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Report of the Study Group on Growth, Maturity and Condition in Stock Projections

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International Council for the Exploration of the Sea

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1 INTRODUCTION

1.1 Participants

A complete list of participants can be found in Appendix D of this report.

1.2 Terms of Reference

The **Study Group on Growth, Maturity and Condition in Stock Projections** [SGGROMAT] (Co-Chairs: C. L. Needle, UK and C. T. Marshall, UK) met at the School of Biological Sciences, University of Aberdeen from 19–23 January 2004 to:

a) review progress in summarising the availability of data on weights, maturity, condition and fecundity for the stocks identified during the first meeting;
b) review the suitability of available process-based models for growth, maturity, condition and fecundity for implementation in medium-term projections and propose modifications where necessary;
c) implement suitable process-based models in medium-term projection methodologies and conduct sensitivity analyses to examine the likely effects of these new approaches on management advice.

The SGGROMAT will report by 31 January 2004 for the attention of the Resource Management, Living Resources, Oceanography and Baltic Committees, as well as ACFM.

1.3 Scientific justification and aims of the Study Group

Medium-term (5–10 year) fish population projections are a valuable means of framing management perceptions about possible responses of stocks to varying exploitation strategies, and are becoming increasingly important following the strong emphasis placed on harvest-control rule simulations in recent notes by ACFM. Current ICES projection methodologies (e.g., WGMTERM, ICP, STPR) do not take account of any autoregressive time-series structure that may be present in the data. Perhaps more significantly, inappropriate growth models (e.g., fixed values of maturity and weight) can seriously degrade the quality of stock projections. Existing knowledge about processes influencing growth (e.g., food availability, temperature) for individual stocks is not incorporated into the projections, and it is currently uncertain what form models for growth should take (e.g., age- or length-based) to facilitate their incorporation into the assessment. Assessment Working Groups rarely have sufficient time or resources to devote to either data collation or model development. This hinders progress in developing and implementing growth models in new projection software. The aim of SGGROMAT is to address and, where possible, rectify these problems.

1.4 First meeting of SGGROMAT

The first meeting of SGGROMAT (ICES 2003) successfully reviewed progress in modelling growth and reproductive potential and laid the basis for future implementation of such models in stock projections. The SG proved to be a valuable forum for evaluating the utility and methodology of integrating biological knowledge in assessments, both by reviewing work done elsewhere and by conducting strategic research under its own remit. The SG agreed that three meetings would be required in order to complete the development of tools that are specifically intended for assessment WG use. This would also ensure that the work done towards the first term of reference (ToR a) was largely completed by the end of the SG lifespan.

1.5 Intersessional work between first and second meetings towards the ToRs

A major deliverable of the SG is the development of tables specifically designed to give an overview of the available information and existing data which can be applied to the estimation of stock reproductive potential, as well as some aspects relevant to modelling growth (ToR a). This activity continued throughout the intersessional period. At present, the tables have been filled out for many ICES stocks (see Section 3 for an update on progress) and more will be filled out over the coming year. This activity will therefore outlast the SG, assuming that the current meeting is to be the last (see Section 6). The benefits of the tables are that they:

- provide metadata that can then be included on the ICES website, which already includes a data inventory (see Recommendation in Section 8.4);

- provide a comprehensive listing of data resources for ICES assessment working groups, client customers, relevant stakeholders and researchers;
- provide a comprehensive listing of scientific literature related to growth and reproduction;
- provide metadata that can then be analyzed to indicate which types of information are *not* being provided by current sampling programmes (e.g., Tomkiewicz *et al*. 2003).

The advantages of such a data collation exercise have been clearly demonstrated by a previous effort for Northwest Atlantic fish stocks undertaken by the NAFO WG on Reproductive Potential. These metadata are included on the NAFO website (http://www.nafo.int/publications/frames/puFrSC37.html) as a permanent resource and there is the intention of updating the tables at regular intervals. A semi-quantitative analysis of the metadata (Tomkiewicz *et al*. 2003) has indicated that:

- there are considerably underutilised data resources related to stock demographics and, in particular, age/length keys, the sex composition and sex specific maturity ogives of stocks. Many stocks have time series of egg and larval stages. The depth of information is not reflected in assessments, which typically only utilise a fraction of the data that are available.
- fecundity data and, to a lesser degree, condition data have not been collected in previous sampling programmes. This hinders efforts to construct alternative indices of reproductive potential and identifies a need for data and studies to establish e.g., growth and fecundity models.

These data are essential for progressing towards more biologically realistic assessments. It is likely that in the near future assessments and stock projections will include alternative measures of reproductive potential, e.g., female-only SSB (see Section 4.5.1). Thus, ICES must anticipate that the requirement for such historical data will increase. Data availability and accessibility will be key considerations when trying to increase the biological realism of assessments**. Issues related to data availability and accessibility are, in general, neglected relative to their strategic importance to ICES**.

During the intersessional period several members of the SG developed improved models for growth, maturity, condition and fecundity (see Section 2). It is clear that these fields are advancing rapidly, as are the supporting databases. Incorporating this knowledge into assessments requires a high degree of collaboration between biologists and assessment scientists. Indeed, one aspect of the original intention of SGGROMAT was to provide a forum for exactly this kind of interaction. The membership of the SG has considerable direct or indirect experience with assessments. This was advantageous as it led to many practical suggestions for incorporating biological information. Unfortunately, the participation rate in the SG by ICES assessment scientists was lower than expected. Prior to the first meeting the Co-Chair s actively encouraged assessment scientists to participate in the SG by informing Chair s of all ICES assessment WG and encouraging members of those WG to join. The Co-Chair s also contacted several individuals, inviting them to the SG. Despite these recruitment efforts, participation by assessment scientists in the SG was more limited than in its predecessor (SGPRISM). This hindered progress towards ToR c (see Section 5). More generally, it has led to the ICES assessment community being largely unaware of many of the developments that are taking place in the field of data collation and growth modelling.

In the intersessional period some progress was made in developing new approaches that could be used to incorporate better information on growth, maturity and condition in stock projections. An example was presented at the SG meeting of how more realistic and variable estimates of growth and maturity could be treated in short term projections using cod in NAFO Div. 3NO (see Section 4.5.2). There are several new approaches to stock projections being examined by SG members including simulation approaches (see Section 5.1) and the use of Kalman filters (see Section 5.2). However, little progress was made towards developing software incorporating new stock projection methodologies (ToR c). In part, this was due to the unforeseen pressures brought to bear on scientific personnel by the ongoing North Sea fisheries crisis. This caused a shifting of scientific priorities for key individuals and progress towards developing the new software was essentially halted. The need for the software has not been eliminated (see Section 6 for a further discussion of this point).

1.6 Future work

Feedback from the parent group (Resource Management Committee) following the 2003 ASC indicated that the second meeting of the SG would, in all likelihood, be the last. The RMC suggested that the SG consider how best to continue with the work within ICES. It was suggested that issues of data availability and their collation (ToR a), along with length-based modelling approaches, could be undertaken by the Study Group on Age-length Structured Assessment Models [SGASAM], whilst stock projection issues (ToR c) might best be undertaken by the Methods Working Group

[WGMG]. The SG did not feel that the first option was acceptable, either for pursuing the collation of metadata or for the development of biological models that are customised for application in age-based assessments. The SGASAM has well-defined and ambitious terms of reference and it would not be appropriate to burden this SG with additional tasks. The WGMG would be an appropriate home for continued work on stock projection methodology. Various possibilities for the continuation of the work were discussed in a plenary session of the SG (see Section 6) and the resulting recommendations are presented in Section 8.

1.7 Structure of the report

Section 2 of the report presents short abstracts for each of the presentations made to the SG and summaries of subsequent discussions. Section 3 addresses ToR a, looking at the current status of intersessional work towards collecting metadata on the availability of historical data. Section 4 presents a record of discussions related to several aspects of ToR b. This section was not meant to be comprehensive in scope, but rather to complement the report from last years SG meeting that covered condition and maturity in considerable detail (ICES CM 2003/D:01). Section 5 relates to ToR c. Owing to the lack of progress in the development of new projection methodologies (as noted above) this section is brief compared to last years' report. Several suggestions for future work are included there that reflect presentations made to the SG.

1.8 Thematic overview of the report

The analyses and proposals in this report can each be viewed as belonging to one of three categories:

1) ***Models and data which are suitable for immediate incorporation in stock assessments***. Examples of these include female-only spawning biomass (which would give a better index of reproductive potential than SSB, see Section 4.5), Kalman filter modelling and projection of recruitment (Section 5.2), age-length keys (Section 4.1), and empirically-derived maturity data (Section 4.2). The SG recommends that strenuous efforts should be made by ICES assessment WG to investigate the utility of incorporating those models and data identified by the SG as belonging to this category. Much of this work would have to be carried out intersessionally, but the SG feels that it is essential that this be done to enable ICES to, firstly, fulfil obligations regarding the ecosystem approach, and secondly, address client customer concerns about assessment quality.
2) ***Advice and recommendations on requirements for future data collection and collation***. Serious deficiencies and omissions in the available data for many stocks in the ICES management area have become apparent during intersessional work aimed at addressing ToR a (Section 3). If not rectified, these will make it very difficult to improve stock assessment and advice. While many of these problems may be reduced by the new EU Data Collection regulations, the SG believes it is still important to ensure that the collection of data on growth, maturity, condition and fecundity should be prioritised.
3) ***More speculative analyses***. This category refers to work which is still in progress, or which is planned for the future, and which may at some unspecified time be suitable for incorporation in assessment methods and management advice. Examples of this include habitat suitability evaluations (Section 5.3), the inclusion of climatological considerations (Section 2.5), and growth modelling (Section 4.1). The SG does not mean to reduce the importance of these approaches by labelling them as speculative, but rather to highlight the fact that they are not yet ready for incorporation into stock assessments.

2 PRESENTATIONS AND WORKING DOCUMENTS

2.1 Marshall: A summary of the final report from the first meeting of SGGROMAT

Summary

A short summary of the final report of the 2003 meeting of the SG was presented as the ToRs for that meeting were similar to this year's. It was noted that, in the chapter entitled "Process-based modelling of growth, condition, maturity, and fecundity," condition was a re-occurring theme throughout several of the sub-sections. In addition, the condition information presented in the maturity sub-section was especially detailed. The intent of this year's discussion related to ToR b is to cover different aspects of growth. The application of age/length keys to growth modelling and fecundity will therefore be highlighted.

Discussion

The SG appreciated this brief review of the main points arising from its previous meeting, which served to set the scene for the current work. It was clear that the emphasis of this year's meeting would be different from that for last year's meeting, at which much of the discussion had centred on modelling of condition and maturity: the focus this year would appear to be more on growth modelling and fecundity. Some assessments do appear to have been modified during the last year to account for the data and models discussed in last year's meeting. Examples include time-varying maturity estimates presented in alternative assessments at the North Sea Demersal Working Group and female maturity proportions applied to the whole-stock biomass to generate reference points at NAFO meetings. The salient point is that in none of these instances was the modification presented as the main assessment for advisory purposes (Marshall *et al.* 2003). The presentation concluded that the recent changes in the ICES advisory structure (with ACFM and ACE merging) should lead to greater opportunities and impetus for inclusion of biological process models and data.

2.2 Marshall: A summary of the recent meeting of the NAFO WG on Reproductive Potential

Summary

Activities of the NAFO WG on Reproductive Potential are highly relevant to this SG particularly with respect to ToR a. The third meeting of the NAFO WG was held at Woods Hole, USA during October 15–18 2003. The ToRs for this meeting were to:

ToR 1: Complete inventory of available data in standardized format on reproductive potential for fish stocks of the North Atlantic and Baltic Sea.

ToR 2: Explore the use of correlation analysis to estimate the reproductive potential of fish stocks having limited data availability.

ToR 3: Model the inter-annual and inter-stock variability in size-dependent fecundity for stocks having multi-year estimates.

ToR 4: Explore how the current use of biological reference points and medium-term projections can be adapted to include new information on reproductive potential.

ToR 5: Explore the consequences of fishery-induced changes in the timing and location of spawning to reproductive success.

ToR 6: Provide recommendations for the collection of required data in existing research surveys, sentinel fisheries and captive fish experiments that are required to improve annual estimates of reproductive potential for stocks varying in data availability.

ToR 7: Explore the effects of the environment on Stock Reproductive Potential and how these relate of ToRs 2, 3 and 4. Progress towards ToR 4 is included in the material presented in Section 4.5 of this SGGROMAT report. The NAFO WG is planning a fourth meeting, tentatively scheduled for October 2004.

Discussion

The work of this NAFO WG is directly relevant to that of SGGROMAT, with a substantial cross-over of ideas, methods and personnel. The SG therefore felt that it was essential that the conclusions of the NAFO WG be considered carefully in its own SG report.

2.3 Dobby: A summary of the recent meeting of the Study Group on Age-length Structured Assessment Models 2003

Summary

The Study Group on Age-length Structured Assessment Models (SGASAM) met for the first time in 2003 to:

a) investigate process model formulations, goodness of fit and model sensitivity in age-length based models;
b) evaluate the usefulness of such tools in specific case studies on stocks with differing life-histories, data availability and quality, such as sprat, anglerfish, blue whiting, *Nephrops*, Greenland halibut and deepwater species.

A number of presentations given under TOR a) illustrated the sensitivity of model results to particular modelled processes such as growth and maturation. However, it was evident that it is not just the choice of process model that is important, but also how the model is implemented numerically (e.g., choice of discretization interval in length) and how the modelled variables are related to the observed data (e.g., level of aggregation and weighting factors).

From the case studies presented under TOR b) it was clear that incorporation of length-structure into stock assessment model is considered to be important in situations when either:

- it is thought that such models are a better representation of biological and fishery related processes, or
- problems with age determination do not permit the use of age-structured models, or make such models less reliable

Further investigation into the effects of incorporating alternative process-based models for growth, maturity and fecundity into existing population model frameworks is envisaged at the next meeting of this study group. Such work is likely to draw on the results of some of the process model studies carried out under the auspices of SGGROMAT.

Discussion

This presentation was felt by the SG to be very informative because there are potential cross-linkages between the activities of the two SG. Few of the models are currently being used in the provision of advice and it would appear that work is required to justify length-based approaches and models to ICES. The simulation models being developed (e.g., Gadget) are relevant to SGGROMAT. It was noted that simulation models are essential for testing assessment methods because it is the only case where the "true" underlying dynamics will be known. The SGASAM is well-positioned to undertake this type of work, which is also being done under the remit of the ICES Working Group on Methods of Fish Stock Assessment (WGMG).

2.4 Brander: Proposal for a Research Training Network on Fisheries Induced Adaptive Change

Summary

Fish species were genetically adapted to the environmental conditions experienced prior to intensive exploitation and the current, drastically altered conditions are unlikely to have left their life-history patterns unaffected. In other words, fishing not only decreases the abundance of fish, but also may also change their genetic composition. This evolutionary dimension of fisheries has been overlooked, but fisheries scientists and managers are awakening to the risks posed by unmanaged fisheries-induced evolution.

Recent scientific studies provide evidence that fisheries-induced evolution is occurring:

- Many fish stocks mature earlier today than they used to only a few decades ago.
- There is evidence that changes in maturation are evolutionary responses, and not only phenotypic plasticity.
- It has been demonstrated experimentally that size-selective fishing can cause genetic reductions in growth that result in a decline of harvestable biomass.
- Earlier maturation may have adverse implications for the reproductive potential of fish stocks, not only because large females produce more offspring per unit of body weight than smaller ones, but also because the size of females and the survivability of their offspring tend to be positively correlated.

The European Research Training Network on *Fisheries-induced Adaptive Changes in Exploited Stocks* (FishACE) aims to (i) develop and apply novel methodological tools for investigating empirical data, (ii) construct theoretical models which complement and build on the empirical analyses and (iii) design and evaluate management options. The network will provide advance training for a new generation of scientists to tackle the challenges posed by evolutionary changes in exploited resources.

Discussion

This is an important issue and there is a substantial and growing scientific literature on the topic. It was noted that it is important to view evolutionary change in relation to other factors that affect life history traits such as maturation, including food availability and growth rates. Not all heavily exploited stocks show earlier maturation. Indeed, later maturation has been noted in some cases. Therefore, it is not a universally applicable process.

2.5 Brander: Comments on causes and consequences of variability in cod growth

Summary

This working paper is reproduced in full in Appendix A.

Discussion

This working paper incited a familiar debate, namely whether or not it was possible to develop environmentally-based models that were useful for medium-term stock projections. One approach to projecting future states would be to provide risks associated with different scenarios (semi-quantitative). The current assumption is that the future will be like the past but often this is a bad assumption. Some types of information or approaches are more amenable to inclusion in management, e.g., female-only SSB, whereas, environmental information is not. Some models are currently available, e.g., circulation models. However, there is the possibility that the advice will be made worse rather than better by including this.

2.6 Witthames: Reproduction and stock evaluation for Recovery (RASER)

Summary

This presentation describes a research partnership between IMR (Norway), CEFAS (England), AZTI (Basque Country, Spain) and CSIC (Spain) which has been funded (Oct 2002-Sept 2005) under EU Framework 5. The purpose of the project is to study the reproductive biology of cod and hake (see http://raser.iMrno/ for details). In the first stage the project will focus on fecundity method development to reduce costs and increase the precision in estimating realised fecundity. Experiments in this part of the project aim to develop realised fecundity models that include condition indices and previous spawning investment. The rates of post ovulatory and atretic follicle degradation will be determined for use in estimating previous spawning history, and to develop models to estimate production rates of atretic follicles (and thus realised fecundity). These improved methods will be used to assess the reproductive potential of each species across their latitudinal range in 2003 and 2004 in relation to the observed variation in environmental conditions including fishing pressure. During the synopsis of the project the consequences for current assessment and advice procedures will be evaluated using a simulation framework that includes mathematical representations of both the 'real' system (the fish population and fleet dynamics) and the 'observed' system (data collected, assessment model used and reference points used to guide management strategies and their implementation, see Figure 1.1). Because the framework includes both the 'real' and 'observed' systems, it is an ideal tool to investigate the robustness of assessment models and management strategies to uncertainty in biological processes.

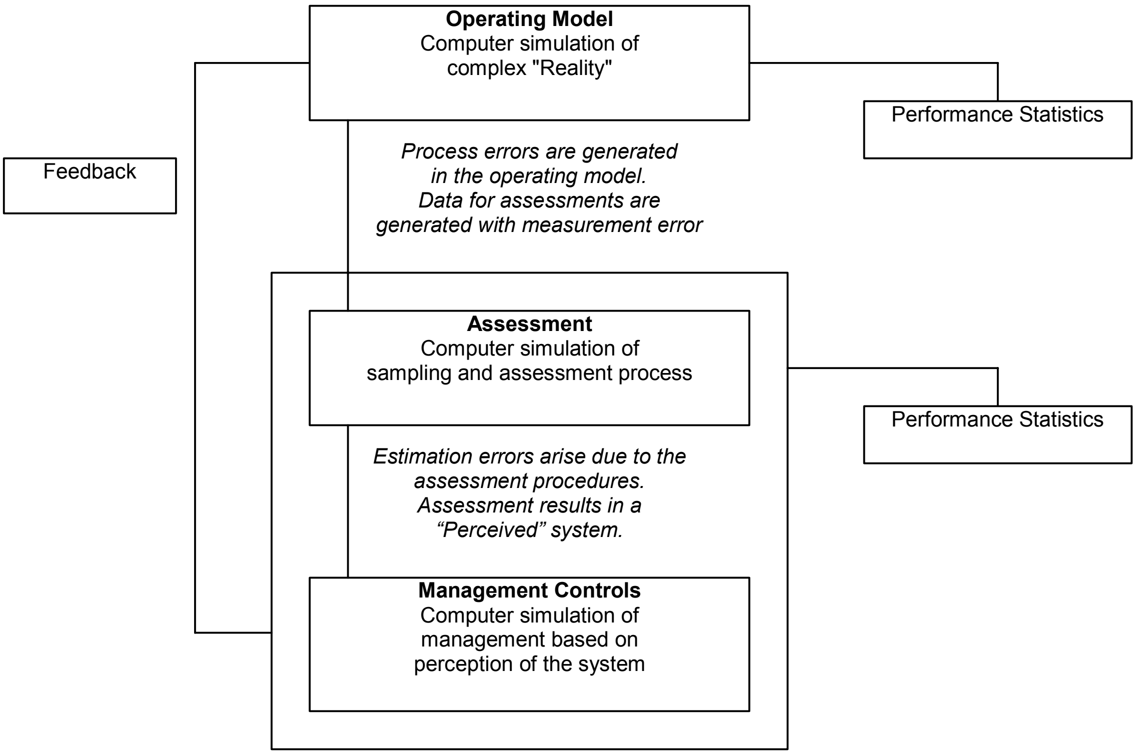

Figure 1.1. Simulation model structure for RASER.

In the last part of the project the new experimentally proven data on atretic and post ovulatory follicle duration will be applied to previous ICES egg production based assessments to determine the potential bias in the assessment of realised fecundity and SSB.

Discussion

This project will yield very novel information, e.g., effect of temperature on realised fecundity. This is potentially important in assessing the impacts of climate change. Over the longer term, the results will also lead to new insights into the magnitude of variability in reproductive potential.

2.7 Casini and Cardinale: Effect of length distribution and sex ratio on length-weight based condition indices: the sprat (*Sprattus sprattus*) in Skagerrak and Kattegat as case study

Summary

Fulton's K and relative condition (Kn) are two morphometric indices commonly used to investigate the well being of an individual fish or population using data on fish length and weight. However, the assumptions behind their application (isometric and constant growth) are not always fulfilled. In this study we tested these assumptions for Skagerrak and Kattegat sprat in November and February by testing for possible differences in condition between females and males and among length classes. The results indicated that condition was a dome-shaped function of fish length for both areas and periods. Moreover, condition was higher for adult females than males in Skagerrak and Kattegat and in both periods. This difference was higher in Kattegat than Skagerrak. The change between November and February was stronger in Skagerrak than Kattegat probably due to a different inter-annual cycle of production in the sea and different spawning time of the two populations. However, further studies should be performed in order to assess whether the observed sex-, length- and locality-related differences in condition are a response to actual different energy reserves of the fish or an artefact due to individual fish different shapes (fish growing along different dimensions).

Discussion

In response to SG queries: the survey programme is planned to be ongoing. The condition indices reported in the presentation are not currently used in assessments principally because there is no analytic sprat assessment for the North Sea. It would appear that sprat growth is driven more by year effects than by cohort effects.

2.8 Blanchard: Modelling spatial distribution of juvenile cod in the North Sea using optimal temperature for growth and ideal free distribution

Summary

Density dependent habitat selection by fish stocks has been shown to have serious implications for fisheries management and for population recovery (Swain and Sinclair, 1994, Macall, 1990, Winters and Wheeler 1994). Several marine fish stocks have been shown to exhibit density dependent habitat selection (DDHS) whereas opposing evidence has been shown for other stocks (Marshall and Frank 1994; Marshall and Frank 1995; Swain and Wade 1993; Swain and Sinclair 1994; Myers and Stokes 1989; Macall 1990). According to ideal free distribution (IFD) theory, as population size decreases, the population contracts into areas of highest habitat suitability. Our objective was to compare survey (English Groundfish Survey) observations with theoretical predictions based on IFD theory and optimal temperature for growth during the month of August for each year (1977–2002). Bottom temperature data collected during the surveys each August were spatially interpolated over the North Sea and values at the centre of each ICES rectangle were used to calculate optimal temperature for growth rate (based on the equation given in Björnsson and Steinarsson, 2002) on an ICES rectangle basis for each year. Growth rate defined by this equation was scaled between 0 and 1 and was used as an index of habitat suitability for age-1 cod. Overall, the relationship between area occupied by the stock versus total abundance as predicted by the model was very similar to that shown by the survey data. Consistent patterns between the survey and theoretical model were also evident across years. As predicted by the model, in years when stock size was low, the highest catch densities from surveys appeared to be located in regions that corresponded to optimal temperatures and when population size was high, catch densities were spread out across the entire area. Although this simple theoretical approach should be considered as a first step in a more complex analysis, its potential applicability to fisheries management was discussed.

Discussion

The SG viewed this as potentially important work, given current moves towards spatial management schemes in the North Sea and elsewhere. These aspects are discussed further in Section 5.3 below. The author was encouraged to extend this work through the consideration of different drivers of habitat suitability and the inclusion of discard estimates, and to submit a discussion paper to this year's meeting of the ICES Working Group for the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK).

