Report of the

Study Group on Growth, Maturity and Condition in Stock Projections

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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, Norway) met at ICES Headquarters from 5−10 December 2002 to:

a) summarize the availability of data on weights, maturity, condition, fecundity, and age-length and length-weight keys for stocks in the North Sea, Irish Sea, Barents Sea and Baltic Sea in the form of standardized tables;

b) develop process-based growth, maturity, condition and fecundity models for a subset of the stocks in a);

c) implement process-based models in a new projection methodology and compare the results to the methodology currently used;

d) agree on an intersessional programme to apply the findings of the Study Group.

The SGGROMAT report will be available by 10 January 2003 for perusal by the Resource Management Committee (who will parent the Group), along with the Living Resources, Oceanography, and Baltic Committees, and ACFM. The report will be brought to the attention of the Working Group on Methods of Fish Stock Assessments (WGMG) to be held in late January 2003.

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. They are of particular importance in the present situation for two main reasons. Firstly, it is highly probable that the current state of fish stocks throughout the ICES and NAFO areas will lead to stringent management measures, either via fishery closures or a combination of severe effort limitation and technical measures. Either way, fishing effort should only be allowed to return to higher levels if it can be shown that such levels are sustainable in the medium-term (which for this purpose we define to be ten years). Secondly, it would appear that the EU are giving serious consideration to the implementation of multi-annual TACs, principally because of the economic benefits of stable quotas to the fishing and fish processing industries. In order to set multi-annual TACs, there needs to be some indication of the likely future performance of the stock under the level of fishing mortality which the TAC would imply. Thus, medium-term projections will be a key component of fisheries management for the foreseeable future.

Given this, medium-term projections need to be made as biologically realistic as possible. Current ICES projection methodologies (e.g., WGMTERM, ICP) do not take account of biological processes, to the extent that weights, maturity and proportion female are all assumed to be constant or vary in a random manner. These assumptions can seriously degrade the quality of stock projections. Furthermore, recruitment is generally modelled as a function of spawning-stock biomass (male and female), which may be a poor proxy for reproductive potential. Existing knowledge about processes influencing growth and reproduction for individual stocks is not incorporated into the projections. It is

currently unclear what form models for growth should take (e.g, age- or length-based). Assessment WGs rarely have sufficient time or resources to devote to either data collation or model development, and this hinders progress in implementing growth models in the new projection software. A major impetus for SGGROMAT has been to facilitate the creation of better tools for assessment Working Groups to use in medium-term stock projections.

The motivation for SGGROMAT came from the activities of the recently-concluded Study Group on Incorporation of Process Information in Stock Management (SGPRISM). SGPRISM identified a clear need to re-direct the formulation of scientific advice away from simple stochasticity and towards an increased level of biological realism. The aim of SGGROMAT was to address these issues. The SG was not instigated as a data collation exercise *per se*. Rather, the intention was that the availability of relevant data would be summarised in tabular form for a broad range of ICES stocks (ToR a), as has recently been done for stocks in the Northwest Atlantic by the NAFO WG on Reproductive Potential. For a subset of these stocks process-based models describing biotic and/or abiotic influences on maturity, condition, fecundity, and recruitment were to be developed for specific application to stock projections (ToR b). The SG would examine the implementation of such models in the new projection software for selected stocks (ToR c). Lastly, the SG would evaluate the potential for broader application of both the software and the modelling approaches in standard assessment protocols (ToR d).

It was essential for work of this kind that a high degree of focus be maintained on the production of *deliverables* for the fisheries advisory process. In order to be useful and relevant to fisheries management, biological process models must be plausible and well-supported by data. Thus, it is important that the SG bridge the gap between current assessment methodology, which may be restrictive, and some of the extant process-modelling work, which may in time be highly beneficial but which is not yet in an implementable state. The SG did not necessarily intend to determine whether the incorporation of a given process would make a significant difference to subsequent management advice, as this is a question best left to sensitivity analyses performed intersessionally in preparation for subsequent meetings (although see Section 5.10). However, what was important was that each potential proposed process should be supported by:

- hypothesised causal mechanisms (i.e., why and in what way the process would affect the particular population characteristic);

- a proposed model and model-fitting methodology;

- actual data on which to base further work.

In preparation for the meeting, analyses were performed modelling condition and fecundity in Northeast Arctic cod (see Section 2.1). This work has been implemented in a software suite consisting of three programs (StockAn, RecAn and MedAn), a demonstration of which was presented to the Group (see Section 2.17 and Section 12). Further implementations presented to the SG were Gadget (see Section 2.15 and WD 1), Stocobar (see Section 2.18 and WD 4), and a spreadsheet-based medium-term projection of Baltic Sea cod (see Section 5.10).

1.4 Structure of the report

Section 2 of the report presents abstracts (and summaries of subsequent discussions) for each of the presentations made to the SG. Section 3 addresses ToR a), looking at summarising data availability. Section 4 presents a record of several process modelling analyses, intended to address ToR b). Section 5 pertains to ToR c), and contains a series of discussions on aspects of forecasting methodology which will have to be considered when implementing software. Sections 6–9 contain conclusions, links to other groups, recommendations and references, respectively. Finally, the appendices present an overview table of stocks to be included in the data collation exercise along with outputs from software currently under development (StockAn and RecAn).

2   PRESENTATIONS AND WORKING DOCUMENTS

2.1 Marshall and Needle: Case study on modelling growth, maturity and condition in north-east Arctic cod

Abstract

The relatively comprehensive time-series data on growth, maturity and fecundity that are available for Northeast Arctic cod allow alternative indices of reproductive potential to be estimated over the time scale of the assessment (1946–2001). Because reproductive traits for this stock are length- rather than age-dependent, a length-based approach was used to estimate total egg production. The VPA numbers-at-age were converted to numbers-at-length using the age/length keys (ALKs) developed from Russian and Norwegian sources. These length-based estimates of cod abundance were then coupled to year-specific models for proportion female, proportion mature, weight, and fecundity at length. The models for proportion mature and weight models were derived from the maturity and weight data used in the assessment. Because of this basic equivalency, differences between SSB and total egg production were introduced through differences in the basic formulation (e.g., sex ratio, fecundity). Preliminary estimates of total egg production show that the relationship between SSB and total egg production can be divided into two time periods at 1980. Prior to 1980 the spawning stock was characterized by long lean females, whereas after 1980 females were shorter and heavier. Faster growth and improved condition (i.e., weight at length) in the latter time period resulted in higher maturation rates and higher fecundities at length. Thus, the shift in size composition of the stock towards shorter females was compensated for by the increased growth and maturation rates. Density-dependent growth and improved feeding conditions are one possible explanation for the dramatic change in growth of the stock. However, the possibility of artefacts in the data series should also be explored in future.

Discussion

The WD provoked a lively discussion on a range of aspects. The features seen in the north-east Arctic (NEA) cod data, such as changes in sex ratios and the preponderance of males at smaller lengths in surveys, have also been observed in other cod stocks with which SG participants have experience, so it was felt that the modelling approach taken in the case study might well have a wider applicability. The point was raised that there is likely to be a difference in sex-ratio data (as with many other metrics) between survey and commercial data – this is indeed the case for NEA cod, and the post-1980 sex-ratio data will have to be revisited intersessionally because they were based on very noisy survey sources only. A major lack in the current analysis was highlighted, namely the emphasis on year effects as opposed to cohort effects in the variables modelled. For the implementation to have broad applicability, both will have to be available (for example, cohort effects are likely to be required for modelling growth in North Sea cod). One potential approach would be to model lengths as a cohort effect and fatness (or relative condition) as a year effect, but this is something to remains to be addressed. For many stocks weight information is not available from surveys, while fecundity data are even more difficult to obtain, and ways to model growth and reproductive potential in the absence of such information will have to be considered if the eventual modelling tool is to be sufficiently inclusive. Much of the effort expended into setting up the necessary models for a particular stock would be taken up with trying to circumvent the inevitable data inconsistencies.

The reliance on length-based modelling was questioned, but was justified by the hypothesis that length variation is likely to be more informative than age variation in a relatively slow-growing stock such as NEA cod. The projection methodology that has been envisaged uses age-based population state variables as accounting devices to track stock dynamics through time, while within each annual time-step, process modelling is done on the basis of length. In this way, both age and length based approaches can be retained.

The condition index in the NEA cod case study was obtained by fitting a global weight/length relationship, and then calculating ln(observed weight/global model weight) for each particular length in each year. This is therefore a relative condition index which does not scale with length – however, it was pointed out by the SG that an appropriate index for certain stocks (e.g., haddock) would have to do just that. One thing that is currently lacking is a comparative analysis of fish condition in general – looking at the reason why, for example, that cod in the Gulf of St. Lawrence have a much lower level of condition than NEA cod. In some instances, a simple condition index based on weights may have very little explanatory power, in which case more sophisticated indices (such as liver lipid content) may be more useful *if* they can be obtained. However, given this caveat, the fact remains that data on weights and lengths are nearly always available (even if the former in particular may be measured very differently in different situations), so the relative condition index presented in the WD is tractable from a fisheries management point of view.

Finally, it was noted that the new reproductive index based on total egg production yields a stock-recruit relationship which is functionally highly similar to that based on spawning-stock biomass. This is principally due to a desire to

maintain comparability with previous approaches, so that the only new piece of information used is proportion female. In promoting new models of this type, a step-wise approach is always likely to stand a better chance of being widely accepted than wholescale changes.

2.2 Tomkiewicz: Review of available information for estimating reproductive potential of demersal fish stocks in the Northwest Atlantic, and extension to the Northeast Atlantic

Abstract

The NAFO Working group on Reproductive Potential has 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. These tables were used to review the available information for 42 commercially exploited Northwest Atlantic fish stocks comprising gadoids, flatfishes, redfishes and grenadiers. Population parameters, such as stock size and composition estimates, often existed for three or more decades. Information about fish age, maturity and weight, as well as sex ratios, was also extensive, often allowing for establishment of variable time-series of spawning stock biomass and female spawning stock. However, possibilities for estimating stock potential egg production (PEP) were constrained by scarcity of fecundity data. Records of fish condition that might be useful in establishing fecundity models were limited in earlier times, but have increased in recent decades. Data quality generally was high also in the past, which favours potential incorporation of existing information. A data richness index, combining information about data quantity and quality, ranked most gadoid stocks as data comprehensive with a high proportion of stocks possessing some fecundity information. Flatfish stocks mainly were moderately data rich due to slightly shorter time series, while redfish and grenadiers largely were data restricted. The probability of published studies relating aspects of reproductive potential with parental characteristics or recruitment increased with increasing stock data richness, but prevalence was generally low. Thus, data seem available for considering natural variability in more parameters, which could be used to improve spawning stock estimates or to develop alternative indices, whereas establishment of egg production time series or more advanced SRP indices requires fecundity studies.

Discussion

The work of the NAFO Working Group on Reproductive Potential in collating data-availability tables for NAFO stocks was highly commended by the SG. The methodology used in this work looks extremely sound, and work such as this on ICES stocks would produce an invaluable resource for many different purposes, not least of which is the work of this SG – thus far only six ICES stocks have been included in the analysis. Of particular interest are the graphical summary diagnostics, showing that condition and fecundity are the aspects on which least as been done The task list adopted by the NAFO WG would also be able to be used as a task list for the SG subgroup devoted to ToR a) on data collation.

2.3 Kraak: Dutch data sets on North Sea plaice

WD 7: Kraak, S. Dutch data sets on North Sea plaice.

Abstract

I described a collection of three data sets on Dutch North Sea plaice that were collated by RIVO.

I. Sex ratio of plaice in the Dutch landings since 1957.

This data set is a spreadsheet containing the numbers of females and males by age (1–15) by year (1957–2001) in the Dutch landings (which comprise 45% of the North Sea plaice).

II. Maturity, age, length, weight of female plaice since 1957.

Data on female plaice were collected in the Dutch market-sampling programme that has been carried out since 1957. Collection of market samples is stratified according to geographical areas and to the four market-size categories used in the Netherlands (27–34 cm, 34–38 cm, 38–41 cm, and >41 cm). Of each area and each category, 20 plaice individuals were sampled at random on a monthly basis. The total market sample consists of 142,614 individual fish of which the date of landing and the position of the catch, length (mm), weight (g), sex, maturity stage (1–7), and age (years) were determined. The spreadsheet contains a sub-sample of 38,182 individuals consisting of females that were landed in the first quarter of the year (only in this period maturity stages of female plaice can be identified well) in the southeastern North Sea (51º-56ºN and east of 2ºE, and 51º-53.5ºN and 1º-2ºE; time of maturation varies with latitude); 20,686 of

these females are 6 years of age or younger (at age 7 all females were mature). A SAS-code is available to calculate maturity ogives per cohort and age-length group.

III. Back-calculated lengths-at-age of 2884 individual female plaice from otoliths.

The length-at-age was estimated by relating the proportion of the distance between growth zones relative to the total size of the otolith, to the length of the fish when it was caught. The 2884 individuals were caught at age 2 to 31 years old, between 1933 and 1999, and represent year classes 1921 to 1996. The lengths-at-age can be used to calculate yearly length increments and/or somatic growth. Discontinuity in growth, corresponding to maturation, can be investigated with these data as well.

Discussion

The SG discussion included the following general points. The spatial distribution of sampling for maturity can introduce bias into the resultant maturity ogives, and the best situation appears to be the presence of both survey and commercial information. The NAFO WG on Reproductive Potential felt that commercial sources were of poorer quality, although for some species the reverse could be true. In the case of the Dutch datasets, spatial coverage appeared to be good.

2.4 Kraak: Other Dutch data sets

WD 8: Kraak, S. Other Dutch data sets.

Abstract

This document is an overview of the data available at RIVO. The table shows per species per year and per sex the numbers of individuals for which data are available and for which maturity data are available. The rough data (representing more than 1.2 million individuals, for more than 800,000 of which maturity data are available) consist of recordings per individual of length, weight, sex, and maturity (if available). These data can be used for rough analyses but not yet for final analyses, because, for example, the weights have not been adjusted according to whether the fish are gutted or not, and the data should still be checked first. The data will be made suitable by RIVO; this task will hopefully be finished in a few months.

2.5 Heino: Establishing growth indices in fish stocks: application to Northeast Arctic cod

WD 6: Heino, M., Vinje, F., Dieckmann, U. and Godø, O. R. Establishing growth indices in fish stocks: application to Northeast Arctic cod.

Abstract

Adequate measures of individual growth are necessary for an understanding of the dynamics and ecology of fish populations. In this paper we develop and evaluate various methods of calculating age-specific and age-nonspecific indices of length increment in fish stocks, utilizing data on Northeast Arctic cod (*Gadus morhua*) in the period 1932–1998. We calculate growth indices for different life history stages: juveniles, maturing cod (caught as first-time spawners) and mature cod (caught as repeat spawners). Cumulative growth index provides a way to establish growth index for juvenile cod for the time period where no representative measures of juvenile cod exist (prior to 1974), with the cost that information on year-to-year variations in growth is lost. Growth of repeat spawners was substantially lower than growth of maturing cod, which was slightly lower than growth of immature cod. Among cod of the same life history stage, older fish had higher growth than younger fish. The methods proved to be suitable for revealing long-term changes in growth rates. Cod growth rates fell in the late 1930s and increased from the end of World War II to early 1970s. Growth fluctuated widely in the 1980s and 1990s, with a distinct drop accompanying the collapse of the capelin stock in the Barents Sea in the mid-80s. The combination of an age-nonspecific averaged cumulative index and an age-nonspecific averaged repeat spawner index proved to be sufficient to relate the history of changes in growth rates in the period studied. Correlation analyses indicate that cod growth rates have been influenced by climatic changes in the Barents Sea, its own population size (that is, growth is density-dependent), and capelin abundance.

Discussion

The method presented in this paper was thought by the SG to show good examples of drivers of changes in growth, and it would be very interesting to compare these with the fitted parameters in models demonstrated for NEA cod. Several further developments were suggested: biomass drivers could be refined in various different ways, according to feeding behaviour; and the exercise of investigating drivers of changes in growth is certainly worth repeating for different stocks.

2.6 Blanchard and Bell: Spatial and temporal changes in growth and condition of Celtic Sea and North Sea fish stocks

Abstract

The objectives of this preliminary study were to evaluate the availability of growth and condition data collected from Celtic and North Sea surveys. These data were then investigated for evidence of spatio-temporal patterns.

The number of individual length, weight and age measurements collected from English Celtic Sea Surveys over the 1983–2001 period was summarised for several Celtic Sea fish stocks. Data for cod and megrim were considered to have the best temporal and spatial coverage out of the stocks considered. These stocks were evaluated for temporal and spatial differences in growth and condition by using generalized linear and generalized additive models. Both linear and explicit year effects as well as the effects of longitude, depth and the interaction between longitude and depth were evaluated on both condition (predicted log(weight) at 45cm) and growth (length at age).

