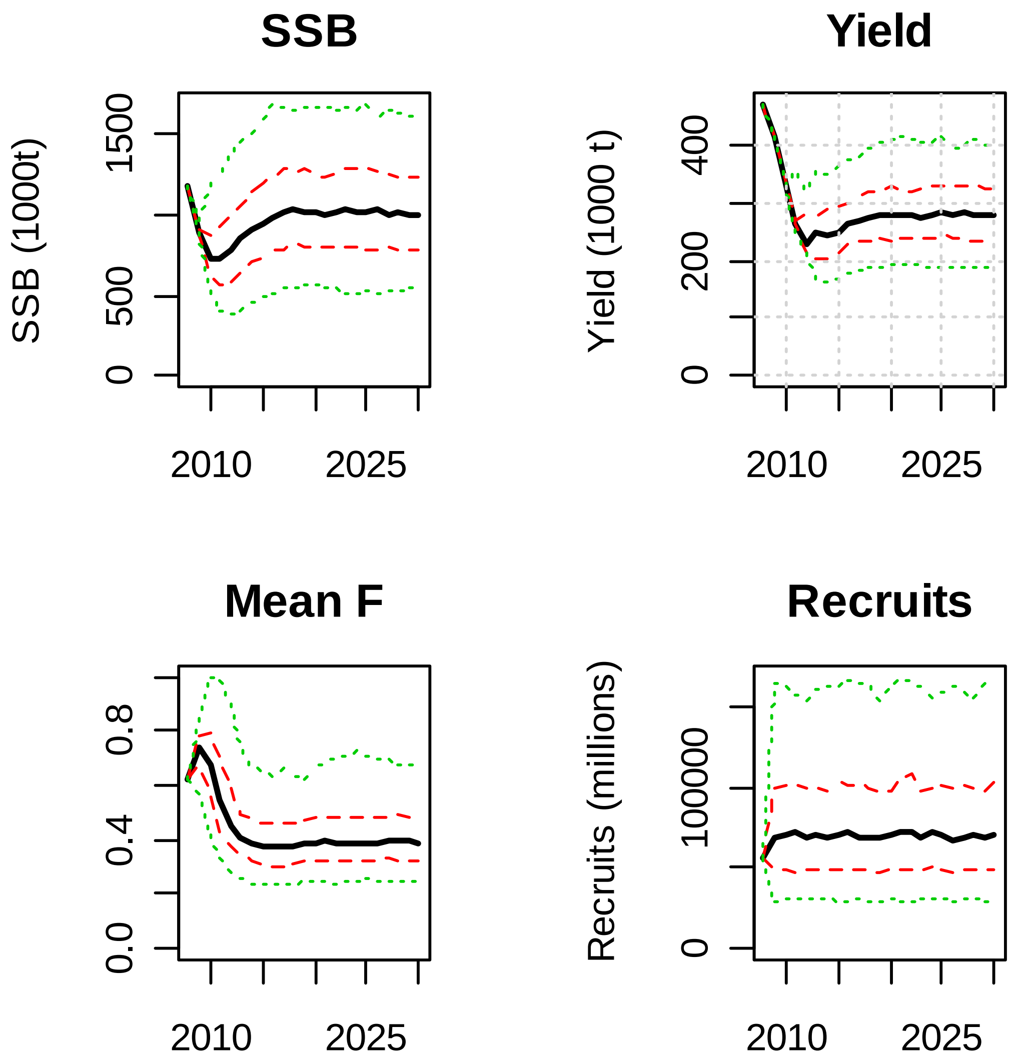

Figure 8.3.3.1a.3 Baltic sprat. Percentiles (5% and 95% – dotted lines, 25% and 75% – dashed lines, 50% – solid line) of SSB, yield, mean F, and recruitment distribution for HCR with a target F of 0.4 [A] and constraints in yearly TAC changes at ±20% [B].

Figures 8.3.3.1a.4–6 show multispecies results for a low cod recruitment scenario.

