Investigating the possibility of North Sea Herring spawning stock biomass rebuilding within a short timeframe

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Summary

The potential for the rebuilding of the North Sea herring spawning biomass to above precautionary limit biomass reference points (1.3 million tonnes) was explored by a short term forecast applying different recruitment trends and productivities and the current management agreement between the EU and Norway. This was carried out, so that the PFA could consider rebuilding the herring stock to above 1.3 million tonnes.

In terms of rebuilding, it is evident that if recruitment stays low, the current management rule will not result in rebuilding the stock to above Bpa (1.3 million tonnes) within 5 years. To reach above 1.3 million tonnes within 5 years either the recruitment must increase again, or the fishing mortalities must be lower than those prescribed in the management agreement between the EU and Norway.

If the management agreement is adhered to, the fishing mortality will be low (F=0.15) and the stock will increase, but to just above 1 million tonnes. Managers and fishers, with the help of ICES, must consider whether the fixed biomass reference points are appropriate in systems where the carrying capacity of stocks changes.

Introduction

The Pelagic freezer trawler association has a Marine Stewardship Council (MSC) certificate for their fishery on North Sea herring. Regular audits on behalf of the MSC must occur to maintain the certificate. On the basis of the last audit (July 2007), the auditor Moody Marine asked the PFA to begin to develop a rebuilding plan for North Sea herring, with the goal of rebuilding the SSB to above the precautionary biomass reference point (Bpa) of 1.3 million tonnes, within a short time period. The rebuilding plan must incorporate the most up to date scientific knowledge on North Sea herring and the most appropriate scientific techniques (ICES 2007a).

Against this background the PFA contracted Wageningen IMARES to investigate the potential for rebuilding North Sea herring spawning biomass (SSB) to above 1.3 million tonnes within 3 to 5 years.

The SSB of North Sea herring recently declined because of an unusual series (5 years) of below average recruitment (ICES 2007b). In recent years North Sea herring has not been over fished. The fisheries that exploit the stock have broadly adhered to the management advice. This resulted in a large SSB. Despite this large SSB the recruitments were poor. This lead to an ageing fish population (ICES 2007a). To prevent over exploitation, the total allowable catches (TACs) were reduced, roughly in line with the internationally agreed management agreement, but not enough to prevent the SSB in 2007 falling below Bpa.

IMARES Assignment

Investigate the time frame for rebuilding the North Sea herring SSB to above Bpa, within the current management agreement under different recruitment regimes.

Materials and Methods

A short term forecast was developed and used to predict the stock numbers in future years. By applying the management agreement, and different recruitment levels the potential for the rebuilding of herring spawning biomass to above precautionary limit reference points was explored.

The starting point of the short term forecast was based upon stock numbers in 2007 (ICES 2007a). Information on harvest, catch composition and biological parameters such as natural mortality, were also taken from ICES (2007a) and are listed in table 1.

Recruitment

In a short term forecast, recruitment plays a major role, affecting the age class compositions over the years, and thus the future SSB. The recent poor recruitment (Figure 1a) has caused the decline in the North Sea herring SSB in recent years (Figure 1b). The herring working group (HAWG) carries out short term projections using geometric means of various time series, whilst the simulations used to test the management rule, used a spawning stock biomass (SSB) to recruit relationship (with a break point) to estimate potential recruitment. In this investigation a range of recruitment trends (independent of SSB) were used. This meant that the choice of break point did not influence the development of the populations, but it also assumed that recruitment would not be limited by SSB (according to current ICES science this assumption should be questioned below an SSB of 800 000 tonnes). Recruitment was estimated in four different ways:

- the average (geometric mean) of the past 5 or 30 years recruitment (GM)
- a continuation of a linear function from the past 5 or 30 years recruitment (LM)

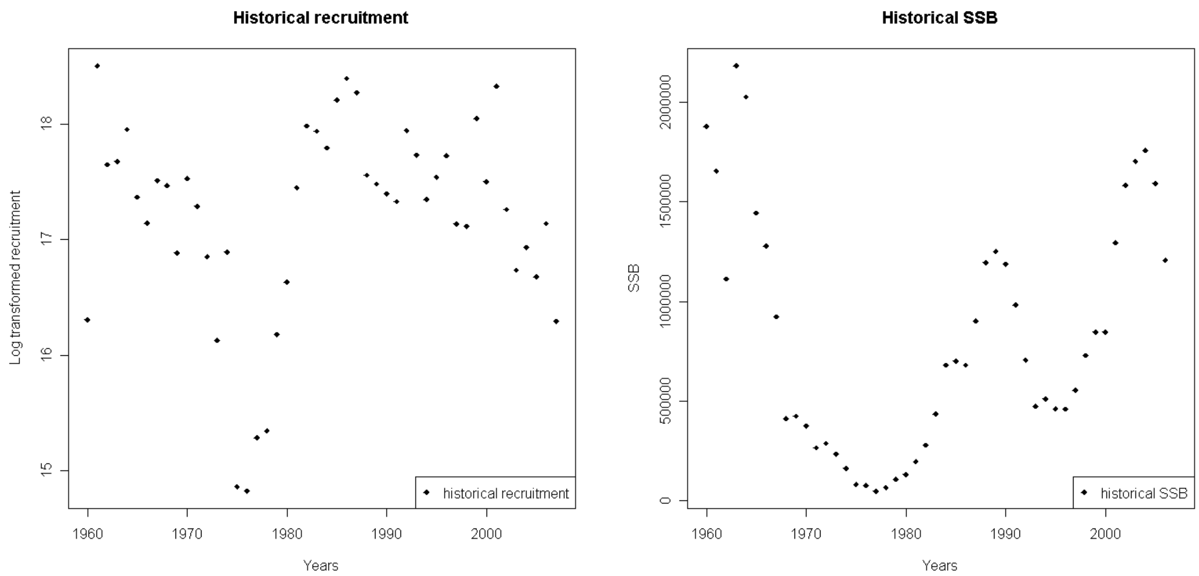

Figure 1. a) Recruitment at age 0, note logged scale and b) SSB (tonnes) over the past 48 years

Figure 2. *left*: Geometric mean over the past 5 years with confidence interval (GM05)
***right*: Geometric mean over the past 30 years with confidence interval (GM30).** Note logged scale