The apparent inter-annual variation in condition was not statistically significant for these stocks. Furthermore, no statistically significant spatial differences were detected. Changes in growth for megrim (at age 7) and cod (at age 3) were not temporally significant but a nonlinear interaction model that included longitude and depth revealed that growth was higher in shallow coastal areas for both cod and megrim. Also for cod, deeper shelf-edge areas corresponded with larger sizes at age. Further analysis will include testing whether spatial effects in growth are driven by maturity and various other factors and the quality of length-weight measurements will be evaluated.

Preliminary investigations into spatio-temporal differences in mean weight at age of cod, haddock, plaice and whiting were made using maps and broad spatial scale statistical models with data from the 3rd quarter IBTS (English data). This work will continue and be extended to use quarterly individual-based data.

Discussion

The spatial differences that were described were from a single year. Oceanographic processes such as the location of fronts could have influenced the spatial patterns that were observed (e.g., inshore and offshore differences). Spatial gradients in condition and size composition have also been noted in the Mediterranean with better condition being observed in the inshore, shallower waters. The splitting of the analysis into immature and mature individuals could possibly be considered. The timing of the survey was around spawning, and it is likely that this influenced the observed patterns in condition. The comparative analyses might be better carried out on the basis of three areas (coastal, central north and central south), as these are more relevant to physical conditions than the two areas currently used (north and south).

2.7 Dickey-Collas: Trends in maturity of Irish Sea stocks (cod, whiting, haddock and herring)

WD 3: Dickey-Collas, M., Armstrong, M. J. and Gerritsen, H. D. Trends in growth and maturity in Irish Sea cod, whiting, haddock and herring.

Abstract

The working document summarised recent studies of growth and maturity of fish in the Irish Sea from surveys and the sampling of commercial landings. Fish surveys have been conducted by DARD since the early 1990s. The maturity and sex ratio of cod at time of spawning exhibited region variation, dependent on proximity to spawning areas. Maturity in cod was age based with no 1 years and all 3 years mature. Interannual variation occurred in two-year-olds. There was no major change in proportion mature in the 1990's compared to the 1970's. The sea temperature of the previous year was significantly correlated with the proportion of age two females that were mature and the growth rate of one and two year old fish. The rankings of the mean length of cod at age 1 by year class, remained stable as the fish aged to two and

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three, suggesting that growth in the first year largely determines the relative sizes of year classes as they age. Fish from year classes with lower abundance were longer than those with higher abundance.

The maturity of Irish Sea whiting appears to be determined differently in males and females. There was a significant relationship between length and maturity in males (L_{50} approximately 19 cm) whereas female maturity was determined by a mix of age and length. A significant negative cross-correlation (at a lag of one year) existed between sea-surface temperature and L_{50} for both sexes. Whilst the size of whiting at age has changed over the last four decades, the proportion mature in the 1990's appears similar to that in the 1950's. The proportion mature in Irish Sea haddock is largely age determined (age 1 not mature, age 2 majority mature).

The proportion mature of Irish Sea herring varies greatly between years and across ages 1 to 3. The proportion mature appears dependent on length rather than age. The size of herring at age increased from 1960 to 1975 and has decreased since and the L_{50} of herring has commensurately declined since 1980.

The high growth rates of these species in the Irish Sea compared to stocks of the same species further north, seems to lead to age, rather than length, playing an important role in the onset of maturity. Interannual variation in the proportion mature is often exhibited in one age group (e.g., female cod at age 2).

Discussion

Much animated discussion was inspired by the use in this paper of temperature as an environmental covariate (or driver) of changes in maturity and growth. The debate crystallised towards two points of view which, however, differed in the end more in details rather than underlying philosophy. On the one hand, the laudable scientific goal of developing models which explain a large proportion of the variation in historical data led to a call for the incorporation of temperature and the like as direct or indirect environmental drivers. On the other hand, the requirement for fisheries stock assessment to generate medium-term forecasts suggested that a reliance on such drivers (for which a causal relationship with fish stocks can be hard to determine, and which are themselves difficult to forecast) might be misplaced, or that the limited resources available might be better utilised in the first instance in modelling stock-specific aspects. The two requirements are not irreconcilable, and a compromise was reached whereby modelling using environmental variables was to be considered more closely if: a) the variables themselves were sufficiently predictable to enable forecasting over the required time-period *or* the effect of the environmental factor was sufficiently lagged that data were already available for the years thought to be important; and b) that the causal mechanisms by which the particular environmental variables affected stock dynamics were very clearly isolated. The question was left open as to whether environmental scenario modelling would be useful or confusing to fisheries managers (see also Section 5).

Regarding other aspects of the presentation, long-term trends in weight-at-age of herring have been observed due to density-dependent effects on growth. Herring only reside the Irish Sea for 3 months during the spawning period, therefore major trophic interactions occur outside the Irish Sea.

2.8 Heino: Reaction norms for age and size at maturation

WD 5: Heino, M. Estimating age- and size-dependent maturation probabilities.

Abstract

The paper deals with the concept of probabilistic maturation reaction norms, defined as the probability that immature fish matures during a given time interval and at a certain age and size (or other relevant state variables). The main advantage of the approach focusing on the maturation process is that the influence of growth and mortality variations on maturation dynamics can be accounted for in a natural way with strong mechanistic underpinning. Probabilistic maturation reaction norms can be used to project maturity ogives, and, more generally, as a part in process-based stock dynamics models.

Probabilistic reaction norms for age and size maturation can be estimated using three different kinds of datasets:

1) A sample of fish, measured for age and size and classified as juveniles, first-time spawners or repeat spawners; the last class is not needed in the analysis.

2) Two consecutive samples of fish, measured for age and size and classified as either juveniles or adults (or as immature and mature). In the case of sampling with replacement, no individual identification is required.

3) Data on individual growth and maturation histories, originating from a mark-recapture (tagging) study in the wild or an experiment with captive fish.

Of these, 3) has never been applied (to my knowledge), and 1) requires ability to distinguish first-time from repeat spawners, which is impossible or impractical in most fish stocks. Thus, method 2) is the one that probably will see the widest applicability.

Probabilistic maturation reaction norms have until now been estimated for altogether six fish stocks representing four species: Northeast Arctic, Georges Bank and Gulf of Maine stocks of Atlantic cod, Norwegian spring-spawning herring, North Sea plaice and Newfoundland American plaice. Five of these stocks show significant temporal changes, an issue that may warrant attention in medium-term projections and that warrants attention in long-term projections.

Discussion

It was pointed out to the SG that reaction norms for time to maturity are much more predictable than maturity ogives, because of the way they have been formulated, and for this reason are a tractable option for use in forecasting. Reaction norms are also suitable for cases (such as Irish Sea cod) where very rapid maturation occurs. The SG requested clarification on why changes in reaction norms in a certain direction are viewed as genetic, and in another as environmental: it appears that the former changes the norm itself, while the latter changes the point at which the norm is reached. Therefore, in theory, the way in which a reaction norm changes over time can give information on the principal causes of that change, with implications for forecasting. However, analyses are still continuing on whether such a distinction can really be made. A time-series effect might prove to be influential, given that growth in the previous year could well explain some of the variability in reaction norms.

The SG noted that the decision to mature is based not just on size, but on how individual fish are building up lipid reserves at the right time of year. Therefore condition at a critical period might have a relationship with time of maturation. For North Sea haddock, for example, this period is thought to occur in the early summer of the year prior to maturation, so it is conceivable that the suitable condition index would have prediction power for the number of fish maturing in the following year. However, this hypothesis has not yet been tested.

The WD included analyses in which first-time and repeat spawners were distinguished. This can be done through otoliths for some stocks, although not for many others, and the technique is not widely accepted.

2.9 Kraak: Trends in the age and length at maturation of North Sea plaice

Grift, R. E., Rijnsdorp, A. D., Barot, S., Heino, M. and Dieckmann, U. (2002) Fisheries-induced trends in reaction norms for maturation in North Sea plaice. ICES CM 2002/Y:04.

Abstract

This document consists of a study on time trends in the age and length at maturation of North Sea plaice. The study has been published as an ICES paper (Grift et al. 2002) and will be published in Marine Ecology Progress Series. The authors studied the decrease in age and size at maturation in female plaice, and tried to disentangle phenotypically plastic changes from evolutionary processes. It is expected that removal of large individuals from the population by selective fishing selects for genotypes with a lower age and size at maturation. The authors constructed probabilistic reaction norms for maturation, and analysed trends in the position of these reaction norms. The reaction-norm analysis suggests a picture in which short-term fluctuations originating from plastic responses are superimposed on a persistent long-term trend resulting from genetic responses.

Discussion

In a corollary to the preceding WD, Kraak showed that there may be a relationship between temperature two or three years previously, and subsequent time of maturation. If proven, this would give a lead-in time to modelling and would be extremely useful for forecasting purposes, in the short-term at least. However, the causal mechansim is still missing in this case, and would have to elucidated for the relationship to be used with any confidence. The SG noted that, in general the use of aquarium-based experimental results might be misleading in modelling wild fish stocks. The SG felt that the paper included relevant information. Predicting time to maturation and converting to maturity ogives could prove to be a useful way of predicting the latter, since it would facilitate the incorporation of biological process models in a logical and consistent manner.

2.10 Wright: Long-term variability in maturation and fecundity of North Sea haddock and its implications for reproductive potential

Abstract

The use of spawning stock biomass in stock-recruitment models has an implicit assumption of proportionality between adult biomass and total egg production. However, spawning stock biomass as a proxy for egg production has been criticised in recent years due to known size, age and condition effects on fecundity and the importance of atresia. In addition, for many ICES stocks a constant maturity at age key is applied to estimate SSB. In the present study, annual sex stratified maturity-length ogives were calculated by logistic regression using data from ICES IBTS surveys. Mature female biomass was found to vary by up to 67% for a given spawning stock biomass. Observed maturity at age data were then combined with annually derived relative fecundity at age data for six years (1976, 77, 78, 85, 96 and 99), in order to derive estimates of stock egg production. For the six year data set, annual variations in mature female biomass differed from SSB by 37% whilst egg production per SSB varied by 70%. The differences in egg production per SSB arose because of age–specific and inter-annual variability in relative fecundity. Investigations of pre-ovulatory atresia over 4 years suggested that oocyte resorption would not have led to a significant reduction in the number of oocytes released following the onset of spawning. Hence, realised fecundity should have been similar to relative fecundity measured just prior to the onset of spawning in this deterministic serial spawning species. The potential of relative condition factor (Kn) and hepatosomatic index (HSI) for predicting changes in maturity and fecundity at size was examined. The addition of Kn did not significantly improve the relationship between maturity and length. Similarly, Kn or HSI explained little of the residual deviance in the fecundity-length relationship. Nevertheless, the importance of age to relative fecundity does mean that it should be possible to forecast some of the annual variability in egg production from projections of stock age structure alone.

Discussion

Atresia was measured during a four year period during which condition varied over a large range. Atresia in haddock likely occurs midway through the spawning cycle. The fecundity analysis methods used during recent years (gravimetric and histological) were comparable to those used by Hislop in the earlier time period. Recruitment of new oocytes is complete at the time samples were collected. The main point of the presentation was that egg production can vary for the same level of SSB. It was also suggested that biomass reference points could give a misleading picture of stock status by not correctly reflecting the impact of interannual variation in the proportion of mature females and other biological variables. However, the comparison with B_{pa} and B_{lim} is not straightforward as new reference points would need to be estimated for the alternative indices of reproductive potential (e.g., female-only biomass). It would be possible to compare the fecundity/length relationships developed for North Sea cod with those developed for Scotian Shelf haddock. Maturation decisions are a two-step process with an initial decision point at relatively young ages. Timing of spawning is determined by energy allocation. Ideally, measurements of condition should be taken at several points in the seasonal cycle.

2.11 Lloret: Use of fish condition indices as indicators of habitat quality

WD 9: Lloret, J. and Rätz, H-.J. Use of condition indices as indicators of habitat quality.

Abstract

We used different condition indices to evaluate habitat quality for several exploited demersal fish species in north-western Mediterranean and Greenlandic waters. We found significant spatial differences in condition of several exploited fish species in both areas, which may be due to different environmental and fishery factors. Considering that condition affects growth, reproduction and mortality of fishes, our results suggest the existence of large and small-scale spatial differences in habitat quality that might affect productivity of fish stocks inhabiting Mediterranean and Greenlandic waters. These differences in condition are useful to determine Essential Fish Habitats and to assess the effect of reserve protection on production of exploited species. The positive relationships we found between the gonadosomatic index and length of spawners also indicate that bigger individuals have a higher reproductive potential than smaller ones. Considering that marine reserves enhance fish condition and protect the largest fish sizes (which in turn have higher reproductive potential), they might also increase the reproductive potential of individuals inhabiting therein and their recruitment into the adjacent areas. Therefore, condition indices (especially physiological and biochemical ones) can be helpful not only for stock assessment but also for the designation of closed areas / marine protected areas to preserve fisheries and their environment.

Discussion

This analysis was welcomed by the SG as providing potentially useful information on which fisheries managers could base decisions about the location and timing of closed areas. Several caveats were discussed, such as the use of latitude or depth possibly being oversimplistic proxies of the factors which are defining essential habitat in reality. This is reminiscent of the use of sea-surface temperature as a proxy for other, more pertinent environmental drivers such as wind flows or tidal fronts. The point was raised that the condition indices used to define such areas are generally very noisy, and would have to be carefully evaluated before use.

2.12 Lloret: Variation in fish condition between Atlantic cod *(Gadus morhua)* stocks, the effect on their productivity and management implications

Rätz, H.-J. and Lloret, J. (2002) Variation in fish condition between Atlantic cod *(Gadus morhu*a) stocks, the effect on their productivity and management implications. *Fisheries Research,* 1436, 1–12.

Abstract

A comparative analysis of the fish condition (Fulton's *K*) of 10 cod stocks in the North Atlantic in relation to the temperature of their habitat, growth rates and their reproductive potential is presented. It is shown that the cod stocks in the North Atlantic display different levels of mean condition, which are partly due to the different temperature regimes of their habitats. Cod living in colder waters, e.g., Greenland, Labrador and Grand Bank stocks, were found to be poorer conditioned than cod living in warmer waters, e.g., North Sea and Irish Sea stocks.

Poor condition causes reduced productivity in terms of slow growth and low recruitment potential. Better-condition stocks display significantly higher weights at age 4 than the poor condition stocks. The *a*-coefficients (the slope at the origin) obtained from standardised Ricker SSB-recruitment relationships were defined as indicators for the recruitment potential of stocks. These *a*-coefficients were found to be positively correlated with the mean condition factor of the 10 stocks analysed. This indicates that stocks consisting of poorly conditioned individuals appear to be very susceptible to reduced recruitment at low SSB, while the stocks that consist of well conditioned fish seem to behave more robust with a higher probability of good recruitment at low SSB. The positive effect of the cod condition on their reproductive potential generally implies that the well-conditioned stocks in the temperate regions of the Northeast and West Atlantic can sustain higher exploitation rates than the poorly conditioned stocks in the colder regimes of the Northwest Atlantic (Greenland, Labrador and Grand Banks). This is confirmed by the positive relationship established between the estimated biological management reference points F_{med} and the mean cod condition factors, as well as by the recent status of these stocks

Discussion

Some considerations were made following this presentation as to whether condition indices should scale with length or not, and examples were offered supporting both approaches. In early-maturing stocks, growth in length might be slowed at a relatively early age but not growth in weight, leading to artificially inflated condition indices. The SG felt that the conclusion that temperate stocks might be more resilient to exploitation was dangerous. High fecundity does not necessarily lead to high recruitment. In addition, many stocks are at such a low level that historical experience might not be much of a guide to future dynamics, although this could be levelled as a more general criticism at much of the modelling carried out in the context of stock projections. The problems inherent in the use of Fulton's *K* as an index of condition were reiterated.

2.13 Scott: Individual based egg production and reproductive output: A spatially and temporally explicit modelling tool for the exploration of state driven processes

Abstract

In this study we model daily reproductive output over an entire spawning season for a range of age/size-structured populations of Atlantic cod which are created under different stock-recruitment and fishing pressure scenarios. An individual based modelling approach is used to link empirical relationships with flexible reproductive parameters to quantify and qualify the effects that variation in individual female condition and egg quality can have on stock reproductive potential (SRP) and the temporal distribution of reproductive output within the contrasting age/size-structured populations. Spatial elements are also considered by allowing fish to aggregate and be fished at different intensities by size and by assuming that different spawning locations can give rise to different egg survival rates.