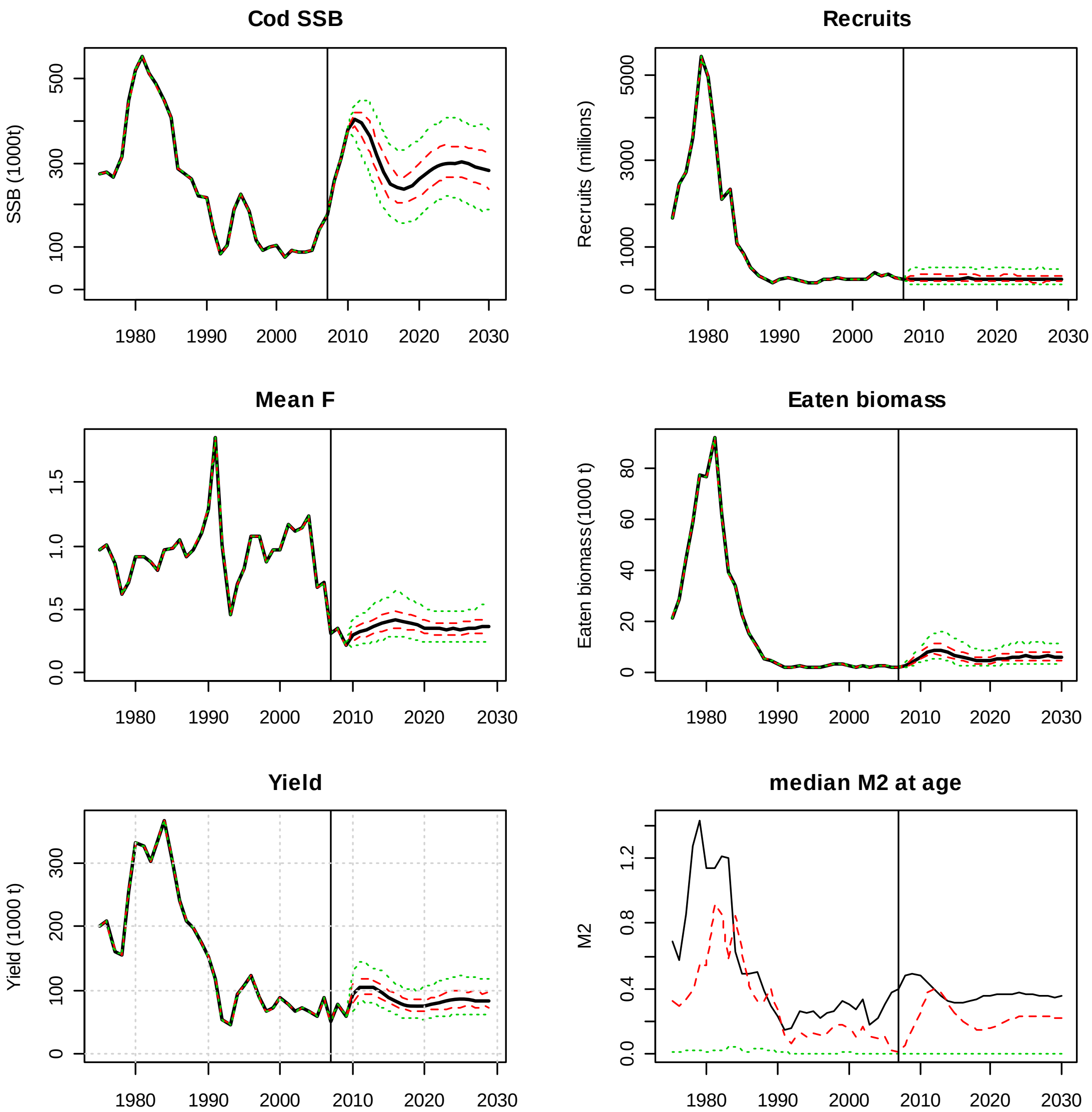

Figure 8.3.3.1a.4 Baltic cod. Historical stock metrics and scenario values for a low cod recruitment scenario. The figures show the mean value for the historical period and percentiles (5% and 95% – dotted lines, 25% and 75% – dashed lines, 50% – solid line) for the scenario period. The predation mortality (M2) is age 0 for the second half year (solid black line) and annual values for the older ages.