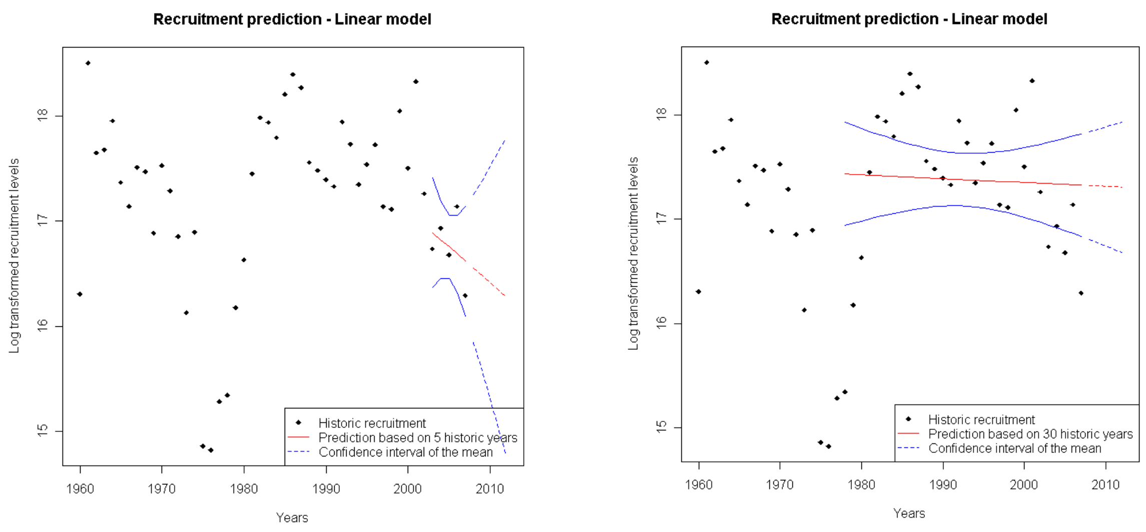

Figure 3. ***left*: Linear model fit on recruitment over the past 5 years with confidence interval (LM05) *right*: Linear model fit on recruitment over the past 30 years with confidence interval (LM30)**

Uncertainty (stochasticity) in recruitment

In the forecast, uncertainty is added to the recruitment. This has been estimated in two ways, dependent on the trend:

- Geometric mean: A value is taken from a normal distribution around the geometric mean of 5 or 30 years and standard deviation based upon the variability in the past 30 years of recruitment (see figure 4). Each new iteration has a new value.
- Linear model: the standard error of the linear model was computed using eqn 1. By taking a random number from a t-distribution, and multiplying this value with the standard error of the predicted value, the added uncertainty is calculated.

$$SE_p = \frac{CI}{t(0.975, df)}$$
$$var = t(n, df) \cdot SE_p \qquad \text{Eqn 1}$$
$$\text{recruitment level} = var + prediction$$

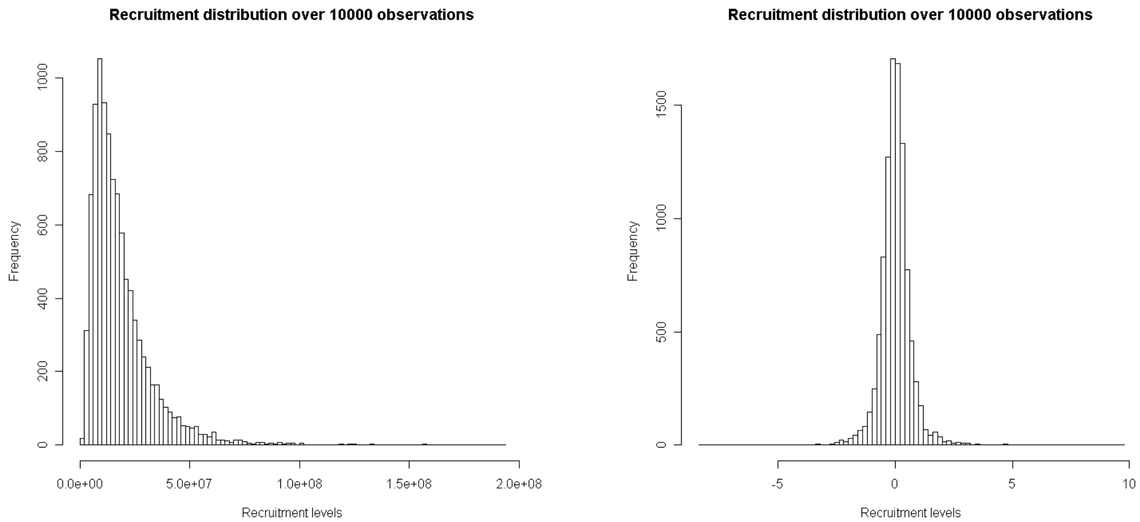

Figure 4. ***left*: Recruitment level distribution for geometric mean scenarios *right*: Additive recruitment level distribution of linear model**

Uncertainty in the assessment

Uncertainty is added to the assessed stock numbers by applying an assessment error (see figure 5 for a graphical representation). This error is a lognormal distributed value with mean zero and standard deviation 0.1 and is multiplied with the stock.

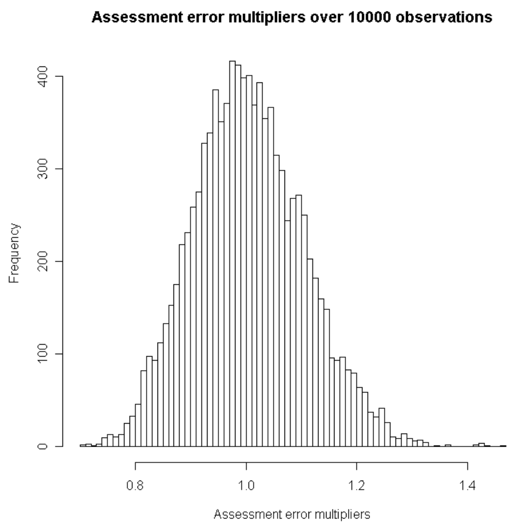

Figure 5. Assessment error distribution. Values are multiplied with the new assessed stock

Harvest

As requested by the PFA, the short term forecasts carried out here applied the North Sea herring management agreement (Norway and EU 2004), which consists of two different rules. The first rule describes the maximum fishing pressure allowed, per fleet (eqn 2). The second rule describes the maximum Total Allowable Catch (TAC) change between two succeeding years. This second rule states that TAC in a year can only deviate by 15% compared to the TAC in the year before. It has been previously shown that restricting the TAC change by 15% results in a less dynamic response of the first rule, therefore if rebuilding it to occur under a relatively short time it is best to operate under the first rule only (equation 2). ICES does not view the second rule as precautionary. It was for these reasons that the second rule was not incorporated in the simulation model. Also at the request of the PFA, the TAC in the forecasts for 2008 did not follow the management agreement but the proposed 35% cut in TAC from 2007 to 2008, as proposed by the Pelagic RAC.