2.9 Kienzle: Density dependent growth of North Sea cod

Summary

Density-dependent growth of North Sea (NS) cod was investigated at the scale of the whole area comparing growth, modelled with Von Bertalanffy function, with the estimation of the total biomass at sea given by the stock assessment model XSA. Average lengths at age taken from the IBTS database for every cohort born between 1980 and 1990 were fitted using the weighted non-linear least square method. The goodness of the fit criterion indicate that VB model for growth provide a good description of the growth of the cohort. Therefore, the integral of the function between age 1 and 7 was used as a index of growth. The negative correlation (-0.48) between the growth index and the estimate of the stock biomass at the start of the cohort's hatch year indicate possible density dependent growth in NS cod.

Discussion

Parallels were drawn between this analysis and that presented by Needle (see Section 2.10 below): the notes on the discussion for that paper are equally applicable here. The SG debated the relative merits of weighted and unweighted regression for fitting growth curves (see Section 4.1 below).

2.10 Needle: Initial thoughts about ALK modelling for fish stock forecasts

Summary

Age and length data have nearly always been collected in historic fish sampling programmes, whether based on markets, discard observer trips, or research-vessel surveys, and these data form the basis of all current fish-stock data collection schemes. Consequently, age-length keys (ALKs) are widely available for many stocks and for long periods of time: other data relevant to process modelling (maturity, weight, condition, fecundity) are less common. Tracing the development of ALKs through the lifetime of a particular cohort (year-class) is one potential way to analyse the mean growth of that cohort, in terms of changes in growth characteristics. Furthermore, this information could then be used to determine the key drivers of changes in growth. Therefore, this approach should be useful in establishing appropriate biological process models on the basis of large amounts of data.

Initial collaborative work between FRS and the University of Aberdeen has begun in this field, using datasets on ALKs maintained at FRS and derived from market-sampling, discard-sampling and research-vessel survey programmes. A two-stage approach has been used to try to distinguish between cohort- and year-effects on growth. Firstly, a scatter plot of length against age is created with one point for each observation. A modified von Bertalanffy curve $L_a = L_1 + (L_2 - L_1)\frac{1 - \exp[-k(a - a_1)]}{1 - \exp[-k(a_2 - a_1)]}$ is fit to the scatter plot using non-linear least-squares regression, so that ages with few observations are automatically downweighted in the model fit. This curve encapsulates any cohort effect on growth. Secondly, normal distributions are fit to the ALK at each age. The vector of parameters of all these distributions for a given year can then be compared with those from other years to evaluate the presence of year effects on growth. Ultimately, year, cohort and age effects would be estimated simultaneously within an ANOVA formulation (similarly to a separable model of fishing mortality). Repeating these two steps for each cohort and each year builds up time-series of parameters (three von Bertalanffy parameters, two distribution parameters). These can then be analysed to look for patterns that could be used in forecasting, such as time-series structure or demonstrable links with biotic or abiotic driving factors.

It is intended that this work will be continued in Aberdeen, through informal links and possible studentships. Issues to be addressed include: model-fitting methods (Bayesian approaches, maximum-likelihood estimation, Kalman filters, or mixed-effect models), effects of length-stratified sampling, determination of biotic and abiotic drivers of change, and ground-truthing with real and generated datasets.

Discussion

A detailed discussion followed on the myriad of problems related to using data from length-stratified sampling programs to model age-based indices (see also Sections 2.10 and 2.12). It is possible to correct the data by raising it by the length frequency. Assuming a normal distribution for length at a given age was considered to be generally inappropriate, as there is often a large degree of skewness and the nature of the skew changes with age. It is also important to consider the level of data aggregation.

2.11 Marshall: Deriving condition indices from standard fisheries databases and evaluating their sensitivity to variation in stored energy reserves

Summary

Variability in condition can affect the yield, mortality, reproductive potential and (possibly) recruitment of fish stocks. To evaluate cross-stock differences in condition it would be advantageous to develop stock-level condition indices from standardized fisheries databases on weight and length. This study describes a method for estimating such an index for Northeast Arctic cod in the situation where individual-level observations on length and weight are not accessible for the aggregate stock. For each year in a 56-year time series (1946–2001) pseudo-observations of weight and length were generated by combining the Norwegian and Russian values for weight-at-age that are provided annually to the assessment working group with estimates of length-at-age that were derived from the same databases. A weight/length relationship was fit to the pseudo-observations for each year and used to predict stock weight-at-length (SW_l) for a range of standard lengths (30 to 120 cm). Over the full time period this index of fish girth was found to be uncorrelated with both the liver condition index that is available from Russian sources and the abundance of the preferred prey of Northeast Arctic cod (Barents Sea capelin). This suggests that, at the stock level, condition indices that represent the girth of cod of a given length are not indicative of the magnitude of stored energy reserves. Over the full time period, small cod (30–50 cm) showed no directional trend in SW_l, whereas larger cod (≥ 70 cm) showed a strong tendency towards substantially larger values. Length and girth were statistically uncorrelated which suggests that using weight as the sole metric of body size potentially confounds the temporal dynamics in these two distinct metrics of body size.

Discussion

The SG noted that it would be extremely valuable for assessment WGs to report routinely age-length keys in their reports, or at least in accompanying data files. The observation was made that liver weights are often not available, and in any case may not be an appropriate indicator of condition for many species. Thus the indicator used would have to be tailored to the species being analysed. A key requirement would appear to be the ability to project weight-length relationships into the future.

2.12 Beare: FRS Age length maturity data

Summary

The characteristics and quality of age, length and maturity data collected by Fisheries Research Services, Aberdeen were discussed. The point was made that such data are length-stratified samples. If these are used for calculating mean length at age directly, then for subsequent use in growth modelling the length sample will be biased. Simple arithmetic methods, of the kind used routinely, for the application of age-length-maturity-sex keys to haddock in the North Sea were then described, followed by a description of a more statistical method. This method involves fitting a series of generalised linear models to the age-length key data. The parameters from such models can then be used to calculate length distributions given age. The model has the advantage of being able to interpolate missing lengths sensibly. The output enables surprisingly detailed appraisals of how population age/length structure changes with time. For example, the haddock population currently consists of mostly age-4 fish.

Discussion

Currently all fish of certain species (particularly cod) are being aged due to a decrease in the number collected. Intra-annual and spatial variation can be large relative to interannual variation. These databases also lend themselves to analyses of sex ratios and maturity. There is a need to standardise the approach to quantifying summary data in a sensible and computationally straightforward way. This problem has been in existence since the inception of surveys and it is frustrating there is no global approach.

2.13 Holmes: Application of Kalman filters to recruitment modelling

Summary

The application of the Kalman filter technique to time series of the SSB-recruitment relationship of three gadoid stocks is presented. The advantage of Kalman filters should be that they can explicitly differentiate between systematic trends in the relationship and random sources of variation independent of any trend.

The recruitment to the stocks was assumed to represented by the Ricker model $R = aS\exp(-bS)$. The density-dependent parameter b was considered to be fixed with respect to time, but the density-independent a parameter was assumed to be subject to a stochastic process. In the interests of parsimony, and following results from a simulation study conducted by Peterman *et al*. (2000), this stochastic process was taken as a random walk.

In one stock (North Sea whiting), applying the filter resulted in a trend of falling a values – indicating a trend of falling stock productivity – that began at the start of the 1980s. This trend is shown to have finished, but not reversed, in the most recent years of the time series. The result is in agreement with the received wisdom on the stock. For two other stocks (North Sea cod and haddock) the Kalman filter showed little variation in a with time and general agreement with a standard, fixed parameter regression model with respect to both parameter values. For these stocks, variations in recruitment unexplained by changes in SSB are ascribed to noise by the Kalman filter.

The presentation discussed how the Kalman filter technique could be applied more generally to the issue of growth, maturation and condition. In particular the possibility was considered of using growth data from different cohorts of a species. If the parameters of growth models fitted to succeeding cohorts are treated as a time series, a Kalman-filter analysis can be conducted to identify any systematic trends. It was considered that in the case of some stocks (haddock, for example), recruitment is not well explained by any of the current recruitment models and this mitigates against the use of any technique trying to identify trends in the models parameter values.

Discussion

The SG pointed out that the original study on which this work was based (Peterman *et al*. 2000) used data from a salmonid stock. The time-series Kalman-filter approach is more likely to be successful when applied to a salmonid stock of this type, in which population numbers show a natural periodicity, than when used for a gadoid stock. In order to evaluate fully this approach, sensitivity analyses would need to be carried out on the influence of the starting values for the Kalman filter, the index of reproductive potential used, and the degree of depensation permitted by the underlying stock-recruitment model. The SG also recommended that two or three parameters be varied at once, rather than just one. There is a natural application of a Kalman filter time-series recruitment model to forecasting, as the estimated state-space can simply be rolled forward in time under a minimal set of assumptions. Therefore, the author was encouraged to submit a discussion paper to this year's meeting of the ICES Working Group for the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK).

2.14 Tomkiewicz: Availability of data and information for estimating reproductive potential of North Atlantic fish stocks

Summary

The NAFO Working Group on Reproductive Potential (WGRP) originally designed tables and developed guidelines to tabulate in a standardised fashion the availability of data and information relevant for estimating stock reproductive potential and stock-recruitment relationships. Relevant information included population parameters such as stock size and composition, fish age, weight, maturity, sex ratios, fecundity and condition, as well as existing studies on e.g., potential and realised egg production, critical life stages and environmental influences on stock-recruitment relationships. Information was gathered for 53 North Atlantic stocks and these tables have been published in the NAFO Scientific Council Studies (Morgan *et al*. 2003) (http://www.nafo.int/publications/frames/puFrSC37.html).

A sub-set of these tables was used to explore and review the availability of information and existing data on reproductive potential for demersal Northwest Atlantic fish stocks (Tomkiewicz *et al.* 2003) (http://www.nafo.ca/publications/Frames/PuFrJour.html). For these 42 stocks, information about stock size and age composition as well as, data on sex ratio, maturity and weight at length or age were often available for two or more decades, whereas fecundity data were scarce. Only a few studies of parental and environmental influences on egg and larval survival and stock recruitment analyses existed, but realised egg production data from ichthyoplankton surveys were common. Data and information on gadoids and flatfishes generally were comprehensive, while both quantity and quality of data on redfish and grenadiers often had constraints. For most stocks, data were available for considering natural variability in more parameters, which could be used to improve spawning stock estimates (e.g., female-only spawning stock) or to develop alternative indices, whereas establishment of egg production time series or more advanced SRP indices requires fecundity studies.

The SGGROMAT ToR a subgroup and the NAFO WGRP are collaborating in the establishment of an inventory of tabulated information including more than 200 commercially-important pelagic and demersal fish stocks in the North Atlantic. During 2003, the ToR a subgroup updated the existing table design to consider e.g., relevant SRP parameters and methodologies for indeterminate spawners, revised the guidelines and elaborated a new example (North Sea autumn spawning herring, ICES Sub-div. IV, IIIA and VIID). Stock and area coverage has been appraised and contributors for the majority of stocks have been identified. Tables have been filled in for a number of stocks, while others are in progress. For some stocks, further efforts are required to appoint contributors. Also a need for circulating tables in progress among institutes involved with the same stock has been identified particularly in the ICES fishing areas. The completion of tables for the selected stocks is expected to continue in 2004 and to be finalised by a review of the data availability during 2005.

Discussion

The work of the ToR a) subgroup has been instrumental in the collation of meta-data tables which will be of great value to the ICES community, and the SG was anxious that a focus be found for the continuation of this endeavour (see relevant recommendations in Section 8). It would be an interesting exercise in the future to compare the availability of data with its use in the assessment and advisory process.

2.15 Schön: Changes in growth and maturity of Irish Sea gadoids

Summary

This preliminary study compared the changes in growth and maturity of the heavily exploited cod and whiting stocks and the expanding haddock stock in the Irish Sea. Data were used from the spring DARD groundfish surveys (conducted since the early 1990s) that coincide with the spawning period of the gadoid stocks.

The sex ratio of cod was independent of length and exhibited regional variation. The sex ratios of whiting and haddock were found to be independent of age but not length and no consistent spatial patterns were apparent.

GLM analysis on the effects of year, region, age, and length on the probability of being mature showed that maturity is determined differently for male and female whiting and haddock, but no differentiation by sex was observed for cod. Maturity was found to be predominantly a function of age in cod. Length was the main factor determining maturity in female whiting and male haddock, while age was the main factor in male whiting and female haddock. Interannual variation in the proportion mature was confined to one age group (mostly age 2) while other age groups were either fully mature or fully immature. Over 99% of 3-year-olds were mature in all three species.

Significant interannual differences in length-at-age were observed for all three species. Temporal trends in mean length-at-age were not observed in cod and whiting. A distinct decreasing trend, however, was observed for 2 and 3-year-old haddock associated with the overall increase in biomass over the survey period. The relative size of cod in different year classes is largely determined by the growth rate in the first year of life. Similarly, growth rates of haddock do differ between year classes, but do not appear related to the strength of the year classes. Rather, preliminary results indicate a strong negative association between growth in the first year of life and the total abundance (all ages) of haddock in the stock. Evidence for density dependence in growth was not conclusive.

Discussion

The SG noted that growth models have already been used in the assessment of Irish Sea haddock, and also that the fit of any model to data must be evaluated before it can be used in this context.

2.16 Morgan: The effect of changes in spawner characteristics on the perceived productivity of three cod (*Gadus morhua*) stocks

Summary

This study examined the impact on indices of reproductive potential (RP) of changes in spawner characteristics for three cod stocks in the northwest Atlantic. Variation in maturity at age, sex ratio and potential egg production (through changes in length at age) was substantial for northern cod (NAFO Div. 2J3KL), southern Grand Bank cod (3NO) and southern Newfoundland cod (3Ps). Estimates of RP were produced by sequentially incorporating estimates of proportion mature at age, sex ratio at age and potential egg production. This sequential approach allowed a comparison between indices to determine the effect of incorporation of these variables on trends in indices of RP. The estimates of RP produced by each method were broadly similar but there were important differences.

The impact of these differences on perceptions of stock productivity was examined using relative recruitment rate (RPS) and spawner stock produced per recruit (SPR). Trends in the standardized RPS for each index showed the same overall patterns within each population. However, depending on the index there was a different impression of the relative productivity of a population across time. Calculation of SPR under an assumption of F=0 gives insight into the potential productivity of a stock under no exploitation. The trends in these metrics were quite different using different methods to calculate RP. When SPR was calculated incorporating the actual F estimated in the SPA, the standardized SPR was similar using all methods, except when F is low.

An illustrative B_{lim} was calculated for each stock using each index of RP. Although any of the RP indices can be used in the setting of reference points the current status of a stock relative to the reference point will vary depending on the index. There was no consistent relationship between indices of RP and perceived stock status (i.e., no one index always gives the highest or lowest result). Rather the ranking of stock status derived from the various indices depends on the current characteristics of the spawning stock, relative to that observed during the period used to construct B_{lim}.

Five year deterministic projections were carried out for each stock using each index of RP. These projections again show that different measures of RP will result in different perceptions of stock status relative to B_{lim}. This is the result both of the evolution of age structure during the projection period and the perceived productivity, both RPS and SPR. As with the setting of B_{lim} there is no consistency in the ranking of stock status using the different indices of RP.

This study clearly indicates that changes in spawner characteristics will produce different trends in indices of RP which will give different perceptions of stock productivity. Any index of RP can be used to set reference points and in stock projections but the different indices will give different perceptions of stock status relative to B_{lim}. This is the result of the particular age structure of the population and differences in perceived stock productivity (RPS and SPR).

Discussion

The utility of simulation approaches in evaluating the different measures of RP was discussed. Also, the analyses that were presented used estimates of potential egg production that were based on limited amount of fecundity data. The modelling approach used to hindcast fecundity would also influence the results.

3 AVAILABILITY OF BIOLOGICAL DATA FOR ICES STOCKS

3.1 Introduction

The aim of ToR a) is to identify available information and existing data, which can be applied to the estimation of stock reproductive potential (SRP) as well as aspects relevant to modelling growth. Unpublished as well as published data may be available for this purpose. These data are frequently not applied in stock assessments. By recording selected stock characteristics (e.g., weights, maturity, condition, fecundity etc.) and data sources in a systematic fashion, the potential for estimating total, realised or viable egg and larval production can be evaluated. An overview of existing data can also identify gaps in research and highlight areas where improved knowledge is needed for specific species, stocks or regions.

A similar task has been undertaken by the NAFO WG on Reproductive Potential (WGRP), which developed standardised tables and recorded the availability of data and information relevant for estimating stock reproductive potential (NAFO 2001). Relevant information was tabulated for 53 North Atlantic fish stocks and published in the NAFO Scientific Council Studies (Morgan *et al*. 2003). A review of the data availability for a sub-set of tables comprising 42 demersal stocks was published in the Journal of Northwest Atlantic Fishery Science (Tomkiewicz *et al*. 2003). The main results of the review are presented in Section 2.14.

The SGGROMAT ToR a subgroup is collaborating with the NAFO WGRP on extending the tabulated information to comprise many pelagic and demersal fish stocks important to the commercial fisheries in the North Atlantic. Intersessional activities performed by the ToR a subgroup include an update of existing tables to consider e.g., relevant SRP parameters and methodologies for indeterminate spawners, a revision of guidelines (Appendix B), the elaboration of a new example (Appendix C) and identification of stocks and contributors, and distribution of tables to distributors. The objective at the present SG meeting was to review the progress in completing tables and update the work plan and timetable for the remaining work that also includes a review of the general data availability for North Atlantic fish stocks.

3.2 Approach

The approach has been to produce an inventory of the availability and quality of data through a series of tables. These tabulate, in a standardised form, the availability of data and information relevant for estimating stock reproductive potential and stock-recruitment relationships. The tables are not designed to include actual data, but to list data and studies published in journals, reports etc. or unpublished data existing in national laboratories. The first table for each stock records on a yearly basis the presence/absence of data for each of nine parameters relevant to estimating stock potential egg production: stock size, stock composition, age, sex ratio, maturity, fecundity, weight, condition and egg/larval abundance. A second table indicates the origin, format and reliability of the recorded data and provides additional information about such things as atresia, spawning time, egg and larval viability. A third table references previous studies of stock reproductive potential and recruitment such as egg production, critical life stages and stock recruitment relationships. A fourth table lists the references of published data and studies or the name and address of contact persons in case of unpublished data. The final table lists the individuals who contributed to the completion of the tables.

The main work of ToR a has been conducted intersessionally via correspondence. Contributors that had been identified at the last meeting of the SG were contacted and requested to fill in the standardised tables and return them to the ToR a member responsible for the area. Attempts have been made to find contributors to fill in gaps and also to contact supporting contributors to fill in additional information if more institutes are involved in the fisheries and investigations of a particular stock.

ToR a has continued its collaboration with the NAFO WGRP. At the NAFO WGRP meeting held in Woods Hole, USA in October, 2003, discussions focused on finalizing a list of stocks for the Northwest Atlantic. Pelagic stocks and additional demersal stocks that had not been included in the previous tables were identified. The area was divided between waters adjacent to the USA and those adjacent to Canada, and area leaders were identified. In addition potential contributors of tables for each stock were identified. It was decided that the highly migratory nature of swordfish and tunas would make data sources extremely difficult to compile and these were not included. It was also decided to restrict the stocks considered in the Northwest Atlantic to the NAFO area, so that no USA stocks south of NAFO Subarea 6 would be considered.

3.3 Results

3.3.1 Revised tables and guidelines

The ToR a group completed as planned a revision of the tables and guidelines to fill in the tables that had been developed by the NAFO WGRP. This included also the elaboration of example tables for North Sea autumn spawning herring. The guidelines and the examples are presented in Appendix B and C. The main focus of the revision was to allow the incorporation of information relevant to indeterminate spawners. Secondly, the review of data availability for the Northwest Atlantic stocks identified a need for further specification of certain variables and studies. In addition, the help function of the tables was improved. The revised tables and guidelines were tested by group members before they were sent to contributors.

3.3.2 Identification of species, stocks and areas

A total of 153 stocks belonging to ICES, NAFO and Mediterranean fishing areas were identified during the SG meeting in 2002. However, some stocks have since been removed from this list, mainly due to lack of contributors, while other stocks relevant to the area have been added by area leaders or colleagues with area-specific knowledge. The updated list includes a total of 159 stocks (Table 3.3.1). These stocks include elasmobranch, gadoid, flatfish, some other demersal stocks and a variety of pelagic fish stocks. The work of gathering the available data will be carried out in collaboration with WGRP. In addition to these, the existing tables of the NAFO WGRP document the data availability for 53 stocks including 22 gadoid, 17 flatfish, 9 redfish, 4 pelagic and 1 other stock, for which 48 are from NAFO area and 5 from ICES area (Table 3.3.2). However, these tables need to be updated to the format of the new ones for the review in order to reflect the same level of information. The number of stocks available for the review of data availability thus will add up to 212 provided that all tables are filled in.

Table 3.3.1. New species, stocks and areas identified.

	Species	Scientific names	Stock	Area
1	Barndoor skate	*Dipturus laevis*	Northwest Atlantic	NAFO 5
2	Porbeagle shark	*Lamna nasus*	Northwest Atlantic	NAFO Subarea 3–6
3	Little skate	*Leucoraja erinacea*	Northwest Atlantic	NAFO 5–6
4	Winter skate	*Leucoraja ocellata*	Northwest Atlantic	NAFO 5–6
5	Smooth skate	*Malacoraja senta*	Northwest Atlantic	NAFO 5
6	Thorny Skate	*Raja radiata*	Northwest Atlantic	NAFO 3LNOPs
7	Thorny skate	*Raja radiata*	Northwest Atlantic	NAFO 5
8	Thorny skate	*Raja radiata*	West Greenland	NAFO SA 1
9	Spiny dogfish	*Squalus acanthias*	Northwest Atlantic	NAFO 5–6
10	Witch flounder	*Glyptocephalus cynoglossus*	Gulf of St. Lawrence	NAFO Div. 4RST
11	American plaice	*Hippoglossoides platessoides*	Eastern Scotian Shelf	NAFO 4VW
12	American plaice	*Hippoglossoides platessoides*	Southern Gulf of St. Lawrence	NAFO Div. 4T
13	American plaice	*Hippoglossoides platessoides*	West Greenland	NAFO SA 1
14	Atlantic halibut	*Hippoglossus hippoglossus*	Northwest Atlantic	NAFO 5
15	Atlantic halibut	*Hippoglossus hippoglossus*	Scotian shelf/southern Grand Bank	NAFO Div. 4VWX3NOPs