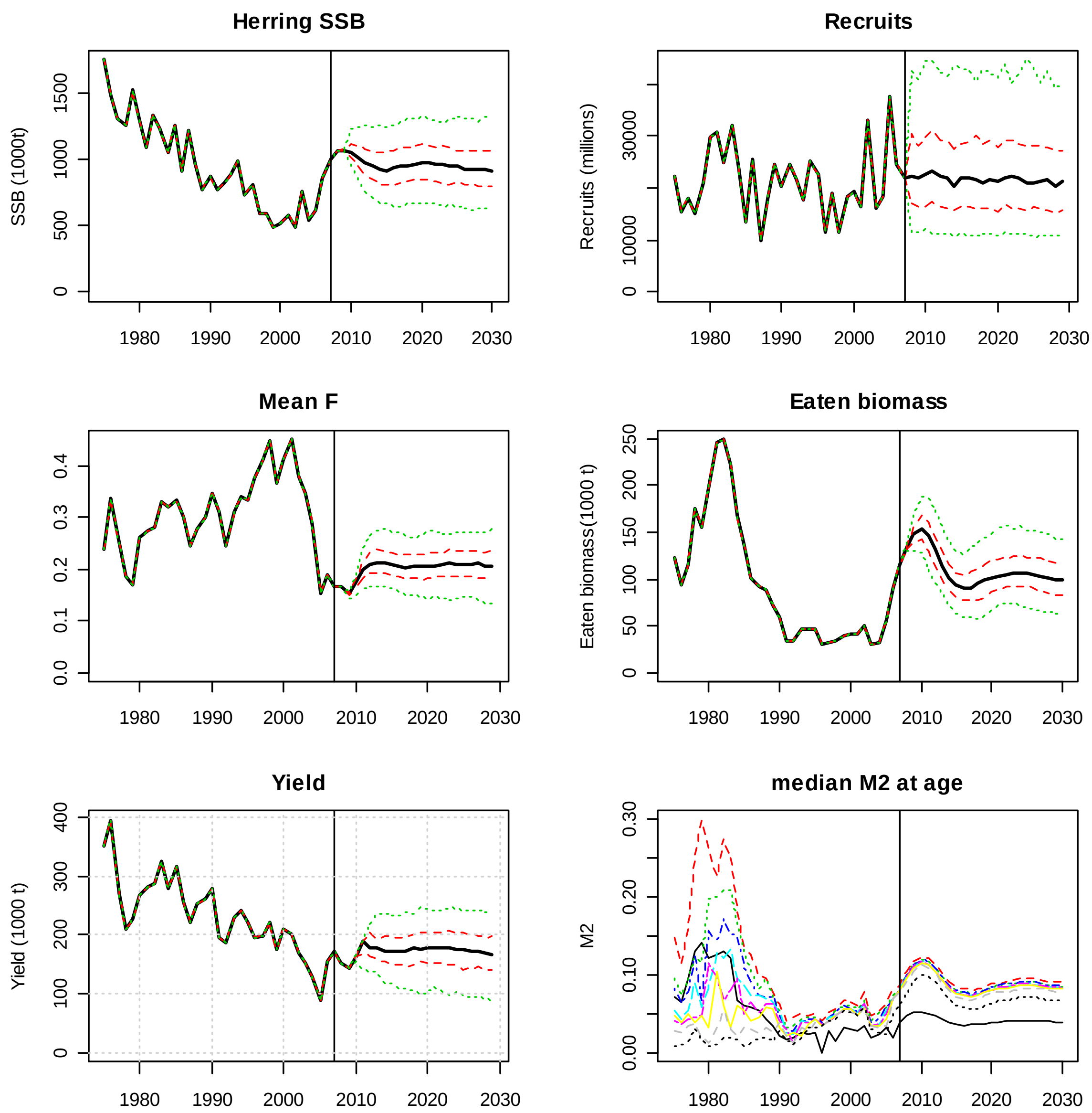

Figure 8.3.3.1a.5 Central Baltic herring (Subdivisions 25–29, 32). Historical stock metrics and scenario values for a low cod recruitment scenario. The figures show the mean value for the historical period and percentiles (5% and 95% – dotted lines, 25% and 75% – dashed lines, 50% – solid line) for the scenario period. The predation mortality (M2) is age 0 for the second half year (solid black line) and annual values for the older ages.