Currently NS Herring is managed with two fleets. The fleet A, mainly fishes for human consumption while fleet B, mainly fishes for industrial use. Each of these fleets has its own management strategy as is pointed out in eqn 2. A graphical representation of this equation can be found in figure 6. In this study however, to improve the computational time, the harvest conditions of fleet B where kept constant at F=0.06, which was similar to the F on age 1 herring in 2006. After the simulations were carried out, it was clear that SSB never dropped lower than that required to reduce F by Fleet B to less than 0.06. So the simulation only involved fleet A following the harvest strategy.

Management strategy

At SSB >= 1.3 million tons

$$F_a = 0.25; \quad F_b = 0.12$$

At SSB < 1.3 million tons and SSB > 0.8 million tons

$$F_a = 0.25 - (0.15 * (1.3 - SSB)/500)$$
$$F_b = 0.12 - (0.08 * (1.3 - SSB)/500) \qquad \text{Eqn 2}$$

At SSB < 0.8 million tons

$$F_a = 0.1$$
$$F_b = 0.04$$

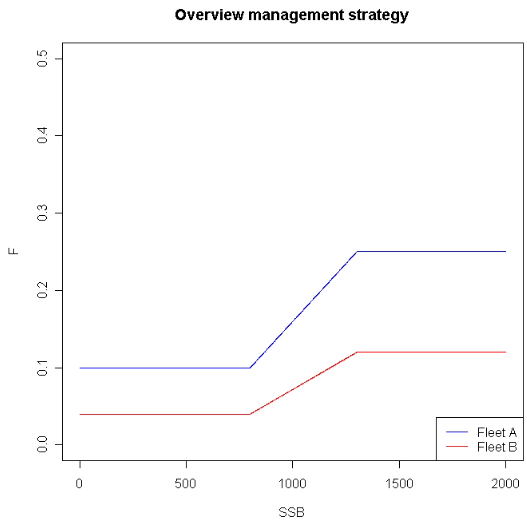

Figure 6. Management strategy for both fleets. Each SSB value has a corresponding F value

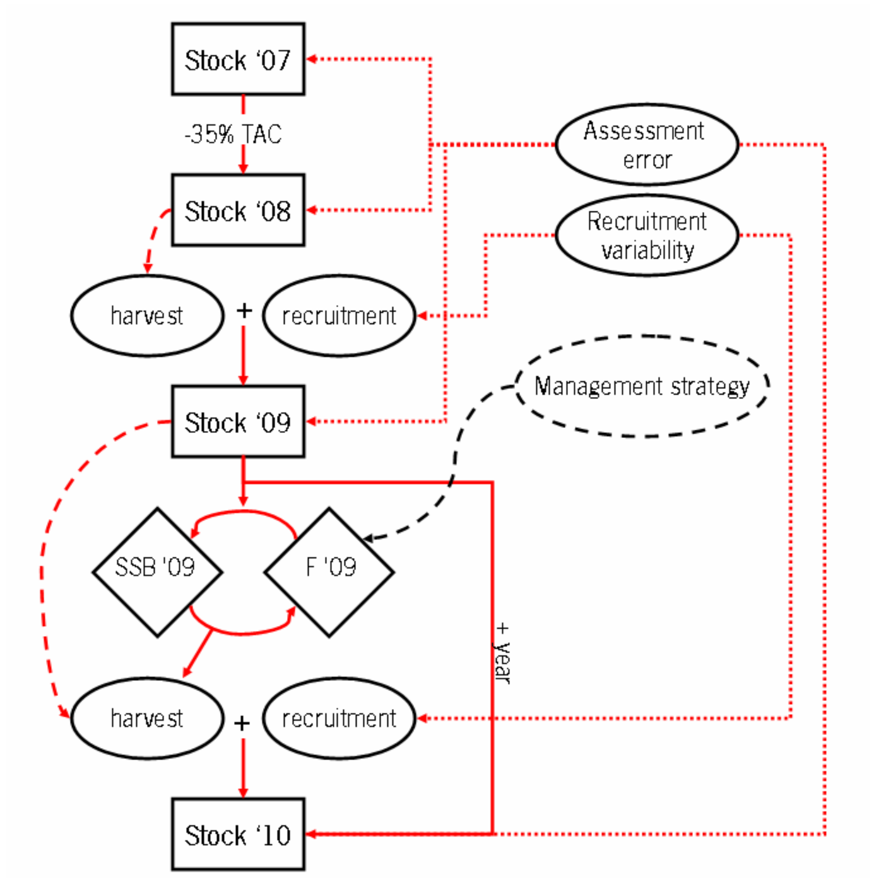

Figure 7. Overview of the simulation routine. Stock numbers are situated in the squares, changes to the stock numbers like harvest are visualized by the eclipses while decision points are represented by the diamonds.

Simulation routine

At the start of the simulation, the stock numbers in 2007 were presumed known (ICES 2007a). As mentioned above, the TAC for 2008, was the 35% cut in TAC recommended by the Pelagic RAC (Fleet A TAC in 2007 = 341000 tonnes, TAC in 2008 = 221000 tonnes). SSB values in 2007 and 2008 were computed based on the stock numbers in the years 2007 and 2008 (eqn 5). The estimation of the SSB in 2009 is not as straight forward as it appears. Under the management agreement the F in one year is not based on SSB the previous year, but on the SSB when the F is experienced. SSB is calculated for the time of spawning, thus in September 2009. So the estimates of SSB and F are linked. You need to "search" for the appropriate matching SSB and F for 2009, and each year after. Once found, the matching F value was used within the harvest equation to compute stock numbers in 2010 and the process was repeated for each year forward. Whilst assessment error is included in the simulations, implementation error is not (under or over catching the TAC).