	Species	Scientific names	Stock	Area
16	Megrim	*Lepidorhombus sp.*	Northern Shelf	ICES Div. VI
17	Megrim	*Lepidorhombus sp.*	Southern Shelf Megrim	ICES Div. VIIb,c,e-k, VIIIa,b,d
18	Megrim	*Lepidorhombus sp.*	Southern Shelf Megrim	ICES Div. VIIIc, IXa
19	Yellowtail flounder	*Limanda ferruginea*	Southern Gulf of St. Lawrence	NAFO Div. 4T
20	Dab	*Limanda limanda*	Baltic dab	ICES SD 22–32
21	Flounder	*Platichtyus flesus*	Kattegat, Skagerrak flounder	ICES Div. IIIa
22	Flounder	*Platichtyus flesus*	Baltic flounder in SD 22	ICES SD 22
23	Flounder	*Platichtyus flesus*	Baltic flounder in 24–25	ICES SD 24–25
24	Flounder	*Platichtyus flesus*	Baltic flounder in SD 26	ICES SD 26
25	Flounder	*Platichtyus flesus*	Baltic flounder in SD 28	ICES SD 28
26	Flounder	*Platichtyus flesus*	Botnian Sea flounder	ICES SD 29–30
27	Flounder	*Platichtyus flesus*	Baltic flounder in SD 32	ICES SD 32
28	Winter flounder	*Pleuronectes americanus*	Southern Gulf of St. Lawrence	NAFO Div. 4T
29	Plaice	*Pleuronectes platessa*	Skagerrak, Kattegat plaice	ICES Div. IIIa
30	Plaice	*Pleuronectes platessa*	Irish Sea plaice	ICES Div. VIIa
31	Plaice	*Pleuronectes platessa*	English Channel (east)	ICES Div. VIId
32	Plaice	*Pleuronectes platessa*	Western Channel Plaice	ICES Div. VIIe
33	Plaice	*Pleuronectes platessa*	Celtic Sea Plaice	ICES Div. VIIf and g
34	Plaice	*Pleuronectes platessa*	South of Ireland Plaice	ICES Div. VIIh-k
35	Plaice	*Pleuronectes platessa*	Baltic plaice	ICES SD 22–32
36	Plaice	*Pleuronectes platessa*	North Sea plaice	ICES Subarea IV
37	Turbot	*Pstta maxima*	Skagerrak, Kattegat turbot	ICES Div. IIIa
38	Turbot	*Pstta maxima*	Baltic turbot	ICES SD 22–32
39	Greenland Halibut	*Reinhardtius hippoglossoides*	NEA	ICES Div. I-II
40	Greenland halibut	*Reinhardtius hippoglossoides*	Greenland	ICES V, XIV
41	Greenland halibut	*Reinhardtius hippoglossoides*	Greenland	NAFO 0+1
42	Greenland halibut	*Reinhardtius hippoglossoides*	Gulf of St. Lawrence	NAFO Div. 4RST
43	Common sole	*Solea solea*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
44	Sole	*Solea solea*	Skagerrak, Kattegat sole	ICES Div. IIIa
45	Sole	*Solea solea*	Irish Sea sole	ICES Div. VIIa
46	Sole	*Solea solea*	English Channel	ICES Div. VIId
47	Sole	*Solea solea*	Western Channel Sole	ICES Div. VIIe
48	Sole	*Solea solea*	Celtic Sea Sole	ICES Div. VIIf and g
49	Sole	*Solea solea*	South of Ireland	ICES Div. VIIh-k
50	Sole	*Solea solea*	North Sea sole	ICES Subarea IV
51	Sole	*Solea solea*	Bay of Biscay Sole	ICES VIII a and b
52	Fourspot flounder	*Hippoglossina oblonga*	Northwest Atlantic	NAFO 5–6
53	Windowpane flounder	*Scophthalmus aquosus*	Northwest Atlantic	NAFO 5–6
54	Cod	*Gadus morhua*	Norwegian Coastal Cod	ICES Div. I-II
55	Cod	*Gadus morhua*	Iceland	ICES Div. Va
56	Cod	*Gadus morhua*	West of Scotland	ICES Div. VIa
57	Cod	*Gadus morhua*	Celtic Sea Cod	ICES Div. VII e – k
58	Cod	*Gadus morhua*	Irish Sea cod	ICES Div. VIIa
59	Cod	*Gadus morhua*	Greenland	ICES Div. XIV +NAFO 1
60	Cod	*Gadus morhua*	Western Baltic cod	ICES SD 22–24
61	Cod	*Gadus morhua*	Sydney Bight	nafo div. 4vn, may-dec
62	Haddock	*Melanogrammus aeglefinus*	NEA Haddock	ICES Div. I-II
63	Haddock	*Melanogrammus aeglefinus*	Iceland	ICES Div. Va
64	Haddock	*Melanogrammus aeglefinus*	West of Scotland	ICES Div. VIa
65	Haddock	*Melanogrammus aeglefinus*	Rockall	ICES Div. VIb
66	Haddock	*Melanogrammus aeglefinus*	Irish Sea haddock	ICES Div. VIIa
67	Haddock	*Melanogrammus aeglefinus*	Grand Bank	NAFO Div. 3LNO
68	Whiting	*Merlangius merlangus*	West of Scotland	ICES Div. VIa
69	Whiting	*Merlangius merlangus*	Irish Sea whiting	ICES Div. VIIa

	Species	Scientific names	Stock	Area
70	Whiting	*Merlangius merlangus*	Southern shelf whiting	ICES Div. VIIe-k
71	Whiting	*Merlangius merlangus*	North Sea whiting	ICES Subarea IV, Div. VIId
72	Saithe	*Pollachius virens*	NEA Saithe	ICES Div. I-II
73	Saithe	*Pollachius virens*	Iceland	ICES Div. Va
74	Saithe	*Pollachius virens*	North Sea, West of Scotland, Rockall, and Skagerrak and Kattegat	ICES Subarea IV, VI and Div. IIIa
75	Norway pout	*Trisopterus esmarkii*	North Sea, Skagerrak and Kattegat	ICES Subarea IV, Div. IIIa
76	Poor cod	*Trisopterus minutus*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
77	Sand lance	*Ammodytes americanus*	Northwest Atlantic	NAFO 5–6
78	Sandeel	*Ammodytes tobianus*	North Sea	ICES Subarea IV
79	Spotted wolfish	*Anarhichas minor*	West Greenland	NAFO SA 1
80	Spotted wolffish	*Anarhichas minor*	Newfoundland	NAFO SA 2+3
81	Atlantic wolffish	*Anarhichas lupus*	Northwest Atlantic	NAFO 5
82	Atlantic wolffish	*Anarhichas lupus*	West Greenland	NAFO SA 1
83	Northern wolffish	*Anarhichas sp.*	Newfoundland	NAFO SA 2+3
84	Striped wolffish	*Anarhichas sp.*	Newfoundland	NAFO SA 2+3
85	Wolffishes	*Anarhichas spp.*	Scotian shelf/Georges Bank/Gulf of St. Lawrence	NAFO SA 4 + Div. 5YZe
86	Cusk	*Brosme brosme*	Northwest Atlantic	NAFO 5–6
87	Cusk	*Brosme brosme*	Georges Bank	NAFO Subareas 4 and 5
88	Lumpfish	*Cyclopterus lumpus*	Southern Newfoundland	NAFO Div. 3P
89	White seabream	*Diplodus sargus*	Gulf of Lions	GFCM 7
90	Anglerfish	*Lophius budegasa*	Southern Anglerfish	ICES Div. VIIb-k,
91	Anglerfish	*Lophius budegasa*	Southern Anglerfish	ICES Div. VIIIc, Ixa
92	Anglerfish	*Lophius piscatorius*	Southern Anglerfish	ICES Div. VIIb-k,
93	Anglerfish	*Lophius piscatorius*	Southern Anglerfish	ICES Div. VIIIc, Ixa
94	Anglerfish	*Lophius sp.*	Northern Shelf	ICES div.IV, VI IIIa
95	Monkfish	*Lophius sp.*	Northwest Atlantic	NAFO 5
96	Monkfish	*Lophius sp.*	Northwest Atlantic	NAFO 6
97	Monkfish	*Lophius sp.*	Grand Bank/Southern Newfoundland	NAFO Div. 3LNOPs
98	Monkfish	*Lophius sp.*	Scotian shelf/northwest Georges Bank	NAFO Div. 4VWX5Zc
99	Silver hake	*Merluccius bilinearis*	Northwest Atlantic (2 stocks)	NAFO 5YZe and NAFO 5Zw6
100	Silver Hake	*Merluccius bilinearis*	Scotian Shelf	NAFO Div. 4VWX
101	Hake	*Merluccius merluccius*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
102	Hake	*Merluccius merluccius*	Northern Hake	ICES Div. II-VIII
103	Hake	*Merluccius merluccius*	Southern Hake	ICES Div. VIIIc and IXa
104	Red mullet	*Mullus sp.*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
105	Striped red mullet	*Mullus sp.*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
106	Axillary seabream	*Pagellus acarne*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
107	Scup	*Stenotomus chrysops*	Northwest Atlantic	NAFO 5–6
108	Black sea bass	*Stereolepis gigas*	Northwest Atlantic	NAFO 5–6
109	Red hake	*Urophycis chuss*	Northwest Atlantic (2 stocks)	NAFO 5YZe and NAFO 5Zw6
110	White Hake	*Urophycis tenuis*	Southern Gulf of St. Lawrence	NAFO Div. 4T
111	White Hake	*Urophycis tenuis*	Grand Bank/St. Pierre Bank	NAFO Div. 3LNOPs
112	White Hake	*Urophycis tenuis*	Northwest Atlantic	NAFO Div. 4VWX5Z
113	Ocean pout	*Zoarces americanus*	Northwest Atlantic	NAFO 5–6
114	redfish	Redfish sp.	NEA (Sebastes mentella)	ICES Div. I-II
115	redfish	Redfish sp.	NEA (Sebastes marinus)	ICES Div. I-II
116	Golden redfish	Redfish sp.	Dermersal fishery (Iceland, Faroes, Greenland waters)	ICES Div. V, VI, XII, XIV
117	Deep-water redfish	Redfish sp.	Dermersal fishery (Iceland, Faroes, Greenland waters)	ICES Div. V, XIV
118	Deep water redfish	Redfish sp.	Irminger pelagic fishery	ICES Div. XII, Va, XIV
119	Redfish spp.	Redfish spp.	Unit 1	NAFO Div. 4RST- 3P4Vn(Jan-May)
120	Redfish spp.	Redfish spp.	West Greenland	NAFO SA 1

	Species	Scientific names	Stock	Area
121	Herring	*Clupea harengus*	Norwegian spring spawning	ICES Div. I, II, V
122	Herring	*Clupea harengus*	Spring spawning herring 22–24, IIIa (Rügen herring)	ICES Div. IIIa, SD 22–24
123	Herring	*Clupea harengus*	North Sea autumn spawners	ICES Div. IV, VIId, IIIa
124	Herring	*Clupea harengus*	Icelandic summer spawning	ICES Div. Va
125	Herring	*Clupea harengus*	West of Scotland, autumn spawners	ICES Div. VIa (N)
126	Herring	*Clupea harengus*	Ireland autumn-spring spawners	ICES Div. VIa (S), VIIb,c
127	Herring	*Clupea harengus*	Irish Sea, autumn spawners	ICES Div. VIIa (N)
128	Herring	*Clupea harengus*	Celtic Sea and VIIj	ICES Div. VIIg, VIIj
129	Herring	*Clupea harengus*	Central Baltic herring	ICES SD 25–29, 32 (minus Gulf of Riga)
130	Herring	*Clupea harengus*	Gulf of Riga herring	ICES SD 28 (Part)
131	Herring	*Clupea harengus*	Botnian Sea herring	ICES SD 30
132	Herring	*Clupea harengus*	Botnian Bay herring	ICES SD 31
133	Herring	*Clupea harengus*	East and Southeast Newfoundland	NAFO Div. 3KLPs
134	Herring	*Clupea harengus*	West Coast of Newfoundland	NAFO Div. 4R
135	Herring	*Clupea harengus*	Quebec north shore	NAFO Div. 4S
136	Herring	*Clupea harengus*	Southern Gulf of St. Lawrence	NAFO Div. 4T
137	Herring	*Clupea harengus*	SW Nova Scotia/Bay of Fundy	NAFO Div. 4VWX
138	Anchovy	*Engraulis encrasicholus*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
139	Anchovy	*Engraulis encrasicholus*	Gulf of Lions	GFCM 7
140	Anchovy	*Engraulis encrasicholus*	Iberian Region (east)	ICES Subarea IXa
141	Anchovy	*Engraulis encrasicholus*	Bay of Biscay, Iberian Region (north)	ICES Subarea VIII
142	Capelin	*Mallotus villosus*	Barents Sea	ICES Div. I
143	Capelin	*Mallotus villosus*	Iceland-East Greenland-Jan Mayen area	ICES Div. V, XIV, Div IIa
144	Capelin	*Mallotus villosus*	Northeast NF Shelf/northern Grand Bank	NAFO 2J3KL
145	Capelin	*Mallotus villosus*	Southern Grand Bank	NAFO Div. 3NO
146	Capelin	*Mallotus villosus*	Gulf of St. Lawrence	NAFO Div. 4RST
147	Blue whiting	*Micromesistius poutassou*	Iberian Mediterranean	GFCM 1, 2, 3, 5, 6
148	Blue whiting	*Micromesistius poutassou*	"Atlantic"	ICES Div. I-IX, XII, XIV
149	Sardine	*Sardina pilchardus*	Gulf of Lions	GFCM 7
150	Sardine	*Sardina pilchardus*	Iberian Region	ICES Div. VIIIc and IXa
151	Mackerel	*Scomber scombrus*	Northeast Atlantic	ICES Subareas IV, Vb, VI, VII, VIII
152	Brill	*Scophthalmus rhombus*	Baltic brill	ICES SD 22–32
153	Sprat	*Sprattus sprattus*	Kattegat-Skagerrak sprat	ICES Div. IIIa
154	Sprat	*Sprattus sprattus*	North Sea	ICES Div. IV
155	Sprat	*Sprattus sprattus*	Baltic sprat	ICES SD 22–32
156	Horse mackerel	*Trachurus trachurus*	Western horse mackerel	ICES Div. Iia, IIIa (western part), Iva, Vb, VIa, VIIa-c, VIIe-k and VIIIabde
157	Horse mackerel	*Trachurus trachurus*	North Sea horse Mackerel	ICES Div. IIIa (excluding western Skagerrak) Ivbc, VIId
158	Horse mackerel	*Trachurus trachurus*	Southern Horse Mackerel (Iberian Region)	ICES Div. VIIIc and IXa
159	Butterfish		Northwest Atlantic	NAFO 5–6

Table 3.3.2. Completed species and stocks for the northwest Atlantic (see www.nafo.int)

	Species group	Species	Scientific names	Stock	Area
1	Flatfish	American plaice	*Hippoglossoides platessoides*	Flemish Cap	NAFO 3M
2	Flatfish	American plaice	*Hippoglossoides platessoides*	Labrador and Northeast Newfoundland	NAFO 2+3K
3	Flatfish	American plaice	*Hippoglossoides platessoides*	Grand Bank	NAFO 3LNO
4	Flatfish	American plaice	*Hippoglossoides platessoides*	Newfoundland South Coast	NAFO 3Ps
5	Flatfish	American plaice	*Hippoglossoides platessoides*	Gulf of Maine/mid Atlantic	NAFO 5+6
6	Flatfish	Greenland halibut	*Reinhardtius hippoglossoides*	Labrador – Eastern Newfoundland	NAFO 2+3KLMNO
7	Flatfish	Witch flounder	*Glyptocephalus cynoglossus*	Labrador and Northeast Newfoundland	NAFO 2J3KL
8	Flatfish	Witch flounder	*Glyptocephalus cynoglossus*	Southern Grand Bank	NAFO 3NO
9	Flatfish	Witch flounder	*Glyptocephalus cynoglossus*	Newfoundland South Coast	NAFO 3Ps
10	Flatfish	Witch flounder	*Glyptocephalus cynoglossus*	Gulf of Maine/Georges Bank	NAFO 5+6
11	Flatfish	Yellowtail flounder	*Limanda ferruginea*	Grand Bank	NAFO 3LNO
12	Flatfish	Yellowtail flounder	*Limanda ferruginea*	Georges Bank	NAFO 5Ze
13	Flatfish	Yellowtail flounder	*Limanda ferruginea*	Southern New England	NAFO 5Zw
14	Flatfish	Yellowtail flounder	*Limanda ferruginea*	Cape Cod	US State areas 514
15	Flatfish	Winter flounder	*Pseudopleuronectes americanus*	Georges Bank	NAFO 5Z
16	Flatfish	Winter flounder	*Pseudopleuronectes americanus*	Coastal-south New England/mid-Atlantic	NAFO 5+6
17	Flatfish	Summer flounder	*Paralichthys dentatus*	Mid Atlantic- Georges Bank	NAFO 5+6
18	Gadoid	Cod	*Gadus morhua*	Flemish Cap	NAFO 3M
19	Gadoid	Cod	*Gadus morhua*	Northern	NAFO 2J3KL
20	Gadoid	Cod	*Gadus morhua*	Southern Grand Bank	NAFO 3NO
21	Gadoid	Cod	*Gadus morhua*	Newfoundland South Coast	NAFO 3Ps
22	Gadoid	Cod	*Gadus morhua*	Northern Gulf of St. Lawrence	NAFO 4RS3Pn
23	Gadoid	Cod	*Gadus morhua*	Southern Gulf of St. Lawrence	NAFO 4TVn (J-A)
24	Gadoid	Cod	*Gadus morhua*	Eastern Scotian Shelf	NAFO 4VSW
25	Gadoid	Cod	*Gadus morhua*	Bay of Fundy/Western Scotian Shelf	NAFO 4X
26	Gadoid	Cod	*Gadus morhua*	Georges Bank	NAFO 5Z + 6
27	Gadoid	Cod	*Gadus morhua*	Gulf of Maine	NAFO 5Y
28	Gadoid	Cod	*Gadus morhua*	North Sea	ICES IV
29	Gadoid	Cod	*Gadus morhua*	Baltic	ICES SD 25–32
30	Gadoid	Cod	*Gadus morhua*	Northeast Arctic	ICES 1+2
31	Gadoid	Cod	*Gadus morhua*	Icelandic	ICES Va
32	Gadoid	Haddock	*Melanogrammus aeglefinus*	Eastern Scotian Shelf	NAFO 4TVW
33	Gadoid	Haddock	*Melanogrammus aeglefinus*	Bay of Fundy/Western Scotian Shelf	NAFO 4X
34	Gadoid	Haddock	*Melanogrammus aeglefinus*	Georges Bank	NAFO 5Z + 6
35	Gadoid	Haddock	*Melanogrammus aeglefinus*	North Sea	ICES IV
36	Gadoid	Pollock	*Pollachius virens*	Scotian Shelf/Bay Fundy/Georges Bank	NAFO 4ZWX + 5ZC
37	Gadoid	White hake	*Urophycis tenuis*	Gulf of Maine / Georges Bank	NAFO 5+6
38	Gadoid	Roughhead grenadier	*Macrourus berglax*	Labrador-eastern Newfoundland	NAFO 2+3
39	Gadoid	Roundnose grenadier	*Coryphaenoides rupestris*	Labrador – eastern Newfoundland	NAFO 2+3
40	Redfish	Redfish	*Sebastes fasciatus*	Flemish Cap	NAFO 3M
41	Redfish	Redfish	*Sebastes mentella*	Flemish Cap	NAFO 3M
42	Redfish	Redfish	*Sebastes sp.*	Flemish Cap	NAFO 3M
43	Redfish	Redfish	*Sebastes sp.*	Labrador-Northeast Newfoundland	NAFO 2+3K
44	Redfish	Redfish	*Sebastes sp.*	Eastern Grand Bank	NAFO 3LN
45	Redfish	Redfish	*Sebastes sp.*	Southwestern Grand Bank	NAFO 3O

	Species group	Species	Scientific names	Stock	Area
46	Redfish	Redfish	*Sebastes sp.*	Unit 2	NAFO 3Ps4VsW-3Pn4Vn (J-D)
47	Redfish	Redfish	*Sebastes sp.*	Gulf of Maine/Georges Bank	NAFO 5
48	Other	Herring	*Clupea harengus*	Mid Atlantic/Gulf Maine/Georges Bank	NAFO 5+6
49	Other	Mackerel	*Somber scombrus*	Northwest Atlantic	NAFO 2–6
50	Other	Bluefish	*Pomatomus saltatrix*	Mid-Atlantic/Gulf of Maine	NAFO 5+6
51	Other	Striped Bass	*Morone saxatlis*	Coastal/mid-Atlantic/Gulf of Maine	NAFO 5+6
52	Other	Thorny skate	*Raja radiata*	Flemish Cap	NAFO 3M

3.3.3 Progress on filling in tables

The tables, guidelines and example were distributed to potential contributors following their revision and testing by SG members. Generally, co-operation from contributors outside the SG has been good. The joint ICES/NAFO nature of the process has increased its acceptability. Substantial progress on filling in the tables of available information has been made (Table 3.3.3). At present, tables for 173 stocks are in progress or have been completed. For the remaining 39 stocks further efforts will be made to appoint contributors. A need for circulating tables in progress among colleagues working with a particular stock has been identified. This is particularly relevant in ICES fishing areas where several institutes or national laboratories often have monitoring and research programs addressing the same stock.

Table 3.3.3. Progress of tabulating available data and information for stocks identified under ToR a.

Areas:	Stocks identified	Contributor lacking	Tables in progress	Establ. tables in circulation	NAFO version exist	Updated/ completed
Northeast Atlantic and Baltic Sea (ICES areas)						
Baltic Sea, Kattegat and Skagerrak	24		12	11	1	
Barents Sea, Celtic Sea, English Channel	16	2	10	3	1	
Iberian Sea, Southern Shelf	14	2	12			
Iceland and Greenland	12	9	2		1	
Irish Sea	9	9				
North Sea	15	1	4	6	2	2
West of Scotland, Rockall	5	4	1			
Northwest Atlantic (NAFO areas)						
USA + Canadian areas	106	12	27	1	48	18
Western Mediterranean Sea (GFCM areas)	11		7			4
Total	212	39	75	21	53	24

3.4 Workplan and time table

The appointment of contributors and completion of tables for the identified stocks will continue in 2004. ToR a members, in collaboration with the NAFO WGRP, will work through correspondence. The overlap in membership between the two groups is fortunate as the ToR a activities will outlast SGGROMAT and progress will be reported at the planned NAFO WGRP meeting in October 2004. However, it is recommended that the resulting inventory of data and information for estimating reproductive potential be placed on the ICES website and maintained as a resource for use in stock assessments and research (see Section 8.4). The data inventory will be advantageous in assisting assessment WGs in incorporating biological data and processes affecting reproductive potential into applied models in order to improve assessments and forecasts. Making it a part of the *Inventory of Data* which is maintained on the ICES website would help to achieve this aim. A continuation of the data-source collation work and regular updates of the inventory is suggested to be integrated in the ToR of the recommended follow-up ICES Working Group (WGISAB: Working Group on Incorporation in Stock Assessments of Biological Models and Data; see Section 8.1).

The completed tables will form the basis of a review of the availability of data and information for estimating the reproductive potential of North Atlantic fish stocks. Data analysis and planning of a subsequent paper for peer-reviewed publication will be initiated in relation to the NAFO WGRP meeting in October 2004 and will be completed during 2005.

Activity	Deliverables	Year	Month
Circulate and complete tables for identified stocks	Data inventory for ca. 200 stocks in ICES, NAFO and Mediterranean fishing areas	2004	10
Analyse the information available as recorded in the tables	Relevant tables analysed	2005	6
Review quantity and quality of available data	Manuscript reviewing the availability and application of information		10

4 PROCESS-BASED MODELLING OF GROWTH, CONDITION, MATURITY, AND FECUNDITY

4.1 Application of age/length keys to growth modelling

4.1.1 Data availability

There exist a multitude of data sources, both at government laboratories and elsewhere, that are under-utilised in current assessments and advice. The datasets available at the FRS Marine Laboratory in Aberdeen, to take just one example, include results of market-sampling, research-vessel survey and discard-sampling programmes. Data from the ongoing IBTS programme are also held in many institutes, and of course at ICES headquarters. These datasets are detailed sources, with many species, often a fine spatial and temporal resolution, long time-series, and good biological data. Importantly for the modelling of growth, they all contain extensive collections of age-length keys.

The SG concluded that the aggregation and application of age-length keys was problematic, and that the information that could be extracted depended on the survey design and the ultimate output required. Detailed spatial information on age-length structures is available for many European stocks but is under-utilised in research and especially in stock assessments. The SG also noted that it is possible to calculate error associated with age-length keys, and to calculate the precision of indices derived from survey data. Currently numbers at age data enter assessment models without any error being calculated. It would be an improvement to incorporate such errors into current statistical stock assessment models such as ICA, ADAPT, SURBA and TSA.

4.1.2 Data processing, aggregation and manipulation

It was stressed that age-length keys are *length-stratified samples*, which is important to note when using them to calculate mean lengths and henceforth quantifying growth rates. The keys provide information on the distribution of ages given length, but the age-length keys cannot be used independently to calculate mean length because they are length-biased samples. In other words the tails of the length frequency distribution are over-represented (Figure 4.1), while the central area is under-represented. In order, therefore, to calculate an unbiased average length-at-age measurement, the age length key should first be multiplied by the overall length-frequency distribution.

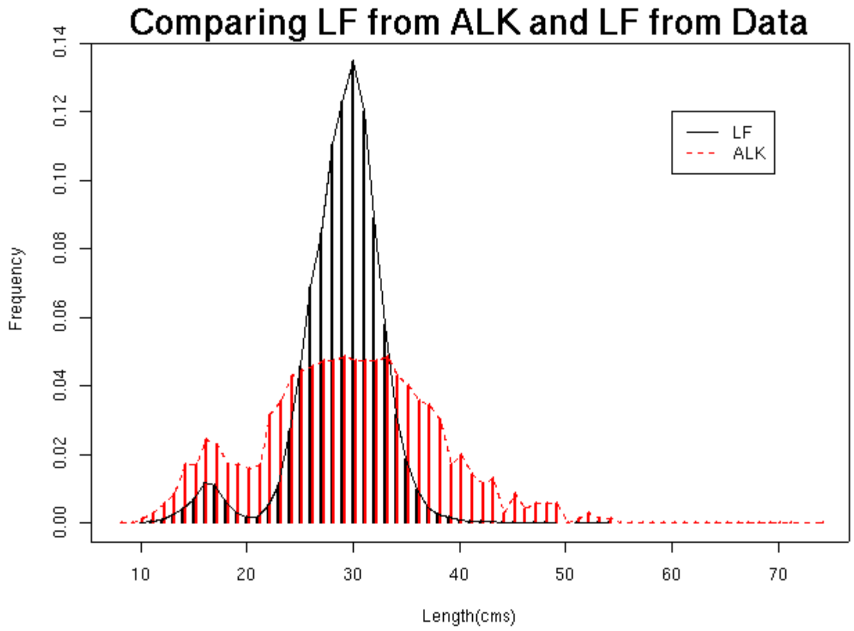

Figure 4.1 Comparison between a length-frequency distribution (LF; black) and the corresponding age-length key (ALK; red).