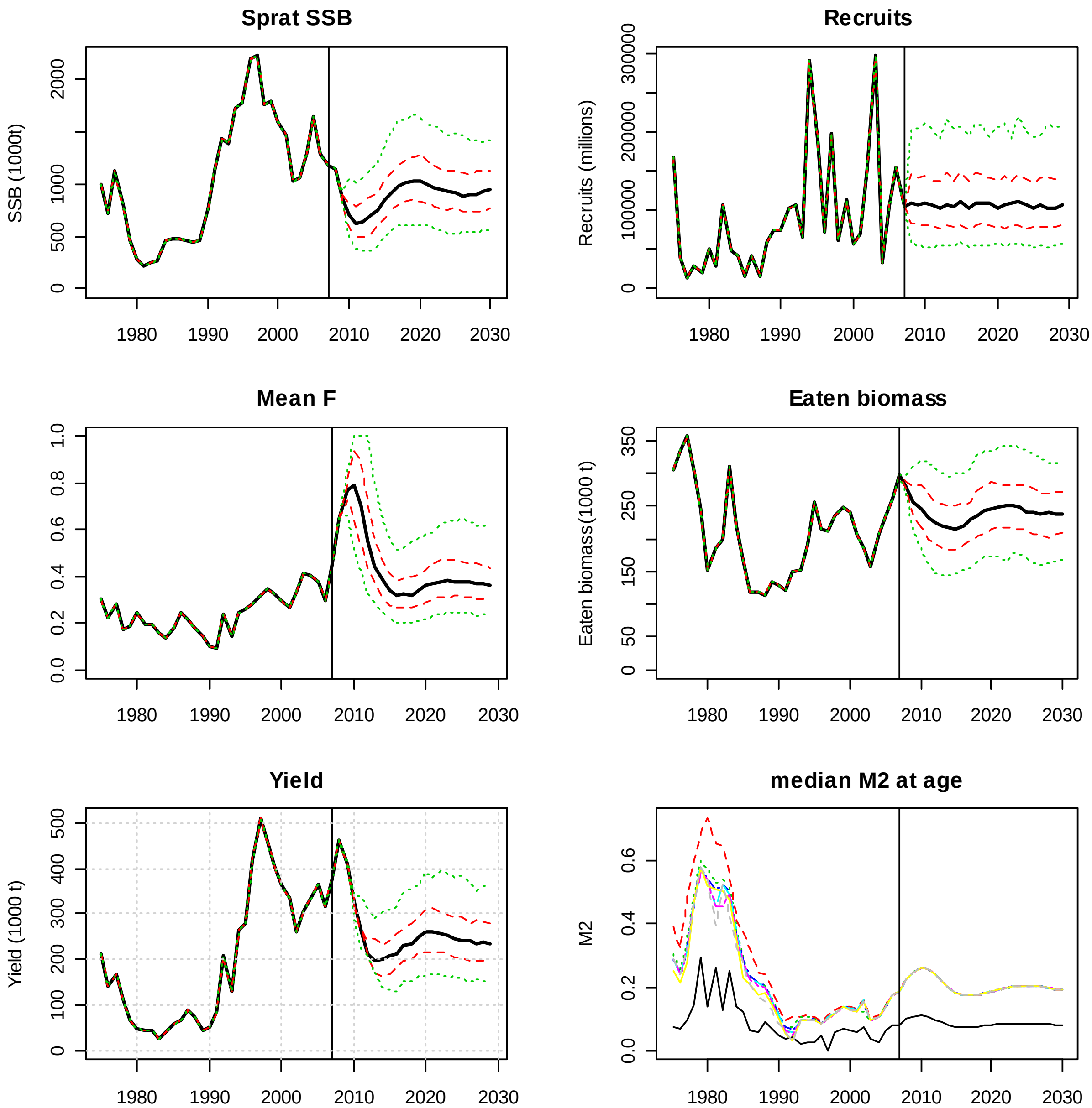

Figure 8.3.3.1a.6 Baltic sprat. Historical stock metrics and scenario values for a low cod recruitment scenario. The figures show the mean value for the historical period and percentiles (5% and 95% – dotted lines, 25% and 75% – dashed lines, 50% – solid line) for the scenario period. The predation mortality (M2) is age 0 for the second half year (solid black line) and annual values for the older ages.

8.3.3.1b Answer to ToR(b) on Multi-annual management of pelagic fish stocks in the Baltic

ICES has not conducted a full analysis of density dependent growth of herring in the Bothnian Sea. Based on literature studies and available data, ICES concludes that reduced growth rates caused by density dependent effects are likely.