The performance of the different recruitment regimes was monitored through comparison SSB relative to 1.3 million tonnes and TACs. These are the indicators used in the evaluation if the North Sea herring rebuilding. The equations used to compute stocks, SSB levels and TACs (eqn 4) are listed below.

$$\begin{aligned} \text{Stockn}_{j,a_{2-10}} &= \text{Stockn}_{j-1,a_{1-10}} \cdot \exp(-Z) \\ \text{Stockn}_{j,a_1} &= \text{Recruitment} \end{aligned} \qquad \text{Eqn 3}$$

$$j \in \{2007...2012\}$$
$$a \in \{1...10\}$$

$$\text{TAC} = \frac{F_A}{F_A + F_B + M} \cdot \text{stockn} \cdot (1 - \exp(-F_{A,B} - M) \cdot \text{catchwt} \qquad \text{Eqn 4}$$

$$\text{SSB} = \text{stockn} \cdot \exp(-F_{A,B} \cdot \text{spwn} - M \cdot \text{spwn}) \cdot \text{stockwt} \cdot \text{mat} \qquad \text{Eqn 5}$$

Table 1) Explanation of variables used in equation 3-5

Variable	Explanation
Stockn	stock numbers
Z	F (fishing mortality) + M (natural mortality)
Catchwt	catch weight per age class
Stockwt	stock weight per age class
Spwn	fraction of the year where spawning finds place
Mat	fraction of age class that is mature

Scenario description

Several different scenarios were explored to see if North Sea Herring had the potential to rebuild above 1.3 million tonnes in a reasonable time frame. We varied the time frame of forecasting between 3 and 5 years. The way recruitment was estimated varied between the two different ways of projecting the recruitment levels: geometric mean of historical data and fitting a linear model to the historical data (see above). In addition, predicted recruitment levels can be based on recent or longer term recruitment trends, thus we used both 5 and 30 years time series. All these options combined results in 8 different scenario's (table 2). Each scenario was run 100 times. The final outputs were checked against a more simplistic approach, as described in Appendix A.

Table 2) Scenario description of the different runs that are executed

		Recruitment based on 5 historical years	Recruitment based on 30 historical years
TAC change of more than 15% possible	Forecast 3 years	Geometric mean	Geometric mean
	Forecast 5 years	Geometric mean	Geometric mean
Respecting the management strategy	Forecast 3 years	Linear model	Linear model
	Forecast 5 years	Linear model	Linear model

Results

As requested by the PFA, two different time frames were used to investigate whether the North Sea Herring SSB could rebuild above Bpa; 3 and 5 years. The final results in the 3-year scenarios are identical to the first three years within the 5-year scenarios. Therefore only the 5-year scenario results will be presented here in the results section, the 3-year scenarios can be found in appendix B. The catches for the B fleet are not presented.

Geometric mean of recruitment (GM5 and GM30)

The geometric mean recruitment based upon 5 or 30 historical data points are respectively 18.9 x10^9 (GM5) and 35.4 10^9 (GM30). Neither of these two recruitments results in the SSB of North Sea herring being above Bpa within 3 years (2010) following the management rule. However, if recruitment returned to the longer term mean (GM30), the SSB would reach Bpa by either 2011 or 2012. However if the low recruitment that has been seen recently is maintained (GM5) , the stock does not rebuild above Bpa, even after 5 years (Figure 8). At GM5 recruitment, the stock appears to reach equilibrium at between 1.0 to 1.1 million tonnes.

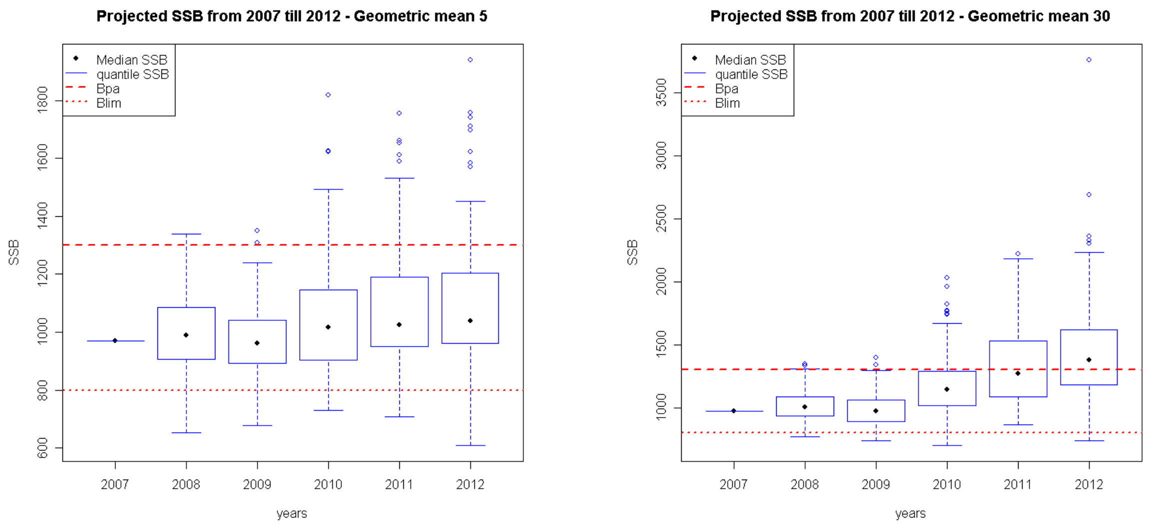

Figure 8. North Sea herring simulations. Change in SSB from 2007 till 2012, at recruitment based upon GM5 (left) and GM30 (right). The median is denoted by the central dot, the 50% confidence interval by the rectangle. The bars represent the lowest or highest outcomes that are considered plausible from a statistical approach. Values outside the bar are inexplicable and called outliers. Note different y axes.

Under the current management agreement rebuilding the stock to above Bpa is very unlikely, unless recruitment returns to a higher productive state. Note that the variation between interactions in SSBs is large. Therefore it is very difficult to predict with certainty how SSB will develop over time. Uncertainty under the GM30 scenario is much greater.

The second part of the management agreement limits the maximum TAC change to 15%. As stated above, this was not applied in this study. Therefore it is important to consider the potential TACs resulting from the simulations (Figure 9). As there was no implementation error built into the simulations, the TACs represent the catch by the Fleet A. Under the mean recruitment of the last 5 years (GM5), and the management rule, the TACs fall until 2009, stabilise about 160 000 tonnes and then begin to rise to 350 000 by 2012. Under higher recruitment (GM30), the TAC also drops but then rises to about 400 000 tonnes. The percent changes in median TAC are approximately a decrease of 30% from 2008 to 2009, and then increases of about 10% per year after that.