The SG also considered whether length-stratified sampling was actually sensible, and whether or not we should be sampling ages, sexes and states of sexual maturity randomly within a catch. On reflection the group concluded that the *status quo* of length-stratified sampling was probably the most appropriate sampling strategy. If a completely random design was adopted it would be possible to miss important components of the population, for example very large fish might not be aged or sexed at all.

All of the work presented at the meeting involved data on stocks from two main sources (commercial landings records, and research–vessel surveys). However, in order to model growth of the entire stock, it would be desirable to make use of all other data sources available, i.e., by combining research vessel, market sampling, and discard data. The obstacle to creating seamless syntheses of disparate data sources is that age-length key data and length frequency data may all be biased in different ways. Commercial data tend to have disproportionate numbers of older fish while the reverse is true for research vessel data and discards. Further investigation is required in this area. We also need to investigate whether commercial age-length keys are affected seriously by misreporting. If they are not, then the commercial data can be combined with age-length data from other sources. At the moment we do not have a solution but the problem is potentially serious. It was also noted that for some species that have been overfished and are now comparatively rare (e.g., cod), then age and sex tend to be measured for every fish caught. The quality of information available, therefore, is different for different species.

The SG noted that modelling average length in order to assess growth rate is less desirable, certainly for stock assessment purposes, than examining weights, although this depends on whether the process of interest is driven by weights or by lengths. For example, maturation is often driven by lengths rather than weights. Often, weight data are unavailable or not measured empirically.

4.1.3 Modelling issues

4.1.3.1 Growth curves

The models to describe growth presented during the meeting were either the Von Bertalanffy growth function (VBGF) or models derived from it, which give generally satisfactory descriptions of the average length-at-age. The fit of the function to the data is performed by various non-linear methods, either weighted or un-weighted. Kienzle (Section 2.9) took the mean and variance of the distribution and fitted the model to the mean length at age weighted by the variance, assuming that the length-at-age data were normally distributed. The advantage is that this generates a goodness-of-fit criterion, which is important for determining whether the parameter estimates are reliable, and whether the assumptions about the shape of the growth curve are supported by observation. Needle (Section 2.10), on the other hand, fitted modified VBGF models to all the length observations at each age. The advantage is that you are assuming less about the distribution of lengths given age. The disadvantage is that the method does not generate an obvious goodness-of-fit criterion, although bootstrapping could provide empirical estimates of uncertainty. Neither technique allows for uncertainty in fish ageing, but it is possible to take this into account and this should be done in the future.

If a VBGF is fitted to individual cohorts then the output is clearly dominated by the cohort effects. For some stocks (e.g., herring) this is not necessarily appropriate. In this case the year effect should be modelled in preference.

4.1.3.2 Discussion of potential covariates

Unfortunately, few presentations were made on any external effects on growth rate. Density dependent effects on growth were described in two studies. In the first study (Section 2.9), a density effect was indicated in North Sea cod, with a negative correlation between the biomass of the entire stock and growth, which might be expected due to intra-specific competition. Conversely, in the Irish Sea Schön (Section 2.14) found only weak evidence for density dependence in the haddock population.

We observed that the case for density dependence can depend on the relative abundance of the species in question. Cod, for example, are unlikely to provide a good case study for density dependent effects on growth because of the reduced state of the stock. The group also discussed the problems relating to separating and quantifying the effects of different variables using the observational data available. Temperature, stratification, food availability etc. are likely to be correlated with the overall stock size (density) and the effect of stock density on growth rate is therefore difficult to isolate from other factors.

4.1.3.3 Comparing parameters

At the moment workers are all fitting non-linear models (von-Bertalanffy) to individual subsets (cohorts) of the data. This, then, presents the problem of comparing the parameters from the models in order to see how growth rates might change between years/areas/stocks etc. There is a problem in comparing the model parameters between years because they are all correlated. Instead of trying to examine the individual parameters, Kienzle opted to calculate the integral under each of the growth curves, which provides a unique index of growth for each cohort. The group discussed the possibility that model parameters could be plotted multi-dimensionally and examined visually in order to see whether clear groups/patterns were likely to emerge. Alternatively, it is possible to fit growth models using several different methods that attempt to account for any time-series structure in the variation of growth parameters from cohort to cohort. There are two families of such models. The first incorporates time-series effects during the parameter-estimation process: examples are mixed-effects models (Pinheiro and Bates 2000), in which one underlying growth model is estimated, along with the extent to which the observed growth for each cohort deviates from it; and Kalman filter time-series estimation of parameters (see Section 5.2). The second fits growth models in the standard way, and then attempts to characterise any time-series structure in the estimated parameters. Examples of these approaches include dynamic factor analysis (Dynamic Factor Analysis; Zuur *et al.* 2003), an analysis technique used to find common trends (factors) between time-series, and vector autoregressive moving-average (VARMA) time-series modelling (see, for example, Needle 2000).

4.1.4 Conclusion

A key objective for the SG was to find ways to incorporate growth models into the stock assessment for projection of population dynamics in the future, with a time scale of 10 years being suggested as a starting point. This work is at a very early stage, but the analyses and suggestions presented here are promising. Growth modelling that is customised for incorporation into stock assessments and projections remains speculative at present, but progress in the future can reasonably be expected.

4.2 Maturity

The number of mature individuals in a population is determined by the processes of maturation and mortality. The dynamic nature of both these processes necessitates their inclusion in the description of stock dynamics. Most of the emphasis in stock assessment has, however, been on the importance of mortality, whereas maturation has only been poorly represented in stock assessments. For example, fixed (time invariant) maturity ogives or knife-edge are still commonly used.

The mechanistic understanding of how the maturity of a population is determined is relevant to stock projections, process-based stock dynamic models and understanding the past (ICES 2003). In fishery management, the inclusion of the dynamics of maturity within the stock assessment process can have direct implications to our perception of the stock and consequently induce changes in management strategies.

4.2.1 Approaches to describing maturity

Approaches to describing maturity have mostly been based on easily measured parameters such as length and age, where the dynamics in maturity are determined by mortality with respect to age and by growth with respect to length.

4.2.1.1 Probabilistic reaction norm approach

The probabilistic extension of the deterministic reaction norm concept (Heino *et al*. 2002) concentrates on the maturation process, i.e., the probability of becoming mature as opposed to the probability of being mature. Age and length are used to describe maturation tendency. The approach has been successfully applied to fish stocks, e.g., Georges Bank and Gulf of Maine cod stocks (Barot *et al*. 2002), North Sea plaice (Grift *et al*. 2002) and Northeast Arctic cod (Heino *et al*. 2002). These studies showed that the prediction of maturity based on age and length works reasonably well, but stressed that a considerable stochastic element is not considered.

ICES (2003) suggested that reaction norms, being independent of changes in growth and survival, might be used to project maturity ogives. The reaction norm approach, however, requires very specific data types and is thus not applicable to all stocks. The application to stocks characterised by a narrow age structure and the variability in maturation being restricted to a single age group, e.g., Irish Sea gadoids (Schön *et al*. WD), is also questionable.

4.2.1.2 Maturity ogive approach

The maturity ogive approach, which concentrates on the proportion being mature rather than the proportion that became mature, is more commonly used. Similarly to the reaction norm approach, ogives are mostly based on length and age (e.g., length (L_{50}) and age (A_{50}) at which 50% of individuals are mature). Maturity ogives are influenced by factors such as changes in relative mortality among immature and mature individuals, size of incoming cohort, growth, and temperature. Although some evidence exists of the influence of such factors, e.g., density dependency and temperature (e.g., Morgan and Colbourne 1999), it is not clearly identifiable for all stocks. For example, no density dependent effect has been found on the variability in maturity of Irish Sea haddock (Schön *et al*. WD).

4.2.2 Projection of maturity

The proportion of mature individuals in a population is highly variable, even in stocks where the event of becoming mature is restricted to one particular age group (Schön *et al*. WD). To date, variability in maturity has proven to be very difficult to predict, with very few predictor variables being identified. Factors that contribute to the variability in maturity in fish populations include physiological factors, such as length, age and growth rate; ecological factors, such as food availability and density-dependency; and, oceanographic factors, such as temperature. Critical periods for the onset for maturity have been proposed for some species of fish, when the reduction of food availability just before or immediately after the spawning period proved to be critical (Burton 1994). Nevertheless, even if determinants could be identified, these would mostly prove to be stock or species- and/or stock-specific.

Changes in growth trajectories integrate all environmental factors that affect growth into length or weight-at-age, which serves as a proxy of conditions favourable for both growth and reproduction. The attainment of a certain size or age might not trigger maturity (Policansky 1983), but the relationships between the variability in maturity and biological or environmental factors are more probably a proxy for changes in another parameter, such as growth, rather than directly affecting maturity.

Maturity ogives have been related to a number of variables, such as age, length, condition, catch weight at age, and liver weight. Therefore, in terms of prediction, it would be a more realistic approach to project another parameter and then relate it back to such established relationships, rather than trying to predict changes in maturity.

The importance of including the dynamics of maturity into stock assessment might prove to be most valuable in terms of redefining reference points. This has been demonstrated for Baltic cod, where a previously unconvincing stock and recruitment relationship what turned into a significant relationship by substituting constant maturity with a dynamic maturity model (Köster *et al*. 2003).

A number of issues have been highlighted that should be taken into account when estimating maturity:

- It is particularly important to base maturity estimates on representative samples when a spatial segregation is evident between immature and mature fish during the spawning season, or when temporal differences in maturity is evident. The Irish Sea cod stock is an example of spatial structuring in maturity (Armstrong *et al*. 2004).
- It is also important that maturity estimates are based on separated sexes, particularly for species that shows sexual dimorphism in growth. In this regard, consideration should be given to the main effects that affects the probability of an individual being mature. Age and length proved to be the main factors affecting the probability of being mature in Irish Sea gadoids, but changed between species and sex (Table 4.1). It is particularly important to separate estimates of maturity by sex if female only spawner biomass is to be used in stock assessments in the future (see Section 4.5.1).

Table 4.1 Results of GLM analyses on the main effects on the probability of being mature for Irish Sea gadoids. From Schön *et al*. WD.

	Male		Female	
Species	Main effects	Deviance	Main effects	Deviance
Cod	Age	931.4	Age	1840.2
Whiting	Length	1977.6	Age	4882.6
Haddock	Age	1376	Length	1703.8

- It is important to acknowledge that maturity ogives cannot be calculated for all stocks, particularly for stocks where the variability in maturation is restricted to a specific age. Armstrong *et al*. (2004) provide such an example for Irish Sea cod, where all the variability in maturity is for two-year-olds. By forcing a maturity ogives on such data, the calculated L_{50} would be an indication of the mid length of age two cod, rather than the length at which 50% of individuals is mature.
- Consideration needs to be given to the occurrence and magnitude of skipped maturity. In some stocks this might prove to be significant, in which case methods should be developed to incorporate it in maturity estimation and the description of maturity dynamics.
- There is still a need for more studies to identify possible factors that directly influence changes in maturity, since it remains important to understand the causal mechanism behind the maturation process.
- Time-varying estimates of maturity are available for most fish stocks and should be incorporated into assessments. There is, however, a need to test the sensitivity of stock projections to the inclusion of such information.

4.2.3 Future considerations

The SG agreed that maturity projection could be improved by modelling the dynamics of maturity on cohorts rather than year. The maturity of the current cohort could be projected by using information from the previous cohorts, with the projection of maturity within the current cohort being increasingly weighted towards data specifically related to that cohort as it becomes available.

4.3 Fecundity

To utilise alternative estimates of reproductive potential in the context of stock projections, a method needs to be established for generating short- and medium-term projections of total egg production. In the first SGGROMAT report (ICES 2003) a recommendation was made to explore the potential of condition indices as explanatory variables for fecundity in a range of stocks. The key examples discussed in the first report were concerned with potential fecundity, that is, the number of vitellogenic oocytes in the pre-spawning ovary. However, in order to predict egg production we need to focus on realised fecundity, which accounts for atretic losses of oocytes throughout the spawning season (Kjesbu *et al*., 1991; Ma *et al*. 1998). Therefore, in this section we consider what factors provide useful predictors both for potential fecundity and also for down regulation of fecundity through atresia occurring during the spawning process. Quantifying reproductive potential at both the individual and stock-levels is currently the subject of the NAFO WGRP. As a result of this increased knowledge about the sources and magnitude of variability in reproductive potential the S/R relationship of several stocks are being re-evaluated using alternative indices of reproductive potential (Marshall *et al*. 1998; Köster *et al*. 2001; Oeberst and Bleil 2003). However these models do not take into account factors like viability of released eggs. Consequently, there may be a need to identify factors such as egg size and fish size in predicting viability.

Figure 4.2 provides a general case to summarise the maternal regulation of realised fecundity that should be considered in fecundity assessment and predictive models for all species with a deterministic type spawning strategy (Kjesbu *et al* 2003, Murua *et al.* in press).

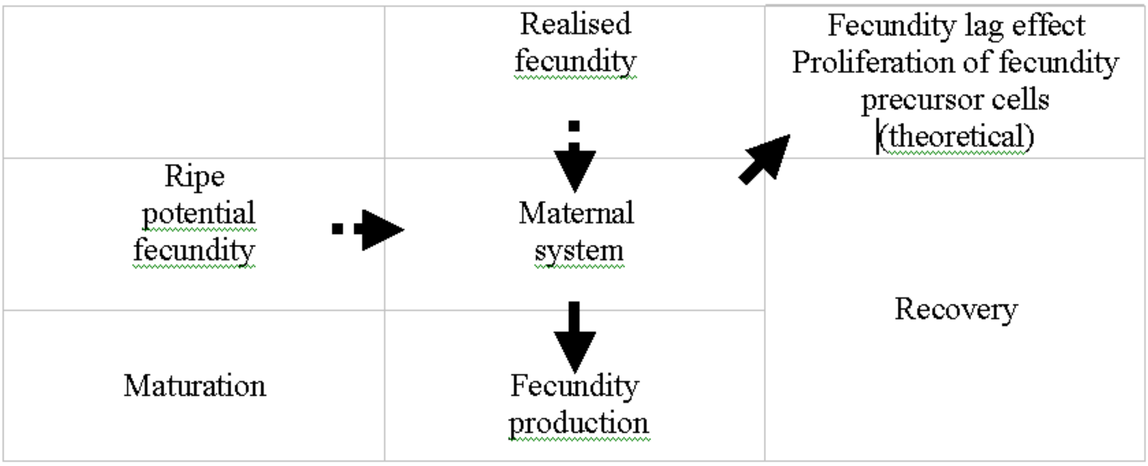

Figure 4.2. Maternal regulation of fecundity. Solid arrows indicate maternal regulation of fecundity from precursor cells (previtellogenic follicles). Dashed arrows indicate down regulation of vitellogenic follicles (potential fecundity) by follicular atresia (resorption of potential eggs into the maternal system).

Examples for this spawning strategy include plaice, sole, cod, haddock and herring. In such species the additional production of vitellogenic oocytes does not take place during the spawning season and the realised fecundity is produced from the standing stock of oocytes present prior to spawning. Fecundity should be determined late in the maturation cycle just prior to spawning to minimise loss of fecundity (Kurita *et al*. 2003). Several experiments using captive cod either recently completed or being carried out in RASER (see Section 2.6) will provide data to develop realised fecundity models including all facets of fecundity regulation that will be applicable to species with deterministic spawning strategy. It should be possible to refine the application of indices such as liver or whole body condition to determine population fecundity

4.3.1 Potential fecundity

Fish size is the most important factor influencing potential fecundity. Whilst length is the measure most generally used weight has been found to explain a higher proportion of the variation in some cases (Kjesbu *et al* 1998, McIntyre and Hutchings 2003). The accumulation of energetic resources in adult fish will be highly important for the enhancement of reproductive output. Since food intake affects the amount of energy available for allocation into gonads, instantaneous indices of energy reserves may also explain some of the residual variation around potential fecundity – size relationships. Examples of such indices include whole body condition indices and relative liver weight (see Section 4.4).

The most relevant index of energy available will depend on the main mode of lipid storage in the fish. Changes in the metabolic activity and chemical composition of different tissues could relate to the transformation and transport of the different biochemical molecules necessary for the development of the ovary (Shatunovsky *et al* 1996). The developing oocytes accumulate some fatty elements (e.g., yolk and oil globules) which are derived from dietary lipids and lipid mobilised from body reserves (Wiegand 1996). As such, the quantity and quality of eggs produced may be related to the total lipid composition in the body. Lipid reserves in gadoids are primarily stored in the liver: in some pelagic fish like herring and anchovy lipid tissues form in the muscle, while viscera and mesenteric fat is a major reserve in perciforms like horse mackerel and sea bass. In cod the energy content of liver increases exponentially in relation to the increase in the lipid accumulation (Lambert and Dutil 1997). As such, liver index in gadoids could be a useful measurement for prediction of fecundity (Marshall *et al*. 1999)

Seasonal variation in feeding and ovarian development could also affect the strength of relationships between these indices of energy reserves and fecundity. Ovarian development occurring during a period of partial or complete fasting could lead to stronger relationships between condition, energy reserves, and potential fecundity than one for a period of feeding. In the first case, energy invested in egg production will come from energy reserves accumulated during periods of abundant food supply while in the second case; energy invested in egg production will be obtained directly from feeding.

The potential of instantaneous condition indices in fecundity prediction is well-illustrated from studies of cod stocks. In Icelandic (Marteinsdottir and Begg, 2002), Northeast Arctic (Kjesbu *et al*., 1998; Marshall *et al*., 1998; ICES 2003) and Gulf of St. Lawrence cod (Lambert and Dutil 2000) body condition in addition to length or weight has been shown to be significantly related to potential fecundity. In contrast, condition factor has a minor effect on potential fecundity--length relationships in Baltic cod (Kraus *et al.* 2000). The potential for a hepatosomatic index to explain the residual variation in the fecundity--length relationship of a gadoid has been demonstrated by Blanchard *et al.* (2003) for Eastern Scotian Shelf haddock. Using the same statistical approach, data collected on North Sea haddock (P. Wright, unpubl. data) have been analysed for comparison and presented in Figure 4.3. This comparison indicates that fecundity for a given length is relatively higher in the North Sea and that HSI explains little of the residual variation. So for example, a change in HSI from 1.5 to 4.5% in a 60 cm female resulted in only a 20% increase in fecundity in North Sea haddock compared to over a 300 % increase in Eastern Scotian Shelf haddock. This example, together with the Baltic cod study (Kraus *et al*., 2000), illustrates that the utility of instantaneous measures of condition to predict fecundity variation needs to be tested for each new stock of interest. Recent experiments at IMR (Norway), and in process under the RASER project (see Section 2.6), should provide data to validate the use of condition indices to predict realised fecundity.

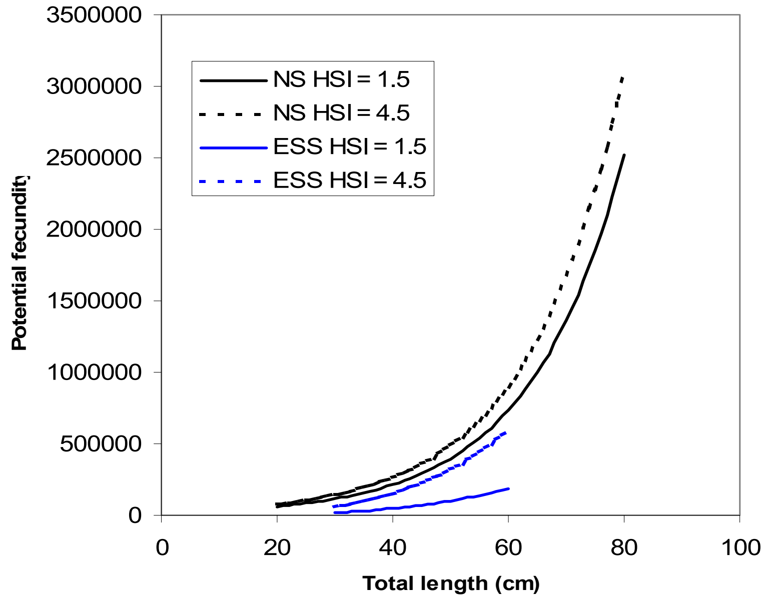

Figure 4.3. Expected effect of two levels of hepatosomatic index on length-specific based on multiple regression models for Eastern Scotian Shelf haddock (ESS; Blanchard *et al.* 2003) and North Sea haddock (NS; P. Wright unpubl. data)

4.3.2 Atresia

Ovarian atresia seems mainly to be initiated under low nutritional condition prior to spawning (Kjesbu *et al*., 1998; Witthames *et al*., 2000), implying that atresia is a regulating factor between the energy resource accumulation during the feeding period prior to spawning and the number of oocytes likely to complete maturation successfully during spawning. There is good evidence that on some occasions and in some species (Atlantic mackerel (Greer Walker *et al.* 1994), sole (Witthames and Greer Walker 1995), cod (Hardardottir *et al.,* 2003)) potential fecundity does not closely approximate to realised fecundity, due to high levels of atresia during the spawning season. For example, in a recent study of Icelandic cod, atresia was prevalent in 42% of pre-spawning females with an average intensity of 11% (Hardardottir *et al*., 2003). When these values are translated into atretic losses over the spawning season they suggest that such losses may have significant effects in egg production. In contrast the average prevalence and intensity of atresia was found to be only 9% and 5.5% in North Sea haddock (P. Wright, unpubl data). These values suggest that atretic losses are insignificant to egg production in this stock, and hence potential fecundity may give a good indication of realised fecundity. Whilst a model has been developed to estimate the down regulation of potential fecundity by atresia from an integration of the standing stocks of atretic follicles (Horwood 1993), this has not been tested in an experimental situation. The two parameters (spawning duration and atretic stage duration) used to correct fecundity from standing stocks of atretic follicles have not been verified in experiment for example considering effects of temperature or stage in spawning (see Section 2.6).

There are few examples of predictive relationships for atresia. The effect of size on atresia is not consistent between studies. Experimental work on herring suggested that atresia is negatively related to size (Ma *et al*., 1998). Sole collected from the English Channel showed a strong age effect on the prevalence of atresia. In the youngest maturing females (3 group) a high prevalence of atresia was found where the leading vitellogenic oocytes were poorly developed (Ramsay and Witthames 1996). Fish 5 years and older all contained larger vitellogenic oocytes in the leading oocyte cohort and the prevalence of atresia was much lower. However, studies in Icelandic cod (Hardardottir *et al*., 2003) and North Sea haddock (P. Wright, unpubl. data) have found no relationship with size. Higher intensities of ovarian atresia are seen prior to spawning in females with low HSI (Rideout *et al.*, 2000). Intensities of post-spawning atresia in herring (Oskarsson *et al*., 2002) and Icelandic cod (Hardardottir *et al* 2003) exhibit a weak negative exponential relationship with condition factor (see Figure 4.4).

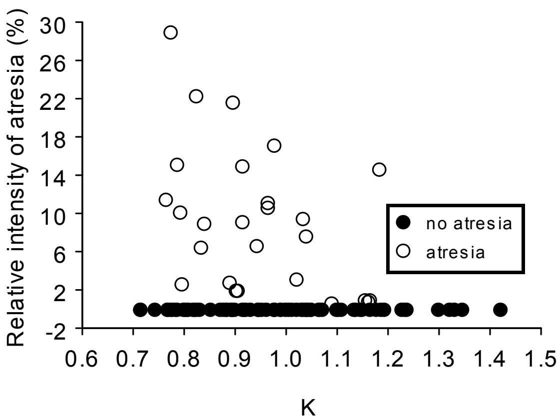

Figure 4.4. Relationship between relative intensity of ovarian atresia (*Ia*) and Fulton condition factor in Icelandic cod (from Hardardottir *et al* 2003).

4.3.3 Viable egg production

Assuming an individual female decides to initiate oocyte development and spawning, total energy reserves can modify the total number of viable eggs produced in that spawning season in several ways. Fish age and condition has been shown to have a significant effect on egg quality and/or size (Kjørsvik and Lönning 1983; Kjørsvik *et al*. 1984, 1990; Knutsen and Tilseth 1985; Solemdal *et al*. 1992, Marteinsdottir and Steinarsson 1998). This provides further support for the inclusion of condition in predictions of reproductive potential and also the demographics of the stock.