The simulation results indicate that the loss of older/larger individuals from populations that have been subjected to heavy fishing pressure, can cause the SRP to fall by 48%, shift the timing of peak spawning by 2 weeks, and shorten the spawning period by 4 weeks. This is the result when the populations are allowed to maintain a constant SSB – meaning that the change in SRP are solely due to the effect of changes in population structure. If egg quality is a function of either the size of an egg or the to spawning history of it's parent then the estimates of losses in SRP can fall by an additional 18 to 26%, respectively. In those populations that not only loose older/larger fish but also show substantial losses in SSB, the decrease in SRP can be up to 98% with a 40% decline in the length of the spawning season. The effects of egg quality are also present under these scenarios (3–5% respectively) but are masked by the simultaneous decease in older/larger fish and SSB.

Female condition can also change the SRP drastically. Within a population, if fish are in very low condition there is nearly complete reproductive failure; a drop of 93% of SRP compared to the same population with individuals in mean condition. Even just a 10% decline in condition can cause a 15% drop in SRP. When fish are in good condition (a surplus of 20% weight at any given length) the SRP can rise by 9%, compared to same population when fish are in mean condition. For any given condition factor the resulting SRP for the different relationships for egg quality does not differ by more than 8%. Condition affects alone can also move the peak date of spawning as well as truncate the spawning period by a maximum of 15 days.

When spatial issues are considered such that fish of different sizes use separate spawning sites and that different spatial locations are assigned differences for egg survival, the changes in fishing pressure (on just the medium and large sized fish) from 0.6 to 0.1 can increase the SPR up to 56.7% (a mean of 53.2% across all 6 populations). This suggests that even in heavily fished populations a reduction of fishing during the spawning season can lead to a very large proportional increase in reproductive potential and likelihood of higher recruitment.

Sensitivity analysis indicates that the SRP is most sensitive to the parameters needed in the relationship between egg size and female size. The 2nd highest ranked is the range of parameter values for the relationship between the proportion spawning per length class and date, as their values affect the temporal distribution as well as SRP. The 3rd highest ranked parameter is from the equation calculating batch size and only effects temporal output. All other parameters have very low elasticity indicating that the effects they are having are more to do with the wide range of possible parameter values (i.e., uncertainty in data) rather than being important in either SRP or temporal distributions.

Results as such supports the view that predictions of recruitment can no longer be based solely as a function of spawning stock biomass (SSB). More careful analysis of the population structure as well as annual dynamics of condition factors and exploration of functional relationships between female characteristics and egg quality are needed to assess and predict survival and the probability of recruitment levels.

Discussion

It would be possible to reparameterise the program for plaice. The most sensitive parameters with respect to the final egg production estimates were: 1) egg size/female size relationship; 2) proportion spawning; and 3) number of batches. The condition and atresia information is also critical to model predictions.

2.14 Mackenzie: Seasonal and interannual variability in condition in Baltic cod

Abstract

Long-term and seasonal variations in cod condition have been investigated as part of the STORE project. The investigations have involved identification and compilation of data sets which could be used to derive indices of condition. Potential indices that can be calculated are based on length, weight and liver weight of individual cod and include Fulton's K (weight/length^3), relative body weight (anomalies of weight from a regression of body weight versus length), and hepatosomatic indices (liver weight/body weight). A large number of datasets exist for evaluating variations in condition, but the nature (e.g., temporal and spatial coverage) and quality are not homogeneous. Data for estimating length- and weight-based condition indices are most numerous (> 50,000 observations on individual fish) and are available from both commercial fishery samples and research vessels surveys. These data have been provided by colleagues around the Baltic Sea. The commercial data are highly resolved in time, and are potentially suitable for identifying seasonal variations and delayed responses to forcing factors (e.g., prey abundance). Preliminary analyses of some of the data (e.g., those from Danish commercial catches in subdivision 25) show that Fulton's K condition index (gutted weight basis) varies significantly between and within years. K also varies significantly among length groups. These patterns were also evident for K (whole weight basis) for cod captured in the northern Baltic (subdivision 29–32) by Finnish commercial fisheries. Some of the interannual variation in K for particular length groups in the first and 2nd quarters was significantly related to indices of relative prey biomass. These findings are promising and further data

compilations and analyses will be conducted in the future. New analyses will involve comparisons with other variables (e. g., abiotic factors, food supply) and temporal and spatial comparisons within the Baltic Sea and with other cod stocks.

Discussion

The SG commended the collation in this WD of extensive sources of data on Baltic Sea cod condition. The strong relationship between relative fecundity and prey availability was noted and its suitability for use in forecasting discussed: the SG concluded that the validity of such an approach would largely depend on the forecastability of prey availability itself. Biology, stock structure and an element of manageability means that prey populations are in principal more forecastable than environmental drivers, suggesting that the immediate modelling priority should be towards biotic rather than abiotic factors. The relatively simple nature of the Baltic Sea ecosystem means that forecasts with a multispecies component are more tractable than they would be in a more complicated system like the North Sea. The diverse locations and seasons in which the extant Danish and Finnish data sources were collected makes comparison difficult, and the study would benefit from German and Swedish data. It was unclear whether the negative relationship between condition and length for cod was a statistical artefact related to the use of Fulton's *K*, or whether it pointed to a real biological effect, but the results were similar for both data sources. Further analyses will need to be carried out to determine whether medium-sized fish have the best condition because of a physiological influence, or something else; and the condition index itself needs to be re-evaluated.

2.15 Bogstad: The effect of using a length-structured model for predictions

WD 1: Bogstad, B. and Howell, D. Use of age- and length-structured models: A way of incorporating more biological knowledge in population models.

Abstract

The Gadget modelling framework was presented. Gadget is a computer program, developed within the EU project dst^2 (2000–2003). It combines mathematical models of population biology with statistical estimation techniques. Gadget allows for, but does not demand, a complex structure, the population models may be multi-species, multi-area and multi-fleet age- and length- structured models. A stock may be divided into several sub-stocks (mature/immature, female/male, juveniles/adults etc.), each with separate population dynamics. Gadget also contains inbuilt optimisation routines in order to tune model parameters to produce a model that best fits the available data from catches, surveys, stomach analyses and tagging experiments. Such optimisations will give estimates of present and past stock sizes, as well as providing starting values and parameters for use in stock projections.

Gadget allows for testing out different process-based models for growth, maturation, fishing mortality, natural mortality, fecundity, recruitment and migration. These processes may at present be made functions of e.g., length, weight, age, food abundance and temperature. Thus more biological realism may be incorporated into such population models than in traditional age-structured models. Teamwork between biologists and mathematicians/statisticians is needed in the model development, testing and implementation. Gadget has been applied to several stocks, and the Fleksibest application for Northeast Arctic cod has been used as an auxiliary model in the assessment of this stock.

Discussion

There is a general need for length-dependent population models. For example, size-dependent models permit selectivity to be investigated, and can potentially incorporate reaction norms. The implementation of the model for Northeast Arctic cod has quarterly temporal resolution and 2.5 cm length resolution. Weight/length relationships for each quarter are from Norwegian data.

2.16 Morgan: An approach to examining factors affecting recruitment.

WD 10: Morgan, M. J., Healey, B. P. and Shelton, P. A. An approach to examining factors affecting recruitment: a work in progress.

Abstract

The aim of this project is to develop improved methods of SSB estimation and choice and fitting of stock recruit (SR) relationships for use in stock assessment and projections and to better understand the biological processes behind recruitment variability. Estimates of both SSB and recruitment rely on the formulation of SPA that is used and in some

cases different SPA formulations can lead to very different views of the relationship between SSB and recruitment. Another important factor in determining the perceived relationship between SSB and recruitment is the choice of maturities. Estimating maturity by cohort will lead to a more realistic view of the proportion mature in the population. The choice and fitting of the SR relationship is another aspect that deserves careful attention. An objective approach to model choice is to use the likelihood ratio test to compare nested models for significantly different fits when additional parameters are entered into the SR model. The comparison of models with the same number of parameters is not as straightforward and is part of the future work for this project. In addition, problems have been encountered estimating parameters in some of these models. One problem in particular is obtaining different "valid" parameter estimates (i.e., the fitting software converges) from slightly differing initial conditions. It appears that these difficulties are primarily resulting from the fact that in some cases the likelihood surface is quite flat in the vicinity of the solution. An alternative to parametric SR models is the fitting of nonparametric smoothers to the data. The method can be rigorously applied by choosing a shape parameter that minimises the cross validated prediction sums of squares and the significance of the fit can be determined through an appropriate randomisation test. In the face of difficulties with model choice and with incorporating variability in growth and maturity another approach may be useful in simulations that try to account for variability in productivity and/or which are longer term. The distribution of weight at age (W), estimated proportion mature at age (P) and SPA estimates of the recruitment rate in terms of annual number of recruits per ton of SSB (R/S) can be examined. For R/S and for each age for W and P, the 10th, 50th and 90th percentiles can be determined and considered to represent low, medium and high productivity conditions (ignoring any change in M that might occur). This type of approach can be used to bracket prospects for a stock at varying levels of F and productivity.

Discussion

It was noted that residuals around the presented smoother model have not yet been investigated, largely because the smoother algorithm fails for the key American plaice stock. Regarding the smoother, the fitted line is based on parametric probability density functions and so can be extrapolated beyond the observed SSB range. The extreme uncertainty of the NAFO 3PS cod assessment was highlighted, as the example given of a stock-recruit formulation being very dependent on the assessment model used is probably one of the more extreme ones. In any case, the correct recruitment model to use is clearly very dependent on the stock in question. The point was made that the lag between spawning and recruitment in American plaice is so large (this species recruits at age five) that any underlying stock-recruitment relationship could well have become obscured by intervening events. Cohort strength models using survey data could provide another estimate of recruitment but recent changes in survey gear have made the appropriate model choice unclear at present.

2.17 Needle: Software implementations of process models for assessments

Abstract

Much of the software currently available to ICES stock assessment Working Groups is awkward to use, outdated and very inflexible. The software demonstrated in this presentation was produced in collaboration with Tara Marshall (IMR, Bergen), and has two main aims in addition to addressing ToR c) of SGGROMAT: firstly, to improve projections by assessment Working Groups; and secondly, to provide a framework in which to evaluate biological process models. The code was developed using Northeast Arctic cod as a case study, and within a Fortran-95 programming environment with a Winteracter front-end and NAG statistical and numerical library routines. The package is intended to be straightforward for assessment Working Groups to use. There are three stages or modules: historical modelling (StockAn), recruitment modelling (RecAn), and projections (MedAn). The models fitted in StockAn correspond to those outlined by Marshall and Needle (see Section 2.1), while a variety of recruitment model-fitting options are provided in RecAn. Development of MedAn has not yet commenced. The presentation also discussed some aspects of software issues, such as the conflicting requirements of assessment and process-modelling scientists, and the consequent need for parallel open- and close-source implementations.

Discussion

The SG emphasised the need for the implementation to be very robust and inclusive: the focus on length-structured data that had been appropriate for Northeast Arctic cod might not be applicable to many other stocks, for which length-structured data are absent or age-structured data are of a better quality. There does not appear to be any requirement for the software to produce estimates of precautionary reference points, as these are intended to be generated externally and at infrequent intervals, but estimates of the probability of going above or below such reference points in the future would be required. The dual-implementation approach (open-source and closed-source) was commended, since for stocks such as North Sea herring substantially different methodologies would be required and would need to be evaluated by stock assessors rather than the programme developer. The SG highlighted that a major difficulty in future

work will be the projection of age-length keys. The ARMA time-series modelling methodology was generally accepted as appropriate.

2.18 Filin: STOCOBAR

WD 4: Filin, A. A. Simulation of cod growth in the Barents Sea as an element of medium-term projection of its stock dynamics

Abstract

Two groups of models describing cod growth can be distinguished: regression and simulation models. Regression models are based on the use of statistically-significant relationships between processes and factors having an effect on them without formalising of mechanisms of such effects. Simulation models reproduce and combine, within the single functional system, different processes underlying the growth. Simulation models differ from regression ones not only in how realistic they are but also in the fields of their application, i.e., in the greater range of situations under which the model is appropriate, and so they should be more suitable for medium-term projection.

However, in comparison to regression models, simulation models of fish growth are far more difficult to apply in fisheries prediction. The main reason for this relates to the estimation of their parameters. Coefficients of equations describing fish growth and attendant processes are usually estimated from experimental studies. However, possibilities to simulate fish growth differ considerably depending on whether they are studied under natural or experimental conditions. Thus, adequate application of experiment-based models of fish growth in the practice of fisheries prediction requires the additional estimation of their parameters accounting for data observed in the wild. This approach implies that the simulation model acquires some features of a regression model.

From these grounds, the STOCOBAR model is being developed to estimate growth rate for cod in the Barents Sea on the basis of data on food supply, water temperature and abundance of cod population. All computations for cod in the model were cohort-based. The time step of the model may be set equal to one year or half a year. The model is disaggregated spatially, i.e., the processes are simulated without area differentiation. The model may include up to six species of cod prey (capelin, shrimp, polar cod, herring, as well as juvenile haddock and cod).

The model structure is not rigid but depends on the requirements of the model analysis and availability of data. Based on unified algorithms, the model may be realised in different structure modifications. The six-species variant may be reduced to the simplest modification when all prey species are taken as a single food item. In this case, cod food supply is assumed constant for the entire simulated period and changes in cod growth are caused only by variations in temperature and abundance of the cod population itself.

Discussion

The growth models were temperature dependent and Kola section temperatures were used. However, the ability to forecast temperature conditions in the Barents Sea is limited. Work by Ottersen suggests that temperature can be forecast only 6 months in advance. In contrast, capelin stock biomass is predictable 1–1.5 years in advance (see Section 5.6). A growth model developed by Jobling was used. It includes a third order term to reflect the fact there is an optimal temperature for growth in cod.

2.19 Brander: Predicting weight at age in cod

WD 2: Brander, K. Predicting weight at age in cod.

Abstract

Assessment Working Groups generally use three-year means for projecting weights-at-age (the "three-year mean" predictor). In this paper, two alternatives to this are proposed. Firstly, the mean weight of a cohort at age $a+1$ in year $y+1$ can be forecast as the mean weight at age a in year y multiplied by an estimated growth rate (the "cohort" predictor). Secondly, the mean weight at age a in year $y+1$ can be predicted by the mean weight at age a in year y (the "previous-year" predictor). The three-year mean predictor had the least explanatory power of the three methods in 10 of the 15 cod stocks analysed. The cohort predictor performed at least as well as the previous-year predictor, and had the additional advantage of being consistent (in terms of tracking year-classes) with the Working Group method of estimating numbers-at-age.

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2.20 Simmonds: Growth models for North Sea herring

Simmonds, E. J. (2001) A method for calculation of optimum mean weights at age for use in the assessments and predictions: an example using North Sea herring data. ICES CM 2001/P:22.

Abstract

Assessment Working Groups adopt different strategies for use of weights at age in the stock: measured values, running means and constant weights. The assessment of North Sea herring uses three year running mean for weights age in the stock estimated from acoustic surveys. This paper presents a study to determine the most appropriate weights at age for North Sea herring for assessment and projections, separating point variability and trend objectively. The average growth is obtained by fitting a simple exponential growth model. The structure around this growth model and the extent of the point variability is estimated using geostatistical variography on the residuals. The appropriately smoothed weights for the assessment are estimated by kriging. These are compared to bootstrap estimates of the precision of the survey data. The best method for estimating mean weight for use in the projections is explored through comparison of projected weights from data in preceding known years to obtain mean weights in the following year. The input data for this were the raw data, or the kriged estimates up to the current year. The best option is that which provides the minimum error between projected and subsequently measured estimates.

3 DATA AVAILABILITY

3.1 Introduction

ToR a) requested the SG to "Summarise the availability of data and information on weights, maturity, condition, fecundity, and age-length and length-weight keys for stocks in the North Sea, Irish Sea, Barents Sea and the Baltic Sea in the form of standardised tables". The purpose of this request is to provide an overview of available information and existing data, which can be applied to the estimation of stock reproductive potential (SRP), including some aspects relevant to modelling growth. A similar review of available data for demersal stocks in the Northwest Atlantic has been undertaken by the NAFO Working Group on Reproductive Potential (Anon., 2001). 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 and larval production can be evaluated. The overview tables may also be valuable for identifying gaps in research and highlighting where improved knowledge is needed for specific species, stocks or areas. Tables including information about available data and their sources could, for example, be listed on the ICES or NAFO web-sites so that readers can avail themselves of information for a specific stock and locate the origin of the information.

3.2 Approach

The work for ToR a) benefited greatly from the work done by the NAFO Working Group. In particular, the tables designed for collecting the information on data availability and quality as well as guidelines for filling in these tables were useful (see Section 10). The tables tabulate in a standardised fashion the availability of data and information relevant for estimating stock reproductive potential and stock-recruitment relationships. The tables were 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 records on a yearly basis the presence/absence of data for each of eight parameters important to estimating stock potential egg production: stock size, stock composition, age, sex ratio, maturity, fecundity, weight and condition. A second table indicates the origin, format and reliability of the recorded data and provides additional information about 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 final table lists the references of published data and studies or the name and address of contact persons in case of unpublished data.