Technical background

In the Bothnian Sea, herring growth rate was exceptionally high in the 1980s. The mean weight at age decreased at the end of the 1980s and the early 1990s, and this trend continued at least until the year 2006. In otoliths of old herring, an abrupt decrease in growth in 1988 and 1989 can be detected, which may reflect a shortage of food availability for older herring in these years. In 1988 and 1989, very large year classes of herring were hatched, which led to the fast increase of herring numbers and biomass in the Bothnian Sea. Since then, the biomass has remained much larger than in the 1980s.

During the 1990s and the 2000s, some eutrophication has taken place, and salinity has decreased in the whole Gulf of Bothnia. The temperatures have also been on average higher than in the 1980s. Low salinity is likely to limit herring growth, however, the mean weights at age in herring from both the Bothnian Sea (salinity 5-6) and the Bothnian Bay (salinity 2-4) have been very similar all the time despite the salinity difference of these areas. This supports the conclusion that the reduced growth of herring in these areas was caused by reduced food availability rather than by physiological effects caused by decreased salinity. One of the reasons for reduced food availability is an increased competition for food, probably caused by the increased number of herring.

8.3.3.1c Answer to ToR(c) Efficiency of existing management areas

Please see comments in the relevant stock sections (Western Baltic Herring section 8.4.3, Central Baltic herring section 8.4.4, and Gulf of Riga Hering .8.4.5).

8.3.3.1d Answer to ToR(d) concerning ecosystem effects of a reduction of the size of the sprat stock

ICES addressed this request by (i) conducting a literature review on Baltic ecosystem functioning and (ii) a modelling study investigating the effect of increased sprat fishing on the ecosystem.

In conclusion, the present knowledge on Central Baltic ecosystem functioning suggests the following ecosystem effects of a sprat stock reduction:

1) weakening of the trophic cascades leading in spring to increased *P. acuspes* and in summer to increased total zooplankton as well as decreased phytoplankton biomass;
2) reduced control of cod recruitment by sprat due to lower predation on eggs and *P. acuspes*;
3) increased growth and improved condition and subsequently an increase in biomass of herring due to reduced competition with sprat;
4) increased growth and condition of sprat due to reduced intra-specific competition and hence a higher quality food supply for seabirds.

In summary the literature review and the performed modelling study indicate a clear positive response by herring on reduced sprat stock, potentially induced by lower competition and an improved zooplankton food supply. Generally the modelling of the lower trophic levels in food-web models needs to be improved. The modelling results with respect to the importance of the indirect effects of species interaction for the recovery of the cod stock are less clear, as all of these interactions could not be included in the models. However, it seems clear from all sources that fishing down the sprat stock or improved abiotic conditions will only lead to a cod recovery if the fishing pressure on the cod stock is significantly reduced compared to previous years.

Technical background

Literature review on mechanisms mediating ecosystem effects of a potential sprat stock reduction

The Central Baltic ecosystem underwent a drastic shift in composition in the late 1980s due to climate change and overfishing (Möllmann *et al*. 2008, 2009). A major component of this regime shift was a change from a cod (*Gadus morhua*) dominated to a sprat (*Sprattus sprattus*) dominated ecosystem state (Köster *et al*. 2003). This remarkable shift in the fish community was triggered by coinciding overfishing and climate change, the latter causing high cod egg and larval mortalities and eventually recruitment failure due to low salinity and low oxygen concentrations (Köster *et al*. 2005). Following the collapse of the cod stock, sprat was released from predation (Köster *et al*. 2003, Möllmann *et al*. 2008, Casini *et al*. 2008), and in combination with temperature-driven high recruitment success, the sprat stock rose to unprecedented levels (MacKenzie & Köster 2004).

The increased sprat stock affected lower-trophic levels with a "spring trophic cascade" on a species-level reducing the biomass of the copepod *P. acuspes* (Möllmann *et al*. 2008), and a "summer cascade" reducing total zooplankton and increasing phytoplankton biomass (Casini *et al*. 2008). In summer, moreover, the effects of the large sprat stock have been also evident in other features of the zooplankton community; i.e. species and stage composition as well as vertical distribution (Casini *et al*. 2009). Additionally, the increased sprat abundance led to strong intra- and inter-specific competition with herring (Möllmann *et al*. 2005, Casini *et al*. 2006), which resulted in poor condition of clupeides and hence less energy content of fish prey for sea-birds (Österblom *et al*. 2006).

