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Executive summary

WKPOOR2 was the second of two meetings to evaluate the potential for extinction on stock and species level for stocks that appear to be in a poor condition. The first meeting outlined principles and methods. These were applied to selected stocks as worked examples in the second meeting. Generic advice for future application of these approaches was generated from the four case studies examined during the meeting.

Standard time trend analyses were attempted, but not considered informative in any of the cases, for various reasons. WKPOOR outlined an alternative approach to understand the state of the stock and the need for adjustments of current exploitation, specifically directed towards ICES' role as advisor on management.

The approach suggested in this report is to assemble information about yield per recruit and the stock recruitment relationship to infer equilibrium yields for likely recruitment levels. From there, one may infer if the current level of catches can be expected to be sustainable, or if further restrictions are necessary. Simulations can be used to evaluate likely effects of management measures, and in some cases to verify hypotheses about the stock dynamics in the past. The main question that can be addressed is whether the current management measures are adequate. A further question is whether reduced recruitment is due to reduced SSB or other causes, which will have implications for expectations about recovery.

1 Introduction

1.1 Terms of reference

WKPOOR2 was the second of two meetings, the first was held in Copenhagen 18 - 20 May 2009, chaired by Chris Legault (USA). That meeting considered principles and guidelines. The present meeting was set up to apply these principles to some selected stocks. The terms of reference for this meeting, which was chaired by Dankert Skagen (Norway) were:

Apply methods and guidelines that were found to be appropriate by WKPOOR1 to evaluate the potential for extinction on stock and species level for the following marine fish species in the North Sea, Norwegian Sea and Barents Sea listed in order of priority:

1) *Redfish (S. mentella and S. marinus), Spurdog, North Sea Cod and Norwegian coastal cod North of 62^{0}N*
2) *European eel, North Sea Sandeel*
3) *Atlantic Halibut, Ling, Blue ling*

(Council Resolution 2008/2/ACOM29b)

The Workshop was attended by four members and one observer. Due to the limited time and manpower, and the limited expertise in the group, it was decided to concentrate on most of the stocks with first priority, and not consider the other stocks. Likewise, the spurdog was left out due to lack of expertise and recognizing that the recruitment dynamics is different and requires careful consideration. Therefore, the Workshop concentrated on two cod stocks and two redfish stocks.

1.2 General approach.

Some basic points were made by WKPOOR1:

1) Applying the IUCN criteria would be problematic for exploited and actively managed fish stocks. The dynamics of such stocks would easily lead to false positives, but also imply a substantial risk that signals indicating severe danger will be ignored.
2) The role of ICES is different from that of IUCN; ICES has an advisory role while IUCN issues warnings. Hence, WKPOOR decided to concentrate on signals and information that may lead to a proactive advice, and avoid competition with organizations like IUCN.
3) Extinction of a stock first requires that the stock is depleted, but then some kind of catastrophe. Such catastrophes are difficult to predict, and with management, the likelihood of bringing the stock in a situation where catastrophes may bring the stock to extinction is highly dependent on management actions. Both these factors make quantification of the risk to extinction less meaningful in our context.
4) WKPOOR1 suggested the stock and recruitment dynamics as the key to understanding the potential for extinction, and as background for advice. Following this line of thinking, the WKPOOR2 outlined essential dynamic properties of the example stocks, as described in detail below.

The understanding of the stock dynamics is always partial, and there are alternative interpretations of the observations that can be made. WKPOOR2 attempted to assemble relevant information, to outline possible interpretations and explore conclusions that would be constructive and useful for managers and robust to the uncertainties in observations and assumptions. Four elements were explored:

1) Analysis of time trends as commonly used as a simple Population Viability Analysis (PVA)

2) Outline the SSB/recruit and Yield/recruit relations.

3) Outline the relation between stock and recruitment

4) Simulate the development of stocks at various levels of exploitation. These simulations may be regarded as substitutes for 'classical' age structure PVA methods.

1.3 Methods.

1.3.1 Time trend analysis

This approach is often referred to as the Dennis diffusion model (Dennis et al. 1991). It is a simple approach that assumes an exponential growth model for the population. The mean (μ) and the variance (σ^2) for the population growth rate are used to project the population into the future as $N_{t+1} = N_t*\exp(\mu+\sigma)$, where N_t is the population at time t. The parameters for a given dataset are estimated by first computing $\lambda_t=\ln(N_{t+1}/N_t)$ and then calculating the mean (μ) and variance (σ^2) of this series. A positive μ means the population will increase exponentially in expectation, a negative μ means the population will decrease exponentially in expectation, and $\mu=0$ means the population size will remain the same in expectation. The variance becomes important when projecting future states of the population. In practice, it is easiest to use the formula $\ln(N_{t+1})=\ln(N_t)+\mu+\sigma\varepsilon$, where ε is randomly selected from a normal distribution with mean zero and standard deviation one. Exponentiation of the series $\ln(N_{t+1})$ produces the projected realization of population size. Many population size realizations are projected forward in time from the last observation to create a distribution of possible abundance levels in each forecast year. These distributions can be summarized in many ways, a common approach is to determine the 90% confidence interval by extracting the fifth and ninety fifth percentiles of the distributions for each year.

The simple population viability analyses undertaken for this workshop were conducted using Excel and the Excel add-in @Risk, a Monte Carlo simulation tool. Many other tools could be used as well because of the simplicity of the approach. Quasi-extinction levels were not considered for any of the cases examined due to the difficulty of determining such a level as well as the inherent difficulty of associating such a risk with true risk of extinction (Coulson et al. 2001). Rather, the projections were made to examine both the short-term (3 years) and long-term (42 years) consequences of assuming the estimated population growth rate and variance were to continue into the future. The long-term projections are not considered at all reliable according to the rule of thumb that forecasts should only be made for periods that are 10% to 20% the length of the observed time series (Fieberg and Ellner 2000). The long-term projections were made to demonstrate exactly this point, many of the long-term projections had extremely large confidence intervals, so large as to be meaningless.

The approach employed here is the simplest one to project time series. More sophisticated methods have been developed that attempt to account for observation uncertainty in the data but require more years of data than the simple approach (Holmes 2004). These more advanced methods were not considered due to the limited number of observations in the stocks examined during this workshop.

As described in more detail in the WKPOOR1 report (ICES 2009a), the major assumption made in these simple PVA approaches is that all processes are stationary or that non-stationary processes can be directly linked to changes in the population growth rate and variance. In the context of managed marine fisheries, it is highly unlikely that fishing mortality rates would be stationary when a stock reaches a low enough level to be under consideration of extinction risk. Additionally, changes in the environment or SSB that caused a decline in recruitment would be assumed to continue in the same direction in order for the population decline to follow the expected exponential decline.

This approach will not respond quickly to actual changes in the underlying process (e.g. environmental changes or management impacts). A long negative trend cannot be offset by a few years of improvement in the calculation of the mean population growth rate. The estimate of μ will increase, but so will the estimate of σ, causing a less pronounced but more uncertain decline in the projected population. Thus, care should be taken when applying this method that the assumption of an exponential trend is met. If it is not, then the projections will not produce reliable results.

1.3.2 Stochastic simulations.

These simulations were done with the HCS program (Skagen 2009). This is a medium term, age structured stock projection program designed to evaluate harvest control rules, which has been used in ICES to evaluate several management plans in recent years.

In brief, the program projects an age structured stock forward in time, reducing the numbers in each year class according to mortalities, and adding a new year class each year. The mortalities are derived according to harvest control rules, that are applied to noisy observations of the stock, and implemented with noise. The program has many options for harvest control rules and for applying noise. Most of the simulations done here were with fixed F or fixed TAC implemented without error. The recruitment is according to a stock-recruit function, with opportunities for sporadic strong year classes, periodicities in recruitment and depensation. Noise is added to the deterministic recruitments, as log-normally distributed multipliers. The program was run for 100 years and with 1000 iterations. Initial values were provided by priming the stock with a fixed fishing mortality and recruitments at a 'normal' level.

1.3.3 Yield and biomass per recruit.

Equilibrium yield and SSB as function of F and the stock – recruit relation is provided as a by-product by the hcs program. The equilibrium includes the relation between SSB and deterministic recruitment. F0.1 and the F-value leading to maximum yield are identified, with corresponding values of SSB and yield. In addition to yield and SSB at each level of F the program provides SSB in percent of virgin biomass, and mean age in the catch and in the SSB (weighted with biomass at age).

1.3.4 General approach.

The approach was to extract as much relevant information as possible from the data, primarily on the following:

1) Yield and SSB per recruit. This depends on weights and maturities at age, natural mortalities and selection in the fishery. For most stocks this was available, for some assumptions had to be made for the selection.

2) Stock and recruitment:

Where an assessment was available, stock and recruitment data were taken from that. If not, assumptions had to be made that could reproduce history to some extent, which would be trends and occasional strong year classes. The breakpoint, where recruitment starts to be impaired was hard to identify, and often had to be assumed. Unless there were absolute values for recruitment available, scaling to realistic levels were made by comparing with reported catches.

It was recognized that the stock-recruitment dynamics might change over time. Hence, plausible time ranges were often used, or the performance of the stock explored with recent low recruitment. Such considerations were made stock by stock, and are discussed for each stock.

2 Coastal cod in Subarea I and Division IIa

2.1 Stock status, biology and problems

ICES has given advice for this stock/ management unit since 2001. The advice since 2004 has been zero catch, due to recruitment failure. This covers cod stocks that are constrained to Norwegian coastal waters (within 12 n. Miles) between 62°N and the Russian border. Genetic studies have revealed that this stock complex contains non-migratory stocks in several narrow fjords (typically where there is a shallow sill) and some more migratory stocks around the outer islands and in the wide and open fjords. The genetic structure and life history of the single components are not fully mapped. The outer stocks are considered to contribute most to the commercial fishery. The inner stocks are considered to be smaller and are to a larger extent taken in recreational fisheries. In the northern areas in the first half of the year the outer stocks are partly mixing with the Northeast Arctic cod on its spawning migration (Lofoten-Finnmark) and when feeding for capelin at the Finnmark coast. In the Norwegian commercial sampling programme cod has been identified to coastal type and Barents Sea type based on otolith characteristics since the 30-ies (Rollefsen 1933). The otolith separation has been largely confirmed by later genetic studies (Berg et al 2005). The cod is not identified to stock at landing. The fisheries for coastal cod are therefore not regulated by a separate quota. The catches are counted against a combined quota for Northeast Arctic cod and coastal cod. The fraction of coastal cod is estimated from the commercial sampling program using otolith types when the full landing statistics and sampling results are available.

Catch number at age and associated weights at age for the commercial landings of coastal cod inside 12 n. mile are available for the years 1984-2008. For the years 1995-2008 there are survey estimates of coastal cod obtained at an acoustic survey in coastal areas.