The SG decided to further develop these tables and guidelines for recording the availability of data and information relevant to estimating reproductive potential. The tables were modified to be compatible with ICES areas and to include pelagic stocks, which were not considered by the NAFO WG. Tables for five ICES stocks with a comprehensive data basis, i.e., Baltic cod, Barents Sea cod, Icelandic cod, North Sea cod and North Sea haddock were already filled out by the NAFO WG and can be used for this ToR. The two latter stocks were illustrated in the most recent SGPRISM report (ICES 2002a).

The SG accordingly agreed on the following objectives of the TOR a:

- Select species and stocks to consider.
- Revise existing NAFO WG tables used to record information and guidelines for filling in tables.
- Identify contributors and document existing information on selected stocks.
- Review availability of information and existing data on reproductive potential by areas and species.

3.3 Select species and stocks to consider

The SG decided to include stocks from areas other than the four ICES areas given in ToR a), but giving highest priority to reviewing the data availability for these four areas. Including more stocks and areas will allow a broader comparison of the data availability, e.g., between stocks of the same species and different areas. Section 11 specifies the stocks according to ICES, NAFO and Mediterranean areas (Fig. 3.1–3.3) and identifies the WG providing assessment or landing data as well as chairs or contact people in the case of non-ICES stocks. The identified stocks were grouped into four categories. Category A represents assessed stocks in the focus areas (North Sea, Irish Sea, Barents Sea and the Baltic Sea). Category B represents assessed stocks in ICES areas not included in category A, whereas category C includes assessed stocks in areas outside ICES. These include pelagic stocks in the Northwest Atlantic, which were not included in the review of NAFO, as well as some assessed demersal stocks that were not covered previously. Also, selected Mediterranean stocks were included. Category D includes stocks with marginal fisheries or landings only. While the SG intends to cover category A, categories B to D rely largely on contributors volunteering to fill in tables. Similarly, stock identification emphasised bony fishes, but potential contributors can also include cartilaginous stocks. Information on growth and reproductive potential of non-fish species may also be relevant, but the parameters included in the tables may not be appropriate.

A total of 153 stocks belonging to categories A-D were identified during this meeting. In addition, a few more stocks from the USA are expected (Section 11). The stocks included gadoid, flatfish, redfish, pelagic and other stocks, with the latter primarily being demersal species. The stocks in categories C and D comprise 40 Northwest Atlantic stocks (excluding the US stocks). The work on the Northwest Atlantic stocks will be carried out in collaboration with the NAFO WG on Reproductive Potential (Chair: E. Trippel). In addition to these, the existing tables of the NAFO WG on Reproductive Potential document the data availability for 47 stocks including 15 gadoid, 17 flatfish, 8 redfish, 3 pelagic and 4 other stocks.

Number of stocks identified

Species group	Category A	Category B	Category C*	Category D	Total
Gadoids (G)	14	12	4	7	37
Flatfish (F)	9	10	7	10	36
Redfish (R)	2	3	2	0	7
Pelagics (P)	11	14	13	3	41
Other (O)	1	3	14	14	32
Total	37	42	40	34	153

*does not include stocks from USA

3.4 Revise existing NAFO WG tables used to record information and guidelines for filling in tables

Based on experience with the existing tables and the information requirements for the ICES stocks (demersal and pelagic species), the ToR a group discussed revisions to be made in order to improve the tables. Table 1 remained largely unchanged, while some changes were suggested for Table 2 (see Section 10). These changes mainly were made to ensure that the information collected on growth and reproduction in this table is appropriate for different reproductive strategies (e.g., indeterminate batch spawners) not previously considered in the NAFO WG tables. Based on experience reviewing the Northwest Atlantic stocks, sections on some parameters (e.g., contamination) were moved from Table 2 to Table 3 and formulated more precisely. Table 4 addressing the source of data was changed into the format of a list of references and the repetition of categories in the existing table was deemed unnecessary from the experience of NAFO WG members. The practical revision of tables and guidelines will be done intersessionally and the revised tables will be circulated within the SG to be evaluated before application.

3.5 Identify and document existing information on selected stocks

To identify existing data sources, specific SG members were appointed to take the lead in the collection of information on different stocks and areas. These members will distribute the tables to potential contributors with expertise in specific stocks to review the literature and identify other sources of data for given species and stocks. Several potential area leaders and contributors for the preliminary list of areas and species of concern (Section 11) were identified during the study group and additional experts will be contacted in the near future. In particular cases it will be necessary to collate information that has been collected by several national laboratories due to the multinational participation in the study of many ICES stocks. This might require that the partially filled-in tables are circulated to more people to add information about national databases. No data will be gathered. The tables are intended to document the existence of data, information and their sources. The ToR a) group will collect the completed tables from the contributors and report on the activities performed (see Timetable below).

3.6 Review availability of information and existing data on reproductive potential by areas and species

Once the forms are completed and returned, the ToR a) group will review them. The group will rank the stocks in terms of the quantity and quality of data and information available using a grading system similar to that developed by the NAFO WG on Reproductive Potential (Tomkiewicz *et al.*, in press). This will allow comparison in terms of the availability of different sorts of data and their quality within and across areas of the North Atlantic. Areas of poor data quality and limitation or where there is a paucity of actual data will be highlighted. The review will focus on information on stocks available from the focus areas (category A) and the Northwest Atlantic (part of category C), but also include category B and D to the extent that the stocks and areas are covered.

3.7 Tentative workplan and timetable

A tentative workplan and timetable to fulfill the requirements of ToR a) is presented below. The species and stocks to include were agreed upon during the meeting and the revision of tables was initiated. The revision and testing of tables should be completed amongst ToR a) members through correspondence and distributed to the SG as a whole for comments. The most time-consuming work will be to identify available data and fill in this information in the tables. Most of the work will be done intersessionally, but SGGROMAT meetings will be very valuable for evaluating progress, ensuring standardised scoring as well as for reviewing the information. A draft manuscript, which provides a review of the availability of information on reproductive potential and a comparison between stocks and areas, is planned to be completed by late 2004.

Activity	Deliverables	Year	Month
Revise of tables and modify guidelines to be compatible with revisions to tables.	Revised, tested tables and modified guidelines for filling in tables.	2003	3
Identify contributors and distribute tables.	Contributors for category A appointed as well as contributors for as many B-D stocks as possible.		4
Appraise completed tables and evaluate the need for further tables.	Tables completed for category A and the need for further stocks in B-D evaluated.		10
Appoint contributors to fill in any potential additional tables.	Tables needed for the review completed.		12
Score and analyse the information available as recorded in the tables.	Category A and relevant B-D tables scored and analysed.	2004	8
Review quantity and quality of available data.	Draft manuscript of review of the available information.		12

Figure 3.1 ICES statistical Division and Subdivisions.

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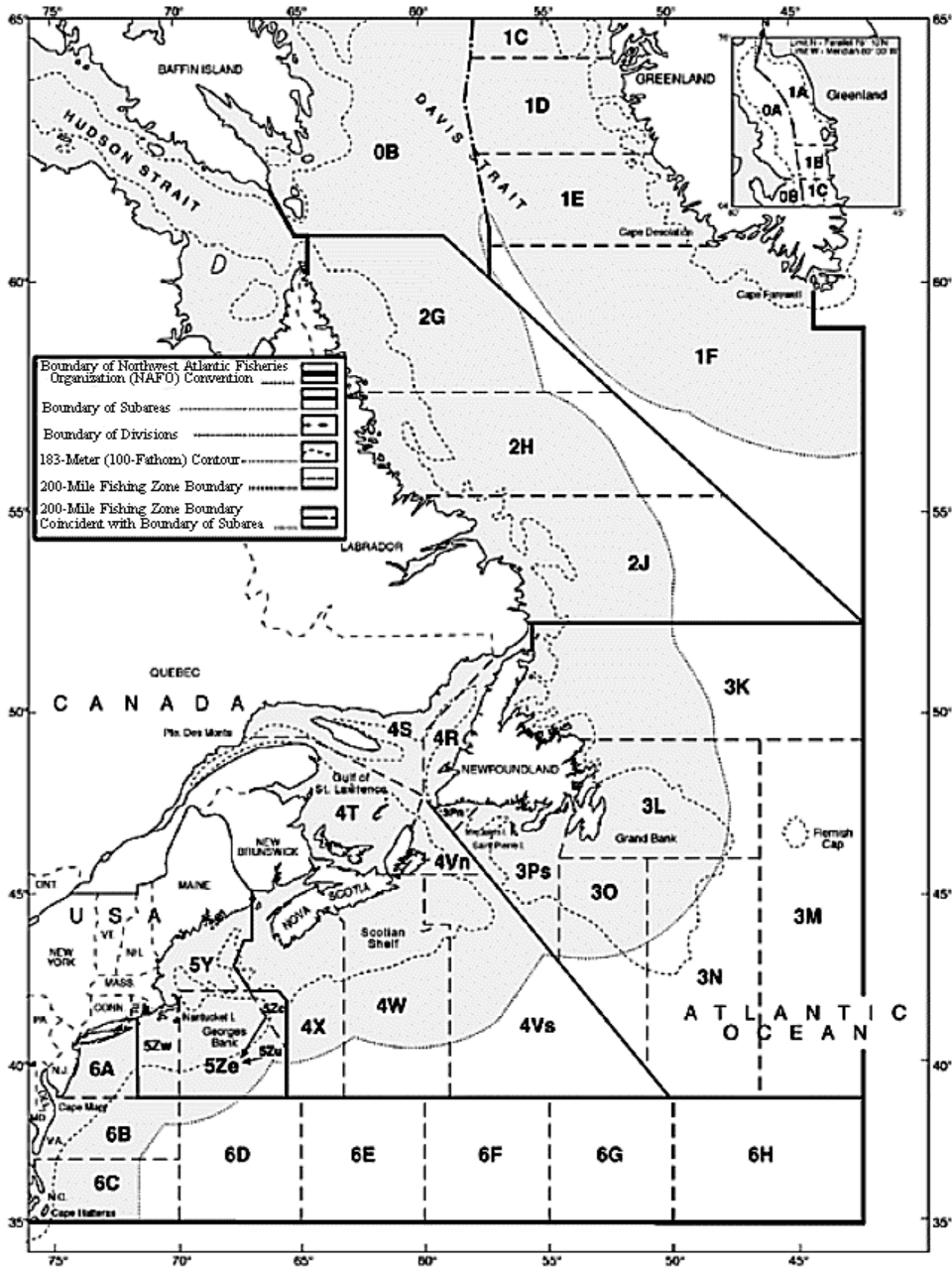
Figure 3.2   NAFO convention area showing scientific and statistical subareas, Division and Subdivisions of the Northwest Atlantic.

GFCM MANAGEMENT UNITS (Alicante, January 2001)
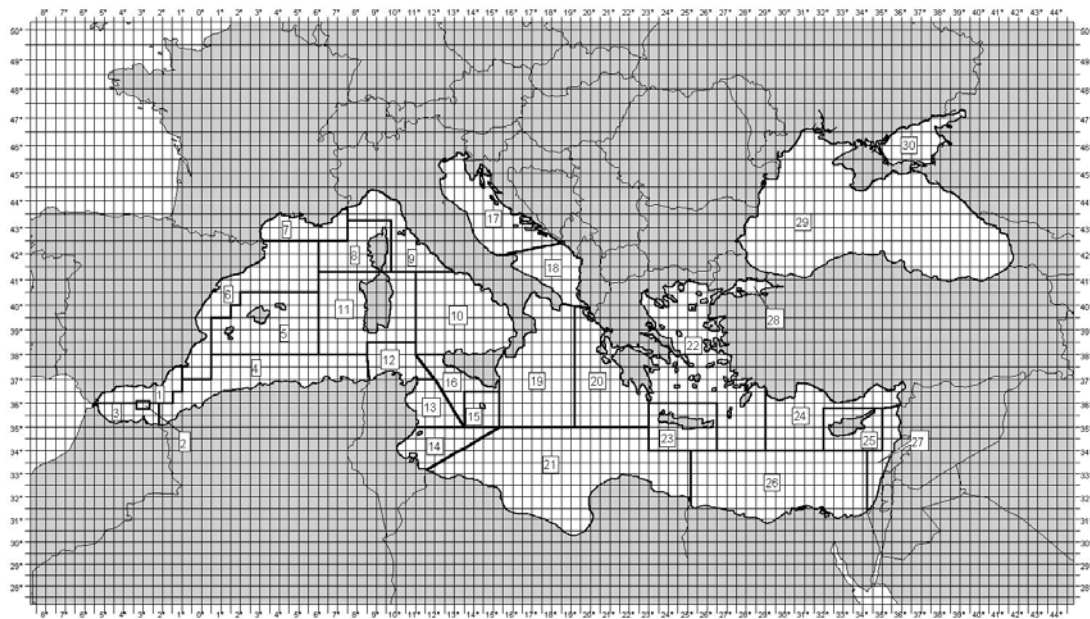
Figure 3.3   GFCM management units of the Mediterranean Sea. Each management unit has a code (shown in the map) and a name (not shown). For the 2002 SGGROMAT meeting, the following management units from the western Mediterranean have been considered: 1,2,3,5 and 6 (grouped in the tables under Balearic area or FAO Statistical Division 1.1) and 7 (Gulf of Lions or FAO Statistical Division 1.2).

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

4.1 Introduction

The use of spawning stock biomass (SSB) in stock-recruitment models assumes that total egg production is directly proportional to adult biomass. This assumption has been criticised in recent years due to known effects of size, age and condition on fecundity and the effects of atresia. There have been significant advances in understanding these processes and other spawning stock characteristics that potentially influence recruitment, e.g., egg viability and hatching success. Quantifying reproductive potential at both the individual- and stock-levels is currently the subject of a dedicated NAFO Working Group on Reproductive Potential. For the purposes of this Section we focus on the egg production aspect of reproductive potential.

As a result of this increased knowledge about the sources and magnitude of variability in reproductive potential, the S/R relationships for several stocks are being re-evaluated using alternative indices of reproductive potential (Marshall *et al.* 1998; Köster *et al.* 2001). To develop these indices, data on maturities, weight, fecundity and sex ratio are being identified (see Section 3) and it is hoped that sampling programs will be modified to include new variables (e.g., liver weights). As a result of such initiatives the constant values that have been used in assessments for maturities and/or weights can be replaced with observed values (as has been done for Northeast Arctic cod), and it will become increasingly feasible to estimate alternative indices of reproductive potential, e.g., female-only biomass or total egg production.

For many ICES stocks a constant maturity at age key has been used to estimate SSB. Such practices can increase the discrepancy between SSB and total egg production. Replacing SSB with a more precise estimate of reproductive potential will potentially alter the perception of stock status. For example, Figure 4.1. shows variation in egg production per SSB for North Sea haddock calculated from annually derived maturity and relative fecundity at age data (see Section 1.11). This shows an almost two-fold difference in egg production per SSB. These differences arise because female maturity is variable and generally higher than the maturity–at-age key currently in use; relative fecundity is also age-dependent and variable.
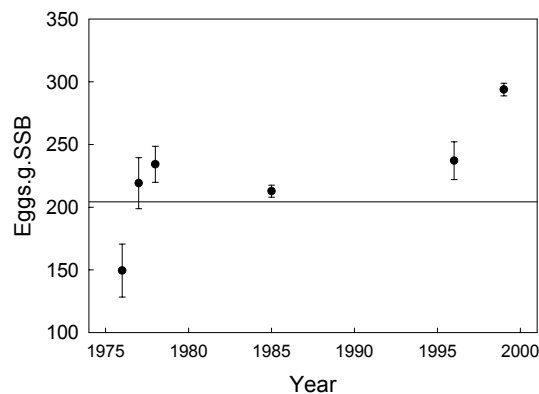

Figure 4.1   Variation in egg production per spawning stock biomass in North Sea haddock. Egg production $= \Sigma_{age} (N_a \times WF_a \times M_a \times PF_a \times RF_a)$, where for a given age-class; N_a= Number of fish at age, WF_a = mean weight at age taken from ICESa (2001), M_a = proportion mature at age, PF_a = proportion of females derived from the ICES IBTS 1st quarter surveys and RF_a is from an annually derived age-specific relative fecundity for the years 1976–1978, 1985, 1996 and 1999. The error bars were derived from $\pm$ 1 SE of RF_a. The line represents the mean relative fecundity for all years.

Clearly, the conversion of SSB to some term that more closely resembles reproductive potential may affect our perception of the stock dynamics. Therefore it is important to identify approaches to forecasting changes in reproductive potential. The biological data that are being compiled to estimate alternative estimates of reproductive potential also lend themselves to the development of process-based models describing for growth, maturity, condition and fecundity. Because these traits often covary the models can potentially be linked functionally. For example, statistical models describing the dependency of growth and condition on prey abundance have been developed (see WD4). In turn, condition can influence fecundity and/or maturity.