Kjørsvik *et al*. (1990) pointed out, that variable egg quality is one of the major factors limiting the successful production of fish fry. It influences the year-classes-strength of wild stocks because poor egg quality reduces the survival potential of the hatched larvae (Chambers 1997). Solemdal *et al*. (1992, 1993) showed that egg diameter, as well as dry weight, are strongly influenced by maternal factors. According to Chambers (1997) the maternal effect on eggs is markedly different for several different marine species; the contribution of females to the total phenotypic variance of the egg diameter ranges from 35% for Atlantic cod in a captive broodstock to 71% in wild capelin. Kjesbu (1998) and Solemdal *et al*. (1992) described significant negative correlations between the stage of spawning and the proportion of fertilized eggs. Kjørsvik and Lönning (1983) defined groups as *normal* or *poor*, depending on egg diameter, and stated that besides other characteristics of normal eggs, a low variability of the egg diameter is correlated with high fertilisation rate. Solemdal *et al*. (1993), Schopka (1971), Hislop *et al*. (1987) and Hislop (1988) showed that highest fertilisation rates can be observed if the egg diameter is in the optimal size range.

The present approach has considered how a proxy of energy reserves (condition) and previous spawning output could be used in a predictive model to assess population fecundity. In a similar way growth, maturity and condition have also been considered separately to develop process models within SGGROMAT. However these processes are all linked in the life cycle of a species and could be used in a holistic approach to predict reproductive potential in relation to stock composition. Figure 4.5 indicates how somatic and reproductive investment change in the life cycle of plaice in the Irish Sea. Somatic allocation is diverted increasingly to reproductive investment until reproductive effort consumes all surplus energy. The two plaice stocks followed different cycles of growth and reproductive investment with sustained lower somatic growth in areas of high population density (western Irish Sea) and an earlier switch to reproductive investment at low stock density in the east. Unfortunately separate region estimates of fishing mortality (*F*) and natural mortality (*M*) are not currently available, but they could possibly explain why the populations followed very different growth trajectories.

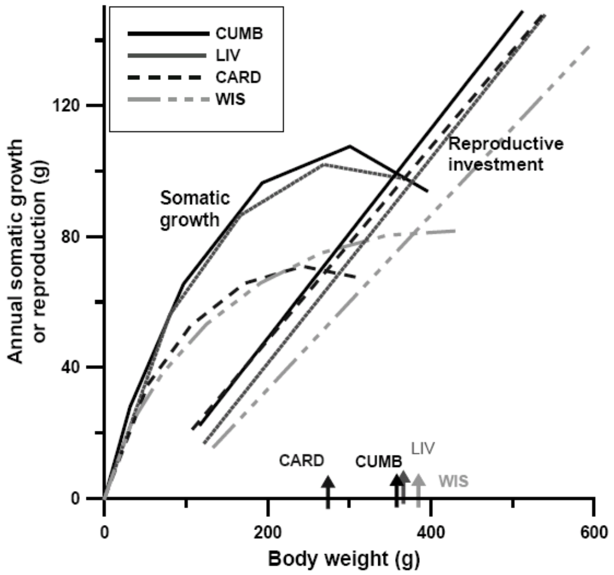

Figure 4.5. Regional variations in somatic growth (curved line) and reproductive investment (straight line) (grams wet weight) for female plaice in the Irish Sea (Cumbrian coast (CUMB), Liverpool Bay (LIV), Western Irish Sea (WIS) and Cardigan Bay (CARD)). From Nash *et al*., 2000.

4.3.4 Summary

Based on this review we can conclude that future attempts to develop predictive relationships for egg production in determinate spawners must take into account the level of atresia during the spawning season within the stock of interest. In stocks where the prevalence of atresia is high there is a need for further work to develop relationships between atresia and condition.

In the longer term, process models of reproductive potential will need to take account of issues related to fertilisation success and parental effects on viability.

4.4 Fish condition

4.4.1 Deriving morphometric condition indices from standard fisheries database

Condition indices are straightforward to compute when weight and length observations for individual fish are available. However, the computation of stock-level condition indices can be problematic if the observations on weight and length for the aggregate stock are not readily accessible. Stock weight-at-age (SW_a) is routinely reported because it is used to estimate spawning stock biomass (SSB). Often, these estimates of SW_a are obtained by averaging weight-at-age (W_a) values provided by more than one country and/or laboratory, both from sampling of commercial landings and from research-vessel surveys. The individual W_a time series that underlie SW_a may or may not be reported in the assessment. Because the original data that were used to estimate the W_a values are archived in different locations and/or formats it can be difficult to access and collate observations for individual fish. In many cases, corresponding values of stock length-at-age (SL_a) are not reported because the information is not used directly in age-based assessments. The net result is that, while considerable amounts of weight and length data exist for many stocks, difficulties in accessing this data, either electronically or in assessment reports, can impede the estimation of a stock-level condition index.

A recent study (Marshall *et al*. in press) illustrates how a stock-level condition index for Northeast Arctic cod can be derived using the W_a time series that are provided annually to the ICES Arctic Fisheries Working Group (AFWG) by Norway and Russia. Briefly, the same primary databases that generated these W_a time series were used to develop year-specific age/length keys (ALK) for both countries and the mean length-at-age (L_a) for each ALK was calculated. These L_a values were then combined with the corresponding W_a value to generate a set of pseudo-observations for each year (1946–2001). A fitted weight/length relationship was used to predict stock weight-at-length (SW_l) for each year (Figure 4.6).

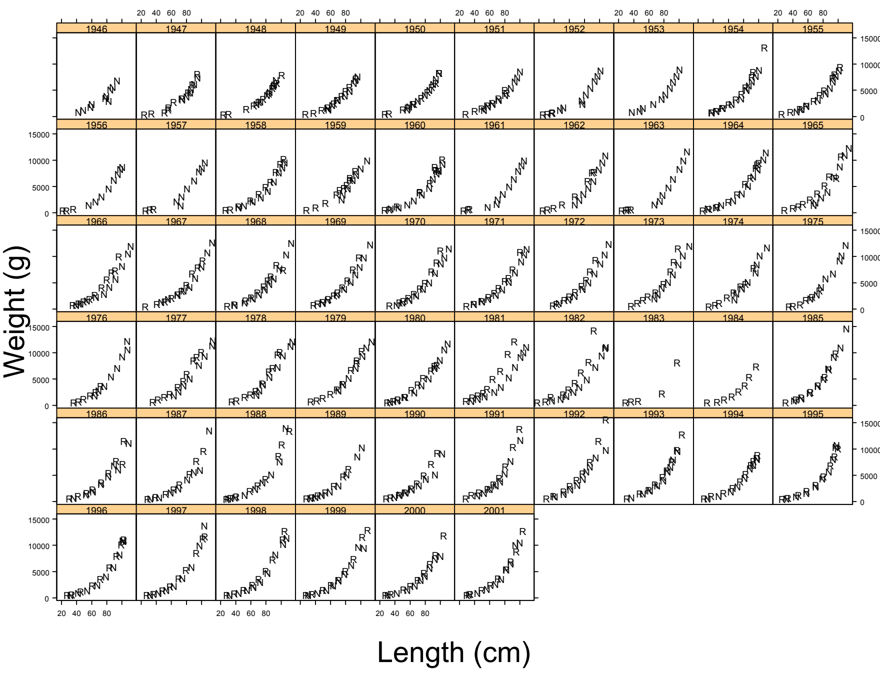

Figure 4.6. A scatterplot matrix showing the relationship between length and weight (all ages combined) for Norwegian (N) and Russian (R) data for the years 1946 to 2001. From Marshall *et al*., in press.

To determine whether SW_l accurately reflects the bioenergetic status of the stock the relationship between the biomass of the preferred prey of Northeast Arctic cod, Barents Sea capelin, and SW_l was evaluated (Figure 4.7a) relative to the significant, positive relationship that has been observed between the liver condition index of cod and capelin stock biomass (Figure 4.7b). A bivariate plot of the SW_{70} against capelin stock biomass shows that there is no significant correlation ($n = 50$, $p = 0.66$, $r^2 < 0.01$) between the two variables (Figure 4.7a). Given that the magnitude of variation in SW_{70} during this time period was substantial the lack of a significant relationship is not due to insufficient contrast in the data. For the same time period there is a significant, positive correlation between $LCI_{61–70}$ and capelin stock biomass ($n = 54$, $p < 0.001$, $r^2 = 0.44$; Figure 4.7b). Because of this latter correlation, there is also a significant, positive correlation between LW_{70} and capelin stock biomass ($n = 50$, $p < 0.001$, $r^2 = 0.24$; Figure 4.7c). Thus, condition indices that are based on liver weights are more sensitive to variation in prey availability compared to condition indices based on total body weight.

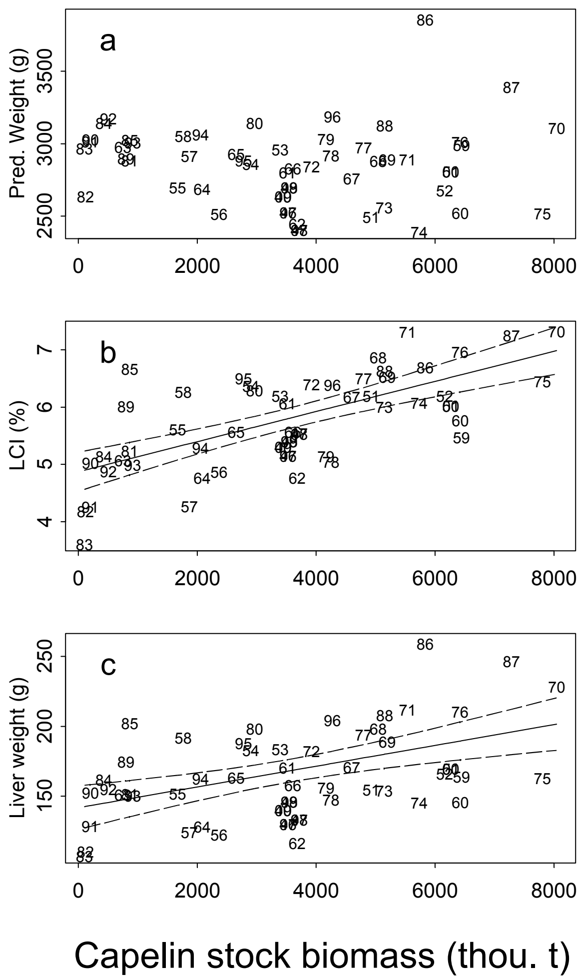

Figure 4.7. The bivariate relationships between capelin stock biomass (thousand t) and a) predicted weight at 70 cm; b) liver condition index of the 61–70 cm length class; and c) estimated liver weight at 70 cm. Observations are denoted by year. Solid line indicates the least squares model fit and dashed lines indicate approximate 95% confidence intervals for the estimate. The model fit is not shown in a) because the correlation was not significant. From Marshall *et al.*, in press.

While it is possible to generate a morphometric index representing the girth of Northeast Arctic cod at the stock-level using standardized fisheries databases the resulting index does not accurately reflect the magnitude of stored energy reserves. It is important to recognize that this conclusion was developed from stock-level data collected over broad spatio-temporal scales and may not necessarily apply to short-term studies conducted at the individual-level. Its applicability to other stocks is difficult to gauge given the relatively small number of stocks having long-term data on fish growth (length and girth), lipid reserves and food availability. The importance of developing time series of condition that accurately track fluctuations in the energy reserves of the stock is increasingly obvious given the impact of condition on all major elements of population dynamics, including natural mortality, fishing mortality, growth (by definition) and recruitment. For commercially exploited stocks that experience variable environmental conditions the technical and logistical impediments to monitoring condition should be considered as minor relative to the costs of not monitoring this key variable.

4.4.2 Effect of length, sex and areas on morphometric condition indices

Morphometric condition indices based on weight-length data are widely used as proxy of stored fish energy reserves. However, several problems and bias may arise if due care is not taken with this procedure. The previous SGGROMAT report (ICES 2003) emphasised the problems connected with the use of Fulton's K and relative condition factor (Kn) in condition estimation. Firstly, if fish do not grow isometrically the exponent b of the weight-length relationship $W=aL^b$ is not constant and equal to 3. Secondly, there is often an undesirable correlation between length and condition, estimated either by K or Kn, respectively (Figure 4.8). Thus, mean condition estimation based on morphometric parameters might strongly depend on the range and length distribution of fish used in the calculation. Thirdly, there are several indications of differences in morphometric condition between sexes. For instance, in Skagerrak, Kattegatt and Baltic Sea adult sprat females present a higher condition than males at the same length (Figure 4.8) and those differences remain throughout different areas and seasons. Lastly, within the same stock different condition values can occur in different parts of the distribution area. Different feeding conditions and different timing of spring bloom and reproduction could influence condition estimation. This may have important consequences for the estimation of condition at the stock level when data collected in different areas are merged.

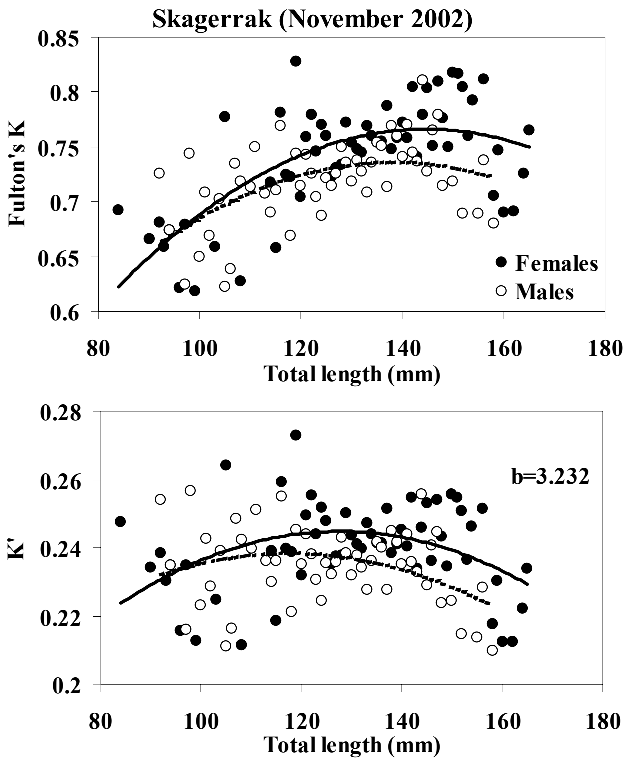

Figure 4.8. Relationship between length and condition calculated as Fulton's K and Kn for sprat in Skagerrak (eastern North Sea) during the month of November. Adult sprat females show a higher condition than males using both Fulton's K and Kn.

4.4.3 Comparing morphometric and physiological condition indices

As already highlighted in the previous SGGROMAT report (ICES, 2003), morphometric indices are not necessarily the best methods to describe the physiological status of a fish although they are used because weight and length are easily and routinely collected. For instance, in the Northeast Arctic cod there is not a close relationship between morphometric indices (weight at length) and liver index (Figure 4.7) (Marshall *et al.*, in press). Therefore, in order to verify the goodness of morphometric indices as a proxy for energy reserves of fish, the comparison with a physiological index should be performed.

Differences in condition between stocks, sexes and length may derive from morphological more than physiological differences at the individual level. Individuals with different sex and length (age) might grow in different spatial dimensions. For example, if females grow faster in height than in length compared to males, the differences in condition observed between sexes would be merely an effect of the different fish shape and not of energy reserves. The same could apply with regard to different length (age) classes and populations.

At the same time, the choice of an appropriate physiological index must be species-specific reflecting the fact that different fish species accumulate energy reserves in different organs (liver, muscle, mesentery) (see ICES 2003).

4.5 Incorporating information on reproductive potential in stock assessments

Given the intrinsic importance of reproductive potential to stock/recruit (S/R) relationships, the setting of biological reference points (BRPs) and stock projections, the alternative measures of reproductive potential that are currently being developed for several stocks merit serious consideration by assessment working groups and fisheries managers. It is important to recognize that the use of these alternative measures in the assessment process should not depend on the alternatives explaining a higher proportion of the variability in the S/R relationship. Assuming they do not result in increased uncertainty in the S/R relationship, the alternative measures should be judged according to, firstly, whether they are more precise **by definition,** and secondly, whether they deviate substantially from SSB.

Resistance to using these alternative measures directly in stock assessment often focuses on several perceived impediments. Data availability is considered to be a limiting factor for many stocks. However, the work already completed by the NAFO WGRP has indicated that there are substantial amounts of relevant data that are available but underutilized (Tomkiewicz *et al*. 2003). It is commonly believed that the alternative measures cannot be integrated with the BRP framework that is currently used to formulate management advice. In practice there are no technical obstacles to determining analogous reference points for the alternative measures of spawning stock size.

Case studies for Northeast Arctic cod and cod in NAFO Div. 3NO were presented to the SG illustrating the progress that is being made towards the overall goal of integrating these alternative measures of reproductive potential with assessment. These case studies are summarized below.

4.5.1 Case study: Northeast Arctic cod

The assumption implicit in the S/R model is that female-only SSB (FSB) is equal to half of the SSB. For species that exhibit strongly dimorphic growth, maturation and mortality this is very dubious. Recently, the estimation of length-based sex ratios and female-only maturity ogives has allowed SSB to be partitioned into FSB. Values of the ratio FSB/SSB deviate considerably from 0.5, reaching maximum values approaching 0.7 and minimum values approaching 0.2 (Figure 4.9). Furthermore, the temporal trends covary systematically with variation in the mean length of the spawning stock (Figure 4.9). Stocks having a higher proportion of large cod have higher proportions of females simply because of the earlier maturation and mortality of males.

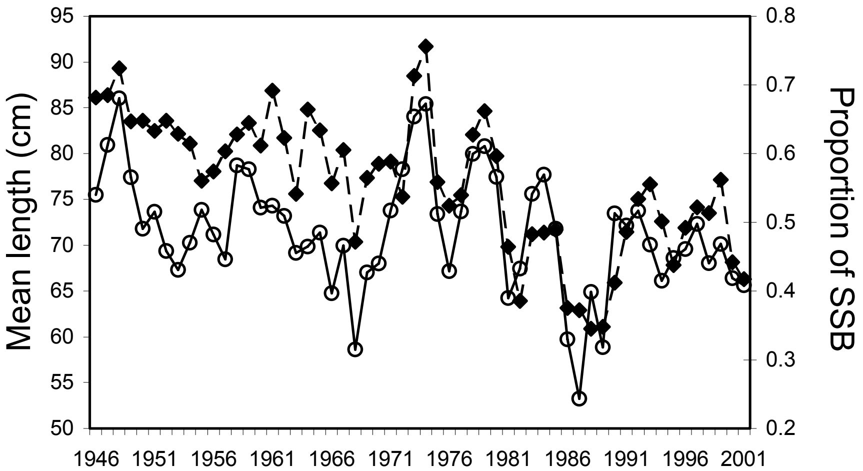

Figure 4.9. a) the mean length of the spawning stock (solid diamonds, dashed line) and female-only SSB (open circles, solid line).

A second assumption of the S/R model is that SSB is proportional to total egg production (TEP) from the stock, i.e., TEP/SSB is constant. A recently developed fecundity model for Northeast Arctic cod (ICES 2003) was used to develop a time series of TEP for Northeast Arctic cod. Over the assessment time period (1946–2001) TEP/SSB varies by a factor of 3 (Figure 4.10). Peak values were observed in the seventies and since the early 1980's values have been near or below the long term mean. This indicates that the reproductive potential of the stock has been relatively low over the past two decades. If TEP is standardized by FSB rather than SSB then the magnitude of the fluctuation is reduced (Figure 4.10). This latter standardization is intuitively more sensible because the number of mature females is common to both TEP and FSB, the difference between them resulting from the replacement of a weight term in FSB by the fecundity term in TEP.

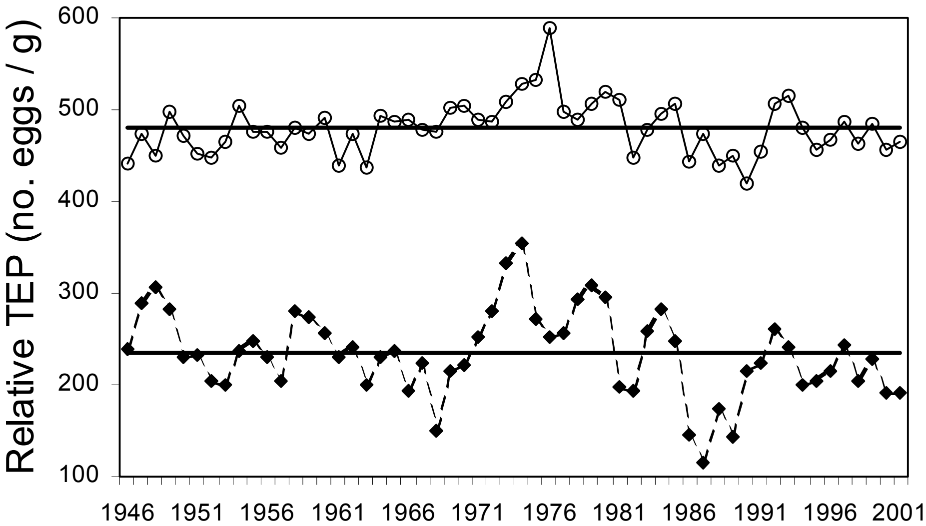

Figure 4.10. Time series of relative total egg production (TEP) standardized by SSB (solid diamonds, dashed line) or by female-only SSB (open circles, solid lines). The arithmetic average of each time series is indicated by the horizontal lines.

The observations that: a) there is considerable deviation from the assumption that FSB is half the SSB (Figure 4.9); and b) the proportionality assumption is better satisfied using FSB as an index of reproductive potential (Figure 4.10) are both strong arguments for using FSB rather than SSB as the independent variable in the S/R plot for this stock. The S/R relationship for Northeast Arctic cod is highly variable for the full time period (1946-present) but shows a strong signal for the recent time period (since 1980). Accordingly, the S/R relationship that used SSB as an index of spawning stock size was compared to the relationship that used FSB (Figure 4.11). To allow a non-zero intercept, a modified Ricker model was fit to the data ($R = \alpha(S-\gamma)\exp(-\beta(S-\gamma))$). This model is a standard Ricker curve shifted along the spawner axis and γ represents the value at which the curve cuts the spawner axis (Frank and Brickman 2000). An estimate of γ that is significantly greater than 0 suggests depensation, whereas, a value of γ that is less than 0 suggests compensation. The most important difference between the two S/R relationships was in the behaviour near the origin. The empirical relationship which used SSB had a positive γ, suggesting depensation, whereas, the empirical relationship which used FSB had a negative value of γ, suggesting compensation. This is a fundamental distinction and establishing which is a more accurate description of cod population dynamics is essential to establishing effective BRPs. Work is continuing on this issue.

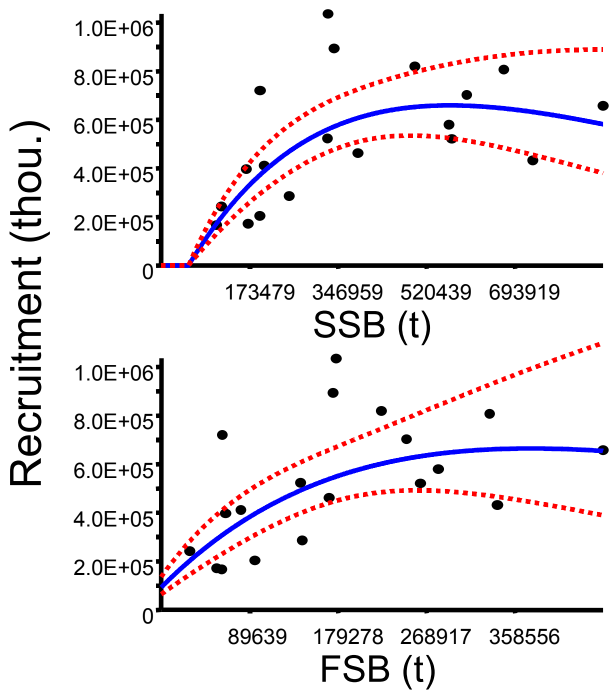

Figure 4.11. Stock/recruit relationships for Northeast Arctic cod. Only the 1980 to 1998 year classes are represented. The models shown are the Frank-Brickman model plus confidence intervals estimated as twice the standard errors.