Since this is a mixture of stocks (or stock components) that in addition mixes with a much larger stock, both stock assessment and fisheries management are difficult.

By using data for the combined stock complex the focus will be on the largest components. The uncertainty related to splitting out the NEA cod is considered to be large. In addition there are no landing statistics for the recreational fishery, and there are also some catches outside 12 n.mile that have not been included in the available data. The survey data are also considered uncertain, both due the complex topography in these areas and due to the limitations of the acoustic method.

The assessments made by the Arctic fisheries Working Group (ICES 2009b) have been partly based on XSA tuned by the survey and partly based on analysing trends in catch and survey data separately. The conclusions are that the stock declined considerably in the late 90-ies and has remained at a low but apparently stable level since 2002. The recruitment has declined rather steadily since the 1995 year-class. Since 1990 the fishing mortality appears to have been moderate (0.3-0.4) compared to most other cod stocks.

A number of regulation measures have been introduced since 2004 (gear restrictions, restrictions on vessel size, closed areas and reduced by-catch limits) to reduce catches of coastal cod.

2.2 Trend analyses

Twelve time series were analyzed for coastal cod: the recruitment series estimated by XSA from the last assessment (ICES 2009b), ten age specific series from the coastal cod acoustic survey conducted in October, and the total over all ages of the acoustic survey. The recruitment time series spanned 1984-2008, while the acoustic survey spanned 1995-2008. All twelve series show an overall declining trend with negative population growth rates estimated (Table 2.1). The uncertainty of the population growth rate is high for the acoustic survey ages 1, 8, 9, and 10+, causing the estimates of population abundance in 2050 to be so wide as to be meaningless. The recruitment time series and the other acoustic survey series have low enough uncertainty that it is overcome by the strength of the negative decline, resulting in population crashes by 2050. All twelve time series have high uncertainty in the short term, with 90% confidence intervals in 2011 that are wider than the average of these end points.

This simple method assumes the time series follows the exponential form. When series trend down then level off or increase, this assumption is broken. For example, the acoustic survey all ages time series decreases on average for the first eight years but then is relatively flat in trend for the remaining 6 years. If the values for this time series were to be uniformly distributed within the range 10,000 to 20,000 for the next 70 years, the population growth rate mean would still be slightly negative (approximately -0.02) due to the initial strong decline during the first 8 years. This clearly demonstrates how slowly this method can adjust to departures from the assumed exponential change in abundance over time.

Comparison of population growth rates for the different ages within the acoustic survey demonstrates another difficulty with this simple method. Specifically, the youngest ages show the strongest decline while the middle ages show less of a decline. These cannot both be true at the same time if projected far into the future because there must be younger ages in order for there to be older ages. This simple method of forecasting can lead to counter-intuitive results such as these when multiple ages or life stages are projected independently. A comprehensive model that incorporates age structure is a preferred approach to forecasting future population abundances.

Table 2.1 Recruitment (thousands of fish) and acoustic survey abundance (thousands of fish) for coastal cod by year along with the estimated mean and standard deviation of the population growth rate for each series and the 5%ile and 95%ile of the projected populations in 2011 and 2050.

	XSA	Acoustic Survey										
Year	Recruits	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+	Total
1984	87,921											
1985	74,454											
1986	35,577											
1987	36,684											
1988	39,976											
1989	43,540											
1990	42,202											
1991	60,282											
1992	49,117											
1993	30,441											
1994	25,552											
1995	33,809	28,707	20,191	13,633	15,636	16,219	9,550	3,174	1,158	781	579	109,628
1996	40,157	1,756	17,378	22,815	12,382	12,514	6,817	3,180	754	242	5	77,843
1997	33,006	30,694	18,827	28,913	17,334	12,379	10,612	3,928	1,515	26	663	124,891
1998	30,735	14,455	13,659	15,003	13,239	7,415	3,137	1,578	315	169	128	69,099
1999	25,327	6,850	11,309	12,171	10,123	7,197	3,052	850	242	112	54	51,960
2000	22,884	9,587	11,528	11,612	8,974	7,984	5,451	1,365	488	85	97	57,171
2001	21,459	8,366	6,729	7,994	7,578	4,751	2,567	1,493	487	189	116	40,270
2002	18,441	1,329	2,990	4,103	4,940	3,617	2,593	1,470	408	29	128	21,607
2003	15,019	2,084	2,145	3,545	3,880	2,788	2,389	1,144	589	364	80	19,008
2004	14,114	3,217	3,541	3,696	4,320	2,758	1,940	783	448	98	110	20,914
2005	12,476	1,443	1,843	3,525	3,198	3,217	1,700	1,120	552	330	78	17,006
2006	10,824	1,929	2,525	4,049	3,783	3,472	2,509	1,811	399	229	13	20,719
2007	9,948	2,202	3,300	4,080	5,518	3,259	2,447	1,444	760	197	34	23,241
2008	8,403	2,128	2,181	2,475	2,863	2,101	1,219	815	403	319	177	14,681
Population growth rate												
mean	-10%	-20%	-17%	-13%	-13%	-16%	-16%	-10%	-8%	-7%	-9%	-15%
stdev	0.22	1.33	0.39	0.35	0.30	0.23	0.51	0.44	0.63	1.42	2.19	0.33
Projected Population Abundance in 2011												
5%ile	3,301	26	421	608	828	676	181	170	53	5	0	3,616
95%ile	11,773	51,157	4,096	4,508	4,638	2,547	3,170	2,079	1,887	14,903	72,011	23,663
Projected Population Abundance in 2050												
5%ile	13	0	0	0	1	0	0	0	0	0	0	1
95%ile	1,439	859,430	115	411	286	33	335	1,017	12,357	4.8E+07	1.0E+11	692

2.3 Stock-Recruitment, Yield and spawners per recruit

The stock recruit plot is to a large extent reflecting the time trend (Figure 2.1). Thus low stock is largely a result of low recruitment, and low stock has not so far produced any large year-classes. Above 100 kt both high and low R are observed, while below 100 kt only lows are observed. A blunt hockey stick fit gives a break point at 129 kt with a R-plateau at 32 mill. The hcs-analyses gives F_{crash}=0.31. In the sloping part of the line the majority of points are below the line; thus indicating depensation.

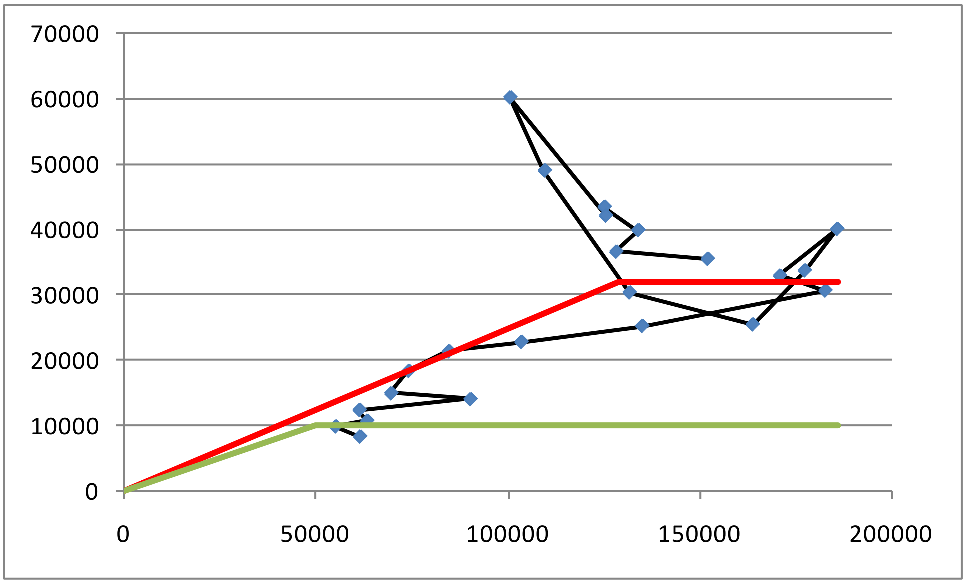

Figure 2.1. Stock-recruit data (year classes 1984-2006) and fitted break point line (red). The green line reflects the assumed low recruitment regime.

If we are within a regime where only low recruitments are possible a break point around the recent stock recruit pairs (R= 10 mill, SSB=50 kt) could be reasonable. This implies the assumption that the recruitment declines further if the stock is reduced from the present level. This break point gives F_{crash}=0.26.

The estimate of $F_{0.1}$ is 0.19. Pure yield per recruit considerations would give an F_{max} of 0.43. This is above the mentioned estimates of F_{crash}. In the table below F_{max} (indicated by *) is considered equal to F_{crash}.

R-plateau	bp SSB	Fcrash	Y at F_{crash}	Y at F_{max}	Y at $F_{0.1}$	SSB at F_{crash}	SSB at F_{max}	SSB at $F_{0.1}$
10	50	0.26	16	16*	15	50	50*	68
32	129	0.31	53	53*	49	129	129*	216

2.4 Simulations

Under this low recruitment assumption fixed annual catches above 16 kt will require F > F_{crash} and will not be sustainable. Some typical variation around the average recruitment could cause some risk for collapse even at lower fixed catches. Some simulations with fixed annual TAC were carried out, under the assumption of low recruitment (10 mill above 50 kt SSB and declining linearly to zero at lower SSB). The recruitment variation around the hockey stick line was assumed lognormal with a cv=0.33, based on the historic data. The stock was "primed" to F=0.2 in the starting year. At 12 kt fixed annual TAC all trajectories allowed for increasing SSB and declining F over the first 10-15 years. Later SSB varied mainly in the range 60 - 120 kt and F varied mainly in the range 0.10-0.15 (Figure 2.2). At a fixed catch of 15 kt nearly all trajectories lead to stock collapse within the 100 year period (Figure 2.3).