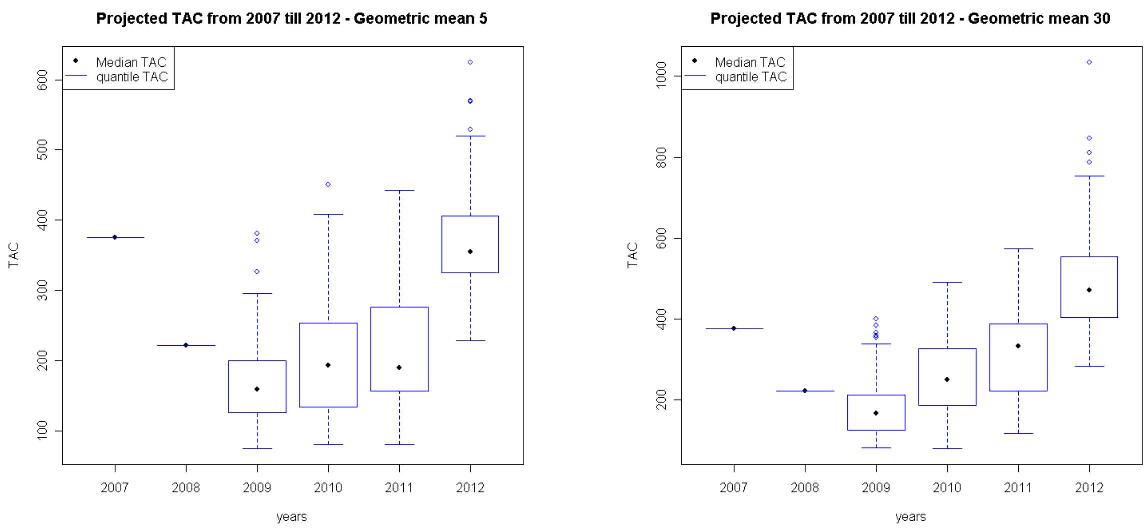

Figure 9. North Sea herring simulations. Projected TAC for fleet A from 2007 till 2012. Note: as requested by the PFA the TACs for 2007 and 2008 were fixed. Variability explained in figure 8. Left GM5 right GM30.

Linear model of recruitment (LM5 and LM30)

The linear model fitted to the most recent estimates of recruitment (LM5) predicts a rapid decline in recruitment in the near future (see figure 3a). The linear model fitted to the longer time series predicts a much slower decline from a much higher starting position of recruitment in the near future (figure 3b).

These runs are more pessimistic than under the GM recruitment approach (Figure 10). There is no potential to rebuild within 3 years. The choice of model, also means that variability in SSB is much greater. Recruitment following LM5, results in a stable SSB of approximately 1 million tonnes by 2012, whilst LM30 results in an SSB at Bpa by 2012. There is a 50% chance of being above Bpa. It is important to note, that trying to manage a stock that has equilibrium at around a fixed reference point (such as Bpa) will be problematic.

Figure 10. North Sea herring simulations. Change in SSB from 2007 till 2012, at recruitment based upon LM5 (left) and LM30 (right). . Variability explained in figure 8. Note different y axes.

As with the GM approach the TACs decline further in 2009 and then rise again (Figure 11). By 2012 with LM recruitment, the TAC is between 300-400 000 tonnes, whilst the potential range is greater with LM30 recruitment, 400 to 600 000 tonnes. However note the very large uncertainty from 2011 onwards.

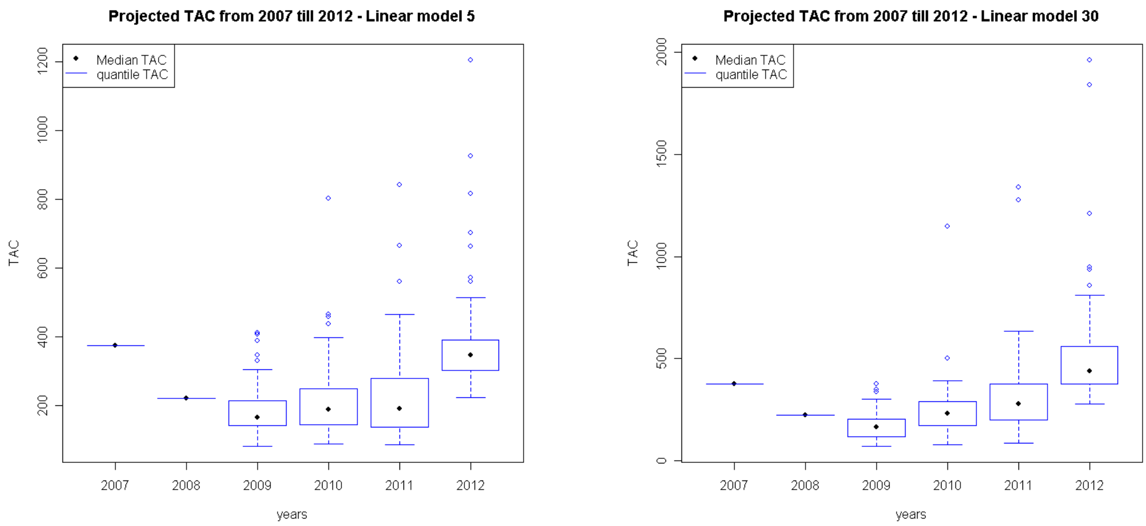

Figure 11. North Sea herring simulations. Projected TAC for fleet A from 2007 till 2012. Note: as requested by the PFA the TACs for 2007 and 2008 were fixed. Variability explained in figure 8. Left LM5 right LM30.

Discussion

In terms of rebuilding, it is evident that if recruitment stays low, the current management rule will not result in rebuilding the stock to above Bpa (1.3 million tonnes) within 5 years. To reach above 1.3 million tonnes within 5 years either the recruitment must increase again, or the fishing mortalities must be lower than those prescribed in the management agreement between the EU and Norway. However, it should be noted that the current Bpa was determined at a different time, when the system produced more young herring per mature adult and thus had a higher carrying capacity. If the management agreement is adhered to, the fishing mortality will still be low (F=0.15 see appendix C) and the stock will increase, but to just above 1 million tonnes. **Managers and fishers, with the help of ICES, must consider whether the fixed biomass reference points are appropriate in systems where the carrying capacity changes.** This is similar to the situation in Baltic Sea cod. ICES has stated that the management agreement (excluding the 15% limit on TAC change) is precautionary. Analyses could be carried out into the suitability of 1.3 million tonnes as a biomass limit reference point for North Sea herring in the current situation.