4.5.2 Case study: Cod in 3NO

For this population there have been significant changes in maturity at age, sex ratio and mean length at age. Four indices of spawning stock size (SSS) were produced to explore the effect of these changes. The first index was simply one half of the 6+ biomass. A second index applied estimates of female proportion mature at age to one half of the biomass at age. The third index used the female proportion mature at age and the estimated sex ratio at age. The final index of SSS was an estimate of egg production. In this case the female numbers at age were multiplied by the number of eggs produced at age. Total egg production was estimated by applying a constant fecundity/length relationship to the mean length at age. These estimates of SSS showed broadly similar trends over time but there were important differences (Figure 4.12). For instance the 6+ estimate of SSS was the highest at the beginning of the time series while the egg production estimate of SSS was the highest during the 1980's. Differences in temporal pattern will lead to differences in the stock recruit scatter produced using the different measures of SSS (e.g., Figures 4.13 and 4.14).

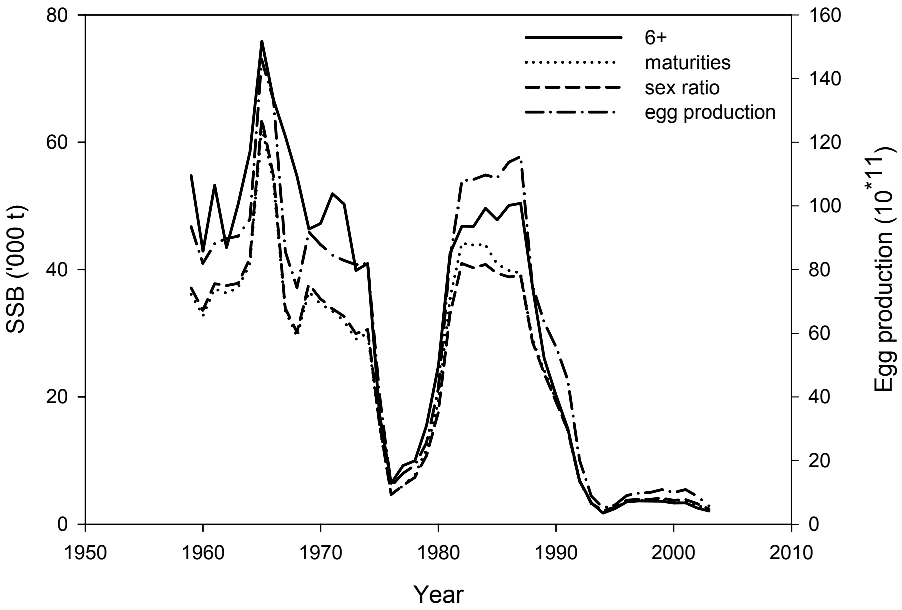

Figure 4.12. Time series of different estimates of spawning stock size for cod in NAFO Division 3NO.

Two of the estimates of SSS (6+ and egg production) were used to estimate B_{lim} reference points using a modified Serebryakov method (Figures 4.13 and 4.14). B_{lim} can easily be estimated using either index of SSS. However, the level of B_{lim} and more importantly the current level of the index relative to B_{lim} is different. It should be noted that neither of these estimates of B_{lim} are being suggested for actual application to the stock. The Serebryakov method is very sensitive to the addition of data close to the origin (Morgan *et al.* 2003). These have been calculated simply to illustrate that it is possible to estimate B_{lim} with a variety of types of estimates of SSS. The important aspect is to find the best estimate of SSS for a stock.

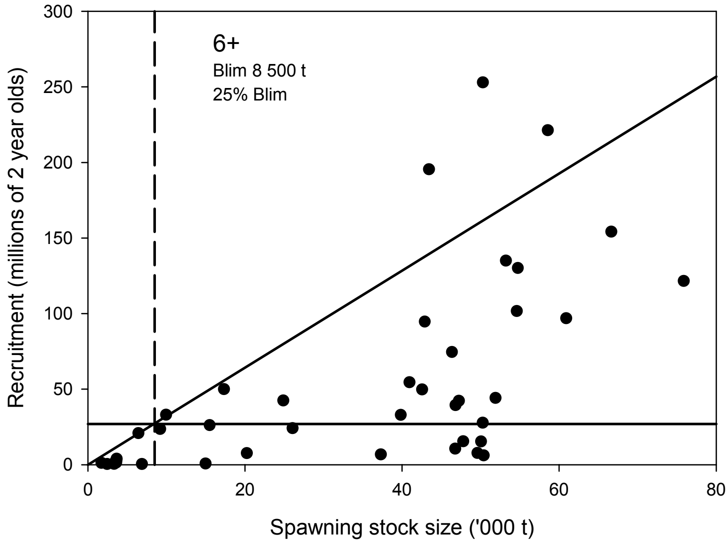

Figure 4.13. Relationship between the biomass of cod age 6+ and recruitment to age 2 for cod in NAFO Division 3NO. Lines are used to estimate B_{lim} via the modified Serebryakov method.

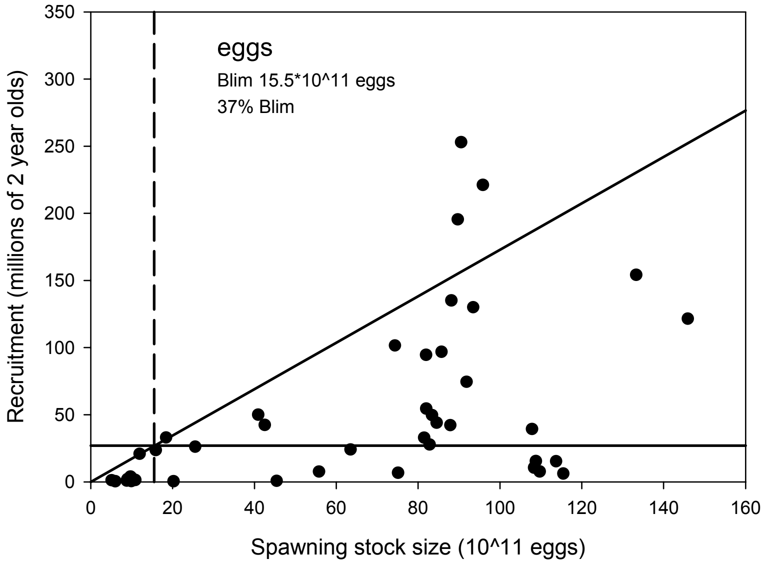

Figure 4.14. Relationship between the number of eggs produced and recruitment to age 2 for cod in NAFO Division 3NO. Lines are used to estimate $B_{\lim}$ via the modified Serebryakov method.

Population numbers at age were projected at F=0 using the same assumptions as in the June 2003 assessment of this stock. The 6+ and egg production estimates of SSS were then calculated over the 5 year projection period (Figures 4.15 and 4.16). Both estimates of SSS show an increase over the projection period but the rate of increase in egg production is greater than that for 6+ biomass. This aspect requires further exploration.

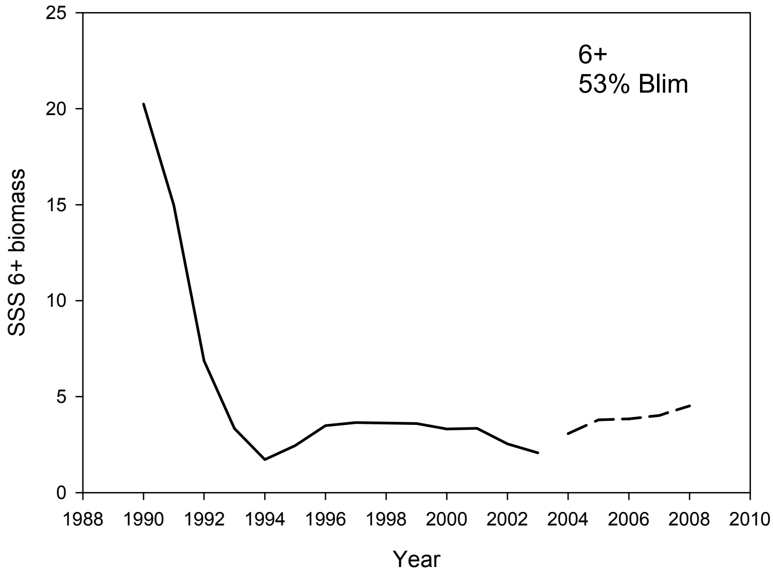

Figure 4.15. Projection of future values of the biomass of age 6+ cod in NAFO Division 3NO based on the assumptions in the June 2003 assessment of stock status.

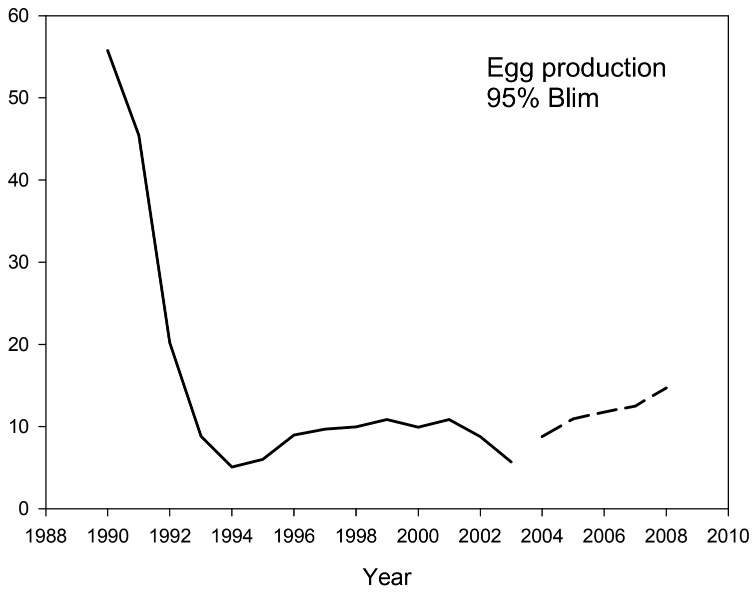

Figure 4.16. Projection of future values of the number of eggs produced by cod in NAFO Division 3NO based on the assumptions in the June 2003 assessment of stock status.

5 IMPLEMENTATIONS OF PROCESS-BASED MODELLING APPROACHES IN STOCK ASSESSMENTS

More pressing matters within fisheries science have meant that time and resources originally intended to the development of process-based projection models have been directed elsewhere. The lack of availability of medium term projection software has resulted in the SG being unable to fully address TOR c). At this year's meeting of the SG several related discussions took place and these are summarised here.

5.1 The use of simulations in stock projections, and in evaluating stock projection methods

An alternative approach to the incorporation of process models in stock projections is to explicitly incorporate mechanistic process sub-models into the stock assessment procedure. However, the widely used VPA type approaches to stock assessment do not have the appropriate flexibility such approaches require. Furthermore, it is unclear whether the most suitable modelling approaches are age-based, length-based or age- and length-based. The incorporation of length-structure into assessment models is investigated at the Study Group on Age-length Structured Assessment Models (SGASAM). A number of case studies presented at SGASAM (ICES 2003) illustrate how the incorporation of biotic and abiotic factors into the assessment model can affect our view of the current stock status. These case-study models are all quite complex population simulation models and as such require a large amount of data for appropriate parameterisation. Being simulation models, however, they do have the advantage that they are can be run without data from observations and therefore can be used for projection as well as assessment.

Population simulation models (not necessarily age-length structured) incorporating particular biological processes may also be used to generate pseudo-stock assessment data sets by making specific assumptions about fishery behaviour and survey data collection. A reduced model with simplified process assumptions (e.g., constant growth as opposed to variable growth) may then be formulated and used to assess the pseudo-stock. A comparison of the reduced-model estimates of stock size and fishing mortality with the known values used in the simulation gives an indication of whether the ability to assess adequately the stock status is seriously degraded by the exclusion or simplification of known processes. It is considered that these types of simulation models (including those developed at SGASAM) may be useful in identifying situations in which process information is essential to the assessment. Further work on stochastic data generation of this type is currently being carried out under the aegis of the ICES Working Group on Methods of Fish Stock Assessment (WGMG: ICES CM 2004/ACFM:03).

5.2 Projection methodologies

The previous study group report (ICES 2003) noted that time-series descriptions of population state-space vectors using Kalman filters or Bayesian MCMC approaches could be used to provide both descriptions of historical trends and forward projections. No such methods have yet been implemented in projection modelling suites, but the SG discussed work that attempts to apply, in relation to gadoid stocks, a Kalman filter to the time series of spawning stock biomass against recruitment. The Kalman filter offers a potential benefit over the random variation in drivers, as used by WGMTERM, in that it should be capable of explicitly differentiating between systematic trends and random sources of variation independent of any trend (that is, noise). In concept it is most similar to the ARMA (autoregressive moving average) modelling of residuals as employed in the StockAn/RecAn/MedAn suite (see ICES 2003).

The Kalman filter technique has applications beyond investigating trends in stock productivity. For example, Kalman filters have been incorporated into the TSA stock assessment model (Fryer 2002). It should also be possible to apply Kalman filters to assess the growth of different stocks. If the growth of different cohorts from one age to the next is represented in the form of a time series then a Kalman filter can be used to identify any systematic trends in the rate of growth. For example, fish growing at a progressively slower rate might indicate a continuing decline in environmental suitability or possibly an evolutionary response to fishing pressure where effort is diverted from growth into reproductive maturity.

A limitation with Kalman filters is that changes in the state-space parameters from year to year must be linear. Furthermore, the errors between predicted values and observations must be assumed to lie on a normal distribution. In extreme cases this can lead to biologically non-sensible projections. The TSA model has experienced instances of predictions of negative recruitment. A third problem arises if a change in the observed quantity is very sharp. The estimates from the Kalman filter will contain some degree of lag, as the initial change will be regarded chiefly as noise. More generally, the reasons for any trends in a time series can never be obtained from such models. Therefore such techniques should be seen as complimentary to process modelling, or even as an interim step until such time as process models can explain and predict the trends in the quantity of concern.

5.2.1 Case study applying a Kalman filter to whiting recruitment

For whiting stocks the relationship between spawning stock biomass and recruitment can be represented by the Ricker recruitment model. In the case of the North Sea whiting stock, although data are available from the 1960s, the regression providing parameter values for this model only makes use of data from 1980 onwards in recognition of a possible “regime shift” that occurred around that time.

Values of spawning stock biomass, (S), and recruitment, (R), come from the assessment of the stock made by the 2003 ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK; ICES CM 2004/ACFM:07). The standard, non-time dependent Ricker recruitment equation can be written as follows

$$\ln(R/S) = \alpha + \beta S$$

where α and β are parameters. As α is a stock density independent term that can be considered to incorporate environmental influences the Kalman filter considers this quantity to be varying in time rather than fixed. The single equation above is replaced by two

$$\mathrm{Ln}(R_t/S_t) = \alpha_t + \beta S_t + v_t$$

$$\alpha_t = \alpha_{t-1} + w_t$$

where the subscripted t denotes time varying quantities, and v and w denote error terms. These two equations are known as the observation and system equations respectively. The system equation shows that the α parameter is now regarded to be subject to a stochastic process. In this instance it is a random walk, although other forms of stochastic process are possible. Parameters are estimated iteratively by moving forward along the stock-recruit time-series.

A comparison between the α value given by the fixed parameter Ricker model and the time series of α values given by the Kalman filter approach is given in Figure 5.1. Two time series of α values are shown, one set are ‘raw’ filtered estimates while the second series are smoothed estimates. The lower panel of this Figure also shows the predictions of recruitment of the alternative approaches in comparison to the recruitment values from WGNSSK (bold line). The Kalman filter approach used still assumes the density dependent parameter β to be fixed in time. Its value is, however, free to change compared to that estimated by the fixed parameter regression. Figure 5.2 contrasts the recruitment curve obtained by the fixed parameter regression to those from three years in the Kalman filter time series. The three years are those with the highest and lowest α values plus the most recent year.

The top panel of Figure 5.1 shows that the Kalman filter estimates of α begin a downward trend just before 1980. This trend continues until the mid to late 1990s at which point a new, reduced but relatively constant value for the parameter has established. This result is in agreement with the perceived wisdom regarding the productivity of the stock. The key point is that with the Kalman filter approach it would have been possible to detect and project this declining trend in stock productivity as early as the beginning of the 1980s. The fixed parameter regression used data from all years in this instance in order to illustrate the problems such an approach can present if a trend or shift in the recruitment relationship has not continued for sufficiently long for the need for ad-hoc intervention to become apparent through visual inspection. The lower panel of Figure 5.1 clearly demonstrates better matches between Kalman filter estimates of recruitment and the values produced from WGNSSK compared to those from the fixed parameter regression. As a time-series model, it is straightforward to project the Kalman filter forward in time, making it ideal for use in projections and forecasts.

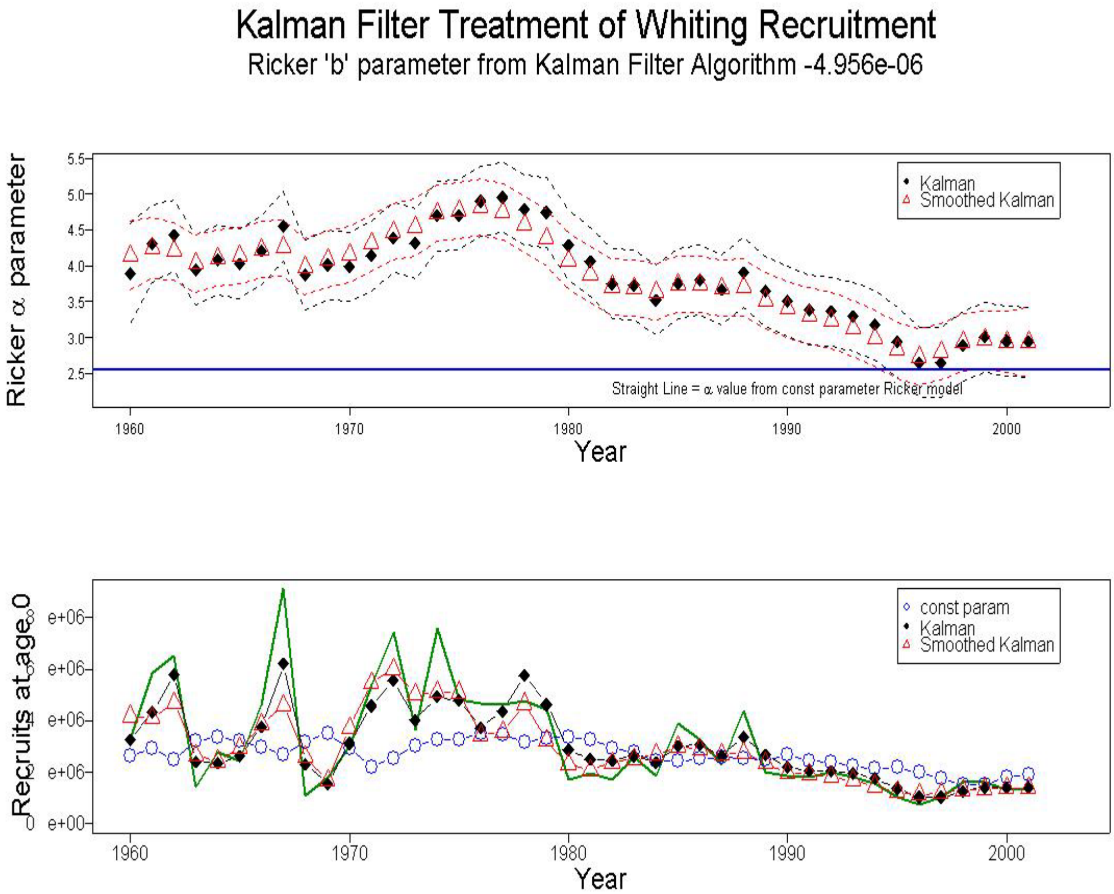

Figure 5.1. Upper panel: Comparison of Ricker recruitment α parameter from regression assuming parameter fixed with respect to time and from Kalman filter assuming parameter the subject of a stochastic process. Dotted lines give approximate pointwise 95% confidence intervals for these estimates. Lower panel: Estimates of North Sea whiting recruitment from fixed parameter regression and Kalman filter against values produced from WGNSSK, (solid line).

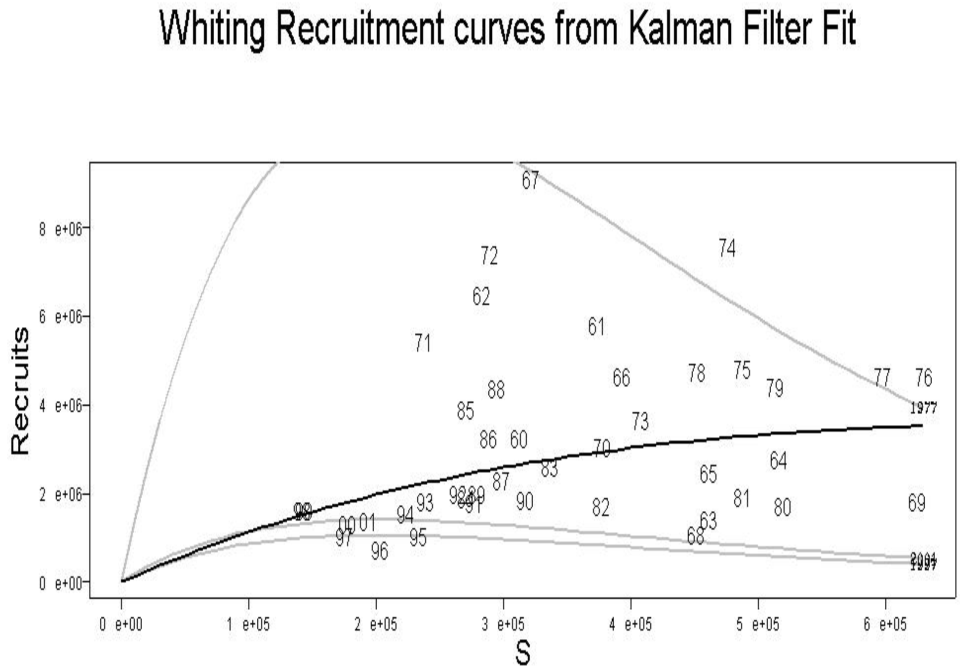

Figure 5.2. Ricker recruitment curve from regression assuming parameters fixed with respect to time, (black) and Ricker recruitment curves having used the Kalman filter to determine time varying values of the density independent, (α) parameter. A different curve exists for each year. Those shown represent years with the maximum and minimum α value as well as the final year in the time series.

5.3 Spatial management schemes

Impetus is growing within the framework of European fisheries for spatially-based management schemes, in which vessels would be punished or rewarded for fishing in specific areas. Given the current crisis in North Sea cod, the emphasis has been on specifying areas where cod bycatch would be minimised. Many within the fishing industry are keen to promote management schemes that reduce the supposed linkage between cod and other key commercial species such as haddock, plaice and anglerfish. In other words, the intention is that quotas for species such as haddock and plaice should not be reduced commensurate with quotas for cod, as long as the catches of these other species are relatively clean.

An example of one of these proposals has been produced recently by the Scottish Fishermen's Federation (SFF 2002). Although this document is not clear about the details of such a scheme, the essentials appear to be that commercial catch records would be used to determine suitable areas for avoiding cod. While this information would undoubtedly be important, it would need to be verified by comparison with distribution maps from research-vessel surveys, and with habitat-suitability distributions. These aspects are discussed further below. The combination of these three sources of data has the potential to lend strong credence to proposed plans for spatial management schemes.

In addition to issues related to cod by-catch, closed areas could be used to protect juveniles or spawning fish. For some stocks, such closed areas have great intuitive appeal due to the high level of disaggregation between juvenile and adult stocks. For other stocks, such as cod, with a more diffuse distribution the benefits are much less obviously apparent but nonetheless still possible. The SG discussed the application of a model combining density-dependent habitat selection with ideal distribution theory to determine the degree of clustering into preferred habitat of fish as stock levels decrease. If such models can be successfully validated against survey data they should prove a very valuable tool in fisheries management. In combination with models projecting the overall level of the stock they can be used to guard against the high catchability of depleted but aggregated stocks yielding a false view of the health of the stock.

5.3.1 Case study: the spatial distribution of juvenile North Sea cod

Changes in the physical environment coupled with the occurrence of different biological processes (feeding, spawning, migration) at different times of year, indicate that a mapping exercise as outlined above requires knowledge of potentially many different factors that could influence habitat selection of the fish stock at different temporal and spatial scales. The possible habitat preference of age 1 cod in the North Sea has however been considered as a starting point.

It was clear that density-dependent habitat selection is likely for age 1 cod in the North Sea. Data from August English Groundfish Surveys (1977–2002) indicated that at very large stock size, the stock was spread out across a much larger spatial range and at low stock sizes the stock appeared to contract into smaller regions.