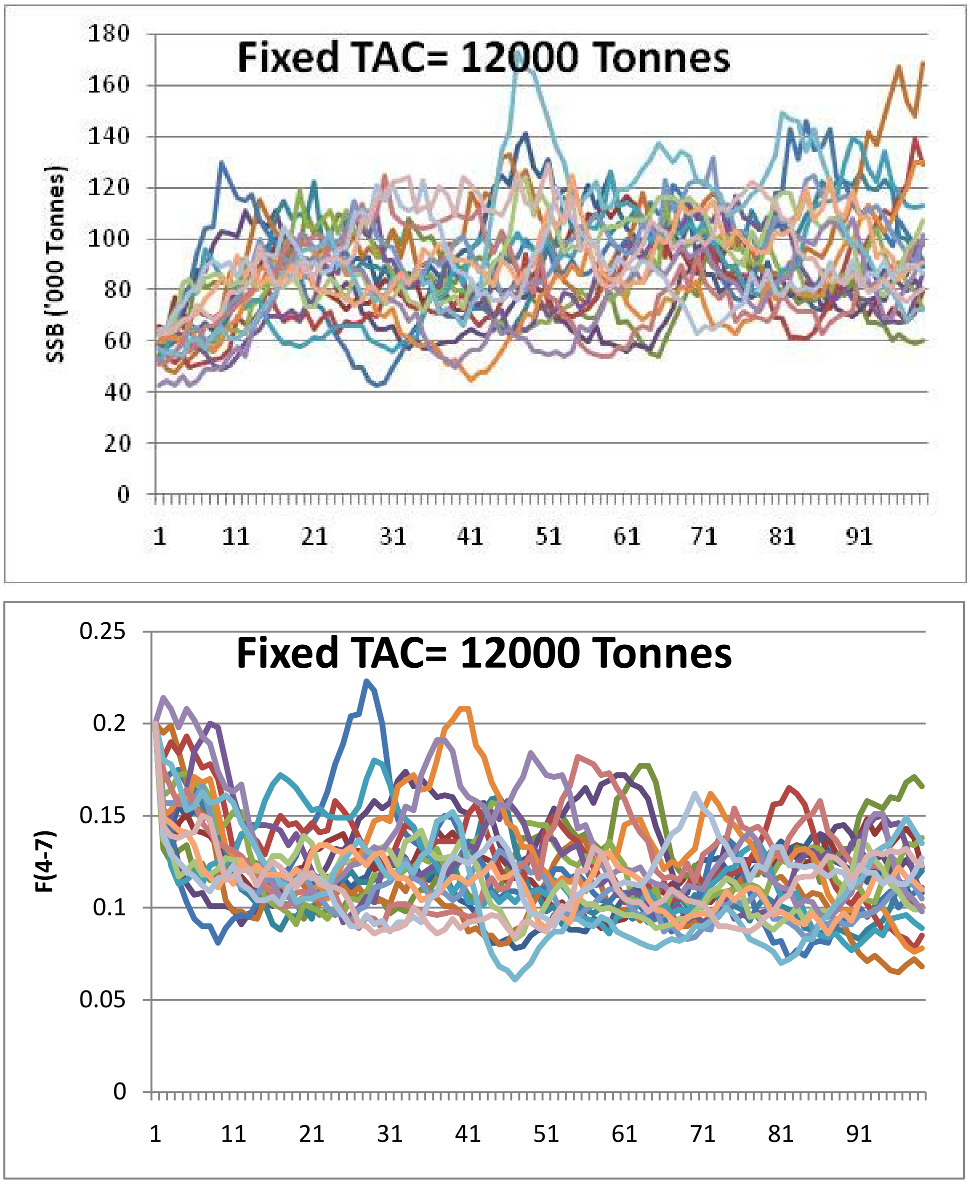

Figure 2.2 Trajectories for SSB and F at a fixed catch of 12 kt, assuming hockey stick recruitment with break point R=10 mill, SSB=50 kt.

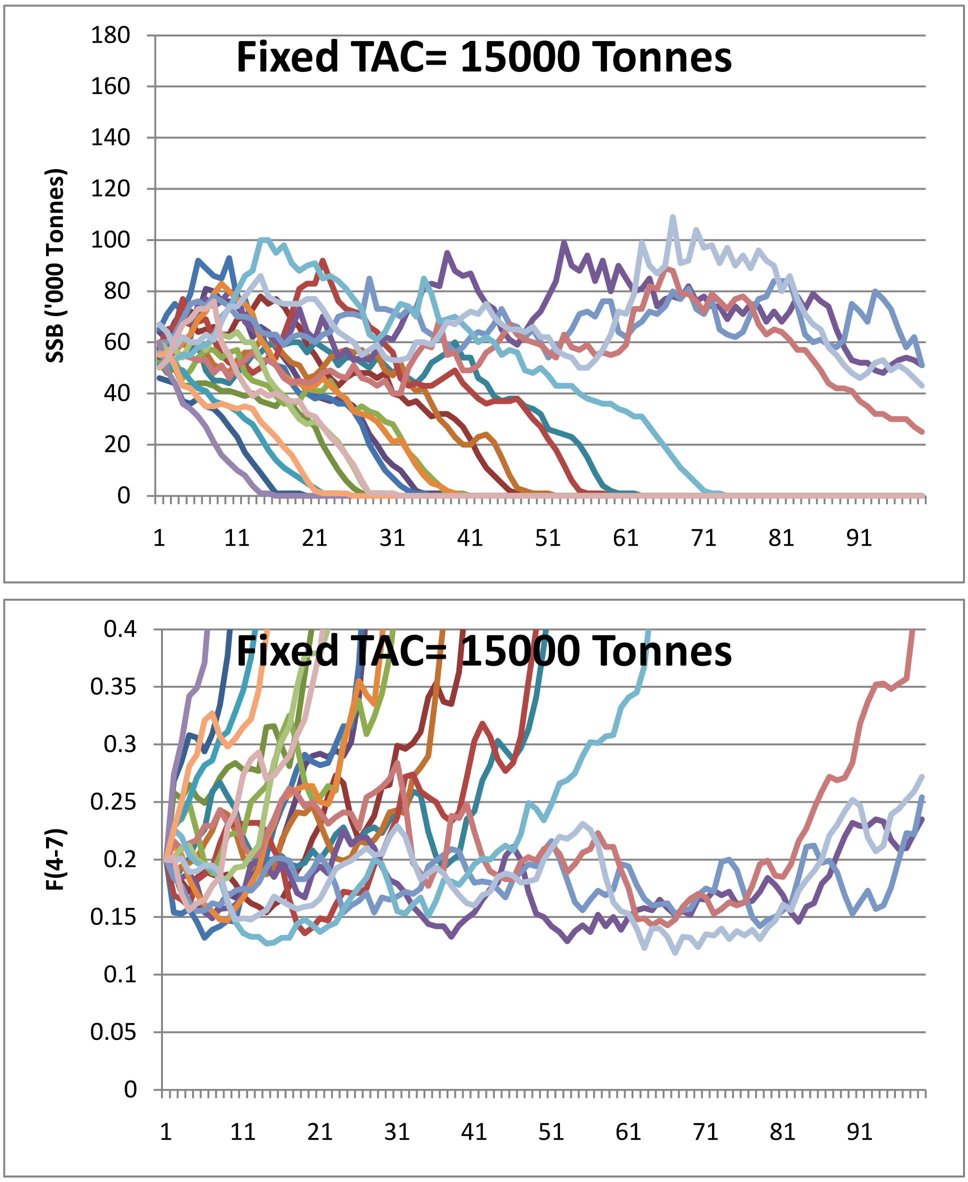

Figure 2.3 Trajectories for SSB and F at a fixed catch of 15 kt, assuming hockey stick recruitment with break point R=10 mill, SSB=50 kt.

2.5 Comments to data and methods

The data used in this analysis are based on incomplete catches. The unaccounted catches (recreational fisheries and catches outside 12 n.mile) are considered to be rather significant (probably in the order of 30%). Including those catches would give a more or less proportional increase of the estimated recruitment, stock size and yield. If the fraction of unaccounted catches relative to total catch has been rather stable over the time series they would not have significant impact on estimated mortalities and the relative stock-recruit relationship. The same considerations would apply to removals by predators. Time trends in unaccounted removals could, however, change the conclusions significantly.

The F_{crash} considerations are here assuming a hockey stick stock-recruit relationship. For the case where the break point is set near the lowest observed SSB, there are no lower observations to support the choice of relationship. At higher SSB the points indicate a depensatory recruitment. These points could have been caused by a less avourable environment, compared to the period before recruitment started to decline.

2.6 Implications for management

The XSA assessment used as basis for the analysis is considered uncertain, but is the best available data on stock trends for a reasonably long time series. The recent F-values in the assessment are above the estimated F_{crash} candidates. After the new regulations were introduced in 2004 the annual catch has varied between 22 kt and 26 kt. This is above the yield expected with continued low recruitment. There is therefore a high risk that current catches and fishing mortality will not be sustainable. The simulations indicate that catches need to be considerably reduced for rebuilding the stock.

3 North Sea cod

3.1 Stock status, biology and problems

The North Sea cod stock is located in the North Sea (Sub-area IV), the Skagerrak (the northern section of Division IIIa), and the eastern Channel (Division VIId). This stock has been exploited for over a hundred years. After World War II, fishing mortality rates increased gradually to around 1.0 by 1981 and have since remained high. Cod are caught by virtually all the demersal gears in Sub-area IV and Divisions IIIa (Skagerrak) and VIId, including beam trawls, otter trawls, seine nets, gill nets and lines. Management actions have been taken in the past decade in an attempt to reduce the fishing mortality rate and reverse the declining trend observed in both stock size and numbers of recruits. Catches have declined since the early 1980s due to both a reduction in the size of the cod population as well as restrictive management measures (Figure 3.1).

Biological and fishery parameters were taken from the most recent assessment of North Sea cod (ICES 2009c). This stock is assessed with the model B-ADAPT fitted to landings data for the years 1963-2008 and ages 1-7+. This model estimated missing catch in years 1993-2008. Discards have been a problem for this fishery for many years due to the wide range of gears that capture cod and the difficulty of estimating discards from such diverse fleets. The estimates of additional removals in 2008 made through the B-ADAPT model were approximately the same amount as the landings, indicating that discards and additional removals may be limiting the rebuilding of this stock. The general results of this model were confirmed with a number of alternative models, including SURBA and SAM.

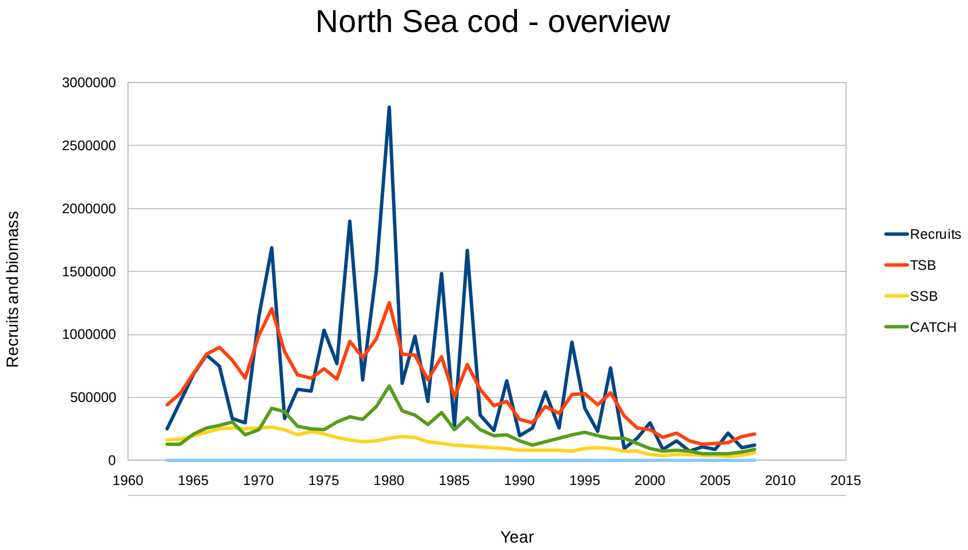

Figure 3.1 Time series of recruits, total stock biomass, spawning stock biomass, and catch for North Sea cod.