In any simulation assumptions have to be made. To correctly interpret the model outcomes these assumptions have to be made clear. We assumed a status quo situation for natural mortality, catch weights, maturity and time of spawning all set to their status in 2007. This is in accordance with the short term forecast settings from the Herring assessment working group (HAWG) in 2007. The implementation of an assessment error was carried out in the same way as HAWG report. For recruitment mean and variability however, a new approach was chosen. We chose both the geometric mean (as used by HAWG in the short term projections) and a linear model to account for a time trend (ICES 2007b). Fitting a linear trend is difficult to justify in terms of process knowledge of the system, but it represents a change in the productivity and shows that we do not assume a system in equilibrium. As a result of the technical implications, no change in fishing pressure induced by fleet B has been incorporated. However, SSB on average never drops below a level where a lower fishing pressure was necessary to follow the management strategy for fleet B as fishing mortality by this fleet is already low. In addition to this, the 35% TAC change from 2007 to 2008 was only applied to fleet A. Fleet B was allowed to fish at constant F, whilst from 2009 onwards the by catch ceiling only varied minimally. One of the problems we had to cope with was the optimization process between SSB and F determination within a year for the management agreement. Including both fleets in this procedure would be very difficult. Therefore we assumed a F-status quo principle for fleet B.

It should be made clear that our estimates of geometric recruitment differ from those in the HAWG report. There is an error in the HAWG report, which was picked up by ACFM, but not by HAWG at the time of writing. In the HAWG report (ICES 2007a) cite recruitment as the mean of the year classes 2002 to 2006, but then used the year classes 2001 to 2005 in the projection.

References

ICES, 2007a. Report of the herring assessment working group for the area south of 62°N. ICES CM 2007/ACFM:11. 550pp.

ICES, 2007b. Report of the Study Group on recruitment variability in North Sea planktivorous fish (SGRECVAP). ICES CM2007/LRC:07. 65pp.

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This report has been professionally prepared by Wageningen IMARES. The scientific validity of this report has been internally tested and verified by another researcher and evaluated by the Scientific Team at Wageningen IMARES.

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Date:	21 November 2007

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Signature:	
Date:	21 November 2007

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Appendix A. Theoretical approach used to confirm the projections

Without stochasticity, the age composition within a stock in equilibrium situation can be computed. The input needed to compute this stock is similar to the input in the simulation model described in the material and methods section above, with the exception of stock numbers in 2007. Only recruitment level is regarded in this computation. I.e. after a year, recruits from year t-1 will occupy the 2nd age class, the year thereafter the 3rd. Natural and fishing mortality are subject to the recruits. But if natural mortality (M) and fishing pressure (F) remain equal over time, the recruits left in age class 10 is equal to the summation of all age specific F's and M's.
This equilibrium stock can be fished at with different F values. A range of F values results, after computation, in a range of SSB values too. In this way, SSB equilibrium values can be computed. Adding stochasticity to the simulation might influence the outcomes, but increases the credibility of the simulation. However most probably the predicted SSB values will be close to the theoretical model. This is only true if recruitment levels remain the same in time, which is not true in our case when a linear model is used to predict recruitment levels.

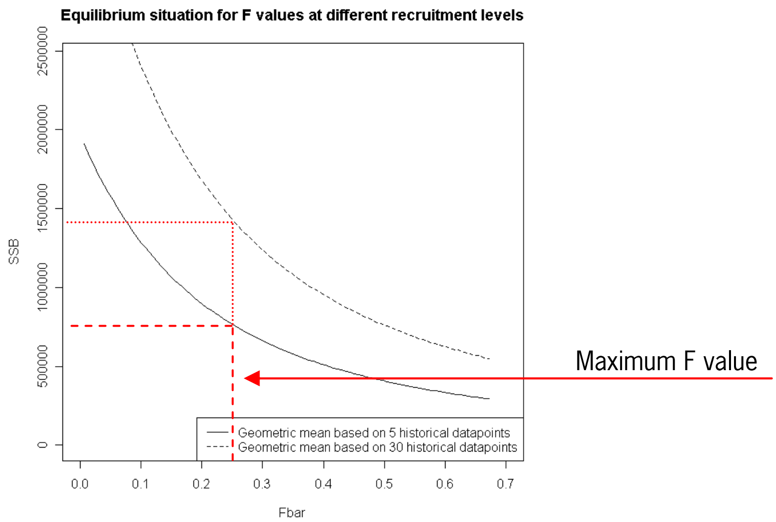

Figure 12. Equilibrium SSB values for fishing at particular F values. If recruitment increases the SSB equilibrium values increase as well. Under the maximum F value, corresponding SSB values can be determined (red dashed and dotted lines).

Figure 12 represents the SSB equilibrium states over a range of different F values. Note that in the simulations described in the results section, SSB is not yet at equilibrium, not even in 2012. Therefore, the SSB values in 2012 might deviate a lot from those found in this theoretical approach.
Figure 12 shows that the higher the recruitment level is (geometric mean over 5 years is 18.9 x10^9 (GM5), geometric mean over 30 years is 35.4 10^9 (GM30)) the higher the equilibrium SSB values will be. Figure 10 also indicates that fishing with a maximum F_A of 0.25 will result in an SSB equilibrium value of approximately 0.75 million tons if the GM5 is used as recruitment level (figure 12 - red dashed line). The GM30 recruitment level will result in an SSB equilibrium value of approximately 1.4 million (figure 12 - red dotted line). Within the simulation model SSB tends to go towards equilibrium as well. However, ending up in an equilibrium situation might take many years. Though the process towards an equilibrium state is subject to the simulation model we have been using, which enables us to verify the results in section 1 of the results in a more theoretical way.

Appendix B. Simulations over 3 years forward

As was explained in the results section already, there is no difference in final state of SSB in the three year scenario's compared to the third year in the five year scenarios.