A preliminary attempt to compare these survey observations of age 1 North Sea cod with theoretical predictions based on ideal free distribution theory using an experimentally derived optimal growth temperature equation to describe habitat suitability (Björnsson and Steinarsson, 2002) revealed consistent patterns with observations. At low stock size, the highest catch densities from surveys appeared to be located in regions that corresponded to optimal temperatures (Figure 5.3) and at high stock size the population is spread out across the entire area. When stock size is very low, identification of optimal habitat is a pre-requisite for the protection of the species core areas. Spatially the areas of highest habitat suitability from this case study corresponded to the darkest regions shown in Figure 5.4a, which shows the average of the entire time series (1977–2002). The extreme years of the time series are also shown (Figure 5.4b,c). These show that, in the same way that weights at age are not considered to remain static with time, maps or habitat topographies are also temporally dynamic.

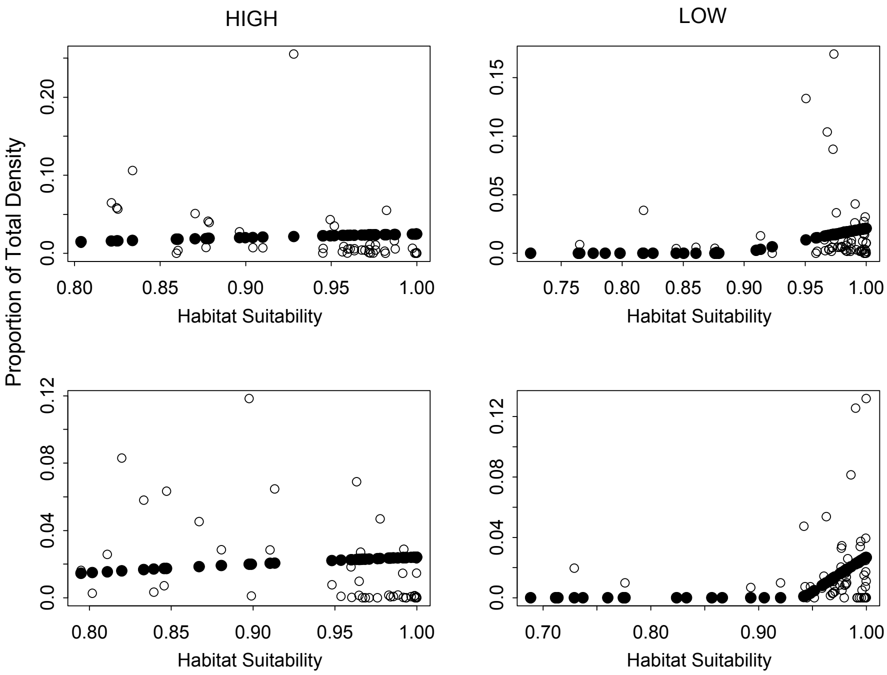

Figure 5.3. Proportion of total density of age 1 cod within an ICES rectangle versus habitat suitability per ICES rectangle for two HIGH abundance (1977 top and 1980 bottom) and two LOW abundance (2000 top and 2001 bottom) years. Open circles are the densities based on the EGFS data (observed) and closed circles are predictions of the ideal free distribution model.

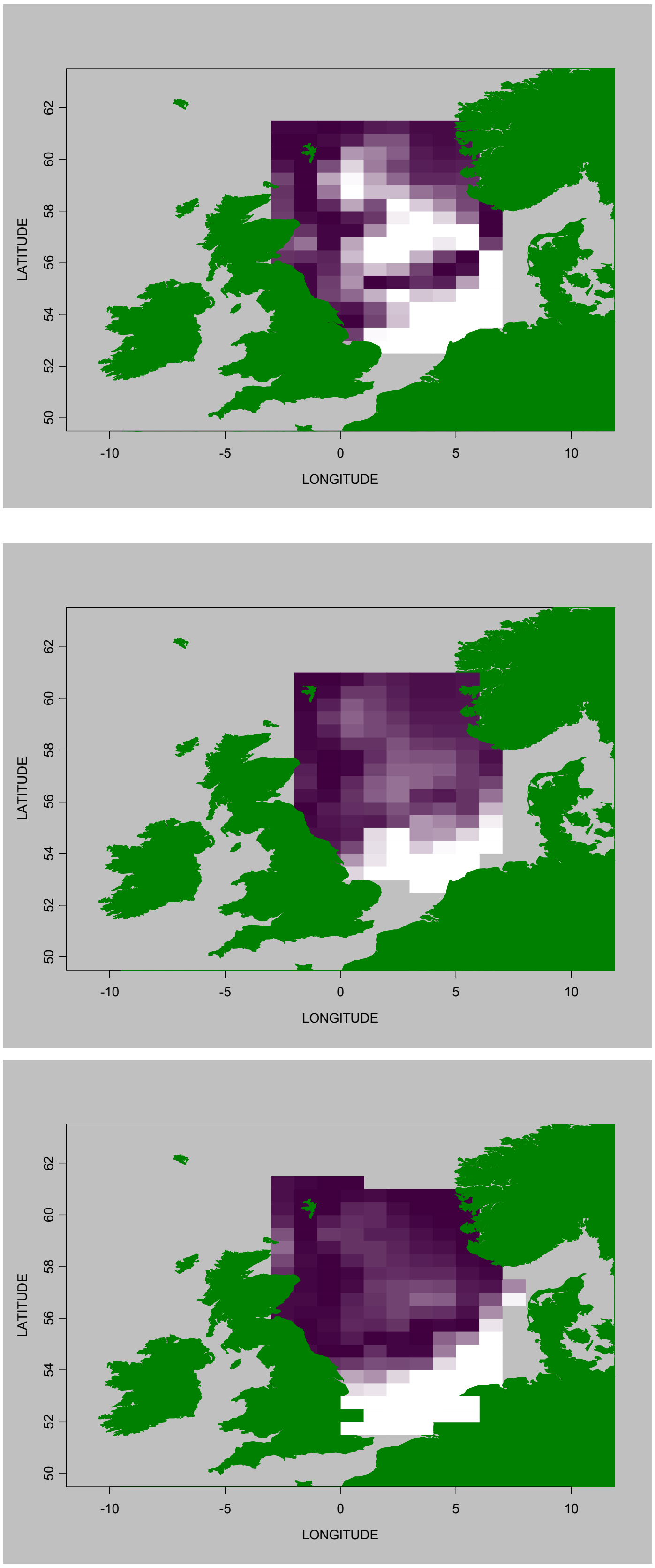

Figure 5.4. Maps of the relative habitat suitability index (based on optimal temperature for growth) for age 1 cod. Darker shades indicate highest suitability whereas lighter shades indicate lower suitability indices. Top panel: habitat suitability map averaged over the entire 1977–2002 period, Middle panel: habitat suitability map for 1986, Lower panel: habitat suitability map for 2001.

There are several caveats involved with using the measure of habitat suitability applied in this case study. First of all, the experimentally derived equation for optimal growth temperature may not be an accurate representation of fish in the wild. Secondly, there are clearly many other factors that influence habitat suitability along with temperature (depth, stratification, substrate type, salinity, and oxygen are only a few examples). A difficulty can arise when these physical parameters are covariates of one another. Stratification maps have shown that the areas within this temperature range co-occur with frontal areas in the North Sea. This finding therefore suggests that the mechanism could be driven by the high productivities generated in these areas instead of being directly linked to the optimal growth temperature. Nevertheless, the consistencies between this simple theoretical model and survey observations support the potential utility of building on this or a similar approach. Of particular use would be the development of habitat indices that are predictive, for example, indices that are derived from physical parameters that are themselves predictive (i.e., via oceanographic models).

5.4 Incorporating biological and environmental information

The dynamics of fish stocks has been influenced by changes in environmental and biological factors in the past and will continue to be in future. Information about environmental and biological variability should therefore be of value in medium-term projections, but in many cases no validated, widely accepted, process-based models, which include such factors exist. SGGROMAT was asked to implement suitable process-based models in medium-term projection methodologies and conduct sensitivity analyses to examine the likely effects of these new approaches on management advice. This continues to be an important development aim, but may take some time to achieve. However even before this is done, biological and environmental information can be useful in assessing current stock status and in evaluating sources of uncertainty in medium term projections. There are many examples of how this may be done, such as the stock status reports produced for NW Atlantic fish stocks, which present and review a variety of environmental and biological information. An example of such a stock status report can be obtained from http://www.dfo-mpo.gc.ca/csas/.

The current form of ICES on fish stocks advice includes little or no information on biological and environmental factors which may affect medium term projections, but the political and public discussion of the advice often focuses on such factors (e.g., observed changes plankton and fish distributions, effects of warming or other environmental variables). It would seem sensible to provide a more extensive review of such factors as a part of the assessment, to serve as a scientifically informed basis for the evaluation of the advice. Validated, process-based models can be included and used to carry out sensitivity analyses as they become available.

6 CONCLUSIONS

SGGROMAT arose from a proposal made during the third and final SGRPRISM meeting (ICES 2002). The original intention of the SG was to concentrate on the development of new medium-term projection tools for use in assessment Working Groups, taking into account biological process models of growth, maturity, condition and reproduction: the process models themselves were to be discussed, but only in the context of implementation.

As it has turned out, this aspect of SGGROMAT (specifically, ToR c.) has not been entirely successful. Work was carried out on implementation during the lead-up to the first meeting: this included the StockAn-RecAn-MedAn suite, the STOCOBAR model, and simulations of the effects of process incorporation in the Baltic Sea (ICES 2003). However, there has been limited development since, mostly because assessment and advice issues have taken precedence in the current situation of declining fisheries (see the discussion in Section 1.5). It is clear, however, that progress does not necessarily depend on new software. For example, the incorporation of new information on growth and maturation into medium-term stock projections for 3NO cod is being explored (see section 4.5.2). These efforts are yielding new insights on how perceptions of stock status are affected by the quality and quantity of biological data that are used in the assessment. In addition new approaches to stock projections are being examined by SG members including simulation approaches (see Section 5.1) and the use of Kalman filters (see Section 5.2).

Although SGGROMAT has been markedly successful as a forum for assessment scientists and biological process modellers to meet and discuss the importance to stock assessments of a variety of issues (including growth modelling, condition indices, fecundity, maturity, and reproductive potential), the lack of progress on ToR c has meant that the SG is now viewed as not having fulfilled its original mandate. For this reason, it seems unlikely that there will be a third meeting, and the SG has proceeded on the assumption that the current meeting is to be the last.

However, there is still a pressing need for an evaluation of the utility of incorporating more biology in stock assessments, projections, and fisheries management advice. This need will not be met by the proposals outlined at the ICES Delegates meeting (see Section 7). Accordingly, the SG **recommends** that a new, permanent Working Group be set up to address this lack. The details of this recommendation are given in Section 8.

7 LINKS TO OTHER GROUPS

At the 2003 ICES Delegates meeting, it was decided that some of the work carried out by SGGROMAT should be carried forward by other Groups. Specifically, the Methods WG (WGMG) should continue work on software development, while the Study Group on Age-Length Structured Assessment Models (SGASAM) would assume responsibility for data collation (ToR a) and the length-based modelling aspects of SGGROMAT. The SG feels that these suggestions are appropriate, except the use of SGASAM as a forum for data collation for which it does not have the time or personnel.

8 RECOMMENDATIONS

8.1 Recommendation for a follow-up Study Group

A **Study Group on Incorporation in Stock Assessments of Biological Models and Data** [SGISAB] [D. Beare, UK and C. T. Marshall, UK] will be established and will meet [location to be decided] for 10 days in spring 2005 to:

a) update and maintain tables of sources of biological parameter data for stocks of interest to ICES;

b) for selected stocks in the Atlantic and neighbouring shelf seas:

   i) collate relevant biological data into stock-assessment input-file formats;

   ii) run sensitivity analyses of the influence of alternative input data or model assumptions on the assessment and advisory process, using the currently-accepted assessment method;

   iii) determine (where possible) the most appropriate biological information to include in the assessments, using both *a priori* considerations of data suitability and *a posteriori* considerations of sensitivity;

c) recommend data configurations for assessment Working Groups.

SGISAB would report to the attention of the Living Resources Committee who will parent the Group. Its conclusions would also be disseminated to the relevant assessment Working Groups.

Supporting information:

Priority:	The work is essential if ICES scientific advice to fisheries management customers is to be based on credible and defensible biological and environmental grounds. The continued use of fixed values for many biological parameters in stock assessments must be analysed critically and with considerable urgency, given concern from customers about assessment quality.
Scientific Justification and Relation to Action Plan:	Many current stock assessments carried out by ICES assessment Working Groups use biological parameters (maturity, natural mortality, growth, sex ratios etc.) which are fixed at values estimated many years ago. For stocks where the real values of these parameters are rapidly fluctuating or have time-trends, the use of these data may be seriously compromising the reliability and utility of the scientific management advice based on them. There is a vast amount of such data available in the ICES community which is never used in assessments, mostly because assessment Working Groups have neither the time to incorporate the data nor (in general) the expertise to determine the most appropriate data to use in a given situation. The aim of the proposed SG would be to collate available data and formulate input data files for assessment models for an agreed subset of ICES stocks (with different stocks considered each year). Extensive sensitivity analyses would then be run to evaluate the magnitude and direction of the effects of using different input data and model settings in stock assessments, forecasts and calculation of biological reference points. Optimum model and data configurations would be proposed for use in subsequent assessment WGs. The principal focus should be on biological parameters and data, although environmental and ecological data could be considered if evidence for their inclusion was strong. In addition, the data-source collation work undertaken in recent years by

	scientists under the aegis of SGGROMAT (following the example of the NAFO WG on Reproductive Potential) would be continued by SGISAB. This work is invaluable in highlighting available (and unavailable) data for stocks under the ICES remit. The first meeting should commence with a brief review of assessments in which biological information has been used in the past (e.g., DFO Stock Status Reports). However, the SG should not become a review group, but should concentrate on analyses and quantitative conclusions. The issues addressed by SGISAB should be explicitly related to problems faced by assessment Working Groups, and these Groups should be solicited to provide requests for analyses to SGISAB. Assessment WG Chairs should be asked to promote the concept of SGISAB as a forum for the analysis and solution of problems related to biological information for the stocks under their remits, and to encourage suitable assessment WG members to attend SGISAB. The SG should aim to produce one or more publications based on their analyses, conclusions and advice.

8.2 Recommendations related to the estimation of condition indices

1) Information on length/age and sex ratio of the analysed sample is important when comparing condition indices. There is the risk of detecting sample differences rather than population differences if the length structure and sex ratio of the sample is unknown. The SG recommends that this information be routinely reported in assessment reports.
2) Comparison between condition and physiological indices should be performed in order to test the appropriateness of weight-length based condition indices as proxy of energy reserves. If this is not the case, the SG recommends that the suitability of others parameters (e.g., height, Richter *et al*., 2000) should be investigated to improve morphometric based condition indices.

8.3 Recommendations related to the estimation of stock reproductive potential

1) Temporal changes in total egg production appear to be more dynamic than temporal changes in spawning stock biomass. This feature of the population dynamics should be investigated further along with the implications for estimation of biological reference points and stock projections.
2) The impact of different indices of spawning stock size on the behaviour of stock/recruit relationships near the origin should be explored along with the implications for the estimation of biological reference points.
3) For many stocks little or no data exists to develop a fecundity model that can be used to hindcast age- or length-specific fecundity. A sensitivity analysis of estimates of realized total egg production to variability in the fecundity model should be undertaken. Stocks having relatively good fecundity data sets (e.g., Icelandic cod, Northeast Arctic cod, Baltic cod) could give guidance on how to model uncertainty in this term. Models incorporating maternal effects on egg quality could also be included in this sensitivity analysis.

8.4 Recommendation for meta-data collation at ICES

The inventory of data and information for estimating reproductive potential of North Atlantic fish stocks should be placed on the ICES website and maintained as a resource for use in stock assessments and research.

Supporting information:

Priority:	This Inventory is essential to the ICES Advisory Process because it identifies data that can be used to produce better indices of reproductive potential for application in stock-recruitment relationships, biological reference points and stock projections.
Scientific Justification:	SGGROMAT had the task to summarise the availability of data and information required to estimate reproductive potential for North Atlantic fish stocks. This task has been largely achieved in collaboration with the NAFO

	WG on Reproductive Potential. The resulting data inventory provides a comprehensive overview of the available data, recording the time periods, quantity, quality, format and sources of existing data, so that researchers can access the information for a given stock and locate specific data sets and published studies which are based on them. This work shows that substantial amounts of relevant data are available, but not incorporated into stock assessments. For many stocks, time series of biological parameters (e.g., weights, sex ratios and maturity) accounting for the temporal variability could replace constant values. This would permit the estimation of female-only SSB (FSSB), which is a more biologically sound estimator of the stock reproductive potential. Integration of condition and fecundity data has also significantly improved stock-recruitment relationships for some stocks. For others, data on population and individual egg production exist that can be applied to estimate FSSB using egg production methods. The purpose of the inventory in this context is to assist assessment WG in incorporating biological data and processes affecting reproductive potential in their models. The inventory is intended to be a widely used resource, which is updated regularly and can be easily accessed. Making it a part of the Inventory of Data which is maintained on the ICES website would help to achieve this aim.
Relation to Strategic Plan	
Resource requirements	Some continuing scientific input will be required to keep the inventory up-to-date.
Secretariat facilities	IT support will be required to put the Inventory on the ICES data site. It is not intended that the actual data sets will be all held by ICES, although some of them may be found within existing WG reports or trawl survey databases. Nor is it intended that ICES should handle requests for the inventorised data.
Financial	None

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APPENDIX A: SOME CONSIDERATIONS IN DEVELOPING PROCESS MODELS OF GROWTH IN COD

Keith Brander ICES, Copenhagen.

A.1.1 Introduction

The data presented here come mainly from assessment reports and are based on sampling of commercial fish stocks. This provides a very large body of data on size at age, from which growth rates can be estimated. However, the selectivity and sampling characteristics of commercial fisheries may introduce some bias, so data need to be used with care.

A.1.2 Variability in growth between and within stocks

Growth rates of cod vary considerably between stocks and also within stocks. The shape of growth curves is by no means regular (see Figure A.1); for example cod at Faroe grow quickly up to a size of about 2 kg and then slow down. North Sea cod have the same average weight at age two as Faroe cod, but subsequently grow much more quickly. The reasons for these differences are not known, but cod at Faroe spend their first two years closer to the islands and subsequently migrate offshore, where they probably experience a cooler, less variable temperature regime (evidence from otolith microchemistry) and possibly less favourable feeding conditions.

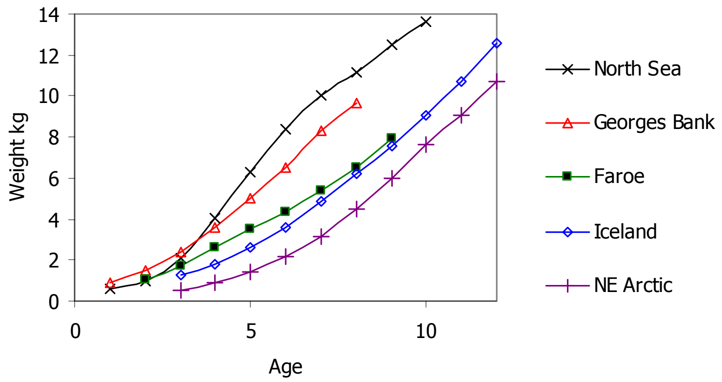

Figure A.1. Average weight at age for five cod stocks, from commercial catch sampling.

Weight at age shows short term variability and long term trends (an example, for Faroe cod, is shown in Figure 2 with evidence of cycles in growth of about 5–10 years superimposed on a long term trend which is steeper in older fish.

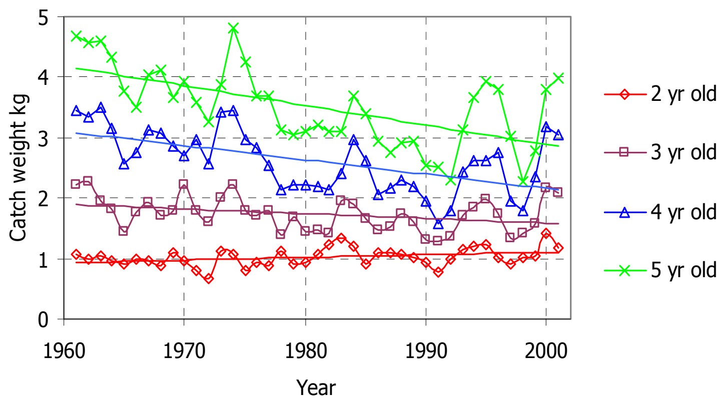

Figure A.2. Average weight at age for Faroe cod aged 2 to 5, from commercial catch sampling.

A.1.3 Why growth rate should be used rather than weight at age for most analyses

Growth rate, rather than weight at age, should be used in process models of interannual variability, because growth rate measures the change during a particular year whereas weight at age is a cumulative state variable i.e., (weight accumulates over several years).

Let weight at age a in year y = Wa,y

$W_{a,y} = fn(W_{a-1,y-1}, G_{a-1,y-1})$ (G is growth rate from year y-1 to y)

WGCCC recommended that growth rate be estimated as

$G_{a-1,y-1}=\ln(W_{a,y} / W_{a-1,y-1})/3.65$, which is close to % per day

G (growth rate) declines with size (Figure A.3) therefore it must be standardised when making comparisons – for cod and saithe the standard size used here is 2.5 kg; for haddock it is 0.5 kg. Age does not affect growth rate once the size effect is removed (Figure A.3).

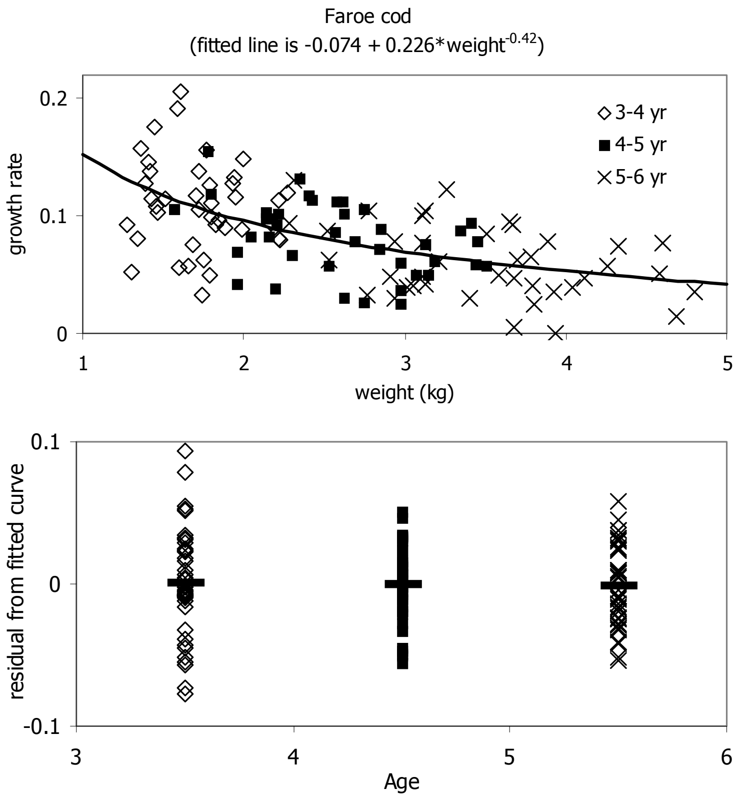

Figure A.3. Growth rate for Faroe cod as a function of weight (upper panel) and residuals from the fitted curve plotted for ages 3.5, 4.5 and 5.5 (lower panel).

The standardised (2.5 kg) growth rate for Faroe cod (ages 3–6) is just under 0.1% per day i.e., 30% per year, but it varies from about 10% per year in 1996/97 to about 50% per year in 1999/2000. Other gadoids (haddock and saithe) show similar patterns (Figure A.4).

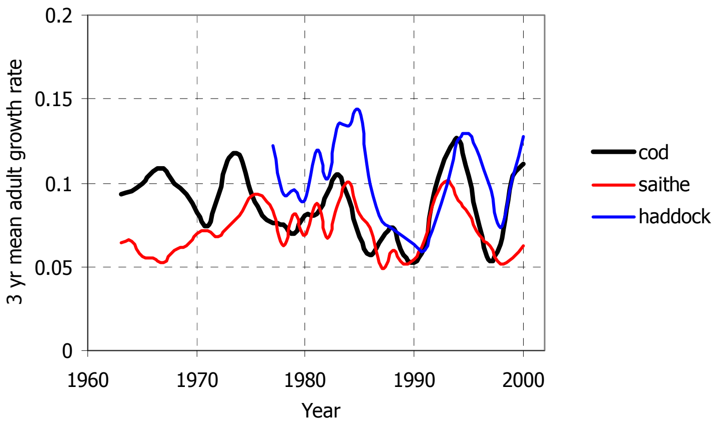

Figure A.4. Running 3-year means of standardised growth rate for Faroe cod (2.5 kg), saithe (2.5 kg) and haddock (0.5 kg).