From a stock assessment perspective, the challenge is to adapt these process-based models for use in stock projections. Presently, there are several examples of stocks for which growth and maturity are being predicted for the short-term projections (see Section 5). Current ICES projection methodologies either ignore time-series structure in the data altogether (e.g., WGMTERM, ICP) or consider only specific aspects (e.g., STPR). As a result, existing knowledge about processes influencing growth and maturation for individual stocks is not incorporated into the projections.

The purpose of this section is to report on some of the progress that has been made in developing process-based models. Adapting this knowledge for implementation in short- and medium-term stock projections is discussed in greater detail in Section 5. The possibility of using indirect and direct indices of nutritional status to predict variability in growth, condition, maturation and fecundity is discussed at the end of the sub-sections on these topics.

Stock assessments typically resolve the reproductive potential of stocks at annual time steps. This overlooks the fact that, within a spawning season, egg survival (i.e., *realised* total egg production) is likely to be affected by the spatial and temporal origin of the eggs. As part of the recently completed EU-project STEREO, a length-based egg production model was created. Differences in stock reproductive potential and temporal distribution of egg production were compared across different stock/recruitment relationships and across populations of highly contrasting stock size structure, egg quality, condition and spatial distribution. This work is briefly described in Section 4.6.

4.2 Growth

Growth rates vary widely among as well as within fish stocks, reflecting the combined effects of temperature, prey availability, maturation schedules, size-selective fishing mortality, changes in activity and adaptive (genetic) change. A detailed treatment of sources of growth variation is beyond the scope of ToR b). Furthermore, there is a considerable literature on the relative importance of different sources of variability in growth. For example, the ICES Co-operative Report on the Dynamics of Cod Growth provides further relevant information (ICES 2002b).

In a general sense, models describing growth can be divided into statistical and mechanistic models. Statistical models describe significant relationships between growth and factors affecting growth without formalisation of the mechanism that gives rise to this relationship. Statistical models can predict growth dynamics over a limited time interval with a fairly high precision and may be effective for making a short-term prognosis. Mechanistic models combine within a single functional system the different processes underlying growth. They are conceptually more realistic, however, their ability to capture stock-level dynamics depends on whether they were derived from natural or experimental conditions. Furthermore, the large number of parameters requiring estimation often limits their application to the real world.

STOCOBAR (WD4) describes a process-based growth model for Northeast Arctic cod that combines elements of both statistical and mechanistic models. The model uses data on food supply, water temperature and the abundance of the cod population. Results suggest that water temperature has a strong effect on growth rate of cod. The inclusion of capelin (the preferred prey of Northeast Arctic cod) as an additional factor only slightly improves the agreement between the observed and simulated cod growth rate (Figure 4.2). However, one should recognize that the results from incorporating or excluding any factor in the model might not serve as a basis for objective evaluation of the direct effect of this factor on the process. For example, the effect of capelin biomass on its own is not explored in Figure 4.2.
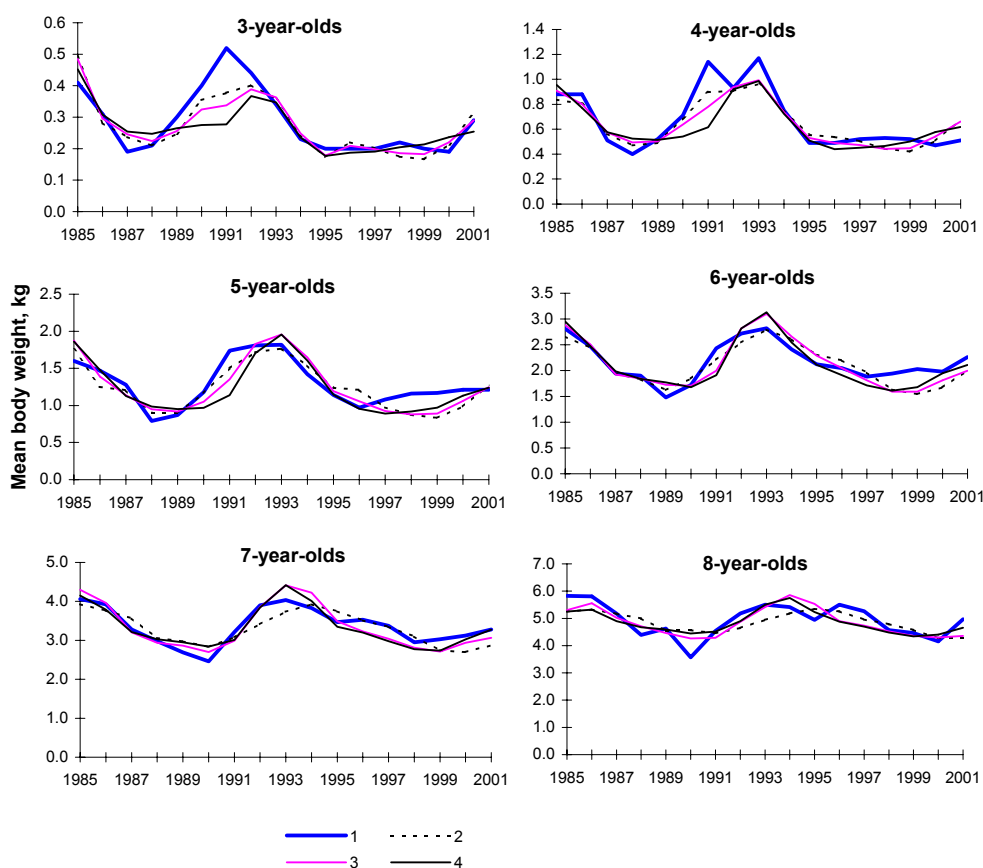
Figure 4.2   Consistency between the observed and simulated cod growth rates in the Barents Sea achieved in the model STOCOBAR: 1 – observed, 2 – simulated taking into account year-to-year variations of temperature, 3 - simulated taking into account year-to-year variations of temperature and capelin stock.

4.2.1   Projecting size-at-age

For many ICES stocks weight-at-age is projected using three-year running means. However, from the evidence presented by Brander (WD2) it seems that this is not empirically justified. Brander proposes a simple approach the "cohort" method, which assumes that past and future growth of a cohort are correlated. Whilst this approach appears to provide a slightly better explanation of growth variation than the three-year running means there are already more advanced approaches to modelling growth (ICES 2002a).

In process-based growth models body size can be parameterised in two basic ways. Many stocks have only weight-at-age data for evaluating changes in growth. It should be recognized that weight-at-age combines length-at-age with weight-at-length such that variation in condition cannot be isolated from changes in the length composition of the stock. The two signals differ in the sense that an individual can increase or decrease in condition while length only increases. For slow-growing stocks different aspects of growth (e.g., sex ratios, maturity and fecundity) often need to be described in relation to both length-at-age and condition separately. This section describes approaches to projecting either weight- or length-at age, whereas, possible approaches to projecting condition are discussed in Section 4.3.3. For further developments on projecting size-at-age see Section 5.

4.3 Fish condition

4.3.1 Evaluation of fish condition

Fish condition can be assessed using a variety of criteria, ranging from simple morphometric measures to physiological and biochemical measures. Morphometric indices are based on length-weight data and assume that for a given length heavy fish are in better condition than light fish. Therefore, they are gross measures of the condition of the fish in a population. Although morphometric indices are not the best method to describe the physiological status of fish, they are commonly used because weight and length observations are more often available than other biological data that would describe fish condition more directly (e.g., liver weights, lipid content etc.).

Physiological condition indices measure the energy reserves of fish more accurately than morphometric indices (Shulman and Love, 1999). Several physiological indices have been used. These include a liver index (hepatosomatic index), a gonad index (gonadosomatic index), a gut index and a muscle-somatic index (expressed as the weight of muscle as a proportion of the weight of the whole animal). Biochemical indices such as lipid, protein and RNA content in fish tissues and haematological parameters (haematocrit, leucocrit, etc.) describe fish condition more precisely. Total lipids are the most common parameters measured. Lipids are critical not only to the survival and fitness of individuals but also to the success of reproduction and recruitment of future year classes within the population. Lipid storage and dynamics within the organism are a particularly important attribute of fish condition because the energetic demands of fish are met primarily by lipid oxidation (Adams, 1999; Schulman and Love, 1999). Furthermore, structural lipids are also essential as they relate to physiological processes such as osmoregulation, particularly at low temperatures.

The source of fat reserves for gonad maturation depends on the fish species. In general, the main energy reserve controlling maturation appears to be: muscle fat in pelagic species such as clupeoids, liver fat in benthic species as the *Gadidae*, and mesenteric fat in salmonids, percids and cyprinids. Some members of the *Scorpaenidae* use both liver and mesenteric fat in gonad development. Therefore, for different fish species the most useful measure of condition will vary. For the *Gadidae*, this will be an index of liver condition, e.g., hepatosomatic index (Lambert and Dutil 1997, Yaragina and Marshall 2000) whilst in clupeoids and some flatfish it will be the content of lipids in tissue.

4.3.1.1 Morphometric condition indices

There are several morphometric indices that are used to describe fish condition, the most common ones being Fulton's condition factor (K) and the relative condition factor (Kn). Fulton's K condition factor is obtained from the expression $K=100(W/L^3)$, where W is the weight and L is the length of individual fish. Fulton's index values change depending on the length and weight units. The relative condition factor is expressed as $\ln(W/\hat{W})$ where W is the observed weight and $\hat{W}$ is the predicted weight (obtained from an estimated weight-length relationship). Although many analyses of K and Kn are based on total (ungutted) weights, the use of total *versus* gutted weights may bias the condition indices as food contents and gonads can be relatively heavy. Both of these condition indices have advantages and disadvantages discussed by Cone (1989, 1990) and Bolger and Connolly (1989). Although Fulton's K condition factor has been the most widely-used, it is only valid for those species that display isometric growth (i.e., the exponent b of the weight-length relationship $W=aL^b$ is 3.0). Otherwise, an apparent correlation between the condition factor and length emerges. A few groundfish stocks, such as the white seabream in the northwestern Mediterranean (Fig. 4.3) and the cod off Greenland (Fig. 4.4) meet this assumption. The b-values from the weight-length relationships of many other species and stocks are, however, not exactly 3.0 (Table 4.1). A substantial deviation from 3 may introduce an unwanted relationship between K and length. In cases where such a relationship exists, the relative condition index (Kn) may be more suitable because it does not assume isometric (b = 3.0) growth. This applies to hake in the northwestern Mediterranean (Fig. 4.5) and to Northeast Arctic cod (Fig. 4.6). Both gadoid species have b-values (3.2 and 3.1, respectively) that are not equal to 3.0, and an increase in K as fish gets longer is observed. For other species or stocks such as flatfish or some pelagic species whose growth is far from being isometric (i.e., b-values from their weight-length relationships are much different from 3.0), the use of K is problematic because it becomes dependent on length. In those cases, even the use of Kn may not solve the problem, e.g., Baltic sprat in subdivisions 25&27 (b=2.3; Fig. 4.7).

4.3.1.2 Weight-length indices

It is important to analyse weight-length relationships before starting any analysis on fish condition. Otherwise, the interpretation of results could be wrong (e.g., we may find that fish condition varies between years, but this could be simply due to a length effect rather than a condition effect). The examples provided in this section show that, even though morphometric data are useful for describing fish condition, there are problems inherent in the condition index used that need to be considered on a case-by–case basis. Garcia-Berthou and Moreno-Amich (1993) and Chouinard and Swain (2001) propose a different approach, which uses log-transformed weight as the dependent variable and log-

transformed length as a covariate (together with other independent factors). Finally, problems with length dependence can be reduced by estimating condition indices for different length intervals separately.

All the condition indices discussed here are "instantaneous" measures in that they represent condition at a single point of time, reflecting energy accumulation and allocation over some unknown time period in the past. The suitability of instantaneous condition indices as proxies for energy allocation may depend on the temporal correspondence between periods of feeding and ovarian development. Ovarian development occurring during a period of partial or complete fasting could lead to stronger relationships between condition, energy reserves and potential fecundity compared to situations where ovarian development occurs during a period of intense feeding. An understanding of such differences in energy storage and transfer could be useful in distinguishing between species and stocks where condition indices are likely or unlikely to be useful.

4.3.2 Seasonal variations in condition

Condition indices in wild fish populations vary at seasonal scales. This variability is due to seasonality in feeding rate and energy allocation within individual fish. These seasonal patterns are, in turn, due to the interaction of intrinsic physiological processes (e.g., gonadal development) with extrinsic factors (e.g., seasonal changes in food supply, temperature and photoperiod). In many fish species energy reserves increase in muscle, liver or as mesentery during the months following spawning in preparation for the next reproductive period.

When the accumulation of energy reserves is greater than the increase in body length, or the energy content of some organs (e.g., liver) increases relative to total body weight, overall condition increases. Condition will decrease when the store of energy has been transferred to gonads and later released during spawning. This decrease during spawning and the recovery afterwards leads to strong seasonal cycles in condition in some species (Lambert and Dutil, 1997; Fig. 4.8). As a consequence condition indices are often strongly coupled to feeding, growth and maturation of individual fish and the allocation of energy between somatic and gonadal production. For example, cod in the Baltic Sea shows an increase in both Fulton's K and liver condition index during gonadal maturation, but a decrease as spawning progresses (Fig. 4.9).

In addition to seasonal variability in condition associated with reproduction, condition can also vary due to changes in food supplies and abiotic variables (e.g., temperature). Fish in poor condition are susceptible to higher natural mortality rates and this mechanism is believed to have contributed to declines of some cod stocks (Lambert and Dutil 2000). Hence, prolonged poor condition following spawning caused by lack of food or cold temperatures could expose some fish to higher mortality risk (Lambert and Dutil 2000; Dutil and Lambert, 2000).

4.3.3 Projecting condition

At present models to project condition are under development. Given the strong dependency of condition on food availability it is possible to speculate on different approaches that could be used. For example, projecting future condition values is equivalent to being able to project the two parameters of the length/weight relationship (to obtain Kn) or projecting K (which assumes b-value = 3). This could potentially be done using time series methods. Density-dependent effects have been observed for weight-at-age values (Section 5.6). Therefore, different indices of stock abundance (e.g., absolute abundance values or abundance expressed relative to prey abundance) might also have an effect on condition.

Table 4.1.   Parameters b of the weight-length relationships W=aL^b for some exploited fish species in the Mediterranean, Baltic and North Atlantic areas, for different seasons and years

Species	Area	Years & Season	b
Diplodus sargus	NW Mediterranean	2001–2002, all seasons	3.00
Lophius budegassa	NW Mediterranean	1994–2001, spring	2.84
Lophius piscatorius	NW Mediterranean	1994–2001, spring	2.92
Merluccius merluccius	NW Mediterranean	1994–2001, spring	3.22
Micromesistius poutassou	NW Mediterranean	1994–2001, spring	3.23
Mullus barbatus	NW Mediterranean	1994–2001, spring	3.36
Mullus surmuletus	NW Mediterranean	1994–2001, spring	3.19
Pagellus acarne	NW Mediterranean	1994–2001, spring	3.23
Pagellus erythrinus	NW Mediterranean	1994–2001, spring	2.96
Phycis blennoides	NW Mediterranean	1994–2001, spring	3.23
Trisopterus minutus capelanus	NW Mediterranean	1994–2001, spring	3.21
Gadus morhua	Greenland(NAFO1+ICES XIVb)	1982–1998, autumn/early winter	3.04
Gadus morhua	Georges Bank (NAFO 5Z)	1992–1999 autumn/early winter	3.12
Gadus morhua	S. Gulf of St Lawrence (NAFO 4TVn)	1971–1998 autumn/early winter	3.09
Gadus morhua	Southern Grand Bank (NAFO 3NO)	1981 autumn/early winter	3.10
Gadus morhua	Northern Cod (NAFO 2J3KL)	1981–1983, 1986–1988 autumn/ early winter	3.12
Gadus morhua	NE Arctic (ICES I+II)	1989–1998 autumn/early winter	3.00
Gadus morhua	NE Arctic (ICES I+II)	1986–1989,1991,1999, 2000 winter	3.14
Gadus morhua	NW Scotland and Ireland (ICES VIa)	1992–1998 autumn/early winter	2.93
Gadus morhua	Irish Sea (ICES VIIa)	1991–1998 autumn/early winter	3.07
Gadus morhua	North Sea (ICES IIIa+IV+VIId)	1993, 1997–1999 autumn/ early winter	3.08
Gadus morhua	Iceland (ICES Va)	1930–1998 autumn/early winter	3.09
Clupea harengus	Baltic Subdivision 23&24	1987, autumn	3.41
Clupea harengus	Baltic Subdivision 27	1996, autumn	2.92
Clupea harengus	Baltic Subdivision 27	1986, autumn	2.74
Sprattus sprattus	Baltic Subdivision 25&27	1999, autumn	2.43
Sprattus sprattus	Baltic Subdivision 25&27	2000, autumn	2.30
Hippoglossoides platessoides	Greenland	1994–1996 autumn/early winter	3.38