3.2 North Sea Cod Time Trend Analysis

The estimated recruitment time series for North Sea cod from the most recent assessment was used in the time trend analysis. This series spans 1963-2008 and shows an overall increase then decrease (Figure 3.2, top panel). However, this change in abundance is not as clearly seen when the annual relative changes ($\lambda_t=\ln(N_{t+1}/N_t)$) are plotted over time (Figure 3.2, bottom panel). The mean of the population growth rates (λ_t) is -1.6% with a standard deviation of 0.945. This means recruitment is expected to continue to decline at a slow rate. However, the relatively large uncertainty causes the projected population distributions to expand rapidly (Figure 3.3). By 2011, the 90% confidence interval is 8,079 to 1,676,048, or less than 1/7th to more than 13 times the 2008 value of 120,160. By 2050, the 90% confidence interval is meaningless, ranging from 2 to 1.5E9. This time series is clearly too variable to support projections using this method.

Given the trend in recruitment, a second analysis was conducted using only the years 1980-2008. This shorter time series eliminates the initial increase in recruitment and shows a more consistent downward trend (Figure 3.2, top panel). This shorter time series has a mean growth rate of -11%, much stronger than the longer time series, but also has a larger standard deviation of 1.039. The net result is that the short term projections are even more uncertain than for the long time series, with a 90% confidence interval in 2011 of 4,482 to 1,659,605. The long term projections are again meaningless, ranging from 0.016 to 7.3E+07 in 2050. Limiting the time series to only the period of decline was insufficient to produce reliable recruitment estimates using this simple approach. This simple method is not recommended as a method to forecast recruitment for North Sea cod due to the high level of inter-annual variability in the observed time series.

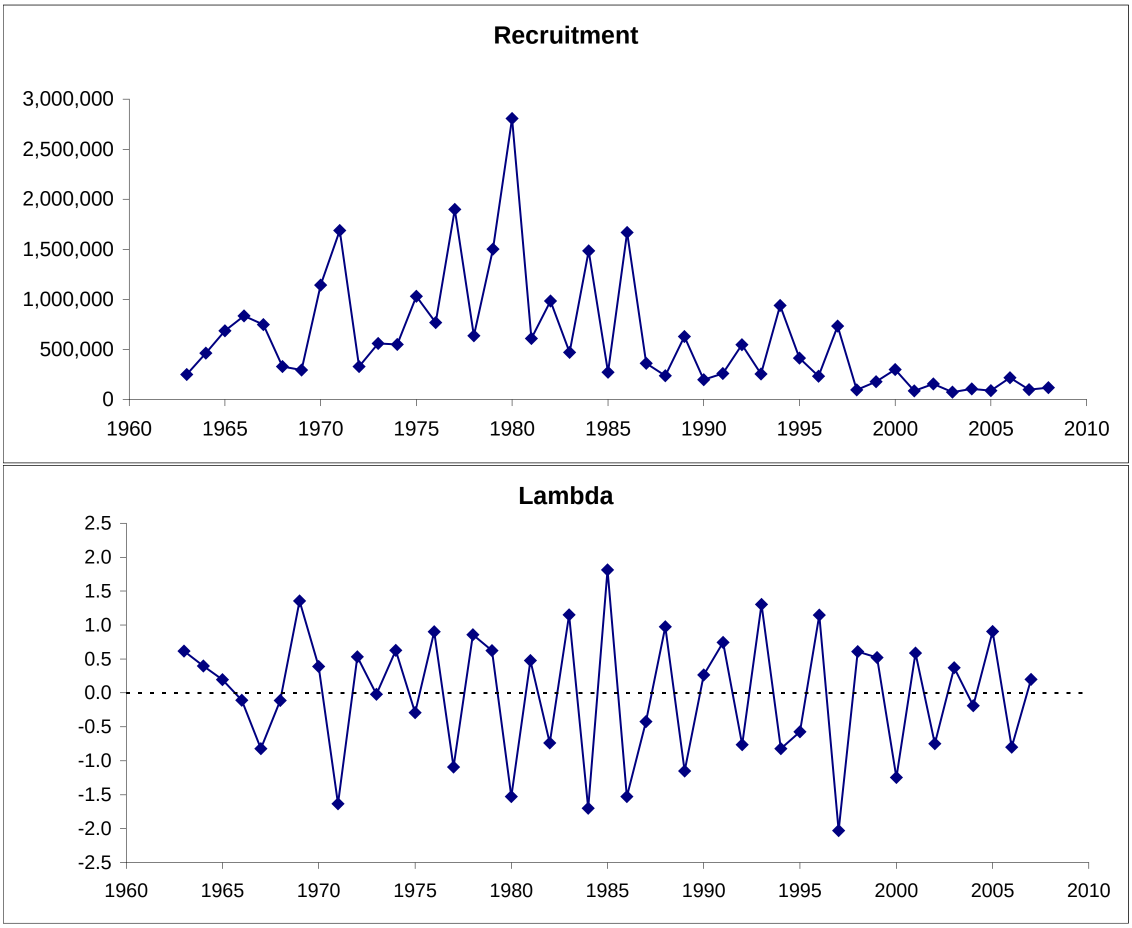

Figure 3.2 North Sea cod time series of recruitment (thousands of fish, top panel) and lambda (=ln(Nt+1/Nt, bottom panel).

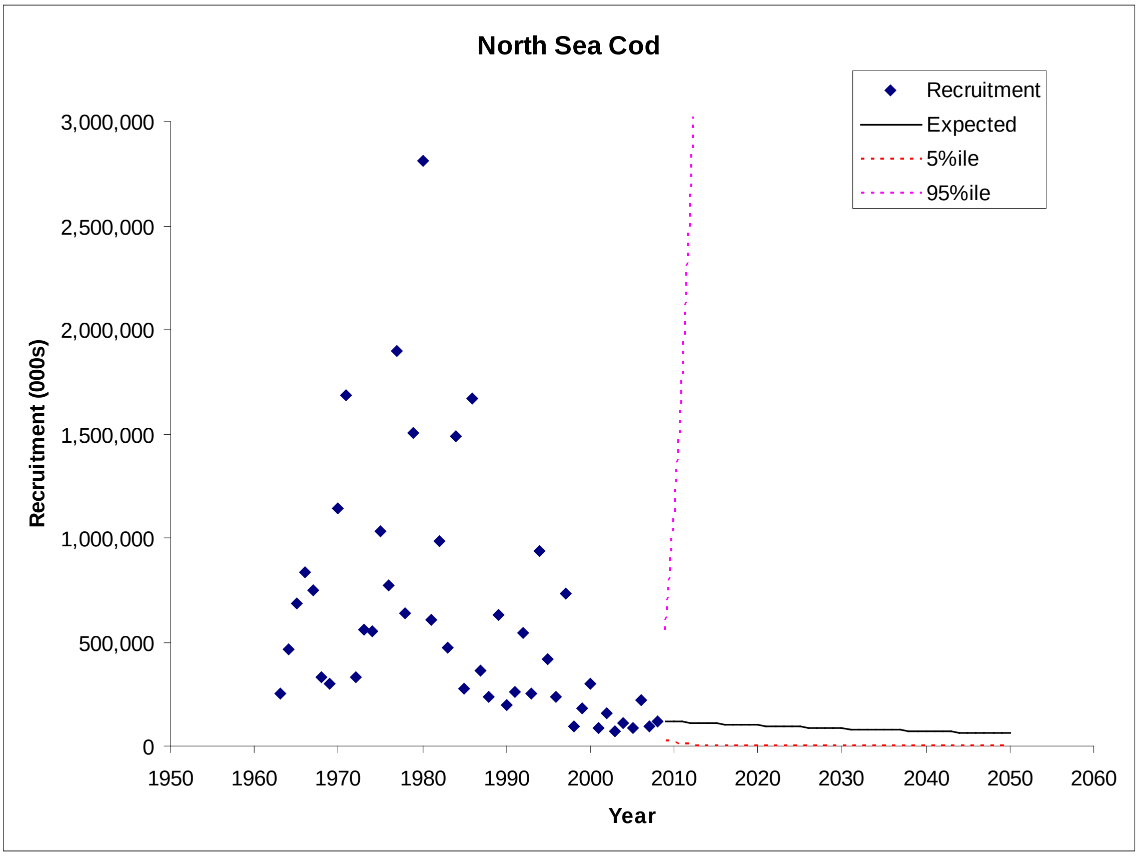

Figure 3.3 Observed recruitment (thousands of fish) time series for North Sea cod (points), the expected future abundance based on the mean growth rate (solid line), and the 90% confidence interval (dashed lines).

3.3 Stock-Recruitment, Yield and Spawners per Recruit

Input values for hcs-analyses are as used by the 2009 WG (ICES2009c): assuming constant maturity, with M and stock weights averaged over the period 2000-2007. Selectivity is averaged over 2005-2007.

The stock recruit plot is shown in Figure 3.4. A hockey stick fit gives a break point at 159 kt with an R-plateau at 626 million (red line in Figure 3.4). The hcs-analyses then gives F_{crash}=0.91. This would be the highest sustainable F if recruitment pattern for the older part of the time series again would reoccur at a rebuilt SSB. The historic data give some indication of depensatory recruitment; more points being below the sloping part of the break point line than above. This would indicate that fishing only slightly below F_{crash} may not be sufficient for rebuilding.