Geometric mean

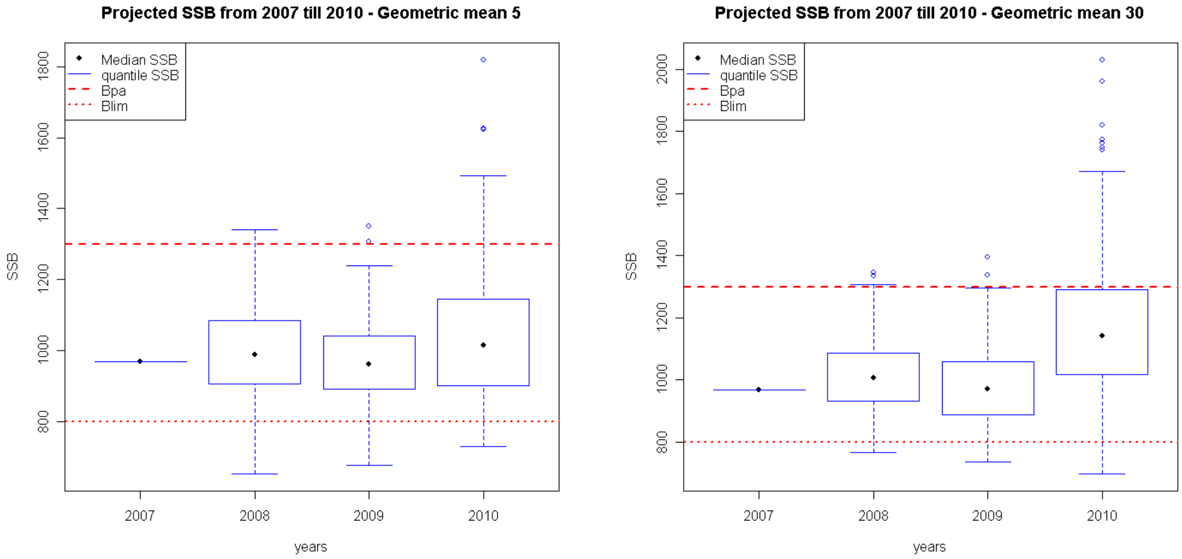

Figure 13. ***left*: recruitment based on GM5 *right*: recruitment based on GM30**

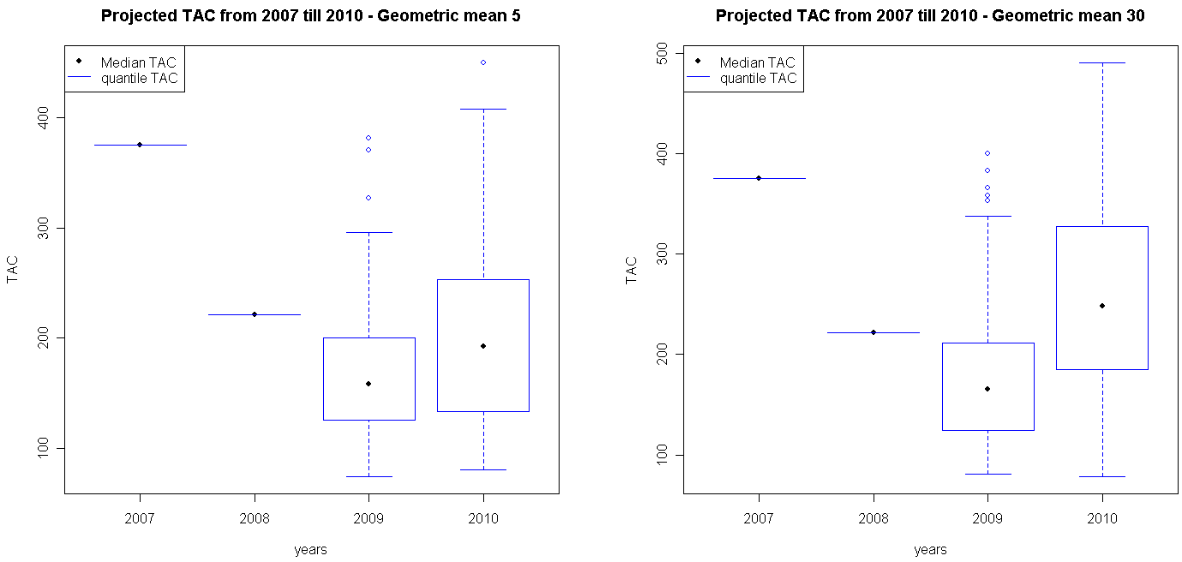

Figure 13. ***left*: TAC based on GM5 *right*: TAC based on GM30**

Linear model

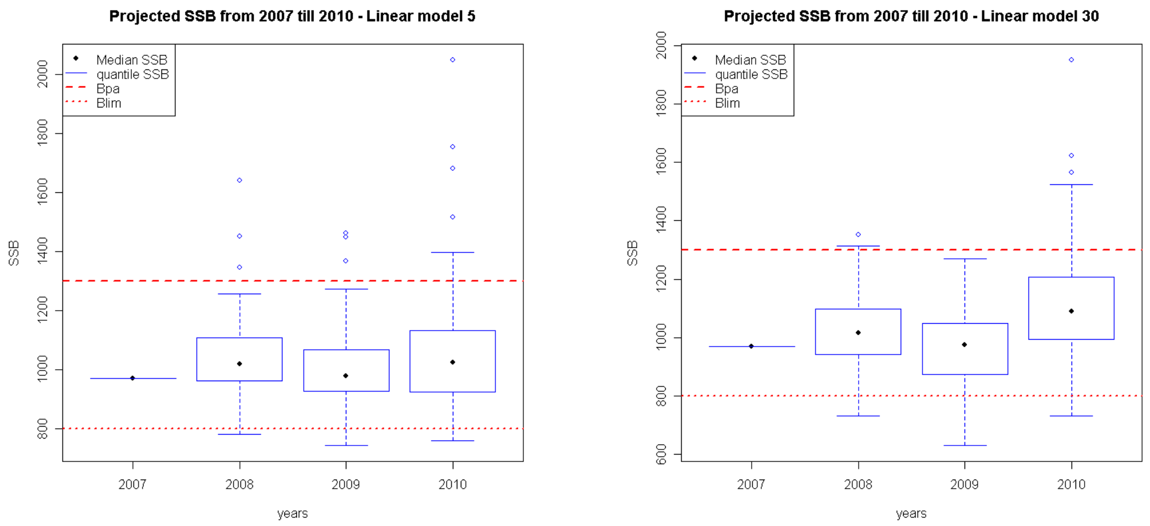

Figure 15. ***left*: recruitment based on LM5 *right*: recruitment based on LM30**