White seabream NW Mediterranean

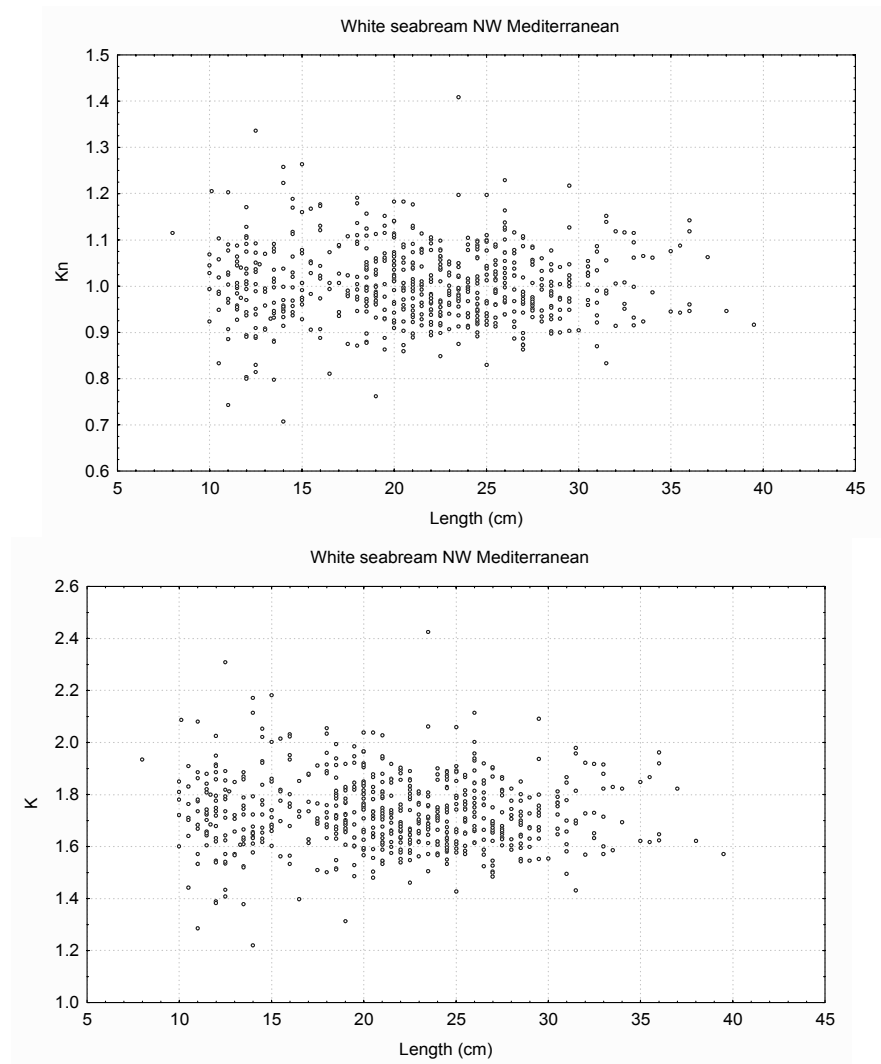**White seabream NW Mediterranean**

Figure 4.3   Scatterplots between length and K (top) and Kn (bottom) for white seabream in the NW Mediterranean. The b-value of the weight-length relationship of white seabream in the NW Mediterranean is 3.00, and therefore K is not correlated with fish length. The use of K gives here the same result as Kn
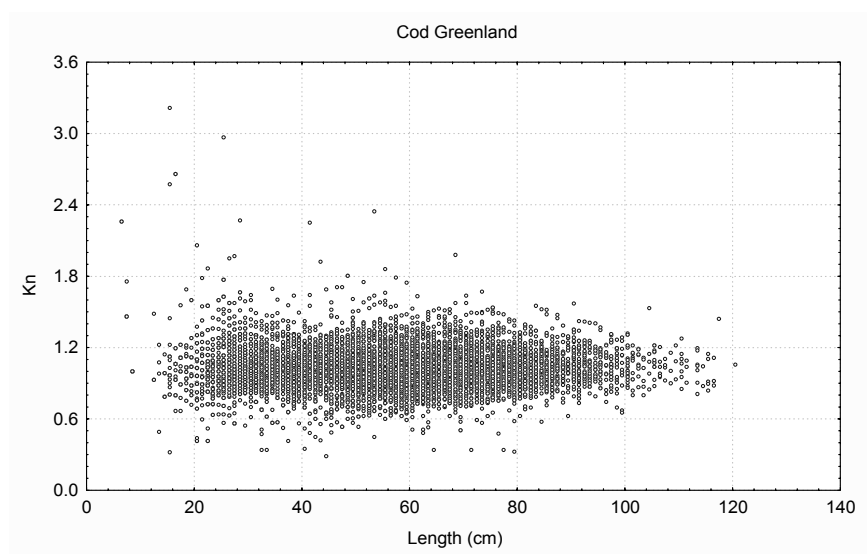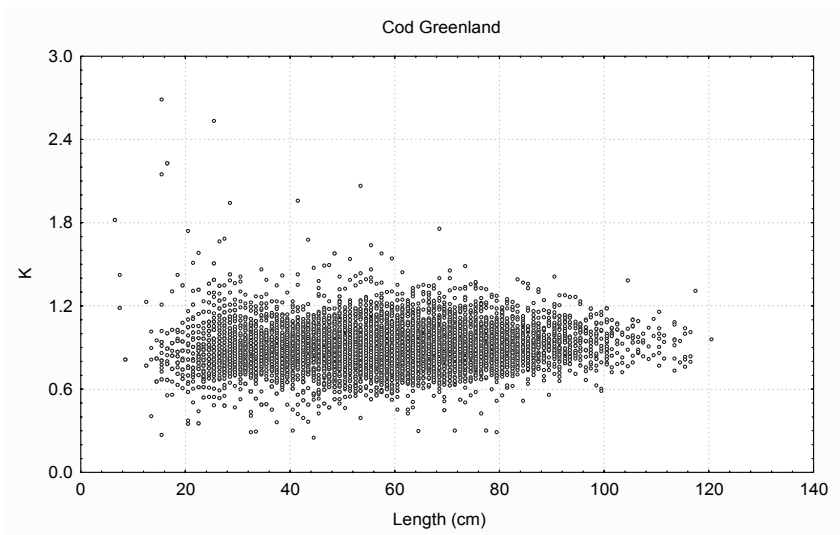
Figure 4.4   Scatterplots between length and K (top) and Kn (bottom) for the cod off Greenland. The b-value of the weight-length relationship of cod off Greenland is 3.04, and therefore K is not strongly correlated with length. The use of K gives here the same result as Kn.

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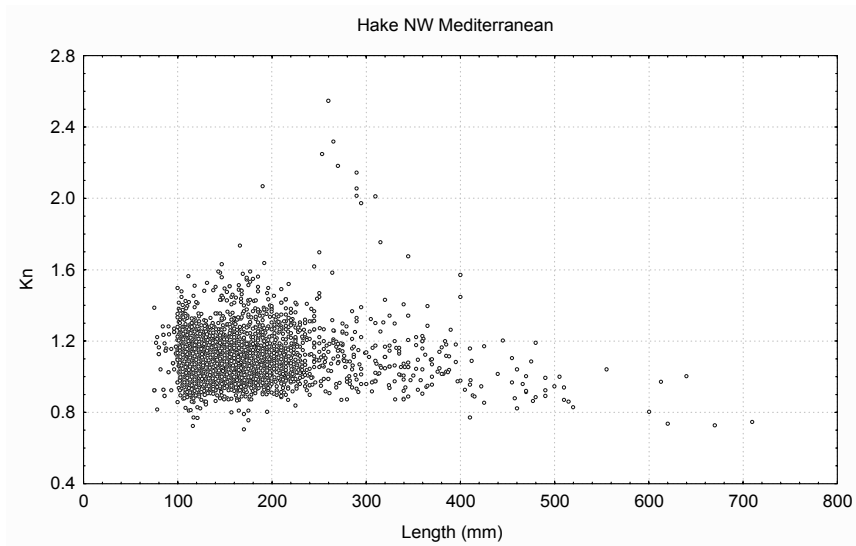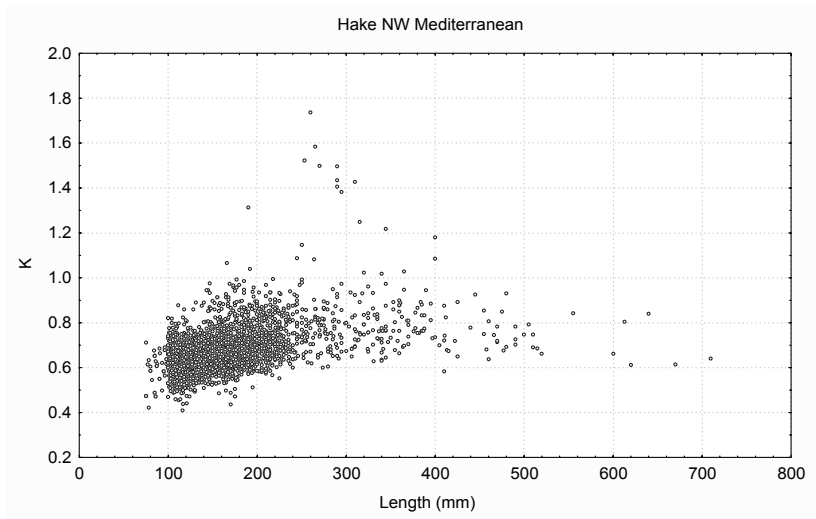
Figure 4.5 Scatterplots between length and K (top) and Kn (bottom) for hake in the NW Mediterranean. The b-value of the weight-length relationship of hake in the NW Mediterranean is 3.22, and a strong positive correlation between K and length emerges. This correlation can be avoided by using Kn instead of K.
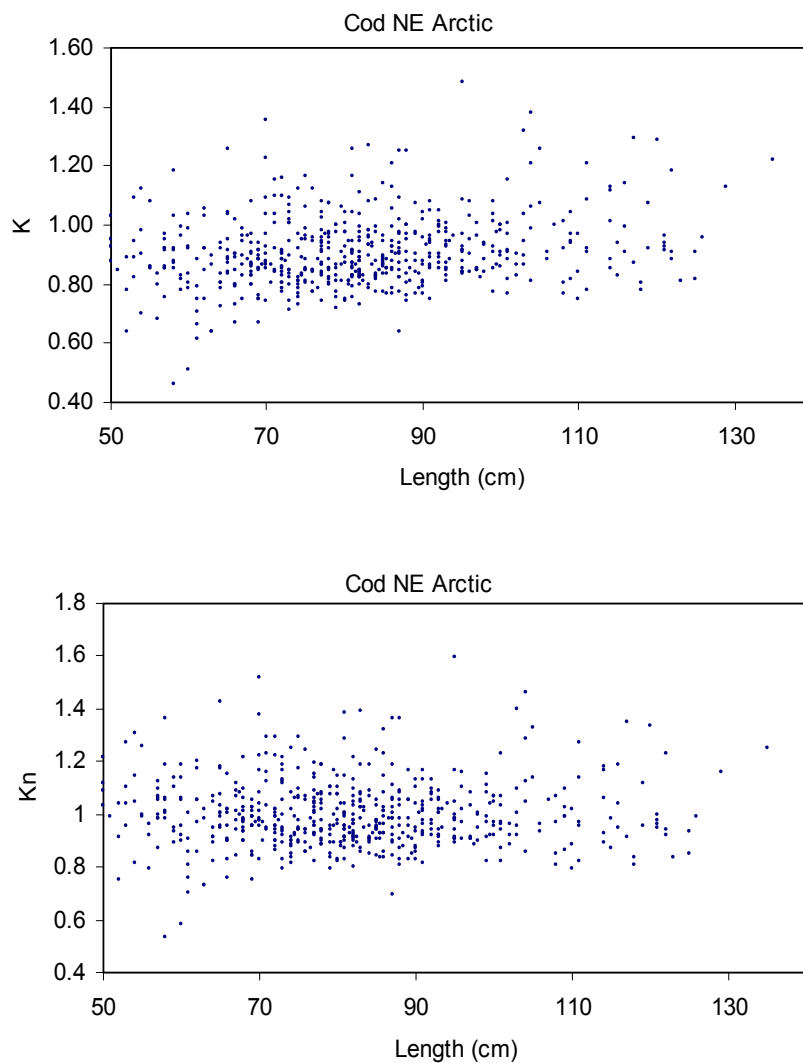
Figure 4.6   Scatterplots between length and K (top) and Kn (bottom) for Northeast Arctic cod. The b-parameter of the weight-length relationship of Northeast Arctic cod is 3.14, and a positive correlation between K and length emerges. This correlation can be avoided by using Kn instead of K.
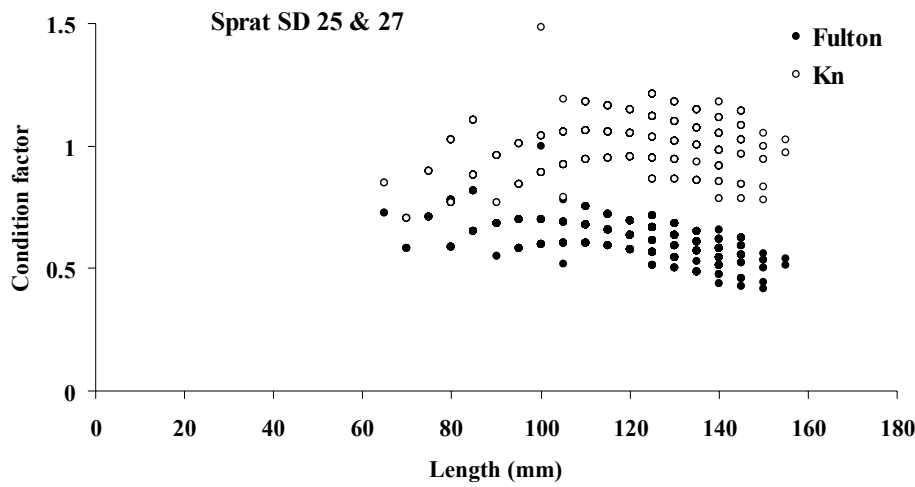
Figure 4.7 Scatterplots between length and Fulton's K and Kn for Baltic sprat (subdivisions 25&27 in 2000). The b-value of the weight-length relationship of Baltic sprat in subdivisions 25&27 is 2.3, and a strong negative correlation between K and length emerges. This correlation is not avoided by using Kn.
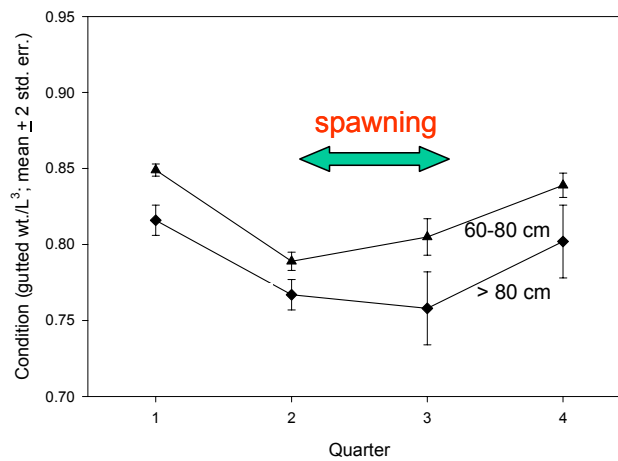
Figure 4.8 Cod condition by quarter for two different length groups during the years 1984–2000. All samples from the Danish commercial fishery in the southern Baltic (mainly subdivision 25). The arrow indicates the timing of peak spawning during the late 1990s. Data source: B. R. MacKenzie, unpublished data.
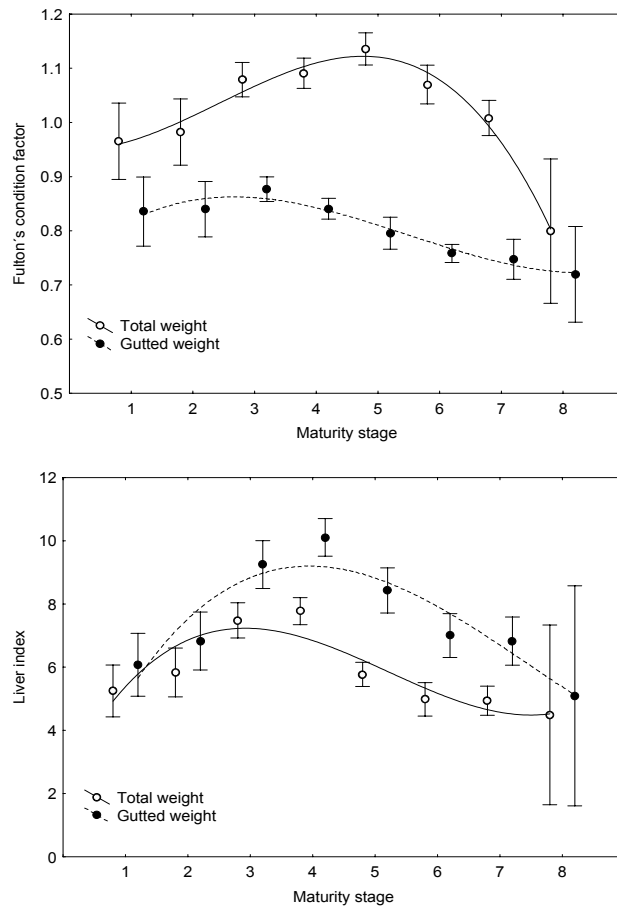
Figure 4.9   Variation in Fulton's K condition factor (whole and gutted weight bases) and a liver index during the gonadal maturation cycle of cod in the Baltic Sea. Data source: G. Kraus and J. Tomkiewicz, unpublished data.