Several authors have argued that the earlier high recruitment (prior to 1985) could be linked to low temperature, and that similar recruitments will not be obtained at the present high temperature (ICES 1999, Planque et al. 1999, O'Brian et al. 2000). There is an intermediate cluster of R-values for SSBs between 75 and 120 kt (years 1986-1999). If we consider the geometric mean of these values (266 million) as the R-plateau under the current regime, but still assume the same break point SSB, the hcs-analyses gives an Fcrash=0.63. Setting the break point just to the left of that cluster (70 kt) gives an F_{crash}=0.90. If we assume the recruitment conditions are best reflected by the most recent observations, we may take the lowest observed (2002-year class) as a candidate for future average recruitment above the 2002 SSB. This break point (R= 74 million, SSB=47 kt) gives F_{crash}=0.62 (green line in Figure 3.4)

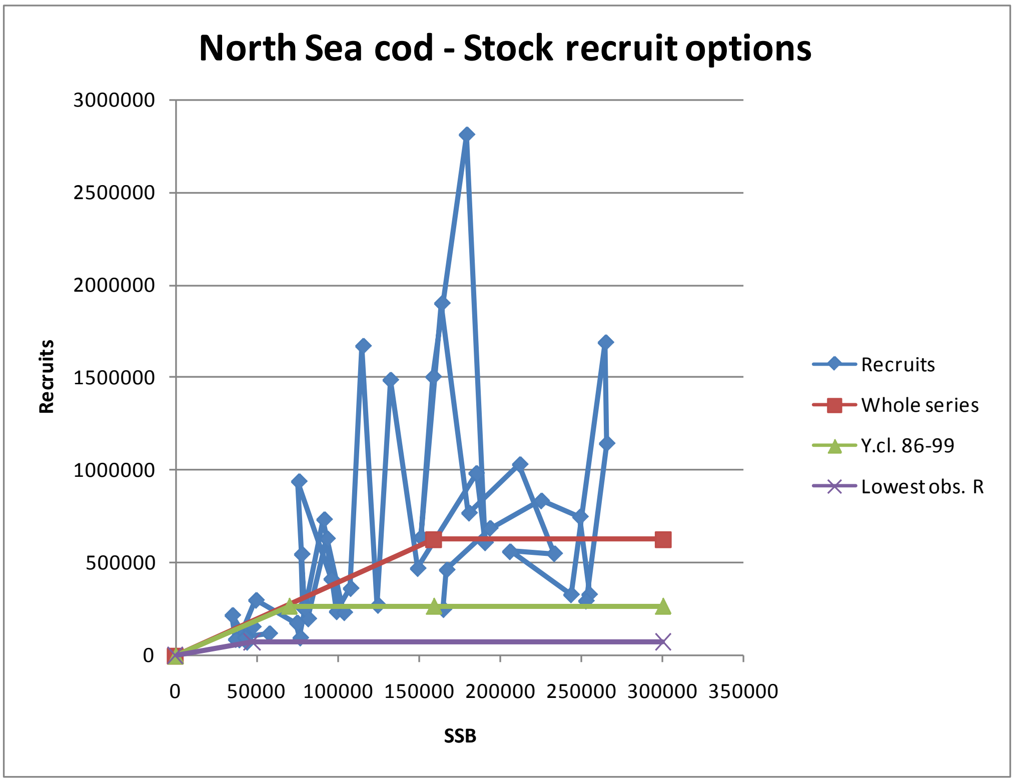

Figure 3.4. Stock-recruit data (year classes 1963-2007) connected with lines. Recent data in the lower left corner. The red line is the break point line fitted to the full series. The green line is the break point line with an R plateau equal to the g.m. of the year classes 1986-1999. The lower dark blue line corresponds to a break point defined at the lowest observed recruitment.

.The Yield and SSB analyses gave F_{max}=0.23 and $F_{0.1}$=0.15. The table below shows yield and SSB levels for the combination of R and F values mentioned above:

R-plateau	bp SSB	F_{crash}	Y at F_{crash}	Y at F_{max}	Y at $F_{0.1}$	SSB at F_{crash}	SSB at F_{max}	SSB at $F_{0.1}$
74	47	0.62	46	61	58	47	230	346
266	159	0.63	163	218	207	159	828	1243
266	70	0.9	134	218	207	70	828	1243
626	159	0.91	314	513	487	159	1950	2925

3.4 Interpretation of results.

The estimated Fcrash at various recruitment assumptions indicate a stock that tolerates quite high Fs. The fish is growing fast and has rather early maturation. However, the decline in both SSB and recruitment since 1980 indicate that catches of the size taken in the 1980s are no longer sustainable under present conditions. It is not clear whether the decline in recruitment is due strictly to the decline in SSB or if a change in the environment has also contributed to the lower recruitments. The recent observations may reflect a depensatory relationship due to either insufficient spawners or highly negative environmental conditions. Various simulations on how climate dependant recruitment for North Sea cod may influence stock dynamics and biological reference points are explored by Clark et al. (2003) and Kell et al. (2005). Regardless of the cause, these low recruitments are a source of concern. If recruitment has indeed changed to a new low level, catches will have to be reduced from current levels in order to maintain the stock at even these low levels. Even larger reductions would be needed to increase the SSB without an improvement in recruitment.

The indication of possible depensation in recruitment means that fishing slightly below F crash is not a wise strategy for rebuilding the stock. Future analyses should explore the possible consequences of depensatory recruitment on catch advice.

4 Sebastes mentella in Subarea I and II

4.1 Stock status, biology and problems

This stock of S. mentella is found in the Northeast Arctic from 62ºN in the South to the North and East of Spitzbergen. The fishery is by trawl. The development of the fishery has been stepwise. It first developed around 1970, and reached a peak at 269 000 tonnes in 1979, where after it declined rapidly, but with a second peak in 1982. A fishery on new grounds developed in the late 1980ies, peaked to 49 000 tonnes in 1991, and then declined to a relatively stable level at 10 - 15 000 tonnes. Since 2004, a new fishery has again developed, this time as a pelagic fishery in international waters, with catches close to 30 000 tonnes in 2004.

The stock has had strong year classes with long intervals, and small year classes in between. The last big year class was from approximately 1989, the previous one may have been around 1980. The evidence for a strong year class around 1980 in survey data is weak, so if there has been such a year class, it may already have been fished out – the earliest survey data are from 1992.

There is no accepted assessment of this stock. Hence, data for stock and recruitment are not available. Therefore, it is not clear to what extent poor year classes can be caused by low SSB. The recruitment dynamics is heavily influenced by the occurrence of strong year classes with long intervals.

The history of the catches may give some indication to the stepwise development of the exploitation of this stock. A possible interpretation of the data may be:

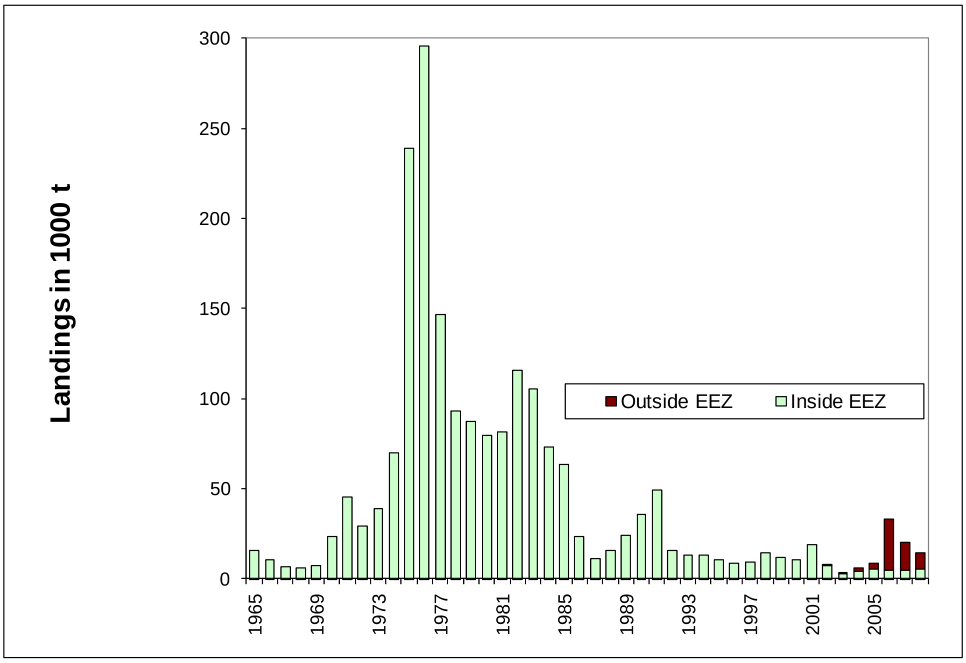

Fig 4.1. Sebastes mentella in Sub-areas I and II. Total international landings 1965-2008 (thousand tonnes). Copy of Figure. 6.1 in the AFWG 2009 report.

Initially, very large catches may have been possible when exploiting a virgin stock with a long life span. The plateau around 1980 may perhaps reflect new strong year classes, or it may have been possible through increasing effort. According to Drevetnyak (1991), the year classes 1966-71 were strong while those throughout the 1970'ies were weak. The peak in 1991 coincides with the development of fishery in new places. The plateau from 1992 onwards may represent an equilibrium, but may also be a gradual depletion of relatively strong year classes from the early 1980'ies, for which there is some evidence in the catch data. The further decline in the catches from 2003 coincides with new regulation, and the new international fishery is clearly visible.

Compared to the early phase, the stock now appears to be in a poor shape, and most fisheries are now (since 2003) restricted to by-catches. The recently developed fishery in the international zone is a cause for concern. The main problem, however, is that the last good year class appeared around 1990, and as that becomes depleted, there is little to replace it.

4.2 Time Trends Analysis

Three survey time series were available for redfish (S. mentella): the Norwegian bottom trawl survey in the Svalbard and Barents regions, and the Ecosystem survey. All three series were limited in time, 1992-2008 for the Norwegian bottom trawl survey and 1996-2008 for the Ecosystem survey. These time series are quite short relative to the lifespan of this species (20+ years). Additionally, there were strong and weak cohort observed consistently in all the time series (e.g. Table 4.1). These strong and weak cohorts caused difficulty for the application of age specific analyses due to the dependence on when in the cycle the survey time series occurred. As an example, the Norwegian bottom trawl survey indices for S. mentella in the Svalbard area were analyzed at ages 3, 6, 9, and 12 (Table 4.1). Age 3 showed a strong decline with an upswing at the end due to an entering cohort. Age 6 showed just a strong decline. Ages 9 and 12 showed increases followed by decreases, with age 12 offset a few years from age 9. The resulting mean population growth rate for the series ranged from -25% to -3%, but all four series had high standard deviations (>0.9, Table 4.1). The large uncertainties associated with the mean growth rates caused large 90% confidence intervals in 2011 and intervals that were meaningless in 2050. The total of all ages time series was more consistent with the exponential decline, producing a 90% confidence interval of 13 to 307 in 2011. The strong negative growth rate overcame the uncertainty by 2050, resulting in a 90% confidence interval of 0 to 36.

Although summing the survey values over all ages produced a more reasonable result for S. mentella in the Norwegian bottom trawl survey of the Svalbard area, this was not the case for all the surveys. The Norwegian bottom trawl survey of the Barents area for S. mentella still showed the impact of the strong cohorts, even when summed over ages (Figure 4.2). The strong increase in the final year is due to a strong incoming cohort. This one value is sufficient to change the mean growth rate from -12% (years 1992-2007) to +1% (years 1992-2008). The addition of this one observation also doubles the population growth rate standard deviation from 0.30 to 0.61. The cyclic or spasmodic recruitment pattern shown by this species means that much longer time series would be needed to determine if there are trends beyond the cycles exhibited in these short time series.