The large sprat stock may now impose a key feedback on cod recruitment by reducing the main food for cod larvae, the copepod *P. acuspes* and directly preying on cod eggs (Köster & Möllmann 2000, Möllmann & Köster 2002, Casini *et al*. 2004). The effect of the egg predation has however to be taken with caution, as it (i) has been demonstrated only for one spawning area (Bornholm Basin), (ii) has limited importance during the present peak summer spawning of cod reducing the temporal overlap with the sprat stock, and (iii) is mediated by the physical environment making it difficult to disentangle the effect from a direct effect of low oxygen on cod egg mortality (Köster & Möllmann 2000, Köster *et al*. 2005, Andersen *et al*. 2008).

Nevertheless, these newly established feedback loops in the ecosystem possibly delay cod stock recovery and maintain the food-web in a new stable state which may be difficult to reverse (Casini *et al*. 2009, Möllmann *et al*. 2009). A further mechanism potentially contributing to a difficult to reverse low cod stable state has been revealed using a stage-structured biomass model for the cod–sprat interaction (van Leeuwen *et al*. 2008). These preliminary modeling results indicate that a lack of cod recovery could be explained by a stunted growth of sprat offering insufficient food for cod to grow and reproduce. This mechanism, referred to as an emergent Allee effect (De Roos and Persson 2002) has been shown to occur in predator–prey–resource systems when predators forage exploitatively on selective size ranges of prey only.

In conclusion, the present knowledge on Central Baltic ecosystem functioning suggests the following ecosystem effects of a sprat stock reduction:

1) weakening of the trophic cascades leading in spring to increased *P. acuspes* and in summer to increased total zooplankton as well as decreased phytoplankton biomass;
2) reduced control of cod recruitment by sprat due to lower predation on eggs and *P. acuspes*;
3) increased growth and improved condition and subsequently an increase in biomass of herring due to reduced competition with sprat;
4) increased growth and condition of sprat due to reduced intra-specific competition and hence a higher quality food supply for seabirds.

With respect to the top-predator cod, the presence of the 2 key feedback loops, i.e. sprat predation on cod eggs and *P. acuspes* (Möllmann *et al*. 2008, 2009) suggests that a reduction in the sprat stock may cut off these processes which potentially hinder or retard a cod stock recovery. However, for a significant increase in the cod stock and a resulting reversal of the trophic cascade to occur, fishing mortality on cod needs to be reduced, and most likely also the physical oceanographic conditions, i.e. deepwater salinity and oxygen conditions, would need improvement as these are a prerequisite for cod egg survival (Köster *et al*. 2005) and an increase in *P. acuspes* biomass (Möllmann *et al*. 2003).

Testing the effect of reducing the sprat stock using Baltic Sea food web models

The relative importance of the different bottom-up and top-down processes involved in modulating the ecosystem effects of a potential reduction in the sprat stock can eventually only be resolved by using suited food-web or ecosystem models. Hence, the *ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea* (WGIAB) used 3 different models to explore the ecosystem effects of increasing the fishing pressure on sprat with a special focus on the fish community (ICES 2009). Effects on lower trophic levels have not been considered due to an insufficient development of these components in the models.

The models used by WGIAB included:

1) a first order multivariate autoregressive model (BALMAR) simulating the dynamics of cod, herring and sprat under different fishing and climate scenarios (Lindegren *et al*. submitted);
2) a Stochastic Multi-Species model (SMS) that represents a stochastic version of the traditional Multispecies Virtual Population Analysis (MSVPA) estimating stock sizes as well as fishing and predation mortalities for cod and its prey species herring and sprat (Lewy and Vinther 2004);
3) a full food-web model (including all trophic levels) using the ECOSIM-model, the dynamic implementation of the ECOPATH approach (Pauly *et al*. 2000).

A fourth food-web model, structurally different from models 1-3 above, was used to test whether their qualitative results were affected by processes omitted from models 1-3: size-selective predation combined with density-dependent body growth (ICES 2009). Models 1-3 were fitted to a reference period (1974-2006) and then projected into the future. Projections were made using 2 different "climate scenarios", i.e. assuming 1) no change in climate, or 2) changes in temperature and salinity, by forcing different components of the models by temperature and salinity. The climate change scenario is based on the International Panel on Climate Change (IPCC) emission scenario A2 and predicted using coupled regional atmospheric and hydrodynamic circulation models (BACC 2008, Meier 2006). Here we present only runs assuming no climate change as climate effects are visible only on a time-scale > 50 years. Runs assuming climate change can be found in ICES (2009).