4.4 Maturity

The numbers of mature individuals are determined by two processes: *maturation*, through which new individuals are recruited to spawning stock, and *mortality*, through which spawning stock is diminished. In other words, maturation refers to the process in which the state of sexual maturity is attained. Maturation has only been addressed sporadically in the context of stock assessments, whereas mortality has always been focal.

Both of these processes that determine the populations maturity are highly dynamic. Maturation depends on population's age and size structure and condition, and mortality is subject to both natural and fisheries-induced variations. In particular, changes in fishing effort (and hence fishing mortality) are the only major tool available for fisheries managers to influence stock dynamics. The dynamic nature of maturity at the population level requires that the description of maturation is included in descriptions of stock dynamics.

Maturity is a key component in the calculation of a population's reproductive potential, whether the latter is measured by total egg production or approximated by spawning stock biomass. In traditional stock assessment procedures, maturity ogives (proportions of mature individuals in a given age or length class) are estimated directly from data and then used in turn to estimate spawning stock biomass and the stock-recruitment relationship. The estimated stock-recruitment relationship may then be used in stock projections, assuming that stock biomass is dynamic but that maturity stays constant. Thus, maturity is taken as a "given", without consideration of factors that influence it.

There are a number of reasons why a more mechanistic understanding is required of how the maturity of a population is determined:

1)   Stock projections. Proportions of mature individuals by age and/or length can change rapidly (e.g., Jørgensen 1990) and often these changes are directional. If maturity is estimated from data, this poses no particular problem for analysis of the present and past. However, rapid changes in maturity may corrupt the quality of stock projections. In particular, ignoring trends in maturity may result in a bias in estimates of reproductive potential. Accuracy of stock projections may therefore be improved if changes in maturity can be predicted. This should ideally be based on understanding of the processes that determine maturity.

2)   Process-based stock dynamic models. Process-based models allow the incorporation of biological knowledge in description of stock dynamics. By definition, process-based models require a reasonable mechanistic description of how maturity is determined, making them more robust than models without mechanistic underpinning. This applies both to modelling of the past as well as to projections into future.

3)   Understanding the past. Age and length at maturation have dramatically changed in a large number of exploited fish stocks (Trippel 1995, Law 2000). Identifying the causes of these changes requires the development of understanding of the factors that determine maturity.

4.4.1   Maturation process

This section describes the maturation process from an ontogenetic perspective. The ultimate physiological triggers of maturation process are also discussed.

A number of factors have been proposed to explain when a fish enters puberty and matures for the first time: the attainment of a critical size, the rate of acquisition of surplus energy, growth rate or condition. Whatever the process, at some point during its development, a fish must assess its physiological status and make the "decision" which induces sexual competency. This decision time is commonly referred to as a "critical period". It is also important to note that a critical period for maturity need not be restricted to first-time spawners but may also be applied to repeat spawners that decide from year-to-year whether reproduction is energetically feasible for the upcoming spawning season

Policansky (1983) proposed that maturity was not triggered by attainment of a certain size or age, as under stable conditions with abundant food supply, fish should grow rapidly and attain maturity as soon as they are developmentally able to do so. Under hatchery conditions, this phenomenon is seen to occur in salmonids causing high proportions of fish to enter maturity at young ages (e.g., Thorpe 1982). Salmonids assess their physiological status and appear to make the preliminary decision to begin the maturation process in autumn (Thorpe 1994). This corresponds to a time before gross changes in the gonads occur or steroidal increases are detectable. In the following spring, under increasing photoperiods fish then decide whether maturation should continue if reproduction is energetically feasible (Thorpe et al. 1998). Critical periods for the onset of sexual maturity have also been proposed for other species of fish. In winter flounder (*Pleuronectes americanus*) skipped spawning is likely to occur when feeding is restricted before and immediately after the current spawning season (mid-April) (Burton 1994). Histological observations of the ovary during this critical time indicate that the non-reproductive state occurs as a result of fish failing to undergo exogenous vitellogenesis, suggesting that nutritional status acts as a control mechanism early in the gametogenic process. The failure of fish with high post-winter condition to become non-reproductive when starved during this critical period suggests that it is not feeding level, but rather some measure of current nutritional status that is acting as a reproductive regulator (Burton 1994).

4.4.2   Probabilistic approach for describing maturation

Maturation process can best be predicted when the actual physiological variables that trigger maturation (see Section 4.4.1 above) are measured. This will seldom (if ever) be practical in the context of modelling fish stock dynamics. In this context, the descriptions of maturation process have to rely on predictive variables that are more easily measured but which probably provide lower predictive power.

The simplest descriptions of maturation tendency involve two determinant variables, age and size (e.g., length). In the deterministic case, the combinations of age and size at which maturation occurs trace a curve that is referred to as "reaction norm for age and size at maturation" (Stearns and Koella 1986) (Fig. 4.10). However, it is obvious that age and size alone cannot provide very accurate description of maturation tendency. This has led to a probabilistic extension of the original (deterministic) maturation reaction norm concept (Heino *et al.* 2002a). The "probabilistic reaction norms for age and size at maturation" are defined by the probabilities that an immature individual matures during a certain time interval and at a certain age and size (Fig. 4.11).

Although neither age nor size is the sole determinant of maturation, practical experience shows that they work reasonably well. One reason that maturation can be explained using these variables is that relatively large size-at-age indicates high energy reserves which leads to both good growth and rapid maturation. Moreover, they are readily measured. An additional benefit is that projecting these two variables is tractable. Dynamics with respect to age will be determined by mortality, whereas dynamics with respect to size are provided by growth models (see section 4.2)

Figure 4.12 shows an example of probabilistic reaction norm for age and length at maturation estimated for Northeast Arctic cod (Heino *et al.* 2002a). The Figure shows that maturation probability rises from 25% to 75% when length increases by from 15 cm to 40cm, depending on age. While the probability of maturing can be predicted by age and length reasonably well, a considerable stochastic element is left. Part of this variability reflects measurement error in the source data. However, part of the variability is biologically interesting and probably highlights the fact that variables not considered in the analysis, such as condition, are also contributing to maturation tendency.

Other explanatory variables could be used. In particular, considering condition or weight seems relevant, since weight-at-age is probably better indicator of body condition than length-at-age. When weight is included in addition to length, these two explanatory variables constitute an implicit condition index. Probabilistic reaction norms for age, length and weight at maturation has been estimated for North Sea plaice. Preliminary results indicate that adding one more explanatory variable increases the explanatory power of reaction norms, albeit slightly.
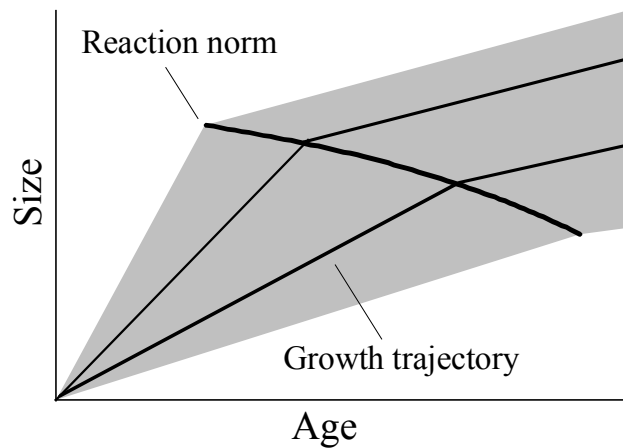
Figure 4.10   Illustration of reaction norm for age and length at maturation (thick curve). Maturation occurs when the growth trajectory hits the reaction norm.
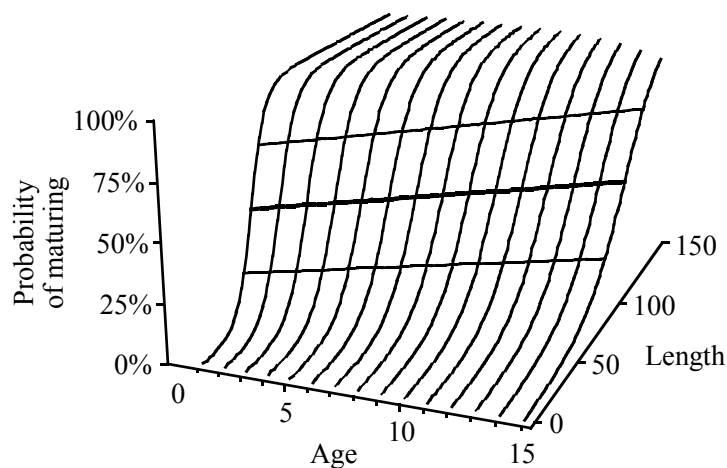
Figure 4.11   Illustration of probabilistic reaction norm for age and length at maturation. Each logistic curve describes the length-dependent probability of maturing at given age. Contour lines for 25%, 50% and 75% probability of maturing are also given. From Heino *et al.* 2002b. In populations with contracted age structure, maturation may occur over one or two ages only (see Dickey-Collas *et al.* WD). In such cases, the estimated reaction norm would only consist of one or two logistic curves.
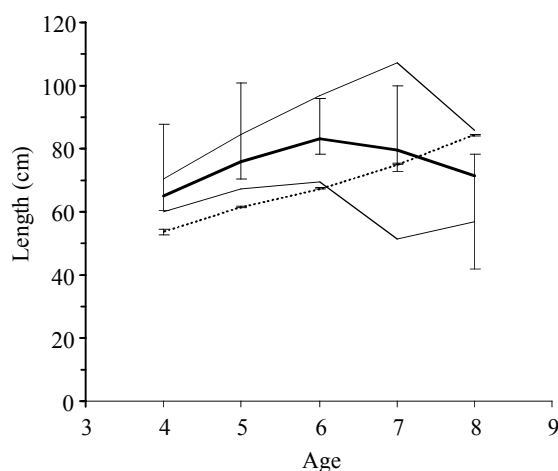
Figure 4.12   Reaction norm for age and length at maturation for Northeast Arctic cod cohorts of 1981–1990. The thick curve shows the length (with 95% confidence intervals) at which probability of maturing is 50%, and the thin curves show the quartiles. The dashed line (with 95% confidence intervals) illustrates how the mean size at maturation varies with age at maturation. From Heino *et al.* 2002a.

4.4.3   Estimation of maturation reaction norms

Three kinds of data sets could be used to estimate age- and size-dependent maturation probabilities (Heino WD5):

1)   A sample of fish measured for age and size and classified as juveniles, first-time spawners or repeat spawners; the last class is not needed in the analysis.

2)   Two consecutive samples of fish, measured for age and size and classified as either juveniles or adults (or as immature and mature). In the case of sampling with replacement, no individual identification is required.

3)   Data on individual growth and maturation histories, originating from a mark-recapture (tagging) study in the wild or an experiment with captive fish.

The first method requires that first-time spawners can be distinguished from repeat spawners. This is seldom possible in routine collection of data (an exception is Northeast Arctic cod, see Heino *et al.* 2002a). The requirement that age and length distributions of immature individuals are known can sometimes be circumvented with a reconstruction method (Heino *et al.* 2002b).

The second method can be used even if first-time spawners are not distinguished from repeat spawners (Barot *et al.* 2002a). The drawback is that it requires a fairly large dataset, thus necessitating pooling data across ages, years or cohorts (Barot *et al.* 2002b). Nevertheless, this method appears to the best method for estimating maturation reaction norms in most fish stocks. Grift *et al.* (2002) provide some further examples.

No attempts to use data on individual growth and maturation histories [method 3] to estimate age- and size-dependent maturation probabilities seems to have been made. The use of such data appears to be both powerful (provided that sufficient number of recaptures) and straightforward. A suite of methods developed for the analysis of mark-recapture and survival data are available (e.g., Diggle *et al.* 1994).

It is important that estimations are based on samples that are representative of the population in question. This is particularly important in situations where immature and mature fish are spatially segregated, which is likely during the spawning season. Dickey-Collas *et al.* (WD3) provide such an example of spatial structuring in maturity in Irish Sea cod.

4.4.4   Condition effects on maturation

A recent study on Icelandic cod exemplifies the importance of condition on maturity. It has been shown that fish in good condition (containing more surplus energy to devote to annual reproduction) mature at a smaller length than fish in poor condition (Marteinsdottir & Begg 2002; Fig. 4.13). This study is based on the results of analysis on length at maturity that were obtained from the annual (1985–1999) Icelandic spring groundfish surveys. In simulations where

condition is changed by ± 20% from 1.0 (Kn=0.8–1.2), the length at which 50% of the fish are mature changes by ± 8 cm (Figure 4.13). In poor condition (Kn = 0.8) the length at 50% maturity changes from 70 to 78 cm, while in good condition (Kn = 1.2) the change is a decrease of 70 to 62 cm.

The parameter values used for the prediction of proportion mature at length are the β parameter values derived from logistic regressions for individual years. The mean of the β values for all years were used as the input parameter values. The proportion mature as a function of length and condition (Kn) is given by the following equation:

$$\log [Pmat_{(i)}/(1- Pmat_{(i)})] = \beta_0 + \beta_1 * length_{(i)} + \beta_2 * Kn_{(i)}$$

where i indexes the length class (1 cm resolution) and the parameter values has been estimated as $\beta_0 = -13.32$, $\beta_1 = 0.123$ and $\beta_2 = 4.80$.
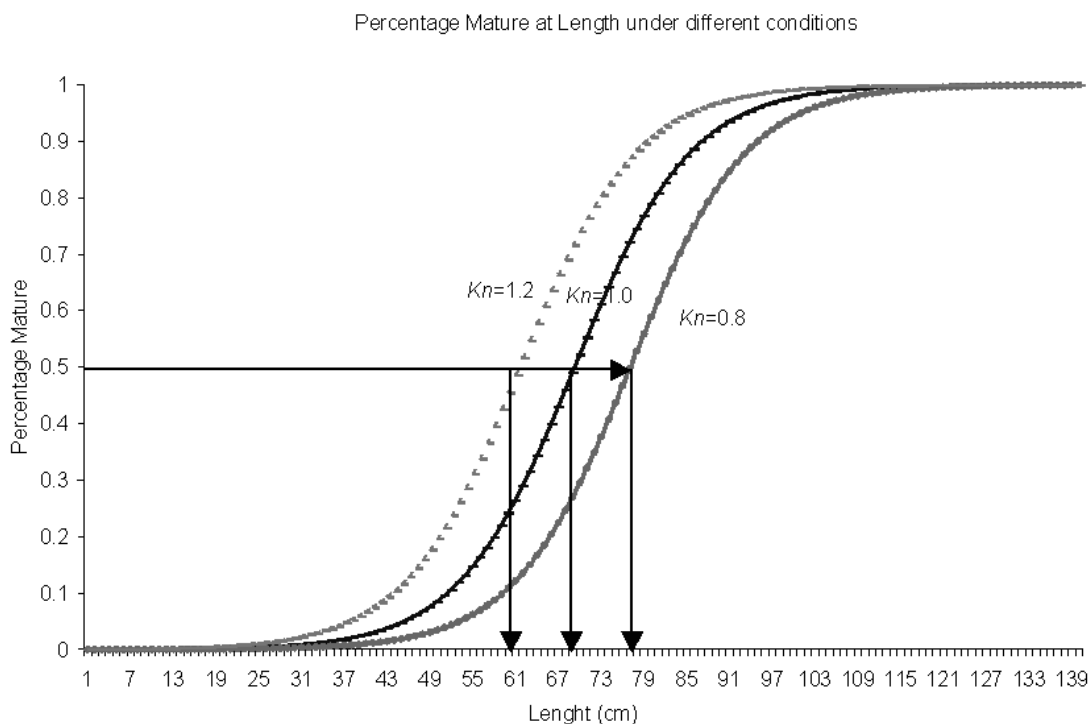
Figure 4.13   Change in condition (Kn) of ±20% in weight at length leads to a ± 8 cm change in the length at which 50% of fish are mature.