The three surveys for S. mentella produce widely different perspectives on the population growth rate and future population levels (Table 4.2). The Norwegian bottom trawl in the Barents area produces a positive population growth rate due to the large cohort observed in 2008, as described above. The Norwegian bottom trawl survey in the Svalbard area has the strongest negative growth rate because it did not detect this strong cohort entering in 2008. The Ecosystem survey is an even shorter time series than the other two, 1996-2008, and misses the large values during 1992-1995 seen in the other two surveys and does observe a strong cohort in 2008, producing a slightly negative population growth rate but with a large standard deviation. Application of this simple time series approach to the three surveys results in wide confidence intervals in 2011 relative to the observed series and either meaningless confidence intervals (Barents and Ecosystem) or a crashed population (Svalbard) in 2050. These contrasting results for the same stock demonstrate that this simple method with such a short time series is not appropriate for such a long-lived species which exhibits cyclic or spasmodic recruitment patterns.

Table 4.1 Norwegian bottom trawl survey indices (on age) for S. mentella in the Svalbard area (Division IIb) in summer/fall 1992-2006 (numbers in millions) along with the estimated mean and standard deviation of the population growth rate for each series and the 5%ile and 95%ile of the projected populations in 2011 and 2050.

							Age								
Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1992	283	419	484	131	58	45	14	8	5	2	7	2	1	3	1,462
1993	2	527	117	202	142	8	23	6	13	1	7	1	1	+	1,050
1994	7	280	290	202	235	42	94	1	1	3	4	1	1	+	1,161
1995	4	50	365	237	132	61	19	17	11	+	1	3	0	0	900
1996	23	47	15	37	105	144	84	17	51	32	34	9	6	2	605
1997	8	43	6	6	40	20	30	25	7	3	1	2	2	1	194
1998	+	26	28	14	10	13	69	66	49	15	1	6	15	5	317
1999	3	16	114	27	36	53	117	78	67	41	45	11	19	13	640
2000	4	6	6	14	35	22	31	54	81	60	24	24	10	8	379
2001	2	4	3	1	9	16	22	30	34	57	57	50	54	6	344
2002	3	2	4	2	5	22	34	23	88	36	62	64	15	21	379
2003	0.3	3	4	3	5	4	29	31	50	59	45	70	38	23	365
2004	1	1	3	3	1	4	2	9	9	18	15	17	19	9	113
2005	1	1	2	3	3	6	9	15	14	16	14	21	22	25	152
2006	33	1	3	3	2	9	17	27	24	35	29	45	25	34	287
2007	23	45	0	0	3	2	5	5	8	5	5	9	29	19	158
2008	6	22	22	12	1	2	2	5	4	4	3	5	10	6	102
Population Growth Rate															
mean		-18%			-25%			-3%			-5%				-17%
stdev		1.193			0.910			1.097			1.787				0.556
Projected Population Abundance in 2011															
5%ile		0.009			0.001			0.003			0.000				13
95%ile		23,933			147			4,299			198,865				307
Projected Population Abundance in 2050															
5%ile		0.000			0.000			0.000			0.000				0.000
95%ile		9.6E+09			1.1E+05			2.6E+12			6.8E+18				36

Table 4.2 Survey time series for redfish along with the estimated mean and standard deviation of the population growth rate for each series and the 5%ile and 95%ile of the projected populations in 2011 and 2050.

		S. mentella	
Year	Barents	Svalbard	Ecosystem
1992	892	1,462	
1993	1,136	1,050	
1994	1,413	1,161	
1995	1,507	900	
1996	1,009	605	1,366,761
1997	808	194	587,223
1998	502	317	577,670
1999	357	640	755,562
2000	385	379	690,837
2001	236	344	507,131
2002	306	379	573,565
2003	301	365	625,687
2004	172	113	314,030
2005	229	152	279,072
2006	180	287	602,255
2007	144	158	876,986
2008	1,073	102	1,024,894
Population Growth Rate			
mean	1%	-17%	-2%
stdev	0.606	0.556	0.442
Projected Population Abundance in 2011			
5%ile	195	13	266,456
95%ile	6,136	307	3,338,319
Projected Population Abundance in 2050			
5%ile	3	0	3,465
95%ile	1.2E+06	36	3.8E+07

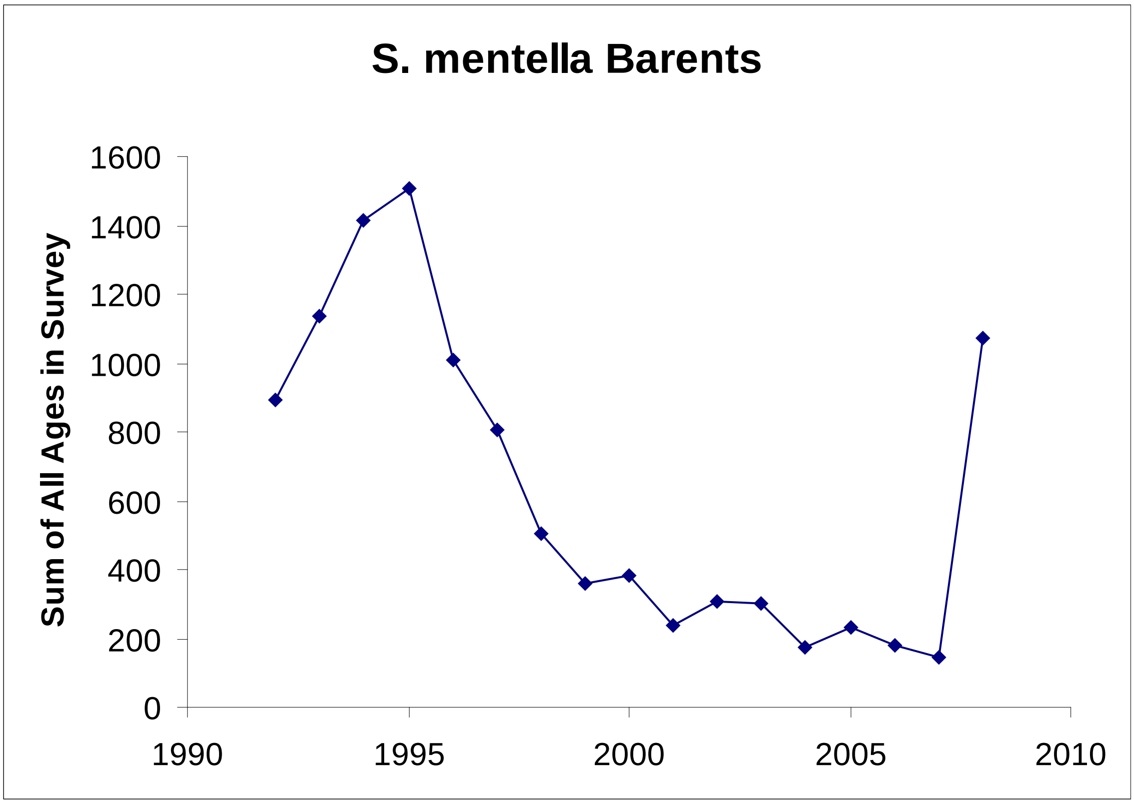

Figure 4.2 Time series of the sum of all ages of S. mentella caught by the Norwegian bottom trawl survey in the Barents area.

4.3 Yield and spawning biomass per recruit

Yield and biomass per recruit was calculated using newly revised weight and maturity data submitted by Planque (pers. comm). The selection at age is poorly know, and for simplicity, it was assumed that it was similar to the maturity ogive (Figure 4.3)[Sme_Yieldrecr.xls]. Implicitly, it is then assumed that the fishery is on mature fish, which has an impact on the shape of the Yield per recruit curve.

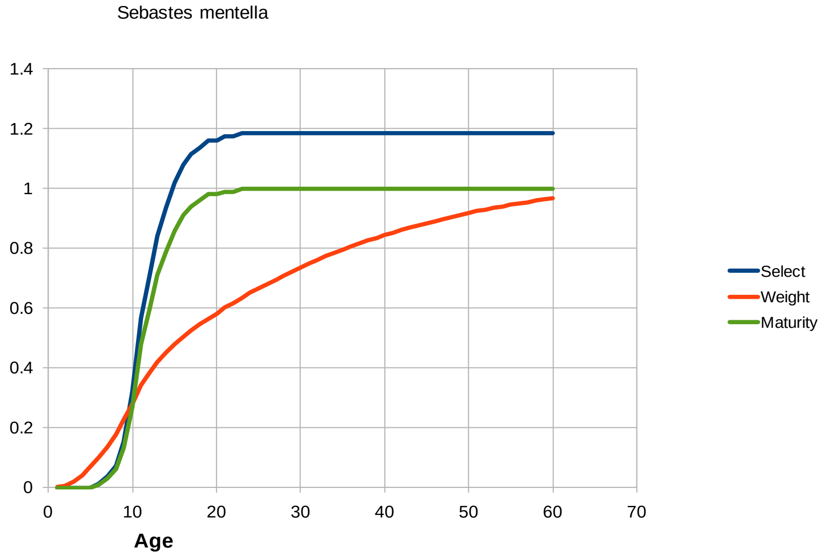

Fig 4.3. Assumed biological properties at age for S. Mentella.

The Yield and SSB per recruit curves, scaled with an arbitrary recruitment, are shown in Figure 4.4. The F0.1 is at 0.12, where SSB is 35% of the virgin biomass. At that level, the yield is approximately 9% of the recruitment, and 13% of the SSB. SSB is approximately 70% of the recruitment. The mean age in the spawning stock at F0.1 is approximately 16 years. The yield per recruit curve is rather flat-topped, with a plateau at approximately 11% of the recruitment.

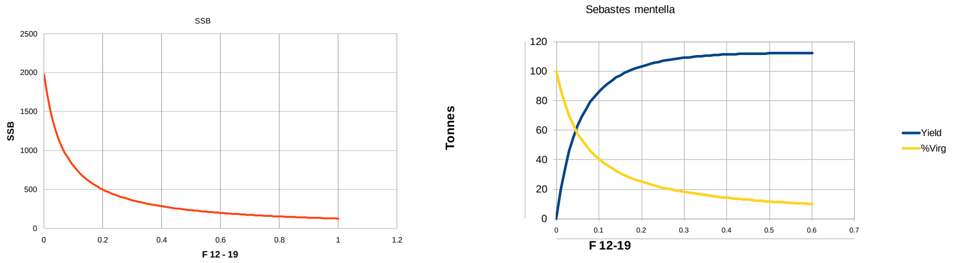

Fig 4.4. SSB in tonnes (left) and SSB in percent of virgin biomass and yield (right) with an arbitrary recruitment of 1000.

4.4 Stock and recruitment

There are survey data indicating strong and weak year classes, but give little indication of their strength. One might try to reconstruct the past history assuming some strong year classes, but the different phases of the fishery complicates the interpretation. To help the understanding of the effect of a strong year class, Figure 4.5 [sme_pulse.xls] shows the effect of a single strong (10 times normal in 'year' 2057) year class on top of a stable recruitment, and with two levels of stable fishing mortality. A marked pulse will appear in the catch when it reaches fishable age, followed by a gradual decline over about 10 years.