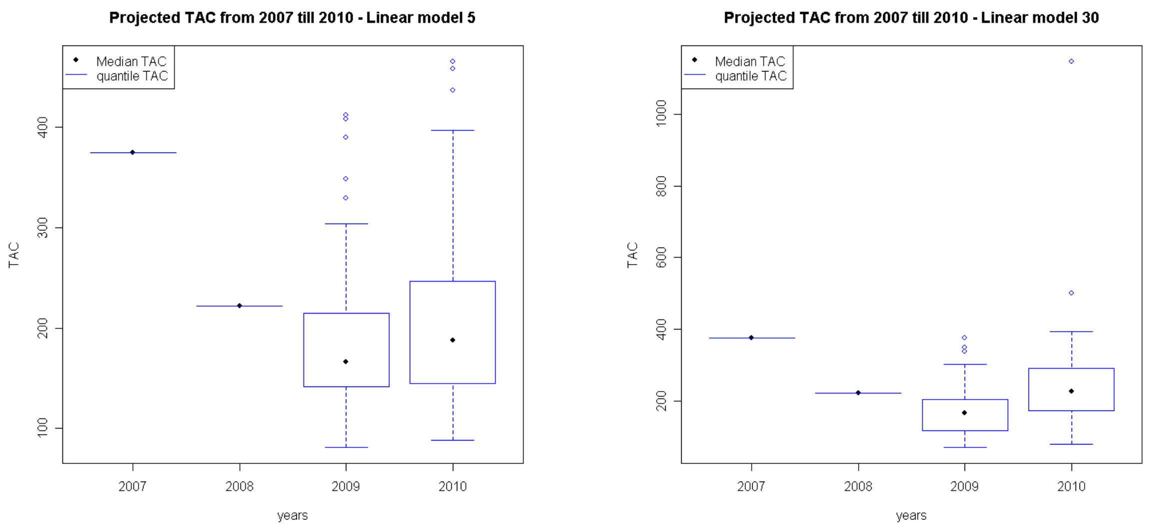

Figure 16. ***left*: recruitment based on LM5 *right*: recruitment based on LM30**

Appendix C. F development of fleet A over time

Following the management strategy results in maximum F values for fleet A. These F values are based on the condition of SSB. The development of F of fleet A over time is graphically represented in the figures below.

Geometric mean

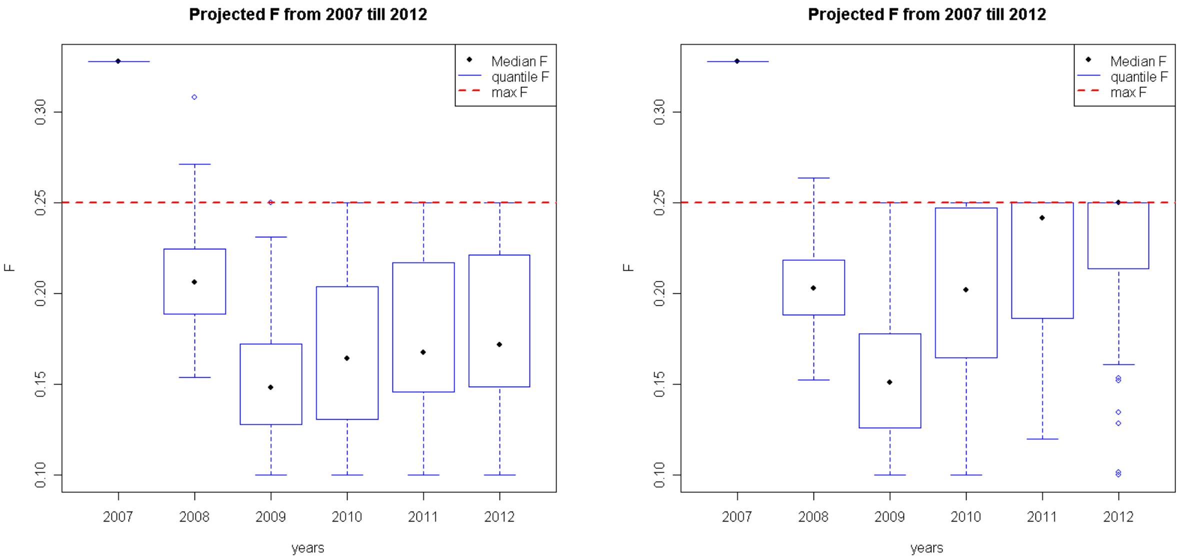

Figure 17. *Left*: The development of F from 2007 till 2012 when recruitment is based upon GM5. *Right*: The development of F from 2007 till 2012 when recruitment is based upon GM30. From 2009 on the management strategy has been followed and therefore F's cannot exceed the maximum F value of 0.25 (red dashed line) anymore.

Linear model

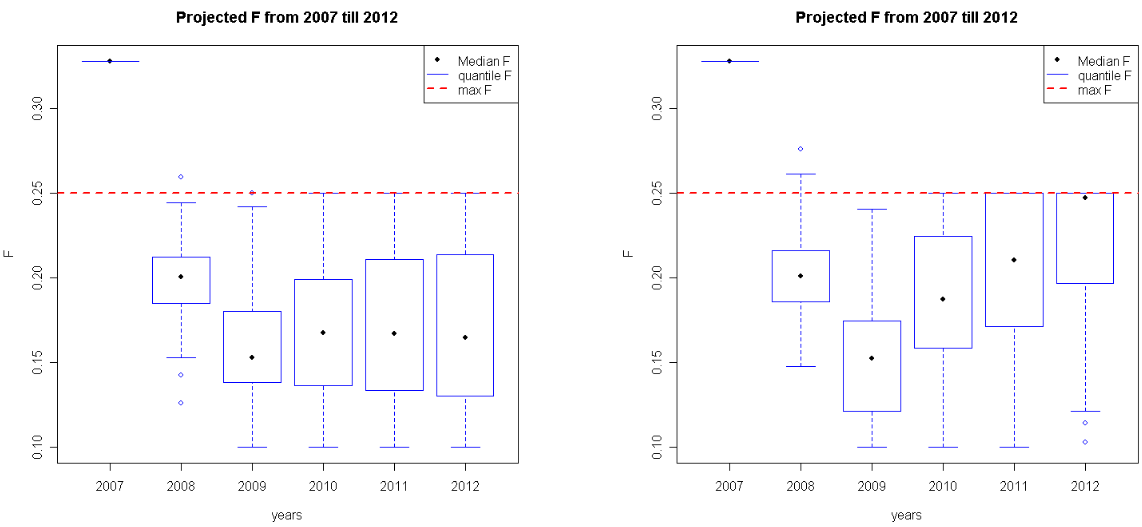

Figure 18. *Left*: The development of F from 2007 till 2012 when recruitment is based upon a linear model fit through 5 historical data points. *Right*: The development of F from 2007 till 2012 when recruitment is based upon a linear model fit through 30 historical data points.