The management scenarios to simulate an increased fishing pressure on the sprat stock included (i) moderately intensified sprat fishing (F_{sprat}=0.6) and (ii) strongly intensified sprat fishing (F_{sprat}=0.8). Detailed descriptions of the models, the modelling strategy and model forcing as well as a discussion of the results are given in ICES (2009).

Figure 8.3.3.1d.1 presents historic and the future developments of the 3 fish stocks until 2025 for the 3 management scenarios. The major trends from this exercise are that in comparison with business-as-usual, BAU (F_{cod}, F_{sprat}, $F_{herring}$ all means of the last 10 years), increased fishing pressure on the sprat stock will result in:

1) a decrease in sprat SSB to an on average stable level;
2) a slight increase in cod SSB;
3) an increase in herring SSB.

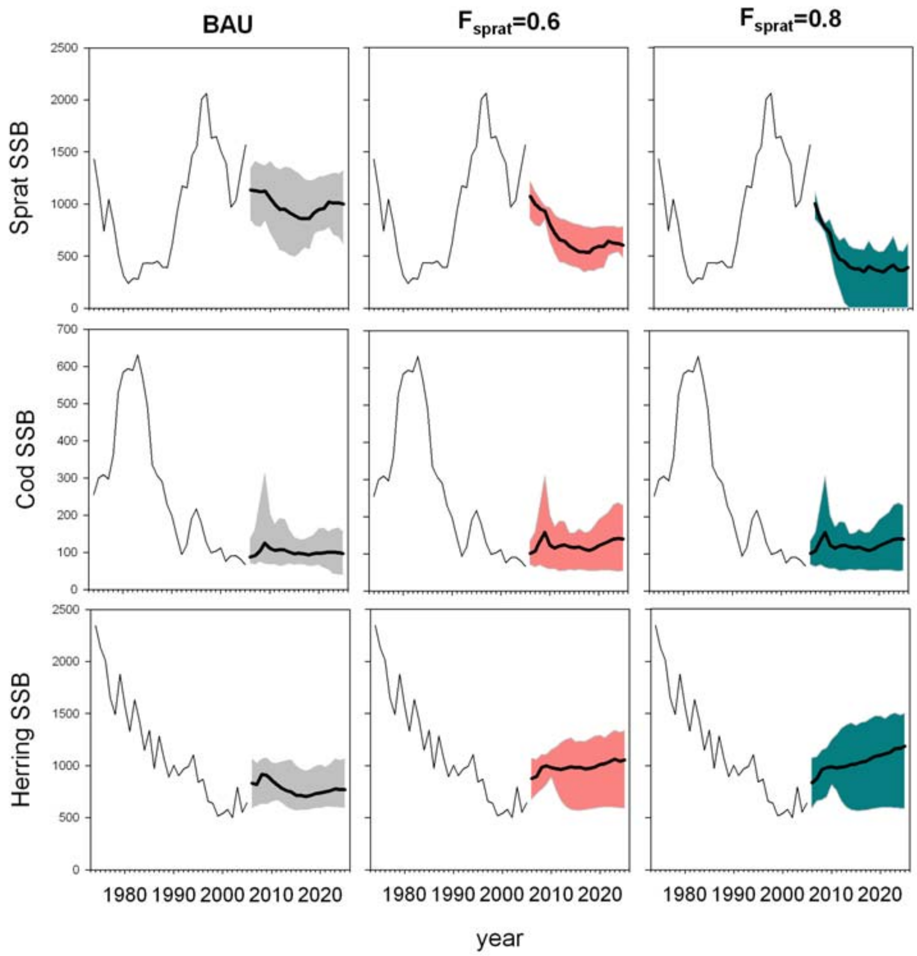

Figure 8.3.3.1d.1. Historical and simulated future development of spawning stock biomass (SSB) in Central Baltic sprat, cod and herring stocks: Thin lines in all plots represent the historic data reconstructed by MSVPA (ICES, 2006). Results of the future simulations for the 3 stocks under business as usual (BAU) and 2 levels of increased sprat fishing mortality (F_{sprat} = 0.6, 0.8) are represented by bold lines and coloured areas – bold lines are the means of the 3 models used, coloured areas are confined by lowest and highest estimates among the 3 models. The shaded areas hence give an estimate of the uncertainty in the future simulations due to model structure. All simulations presented here assume no climate change.