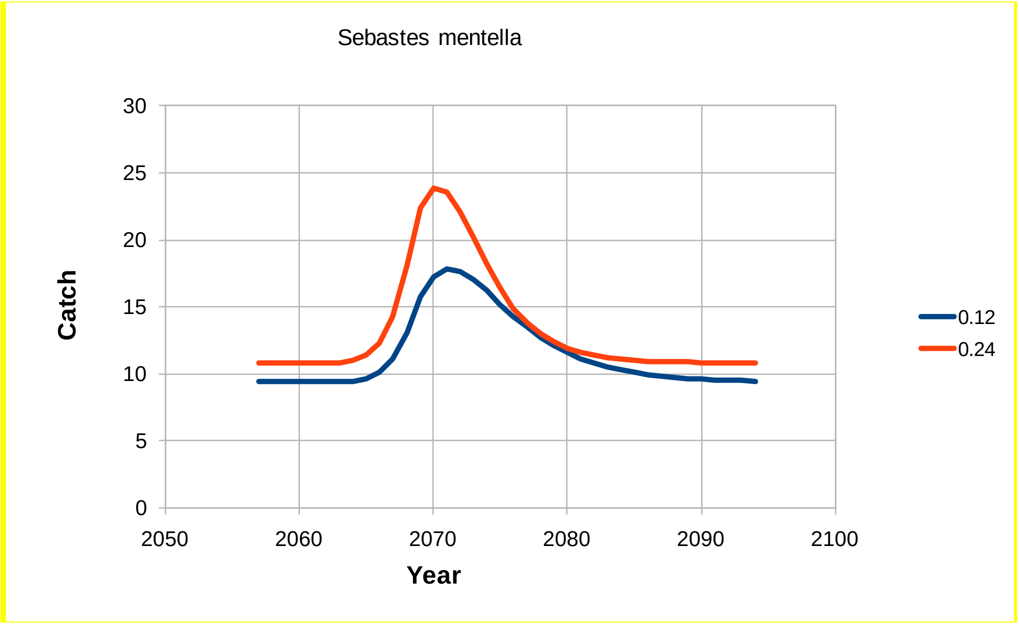

Fig 4.5. Time course of catch after a pulse recruitment in year 2057, for two levels of fishing mortality

Assuming that the catches 1992 - 2002, with an average of slightly above 10 000 tonnes result from a period with stable exploitation, would imply an average recruitment in the order of 100 000. It may be lower if there still are remnants of an earlier year class contributing, and the strong year classes near 1990 might contribute in the last part of the period.

From this, one may infer that under the present assumptions, the catches at the 2003 level could be sustainable provided that the average recruitment remains at the previous level, while those from 2004 onwards can only be sustainable if the recruitment is higher than assumed here.

4.5 Comments to the results

The considerations above were made to indicate some ways of reasoning when much quantitative information is lacking and are to some extent poorly substantiated. Several of the assumptions that have to be made can probably be explored further (for example the possible influence of a strong year class in the past, and the assumption of stable exploitation in 1992 - 2002). Likewise, the assumptions above are based almost solely on the information that is available in the recent WG report, and there probably is more information to be found. This underpins that providing advice on a stock which may be in a poor shape requires a more extensive process than what was possible during this short meeting with limited expertise. Nevertheless, some guidance to management can be inferred, which may be better than nothing while better advice is developing.

5 Sebastes marinus

5.1 Background

The stock is distributed along the coastal shelf from beyond 62ºN to Spitsbergen. The Barents Sea is mostly a spawning area.

For this stock an assessment (with Gadget covering 1987 - 2008) is available, and the considerations here are based on that.

The recruitment has been poor since the early 1990ies. The fishery was previously unregulated, but due to the poor recruitment and subsequent decline in SSB, the directed trawl fishery in Norwegian waters was stopped in 2003. Since then, further restrictions to protect S. marinus have been introduced in other fisheries, and the catches have stabilized at about 7000 tonnes, compared to 15 - 30 000 tonnes or more in previous years.

5.2 Time Trends Analysis

Two survey time series were available for redfish (S. marinus): the Norwegian bottom trawl survey in the Svalbard and Barents regions. Both series were limited in time, spanning only 1992-2008. These time series are quite short relative to the lifespan of this species (20+ years). As in S. mentella, there were strong and weak cohort observed consistently in both time series. The two surveys for S. marinus also produce widely different perspectives on the population growth rate and future population levels (Table 5.1). The Norwegian bottom trawl survey in the Barents area time series has a stronger and more certain negative population growth rate that the time series from the Svalbard area. This causes the Barents time series projection for 2011 to have a much smaller 90% confidence interval than the Svalbard time series and to collapse by 2050. In contrast, the Svalbard time series has a wider 90% confidence interval by 2011 than the range of observed values and so wide a 90% confidence interval by 2050 as to be meaningless. These contrasting results for the same stock again demonstrate that this simple method with such a short time series is not appropriate for such a long-lived species which exhibits cyclic or spasmodic recruitment patterns.

Table 5.1 Survey time series for redfish (S. marinus) along with the estimated mean and standard deviation of the population growth rate for each series and the 5%ile and 95%ile of the projected populations in 2011 and 2050.

	S. marinus	
Year	Barents	Svalbard
1992	67,042	51,530
1993	40,568	39,215
1994	59,766	20,155
1995	69,930	23,400
1996	55,030	6,500
1997	60,980	16,950
1998	48,487	15,696
1999	27,879	19,748
2000	20,230	6,250
2001	20,380	12,940
2002	17,814	2,518
2003	15,230	2,229
2004	13,520	2,430
2005	8,944	1,177
2006	15,030	1,148
2007	7,652	7,702
2008	6,306	11,292
Population Growth Rate		
mean	-15%	-9%
stdev	0.326	0.889
Projected Population Abundance in 2011		
5%ile	1,639	711
95%ile	10,301	109,255
Projected Population Abundance in 2050		
5%ile	0	0
95%ile	399	2.9E+06

5.3 Biological characteristics

The input data to simulations are those going into or derived from the Gadget assessment. Weights in catch and stock (assumed equal) are taken from the WG report for ages up to 23. These weights were extrapolated up to age 30 assuming a von Bertalanffy growth model. The proportion mature and the fishing mortalities at age are estimated by the assessment. For selection, the average over the last 5 years is used. Fish older than 23 years were assumed to be fully recruited to the fishery and fully mature. The biological input data are shown in Figure 5.1.

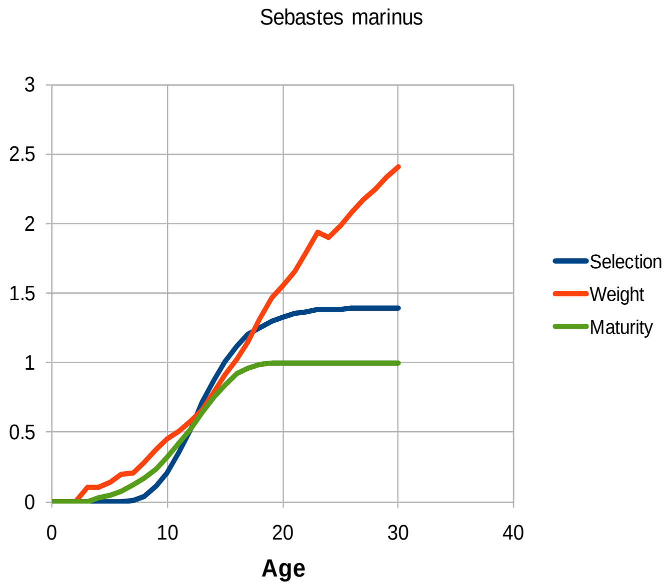

Fig 5.1 Biological input data for Yield and biomass calculations for S. marinus

The resulting yield and spawning biomass per recruit are shown in Figure 5.2, for a recruitment at the average of the period 1996 - 2000. The main results are summarized in Table 5.1.

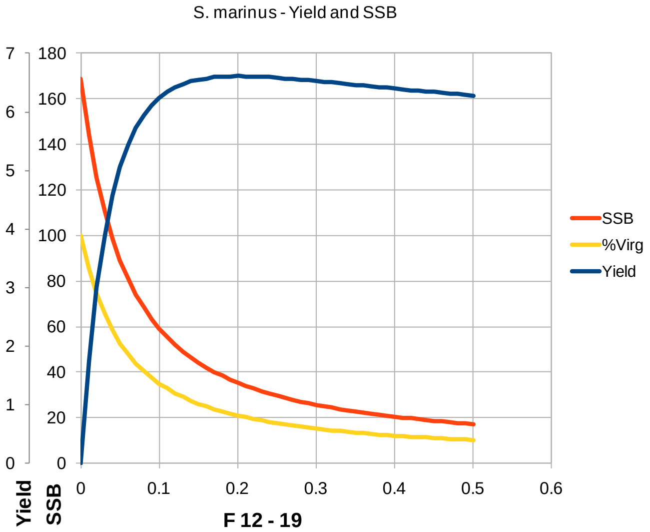

Figure 5.2. Yield and SSB (in tonnes and as percentage of virgin biomass) assuming a recruitment of 26.8, which is assumed to be representative of the low recruitment 1999-2002.

	Value	Catch	SSB	SSB % virgin biomass
Recruitment	26.8			
$F_{0.1}$	0.08	5.94	68.31	40
F_{max}	0.20	6.61	35.36	21

Table 5.1. Main values for yield/recruit calculations, assuming a recent low recruitment.

5.4 Recruitment and Stock-recruit relation

There has been a remarkable reduction in recruitment, which apparently came before the decline in SSB (Figure 5.3). That indicates that the recruitment has been reduced for external reasons, and the SSB reduced because of reduced recruitments. The recruitment is at age 3, but the recruitment years refer to the year class. The points are connected to indicate the time course.

The estimates for the last years are highly uncertain, and it is still unclear whether the recruitment is improving.

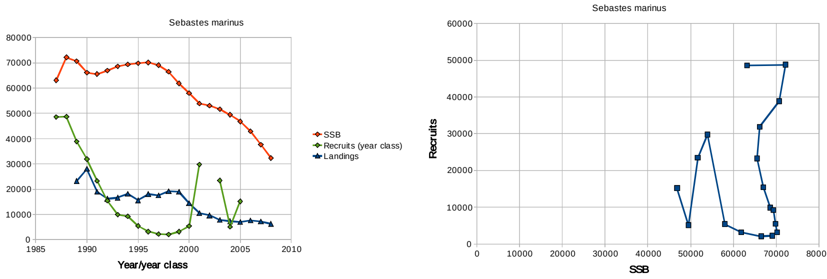

Figure 5.3. S. marinus. SSB, recruitment and landings from the Gadget assessment. Left: Summary plot. Right: Time course of stock-recruit pairs.