Biological and environmental factors cause variability in growth rates, with big effects on production (Dutil and Brander 2003).

A.1.4 Process models which use weight at age may misrepresent the time dimension

Gaard *et al*. (2002) relate growth (and recruitment) of cod and other species at Faroe to plankton production (as represented by nitrate loss during spring). However this conclusion is based on averaged weight for ages 2–5, which is a cumulative measure of growth over several years. When standarised annual growth rates are used (Figure A.5) the relationship is not clear.

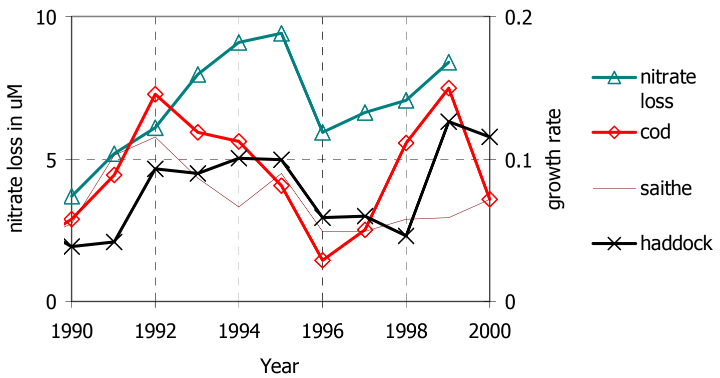

Figure A.5. Annual standardised growth rates for Faroe cod, saithe and haddock and the index of primary production from Gaard *et al*. (2002).

Mean weight-at-age of Iceland cod correlates with the biomass of the capelin stock (Figure A.6). For five and six year old cod the correlation coefficients are 0.79 and 0.72 respectively ($p< 0.0005$). Capelin stock biomass has been used as a predictor of average weight-at-age since 1991 (ICES, 2003). However this implies that the process relating capelin biomass to cod weight-at-age is more or less instantaneous. An alternative analysis using growth rates shows that growth is high during the years preceding the high capelin biomass. This suggests that the factors and processes causing high growth rates of cod and eventually high weight at age are also causing the biomass of capelin to increase. The two may thus be indirectly rather than directly causally related.

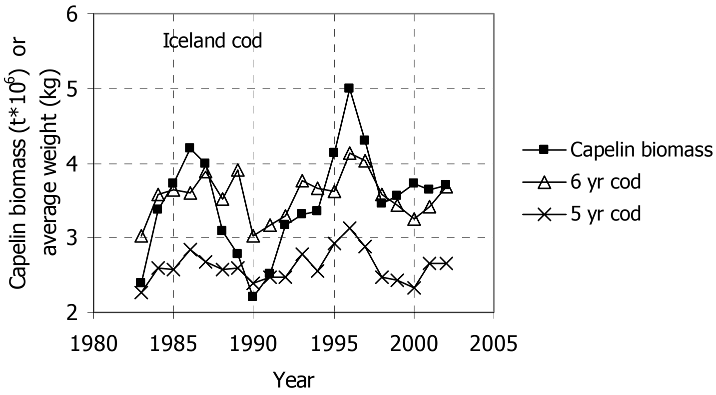

Figure A.6. Capelin stock biomass and average weight-at-age of Iceland cod ages 5 and 6. Data from ICES 2003.

A.1.5 Evidence that growth rate and recruitment are sometimes related

Cod recruitment and growth rates are strongly correlated at Faroe ($r^2 = 0.45$, $p < 0.0005$; Figure A.7)

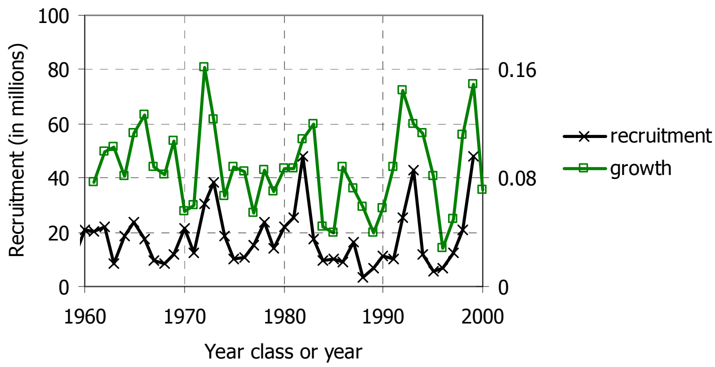

Figure A.7. Annual growth rate and recruitment for Faroe cod.

Haddock growth and recruitment is also correlated ($r^2= 0.16$, $p<0.05$), but saithe does not show a significant effect. The explanation for the correlations may be that a common factor is affecting growth of adults and larvae and that survival of larvae depends on growth rate. Recruitment and growth rates are also correlated for Iceland cod ($r^2 = 0.21$, $p<0.05$), but not for haddock or saithe.

A.1.6 Conclusions

Growth of cod may be very different in different stocks and also shows variability at various time scales within stocks. Faroe cod, for example, show rapid initial growth, but grow very slowly after they attain a weight of about 2 kg. This may be related to their ontogenetic migrations and also to maturation.

Standardised growth rates should be used to compare growth between years and across stocks. Growth rate declines with increasing size. The evidence for an effect of age is very weak (there may not be an age effect on growth rate).

Growth rates of gadoids show some common patterns of interannual variability and in some cases growth and recruitment rates are correlated.

Process models which analyse weight at age rather than growth rate when looking at interannual variability may be misleading, because weight at age is a cumulative function and depends on previous size. Even strong correlations must be given realistic explanations in terms of processes. Instantaneous changes in weight at age are inherently unlikely.

A.1.7 References

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NAFO Working Group on Reproductive Potential &
ICES Study Group on Growth, Maturity and Condition in Stock Projections

GUIDELINES TO FILL IN TABLES ON STOCK REPRODUCTIVE POTENTIAL

INTRODUCTION

The purpose of the tables is to provide an overview of available information and existing data that can be applied to estimate stock reproductive potential. Unpublished as well as published data may be available for this purpose and, by recording identified stock characteristics (e.g. stock size, maturity, fecundity, etc.) and data sources in a systematic fashion, the potential for estimating the total, realised or viable egg/larval production can be evaluated for different stocks. The tables, including information about available data and their sources will be published or listed on the NAFO/ICES web-sites so that readers, e.g. assessment Working Group members, can avail themselves of information for a specific stock and locate the origin of the information.
The tables were not designed to include actual data, but rather to reference existing data and studies published in journals, reports, etc. or to identify persons who might provide information relative to data, which may exist in national laboratories but have not been analysed or published. The file containing this information consists of five tables: 1) Data Availability; 2) Data Basis, Format and Quality; 3) Studies of Stock Reproductive Potential (SRP); 4) Data Sources; and 5) Contributors. The first table provides on a yearly scale an overview of the availability of basic data to estimate the reproductive potential of a given stock inclusive ichthyoplankton data. Table 2 provides more details about the available data and adds information about compatibility of different data sets (e.g. age-based versus length-based data) and their quality (e.g. differences in accuracy due to differences in methodology, sampling intensity, experimental design, etc.). This table includes more variables than Table 1, and some variables have been divided into sub-levels to specify different data types. Table 3 refers to existing studies that estimate reproductive potential or evaluate stock-recruitment relations. In both Tables 2 and 3, a reference number links the identified data and studies with their sources in Table 4, where the full reference to journals, reports etc. or for unpublished data, the name and address of the contact persons and laboratories is given. An additional table, Table 5, identifies the persons, who have contributed the table and the date of their submission of the tables. An example of a completed table is provided, i.e. North Sea Herring – autumn spawners.
The listed variables are intended to primarily cover aspects related to parental, environmental and anthropogenic influences on the stock reproductive potential, i.e. at the basic level estimating the total egg production, to the ultimate level of estimating the viable larvae production. The influences of e.g. the ambient environment on egg and larval survival during the recruitment process have had a lower priority but may be very important to stock-recruitment relations; options to record information of this type exist in both Table 2 and 3.

2. FILLING IN TABLES

The template file (SRP Table Templates revised 200300917.dot) is protected, and should be opened as “read only”. The file includes the tables 1-5, which consist of text and form fields indicated by shading. Only the form fields can be filled in. The tabulator function allows subsequent movement from one form field to next. The mouse allows free movement to previous fields, preceding fields and to other pages. Two types of form fields are applied, i.e. text and drop-down form fields. Numbers or text of variable length can be filled in the text fields with standard formats. The drop-down fields offer different choices, but no text can be added. A help function providing an explanatory text is available for each form field and appears when positioning the cursor on the form field and pressing F1. To obtain help for drop-down form fields, click first on the field (the form field occurs) and then on the arrow to the right before pressing F1. The help function includes generally both an explanation and an example. The example of a completed table, i.e. Herring - North Sea autumn spawners - ICES IV, IIIA and VIID, may also serve as a guide to fill in the tables. Filled-in files should be saved as a word document (default) under a name identifying the stock i.e. "Common name of species - stock - management code.doc" (as in the example: "Herring - North Sea autumn spawners - ICES IV, IIIA and VIID").

Table 1
The form fields in the header of Table 1 specify the fish species, area and stock. The latter two are applied as headers in subsequent tables, but the records should only be filled in once, i.e. in Table 1. The corresponding text boxes in Tables 2-5 will be updated automatically when using print preview, printing or closing the file. The person(s) initially reviewing the literature and creating the table should be referenced in the lower header of Table 1, and the date of finalising the tables should be included. If the tables are updated later, the name of the person(s) providing new data or reviewing the tables as well as the date should be recorded in addition.
The review of a specific stock should aim at covering all data and information that can be used to quantify the total or realised egg production inclusive ichthyoplankton data. This implies that highest priority should be given to identification of quantitative measures that can be used as parameter estimates. The review should preferably extend as far back in time as possible. In this overview table, three different options exist in the drop-down form fields. Option 1: "blank" which is default indicates that no information is available. Option 2: v is selected in the form field if proper information about a given variable is available. Option 3: (v) is chosen from the form field if e.g. no applicable estimates are available, but basic data or information exist although not analysed or published. The reason for choosing Option 3 should be specified under comments in Table 2. Correction of v or (v) entered in a form field that should be blank is made by choosing the first field in the drop down list, which is "blank". The availability of data or information about the specific variables should be recorded on a yearly basis back to 1960. If information before 1960 exists, particular years can be included or data availability can be registered on decadal basis, e.g. 1950s to record specific information about the variables.

Table 2
The form fields specifying the fish species, area and stock will be filled in automatically when the file is updated. The text fields in the header to be filled in include information about "Reproductive Strategy", "Timing of Spawning" and "Optimal Time for Maturity Sampling" as well as their references. This information is intended to provide the reader with some criteria to evaluate the data quality. The data types and analytical methods needed to estimate the total egg production and other SRP indices depend on the type of reproductive strategy. The timing of spawning is important in relation to the timing of fecundity sampling for the given species and stock. The optimal time for maturity sampling is normally during the pre-spawning period when fish that will participate in spawning will have initiated the gonadal maturation process, but before e.g. spawning migration has started.
The table: "Data Basis, Format and Quality" provides the opportunity to enter detailed information about data or studies for specific variables. The variable column lists different categories and sub-categories, which may be utilised in the estimation of the reproductive potential of a stock. The list

categories, which may be utilised in the estimation of the reproductive potential of a stock. The list is not meant to be all encompassing, but to specify the data basis, format and quality of important variables making an evaluation of the compatibility and applicability of data possible as well as identifying data sets potentially complementing each other. In the event that the listed categories do not suffice, information can be added under "Other parameters" at the end of the table – specifying under "Notes on method, sampling coverage, etc." the kind of information; if sub-categories are incomprehensive, the information can similarly be entered under the sub-category "Other". For each data source, the following information should be entered: the year range, the data basis, data origin, sampling frequency and the reference number referring to the source of the study (should be given in full in Table 4). Under "Notes on methods, sampling coverage, etc.", additional information about the particular data source can be added. The help function (F1) provides information about the data to be entered in the specific columns and form fields.

Table 3

In some cases, studies of the reproductive potential of the stock may have been performed and estimates of egg or larvae production may be available. This information should be included in Table 3. The headers will be updated automatically. The table lists different subject-related categories to include information about the reproductive potential and stock-recruitment relationships as well as about processes affecting stock reproduction and critical life stages. For each study, a brief description of its focus should be filled in as well as the year range covered and the reference number referring to its source (and provided in full in Table 4).

Table 4

This table references the sources of data or other information referenced in Tables 2 and 3. The headers will be filled in automatically as in previous tables. For each reference number applying to the studies listed in the proceeding tables, the data source should be filled in. The following system should be used (the North Sea Herring tables provide examples):

Journal papers: Names and initials of all authors, year. Title of paper. Journal name (abbreviated), volume number (issue number): first and last page numbers of the paper.

Monographs: Names and initials of all authors, year. Title of the monograph. Publisher, location of publisher.

Edited volume papers: Names and initials of all authors, year. Title of paper. In: Names and initials of the volume editors (eds.), title of the edited volume. Publisher, location of publisher, first and last page numbers of the paper.

Conference proceedings papers: Names and initials of all authors, year. Title of paper. Name of the conference. Publisher, location of publisher, first and last page numbers of the paper.

Unpublished theses, reports, etc.: Names and initials of all authors, year. Title of item. All other relevant information needed to identify the item (e.g., technical report, Ph.D. thesis, institute).

Unpublished data: Name and initials of contact person, affiliation, and postal address.

If the number of references exceeds 50, additional rows are available to fill in reference numbers and references. It is possible to fill in more than 1 reference per row.

Table 5

This table identifies the persons, who have contributed with information referenced in Tables 1-4. The headers will be updated automatically. For each contributor the full name and affiliation including postal address should be filled in as well as the date of submission of the tables. If more contributors created the first version or updated tables in collaboration, their names can be listed below each other under the same date.

Filled in tables
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We thank you for your contribution.

APPENDIX C: EXAMPLE OF FILLED IN TABLES ON STOCK REPRODUCTIVE POTENTIAL

NAFO Working Group on Reproductive Potential &
ICES Study Group on Growth, Maturity and Condition in Stock Projections

INFORMATION ON STOCK REPRODUCTIVE POTENTIAL

TABLE 1: DATA AVAILABILITY *(press **F1** on form fields for help)*

COMMON NAME:	HERRING	**SPECIES:**	*Clupea harengus*
AREA:	NORTH SEA (ICES IV, IIIA AND VIID)	**STOCK:**	NORTH SEA AUTUMN SPAWNERS
ENTERED BY:	MARK DICKEY-COLLAS 2003-07-10	**LAST UPDATE:**	PETER MUNK 2003-05-09

Data availability									
Year	**Stock size**	**Stock composition**	**Age**	**Weight**	**Condition**	**Sex ratio**	**Maturity**	**Fecundity**	**Egg/larval abundance**
2005									
2004									
2003	√	√	√	√	√	√	√		√
2002	√	√	√	√	√	√	√		√
2001	√	√	√	√	√	√	√		√
2000	√	√	√	√	√	√	√		√
1999	√	√	√	√	√	√	√		√
1998	√	√	√	√	√	√	√		√
1997	√	√	√	√	√	√	√		√
1996	√	√	√	√	√	√	√		√
1995	√	√	√	√	√	√	√		√
1994	√	√	√	√	√	√	√		√
1993	√	√	√	√	√	√	√		√
1992	√	√	√	√	√	√	√		√
1991	√	√	√	√	√	√	√		√
1990	√	√	√	√	√	√	√		√
1989	√	√	√	√	√	√	√		√
1988	√	√	√	√	√	√	√		√
1987	√	√	√	√	√	√	√		√
1986	√	√	√	√	√	√	√		√
1985	√	√	√	√	√	√	√	√	√
1984	√	√	√	√	√	√	√	√	√
1983	√	√	√	√	√	√	√		√
1982	√	√	√	√	√	√	√	√	√
1981	√	√	√	√	√	√	√		√

1980	v	v	v	v	v	v	v		v
1979	v	v	v	v	v	v	v		v
1978	v	v	v	v	v	v	v		v
1977	v	v	v	v	v	v	v		v
1976	v	v	v	v	v	v	v		v
1975	v	v	v	v	v	v	v		v
1974	v	v	v	v	v	v	v		v
1973	v	v	v	v	v	v	v		v
1972	v	v	v	v	v	v	v		v
1971	v	v	v	v	v	v	v		v
1970	v	v	v	v	v	v	v		v
1969	v	v	v	v	v	v	v		v
1968	v	v	v	v	v	v	v		v
1967	v	v	v	v	v	v	v		v
1966	v	v	v	v	v	v	v	v	v
1965	v	v	v	v	v	v	v	v	v
1964	v	v	v	v	v	v	v	v	v
1963	v	v	v	v	v	v	v		v
1962	v	v	v	v	v	v	v	v	v
1961	v	v	v	v	v	v	v	v	v
1960	v	v	v	v	v	v	v		v
1959	v	v	v	v	v	v	v		v
1950s	v	v	v	v	v	v	v	v	v
1940s	v	v	v	v	v	v	v		v
1930s	v	v	v			v	v	v	
1920s	v	v	v						
1910s	v	v							v
1900s	v	v							
1887								v	

TABLE 2: DATA BASIS, FORMAT AND QUALITY

COMMON NAME: HERRING

AREA: NORTH SEA (ICES IV, IIIA AND VIID)

STOCK: NORTH SEA AUTUMN SPAWNERS

REPRODUCTIVE STRATEGY: SYNCHRONOUS DETERMINATE TOTAL SPAWNER — **REF. NO.:** 20, 33, 22

TIMING OF SPAWNING: AUTUMN/WINTER — **REF. NO.:** 24

OPTIMAL TIME FOR MATURITY SAMPLING: AUG/SEP — **REF. NO.:** 5

Data basis, format and quality						
Variables	**Year range**	**Data basis**	**Data origin**	**Sampling frequency**	**Notes on method, sampling, coverage, etc.**	**Ref. No.**
Stock size:	1903-1972 1961-2002 1989-2003	AL LWA LWA	CL CL, S S	M M SUMMER	VPA - annual estimates ICA - annual estimates Acoustic - calibrated	2,26 1 1
Stock composition:	1903-1972 1961-2002 other issues	LA LWA	CL CL, S	M M	Cohort analysis - annual ICA - annual estimates	2 1 4,21, 22,6,31
Age determination:	1930-1972 1960-2002	LA LWS	CL CL, S	M JUN-DEC	Otoliths Otoliths with regular exchanges	2, 28 1
Weight:						
A. Round weight	1920-2003 1950-2003 1980-2003	SAL SAL SAL	CL CL S	M M Q3	Individual weights Individual weights Acoustic, individual	28 30 1,29
B. Gutted weight						
C. Estimated weight	1960-2003	AL	CL	Q	Annual L/W relationships by area	29
D. Other						
Condition and energy indices:						
A. Morphometric (K, Kn, etc.)	1920-2003 1950-2003 1980-2003	SLWA SLWA SLWA	CL CL S	M M Q3	Individual sampling, K Individual sampling, K Acoustic survey, individual sampling, K	28 30 1,29
B.Physiological (HSI, GSI etc.)						
C. Biochemical (lipids, proteins, etc.)	1956-1957	SWLA	CL	M	Study of protein and fat metabolism and allocation	36
D. Other (parasitism, etc.)						

Sex ratio:	1940-2002 1980-2002	LWA LWA	CL S	M SUMMER	Landings Acoustic surveys	28, 30 29
Maturity:						
A. Ogives or spawning prob.	1935-1971 1955-1961 1955-1973 1960-2002 1980-2003	LA LWAS LA LWA LWA	CL CL CL CL S	Q3 Q3 Q3 Q3 SEP	AL Macrosc., AL-mat key Macrosc., AL-mat key Macrosc., AL-mat key Macrosc., AL-mat key	19,13 35 5 1,28,30 1,29
B. First time spawners	1903-1972 1960-2002	LA LWA	CL CL	A A	Macrosc. AL-mat key Macrosc. AL-mat key	2 1
C. Skip of spawning						
D. Other						
Fecundity:						
A. Potential total fecundity	1887 1933 1950-1953 1954-1957 1954-57, 1964-66, 1957-1958 1961 1962, 1965-1966 1982 1984-1985	L L AL ALW ALW ALW AL ALW L AL	L CL CL CL CL CL CL CL S CL	(Late summer all)	Mostly length-based with some weight, coverage good in most cases. No year effects detected, age effect found by some (older fish less fecund relative to length)	14 16 27 15 19 17,18 13 12 11 32
B. Batch fecundity						
C. Atresia						
D. Other						
Egg/larval abundance:	1903-1905 1964-1975 1953-1971 1958-1973 1960s 1972-2003 1976-2003	Early larval stages larvae ½Y	S S S S S S S	A A A A A A A	National ichthyoplankton surveys of various areas of the North Sea at hatching time Int. co-ord. since 1972 Int. co-ord. survey - directed to larvae ½ year	25,34 7 8 3 39 1 23
Spawning:						
A. Population spawning period	1910, 1970-2003 1950s- 1990s	Egg/larvae? gonadal maturity	S CL	A M	Ichthyoplankton surveys, good coverage Based on targeted fisheries	25,7,8, 3,1 24,31,3 7
B. Individual spawning period	1960s	SL	CL	A	Many fisheries target spawning events so coverage is good	20,33
C. Spawning frequency						
D. Other						

Egg viability:						
A. Egg quality	1964-1966 1984-1985	ALW AL	CL CL	Q3-4 Q3-4	Egg size and weight Egg size and weight	19 32
B. Fertilisation success						
C. Egg mortality	1955-1956	Density	EW	Wild obs	Mortality of eggs in mats	40
D. Other						
Larval viability:						
A. Hatching success						
B. Larvae quality	1987-88 1995 1993-1994	Env. parents & env. parents & env.	S EC EC	4 single occassions 512 larv. 1 single exp. 398 larv. captive, single occassion	Sample size: 100s, Spatial growth diff. Sample size: 100s, effects on otoliths Samples size 100s, hieracy of larvae and effect on population	42 44 41
C. Mortality						
D. Other						
Other parameters:						

TABLE 3: STUDIES OF STOCK REPRODUCTIVE POTENTIAL

COMMON NAME:	HERRING
AREA:	NORTH SEA (ICES IV, IIIA AND VIID)
STOCK:	NORTH SEA AUTUMN SPAWNERS

Studies of stock reproductive potential (SRP)			
Subject	**Brief description**	**Year range**	**Ref. No.**
Estimated potential egg production:	Egg production estimates with worries about first time spawners.	1950-1964	31
Estimated realised egg production:	Larval survey of Downs herring.	1951-1972	8
Estimated viable egg or larvae production:	Larval production in relation to temperature.	1951-1972	8
Existing SRP indices:	From larval abundance to spawning potential using fixed fecundity.	1951-1972	8
Parental influences on SRP:	Differences in survival and growth of offspring originating from different spawning areas utilised by different stock components.		46

Environmental influences on SRP:	Larval production in relation to temperature Larval growth to juvenile based on temp, food and density dependent effects	1951-1972 1960-1980	8 24
Anthropogenic effects on SRP:			
Stock-recruitment relationships:	Linear SSB to recruit relationship in some components Different recruitment patterns in components of stock Recruitment strengths Paulik diagrams	1940-1985 1950-1970 1967-1981 1977-2002	6 38, 43 10 9
Critical life stages:	Larvae to metamorphosis	1950-2002	9, 31
Other studies:	Studies of reproductive strategies of herring Conservatism in herring	1960-1990 1960-1990	22 45

TABLE 4: DATA SOURCES

COMMON NAME:	HERRING
AREA:	NORTH SEA (ICES IV, IIIA AND VIID)
STOCK:	NORTH SEA AUTUMN SPAWNERS

Data sources
Reference number and literature citation or for unpublished data the contact person
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28.	Unpublished data: Dr. Beatriz Roel, CEFAS Lowestoft Laboratory, Pakefield Road, Lowestoft Suffolk NR33 0HT, UK.
29.	Unpublished data: Dr John Simmonds, FRS Marine Laboratory, PO Box 101, 375 Victoria Road, Aberdeen, AB11 9DB, UK.
30.	Unpublished data: Dr. M. Dickey-Collas, RIVO, P.O. BOX 68, 1970 AB IJmuiden, The Netherlands.
31.	Cushing, D.H. and Bridger, J.P., 1966. The stock of herring in the North Sea, and changes due to fishing. Fishery Investigations, London, Ser. II, 25 (1): 1-123.
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47.	
48.	
49.	
50.	

TABLE 5: CONTRIBUTORS

COMMON NAME:	HERRING
AREA:	NORTH SEA (ICES IV, IIIA AND VIID)
STOCK:	NORTH SEA AUTUMN SPAWNERS

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