By nature, these future projections incorporate many sources of uncertainty as partly represented in the given projection envelopes (coloured areas around the means in Fig. 1). Uncertainties are beside the model structure due to the used abiotic forcing time-series (salinity and temperature) and the applied forcing functions (ICES 2009). The projection envelopes indicate the highest uncertainties to exist in (i) the risk inherent in a higher fishing mortality for sprat which might result in strong overfishing of the stock, and (ii) the level of recovery of the herring stock. The latter is clearly a result of reduced competition with sprat captured by models 1 and 3, but due to model set-up not by model 2 (the SMS).

Uncertainty exists also in the reaction of the cod stock on the sprat reduction. The future SSB trajectory is largely independent on the level of sprat stock reduction which points towards other factors being important for cod SSB in these models. As fishing mortality of cod is kept at BAU-levels in these simulations, this high fishing mortality and recruitment driven by abiotic conditions are the most likely factors.

The question if with the decreased sprat stock the above described feedback loops are weakened can only to a limited degree be answered by the applied models. Egg predation is included implicitly but not mechanistically in models 1 and 3, and *P. acuspes* availability only in model 3. However, the parameterization especially in model 3 needs further improvement. The results of these three models so far suggest that cod fishing mortality is the limiting factor of cod SSB, which does not preclude that weakening the feed back loops caused by species interactions can be a pre-requisite for cod stock recovery when abiotic conditions improve and cod fishing mortality decreases.

The question if reducing the sprat stock can result in a recovery of the cod stock alone was addressed additionally with a stage-structured multi-species biomass model of cod, sprat and their zooplankton resources, which mechanistically includes size-dependent predation and resource-dependent body growth (van Leeuwen *et al*. 2008). Similar to models 1-3, this model predicts that increased sprat fishing alone is not sufficient to shift the food-web from the current cod depleted state, because the fishing mortality on cod is still too high (ICES 2009). These simulations show that only if the increased sprat fishing is combined with a reduced cod fishing mortality, the cod stock can recover.

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8.3.3.1e Answer to ToR(e) on *industry contributions to an improvement of the assessment*

ICES sees plenty of opportunities to enhance the cooperation with the fishing industry in order to improve the assessment for Baltic pelagic stocks. Communication between science and fishery appears to be the key issue. A non-exhaustive list of possible actions which could be implemented in the short to medium term is given below:

- The fishery often has available **distribution data** earlier than science. Communicating this information to scientists can improve the coverage of surveys and commercial sampling strategies and hence improve the quality of data and the assessment. An example is the annual hydroacoustic survey on sprat, conducted in May. In 2007, sprat altered the distribution area towards the North and towards more coastal areas, and the survey missed important parts of the population outside the ordinary survey area. The survey results had to be excluded from the assessment for that reason. The fishery starting in early spring had detected the distribution shift early enough to allow for an amendment of the survey, but this information was not communicated. A more formal way of incorporating such qualitative information into the scientific planning should be implemented.

- **Biological sampling**: There are indications that Central Baltic herring displays different growth rates in different parts of its distribution area. Fine scale sampling of the pelagic fishery for herring and sprat is required for a statistically sound detection of these differences and the incorporation of such data in the assessments. This kind of sampling could easily be performed by the pelagic fishery, as it requires only little additional effort for taking, marking and storing these small samples.

- **Reference fleets** are known to enhance the knowledge of changes in fishing patterns and catch composition in many areas. Norway and Sweden have introduced such a system with good experience. Most EU member states are presently exploring possibilities to create such reference fleets on a regular scale, also in the Baltic (see e.g. the results of the EU-Study JOIFISH, 2009). Financial constraints are an issue for some of the scientific institutes. These could be solved by a contribution of the fishery, providing work rather than funding, or accepting a higher quota share for their effort in reference fleets rather than financial compensations. Those reference fleets could also provide bycatch data for seabirds and mammals, which is known to be incomplete but problematic in some Baltic pelagic fisheries.