To further confirm the hypothesis that recruitment was impaired independently of SSB, simulations were done to reconstruct the time course since 1987. A cosine curve with period 60 years was adapted to the recruit time series (Figure 5.4). This time course in recruitment was assumed in a simulation run, with no dependence on SSB. the stock was primed with a fishing mortality of 0.2, and then run from 1987 onwards with various constant fishing mortalities. The resulting SSB and catch are shown in Figures 5.5 a,b). With a fishing mortality of 0.2, the time course of SSB is reproduced quite well. The catches deviate in the first year, indicating that there may have been a higher fishing mortality in the early part of the period. However, the results suggest that the data are compatible with a gradual reduction in recruitment and a fishing mortality in the order of 0.2 – 0.3.

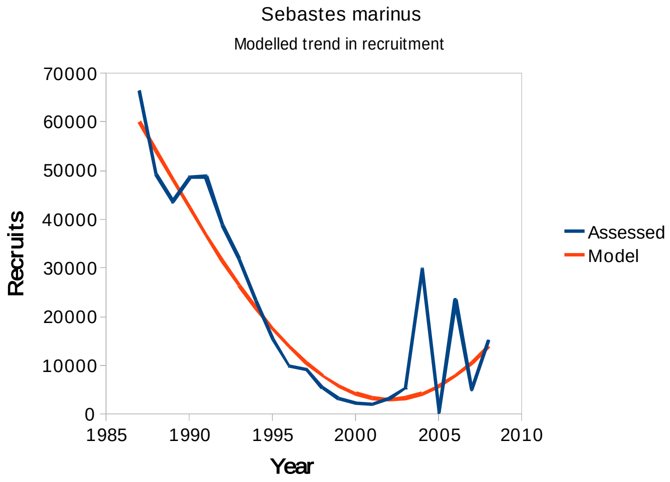

Figure 5.4. Fit of a cosine curve to the historical time trend of recruitment

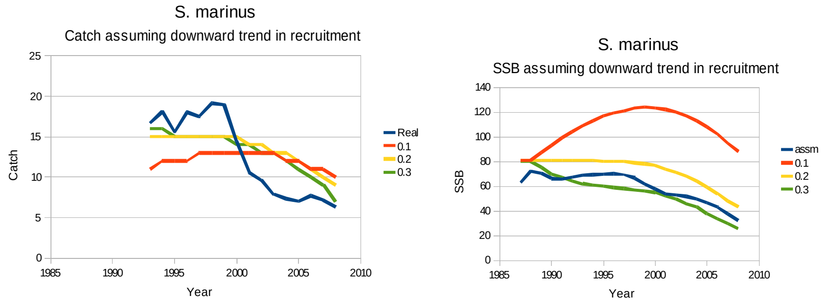

Figure 5.5. Simulating catch and SSB for the years 1987 - 2008 assuming a cosine downslope recruitment, and fixed fishing mortality. The stock was primed with a fishing mortality of 0.2 and a mean recruitment at 60 000.

5.5 Simulations

There are some indications in the survey data that recruitment has been improving in the most recent years, and this is reflected in the estimates by Gadget. However, there results are considered highly uncertain, and even if there is an improved recruitment, it will still take some years before these year classes reach fishable age. Therefore, simulations of various harvest rules were made with the assumption that the recruitment is as at the of the decline period (26.8 = Average 1999-2002). The recruitment was assumed to be independent of the spawning biomass.

A set of simulations with fixed F-values gave catches slightly above 6000 tonnes. This is lower than the recent catches between 7000 and 8000 tonnes. Hence, these catches may not be quite sustainable with the assumed low recruitment. To further explore the effect of catches at this level, simulations were made with a fixed catch regime, at a range of TAC levels. Again, the starting values were obtained with priming at F = 0.2. The stock was considered collapsed if that TAC could not be taken with even with a highly unrealistic fishing mortality of 3.0. This is not the same as risk of extinction, but rather an indication that the fishery is far from sustainable.

Results in terms of time course of mean SSB and mean catch are shown in Figure 5.6. The lines are broken when mean F exceeded 1.0

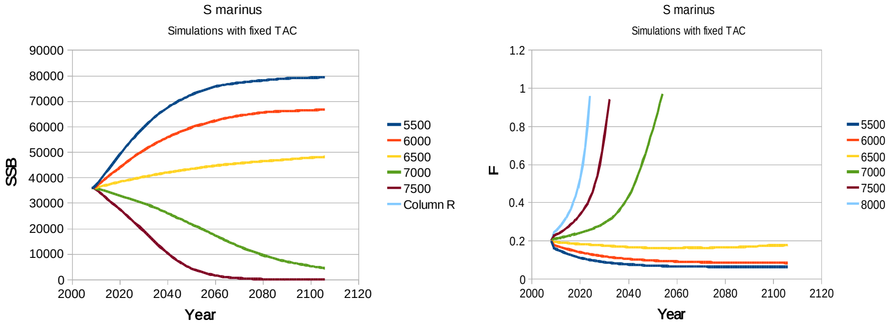

Figure 5.6. Simulation with fixed F TAC, assuming a recruitment at the recent low level of 26.2. The simulated stock was primed with a fishing mortality of 0.2.

To illustrate some detail behind the mean values, Figure 5.7 shows the time course of SSB in 20 individual trajectories with a fixed TAC of 7000 tonnes, i.e. slightly above the MSY and a low recruitment as above.

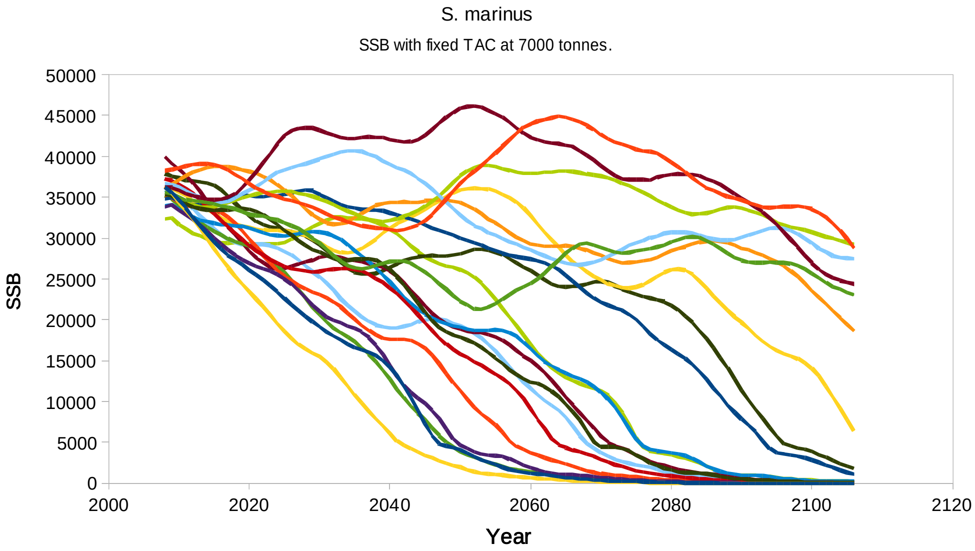

Figure 5.7. Time course of individual trajectories (realisations) of SSB for S. marinus with fixed catches.

5.6 Implications for management

The recruitment for this stock has declined progressively throughout the whole time period that is covered by the current assessment. The decline may have stopped around 2003, but the recent recruitment estimates are highly uncertain. The stock has declined, but delayed compared to the decline in recruitment. Simulations of the historical period with a downward trend in recruitment indicates that the time course of the SSB and the catches are compatible with a gradually reduced recruitment and a fishing mortality between 0.2 and 0.3.

Analysis of yield and biomass per recruit indicate an F0.1 at 0.08 and FMSY at 0.2. Assuming a recruitment at the low end of the decline phase, these values correspond to catches of 5900 and 6600 tonnes respectively. Currently, the catches are between 7 and 8 0000 tonnes. With the current low recruitment, these catches are probably not sustainable.

Simulations indicate that a constant catch above about 6500 tonnes will lead to a progressive reduction of the stock, and a collapse within 10 - 15 years if recruitment remains low. However, small changes in recruitment and other parameters that go into the assessment will alter these limits. Nevertheless, it seems clear that the current level of catches is at best marginal, and most likely will lead to a stock collapse without a substantial increase in recruitment.

6 Some discussion points.

- The WKPOOR2 had to restrict the stocks to be considered to those with highest priority, due to limited time and number of participants.
- All of these were stocks considered to be in a poor condition. Inspecting the available data indicated that all these stocks suffered a poor recruitment in recent years. The reason for this poor recruitment is not clear, but at least in some cases (e.g. the Sebasetes marinus) it could not be attributed only to a reduced spawning stock biomass.

- Time trend analysis was performed on all stocks, and was not considered informative in any of them. The main reasons were.
    - Time series do not follow the expectation of exponential decline or increase (all)
    - Time series are too noisy to allow reliable forecasting using this simple method (NS cod especially)
    - Cyclic or spasmodic recruitment events causes periodicity in time series that is not modelled by this method (redfish)
    - Different surveys of same stock or different ages within same survey can produce contrasting results – there is no synthesizing mechanism in this approach
    - Short time series for long-lived species are not sufficiently informative (redfish)
    - Long time series makes the stationarity assumption difficult to meet (NS cod)
- The WKPOOR2 attempted the following approach to understand the state of the stock and the need for adjustments of current management:
    - Assemble info on stock dynamics, direct or indirect.
        - Yield and biomass per recruit,
        - Establish likely recruitment level
        - Identify possible breakpoints where recruitment gets impaired due to low SSB
        - Compare catches with equilibrium yield for various recruitments.
    - Is the current level of catches likely to be sustainable?
    - Linking this to management measures, do they appear to be sufficient?
    - Simulations to
        - Evaluate likely effect of management measures.
        - Sometimes to justify assumptions about the past.
- Main questions that can be addressed:
    - Is the reduced recruitment due to reduced stock (or vice versa?), note that this determination is not always possible
    - Is the current management adequate?
        - If yes, is it borderline?
        - If no, adjustments needed.

The conclusion from this study was that the suggested approach appeared to be promising, and probably more useful as guidance to management than a classification (e.g. redlist).

Clearly, to follow this approach implies assembling and inferring all possible relevant information. This has to be a process, involving experts on the stock biology and dynamics of the stock as well as modellers. To be successful, this process requires

- Effort and insight to justify crucial assumptions
- In depth examination of management measures
- Examination of alternative future recruitment scenarios should include considering "what if" scenarios where declines continue, and alternatively how much does recruitment need to increase to sustain current catches at a reasonable level, corresponding to a low F leading towards rebuilding target.

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