Data for Northeast Arctic cod also show that over the full time period (1946–2001) there is a condition effect on maturation. This is illustrated by a highly non-linear and positive relationship between condition (expressed as weight at length) and proportion mature at length (Fig. 4.14). For intermediate length classes in particular, the effect of increasing weight at length on the proportions mature at length can be dramatic (e.g., for 82.5 cm cod a 50% increase in weight-at-length is associated with an increase in proportions mature from 5% to 80%). There is a clear time trend in these data as well. Since 1980 cod have been heavier for a given length with a higher proportion mature.
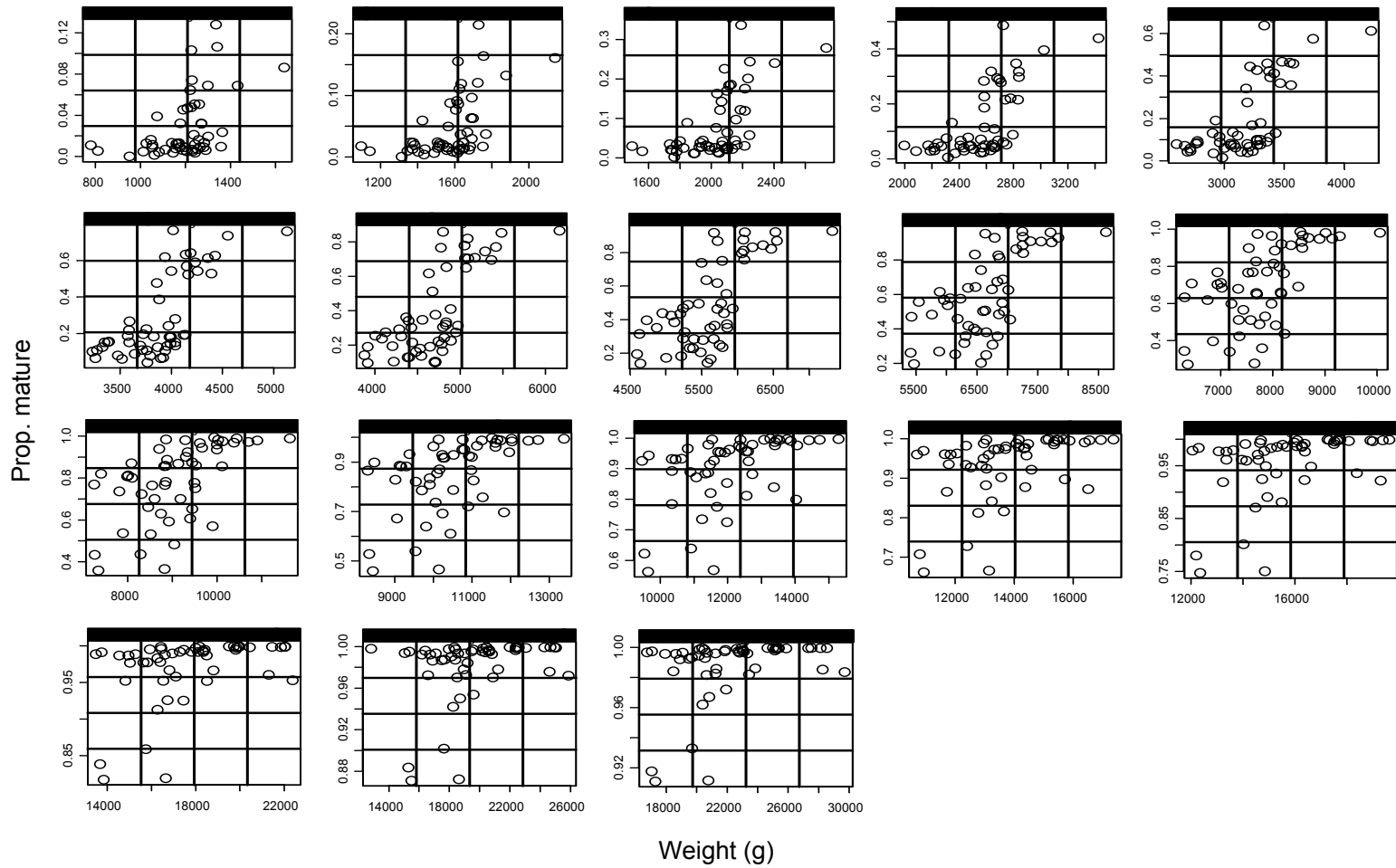
Figure 4.14   Scatterplot matrix showing relationship between weight-at-length and proportion mature-at-length for different length classes (ranging in 5 cm intervals, having midpoints of 52.5 to 137.5 cm).

4.4.5 Projecting maturity ogives

Maturity ogives are not expected to stay constant over time as they are influenced by such factors as changes in relative mortality among immature and mature individuals, the size of incoming cohorts, growth, and temperature. Maturation reaction norms may provide a way to project maturity ogives as the ogive can be constructed by summing the probability of maturing at each age across ages. The probability of maturing can be predicted by projecting the numbers of immature individuals as a function of chosen variables such as age and length at the time at which maturation takes place and the maturation probabilities as a function of those variables. Predictions further ahead require the modelling of stock dynamics (including recruitment) in the chosen state space, and this needs more specialized software. A probabilistic maturation process has been implemented in 'Gadget' (Anon. 2001b, 2002a), 'Fleksibest' (Frøysa *et al.* 2002), some specific population models (Parma & Deriso 1990, De Leo & Gatto 1995), and in an *ad hoc* maturation dynamics model for Northeast Arctic cod (Heino *et al.* 2002a,b).

4.4.5.1 Consequences of genetic change to projection

Evidence that maturation reaction norms in many exploited fish stocks are undergoing adaptive genetic change is currently accumulating (Barot *et al.* 2002b, Grift *et al.* 2002, Heino *et al.* 2002c). It may therefore not be possible to assume that maturation reaction norms remain constant over time. The significance of this issue depends on the time scale of stock projections relative to the rate of change in reaction norms.

Time scale of genetic changes is determined by generation time, heritability of traits in question and intensity of selection. Case studies indicate that significant changes can be observed after few generations when selection pressures have been strong (Barot *et al.* 2002b, Grift *et al.* 2002, Heino *et al.* 2002c). This means that for a stock with a short generation time of about 2–3 years (e.g., gadoid stock with truncated age structure and maturation at age 1–2 years, cf. Dickey-Collas *et al.*, WD3), significant change may occur in 10 years, i.e., within the time horizon of a medium term stock projection. However, it is premature to assess whether or not a genetic change in maturation could cause a bias that is significant relative to other uncertainties in stock projections with 10 years time horizon.

In long-term stock projections, genetic changes in maturation tendency cannot be ignored: the effect of genetic change may be that maturation is accelerated by about two years (cf. Heino *et al.* 2002c). Genetic changes in maturation may also have adverse effects on characteristics such as productivity, egg quality, average size of catchable fish, etc., warranting a specific management focus on these changes as such. The driving forces of evolutionary changes in maturation are theoretically well understood. However, the actual rate of change will probably be difficult to estimate accurately.

4.5 Fecundity

Total energy reserves and the inter- and intra-annual patterns of energy allocation affect the reproductive potential of a stock in several ways. Firstly, total energy reserves determine whether an individual starts the process of oocyte maturation. If energy reserves are higher than a threshold value (see also Section 4.4.1) then the development of sexual products starts. Otherwise the individual can skip spawning in the current year. Skipped spawning has been observed for several fish stocks (Marshall *et al.,* 1998; Bromley *et al.,* 2000; Rideout *et al.,* 2000). Because the phenomenon of skipped spawning is not captured by sigmoidal maturity ogives, this would lead to an overestimation of stock reproductive potential.

Assuming an individual female decides to spawn, total energy reserves can modify the total number of viable eggs produced in that spawning season in several ways. For example, condition (often used as a proxy for total energy reserves) has been shown to have a significant effect on individual fecundity (Kjesbu *et al.* 1998; Marteinsdottir and Begg 2002), rates of atresia (Kjesbu *et a*l. 1991; Ma *et al.* 1998; Hardardóttir 2001) and egg quality (Knutsen and Tilseth 1985; Solemdal *et al.* 1992; Marteinsdottir and Steinarsson 1998). Consequently, historical reconstructions of both potential and realised individual fecundity should account for effects of inter-annual variation in condition.

4.5.1 Modelling fecundity

The following sections review fecundity relationships that have been developed for western Baltic cod and Northeast Arctic cod. These relationships were developed for the purpose of estimating the reproductive potential (i.e., total egg production) of both stocks. A condition effect on fecundity was detected for Northeast Arctic cod (Section 4.5.1.2) and Icelandic cod (Marteinsdottir and Begg 2002) but not for western Baltic cod (section 4.5.1.1; Bleil et al. 2001). However, food availability and growth anomalies in quarters leading up to spawning affect relative fecundity in eastern Baltic cod (Kraus et al. 2002). Because energy reserves have a central role in fecundity regulation the lack of a significant condition effect could be due to the insensitivity of an instantaneous condition index to patterns of energy

allocation within the spawning season, or to a lack of contrast in condition of the females. The final section identifies approaches that can be taken to projecting fecundity over short-term based on knowledge of either direct or indirect (e.g., abundance of prey) measures of total energy reserves.

4.5.1.1 Modelling fecundity in Baltic cod

Analyses of the fecundity of Baltic cod between 1993 and 1999 showed a strong correlation between the potential absolute fecundity at age (F_a) defined as number of developing oocytes in female fish prior spawning (Kjesbu *et al.* 1991) and the total length (L) as well as the total weight (W). General relations were estimated for cod in maturity stage IV (Sub-divisions 22, 24 and 25) from 1993 to 1999 as follows:

$$F_a = 7.05 \, L^{3.079} \, (r = 0.89) \qquad\qquad \text{Eq. 4.1}$$

$$F_a = 23102 + 933.2 \, W \, (r = 0.86) \qquad\qquad \text{Eq. 4.2}$$

The linear model above was the most suitable model to describe the relationship between F_a and W. Additional regression analyses have shown that length explains a large proportion of the variability in Baltic cod absolute fecundity, and that the additional use of weight and/or condition in the model did not result in a significant increase in explained variation. Thus, good somatic growth positively influences F_a. Similar results were described by Botros (1959, 1962), Strzyzewska (1962), Kosior and Strzyzewska (1979) for Baltic cod and also for other fish species and different areas (Oosthuizen *et al.* 1974; Kjesbu 1988; Kjesbu *et al.* 1991; Trippel *et al.* 1997).

If the data are separately analysed for each subdivision differences in the fecundity/size relationships are found. The relationship between F_a and W in western Baltic cod did not change during the period of observations. In contrast, the same relationship changed significantly in the eastern Baltic Sea. Consequently, the relative fecundity of the western Baltic cod was constant during the period of observation and an increase was observed in the eastern Baltic Sea (Bleil et. al 2001, Kraus et. al 2002, 2002). Further analyses showed that the mean dry weight of oocytes significantly decreased in the eastern Baltic cod during the same period. Compensatory effects of adaptation are probably the reason for the different development of the absolute fecundity of the two Baltic cod stocks (Nikolsky *et al.* 1973; Trippel *et al.* 1997; Koslow *et al.* 1995).

4.5.1.2 Modelling condition effects on fecundity of Northeast Arctic cod

Fecundity determinations were made for Northeast Arctic cod for the years 1986–1989, 1991, 1999 and 2000. These data were used to develop a process-based model suitable for application to the stock-level over a long time period (1946–2001). Given that there are significant interannual differences in condition for this stock (Fig. 4.15) a model that explicitly accounted for variation in condition separately from length was required. This was achieved through the following steps.

1. Estimation of condition of pre-spawning females in the fecundity dataset:

Relative condition (Kn) was estimated for the pre-spawning females used in the fecundity determinations. Predicted weight was obtained using the following length/weight relationship:

$$W = 0.0049 \, L^{3.138} \qquad\qquad \text{Eq. 4.3}$$

which was obtained by fitting a generalized linear model (assuming a gamma error distribution with a log–link function, d.f. = 575, p < 0.001) to the length and weight data for the pre-spawning females pooled for all seven years. Thus, Kn expresses condition of individual females relative to the condition of all of the females sampled during the seven year time period. Fortuitously, the seven year time period was marked by dramatic variation in both capelin stock biomass and cod liver condition index. This makes it suitable for application at the stock-level over long time scales

2. Development of the fecundity model:

For the fecundity data set, residual variation in the fecundity/length relationship showed that the residuals scaled positively with Kn. Accordingly, both length and Kn of the pre-spawning females were significantly correlated with fecundity (Table 4.2). The resulting model:

$$\text{Fecundity (millions)} = 4.179\text{E-}7\ L^{3.52}\ Kn^{2.16} \qquad\qquad \text{Eq. 4.4}$$

captures the range of variability in observed fecundity (Fig. 4.16) and the residuals showed no pattern with either length or K_n. Egg diameter was significantly ($p < 0.01$) and negatively correlated with the residuals from Eq. 4.4 indicating that the stage in the spawning cycle at which the sample is collected influences the fecundity estimate. However, this variable is not relevant to the stock-level application for which this particular model is intended.

Table 4.2: Summary statistics to a generalized linear model fit (family = gamma, link =log) to fecundity data for Northeast Arctic cod. Data are from Kjesbu et al. 1998 and O.S. Kjesbu and A. Thorsen (Institute of Marine Research, Bergen).

	d.f.	Deviance	Resid. d.f.	Resid. Dev.	F	Pr(F)
Null			580	375.6280		
Log(Length)	1	271.5072	579	104.1208	2106.034	< 0.001
Log(Kn)	1	48.0556	578	56.0653	372.759	< 0.001

3. Estimation of Kn at the stock level:

In order to apply Eq. 4.4 to the stock level, year- and length-specific values of Kn were required for the full time period (1946–2001). Year-specific weight/length relationships were developed using paired values of weight-at-age and length-at-age from Russian and Norwegian sources (see Fig 4.15). The resulting year-specific weight/length models were then used to predict weight for lengths ranging in five cm increments between 50 and 140 cm for each year. These model-derived values were then treated as the "observed" weights. To express condition in a specific year relative to longterm (1946–2001) trends in condition the "predicted" weight was estimated by pooling all of the "observed" weights for standard lengths and fitting a weight/length relationship to those data (Fig. 4.16). The resulting equation was:

$$W = 0.0081\ L^{3.010} \qquad\qquad \text{Eq. 4.5}$$

which was fit using a generalized linear model (assuming a gamma error distribution with a log–link function, d.f. = 1007, $p < 0.001$). Kn was then estimated by the ratio of the "observed" weight to the "predicted" weight (see also Section 4.3.1.1). The resulting values of Kn were then substituted into Eq. 4.4 to estimate F at each of the standard lengths for each year. Note that because the b-value in Eq. 4.5 is close to 3.0, results obtained using Kn will not differ greatly from those that would have been obtained using K (see Section 4.3.1).

4. Application of the fecundity model to the stock

For each year fecundity was estimated using Eq. 4.4 and the year- and length-specific values of Kn estimated as described in step 3, for lengths ranging in five cm increments between 50 and 140 cm. Total egg production (TEP) for the stock was then obtained by multiplying fecundity at length by the corresponding number of mature females at that length and summing these values across length.

Preliminary estimates of TEP indicate that relative fecundity at the stock level (i.e., TEP/SSB*0.5) has not remained constant over time scales (Figure 4.18). This result is analogous to that shown in Figure 4.1. This violates a key underlying assumption of the stock/recruit relationship, that relative fecundity is constant. Further investigations are underway to determine the causes and consequences of long-term shifts in relative fecundity of the stock.

4.5.2   Projecting fecundity

To utilize 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 fecundity. Given that individual fecundity is a reflection of total energy reserves, it is not surprising that fecundity investigations for both Baltic and Northeast Arctic cod show that fecundity values for individual years are strongly correlated with indices of feeding (Fig. 4.19). Thus, if information on prey dynamics were available for the upcoming year(s) then one approach would be to use this

information to project future fecundity values. For example, if future values of condition (Kn) of Northeast Arctic cod could be forecast from capelin stock biomass projections (Section 5.6.1) then fecundity in the upcoming year(s) could be predicted using Eq. 4.4.

There are important distinctions in the formulations of the fecundity models for Baltic and Northeast Arctic (e.g., age- or length-based, significance of the condition term). This reflects the fact that stocks vary considerably in their growth rates and seasonal and interannual patterns of energy allocation. Food limited environments will potentially give more pronounced effects of condition on reproductive potential. The large variation in the nutritional condition of cod in the Northeast Arctic (Kjesbu *et al.* 1998; Marshall *et al.* 1998) and Northern Gulf of St. Lawrence (Lambert and Dutil 1997) stocks and the generally poor condition observed near the spawning period in some years could indicate that these fish are in food limited environment. For some stocks, fecundity/size relationships may not vary substantially among years (e.g., western Baltic cod, Bleil *et al.* 2001). For example, Baltic cod (Kraus *et al.* 2000) show higher and more stable condition indices and consequently condition was not found to be significant.
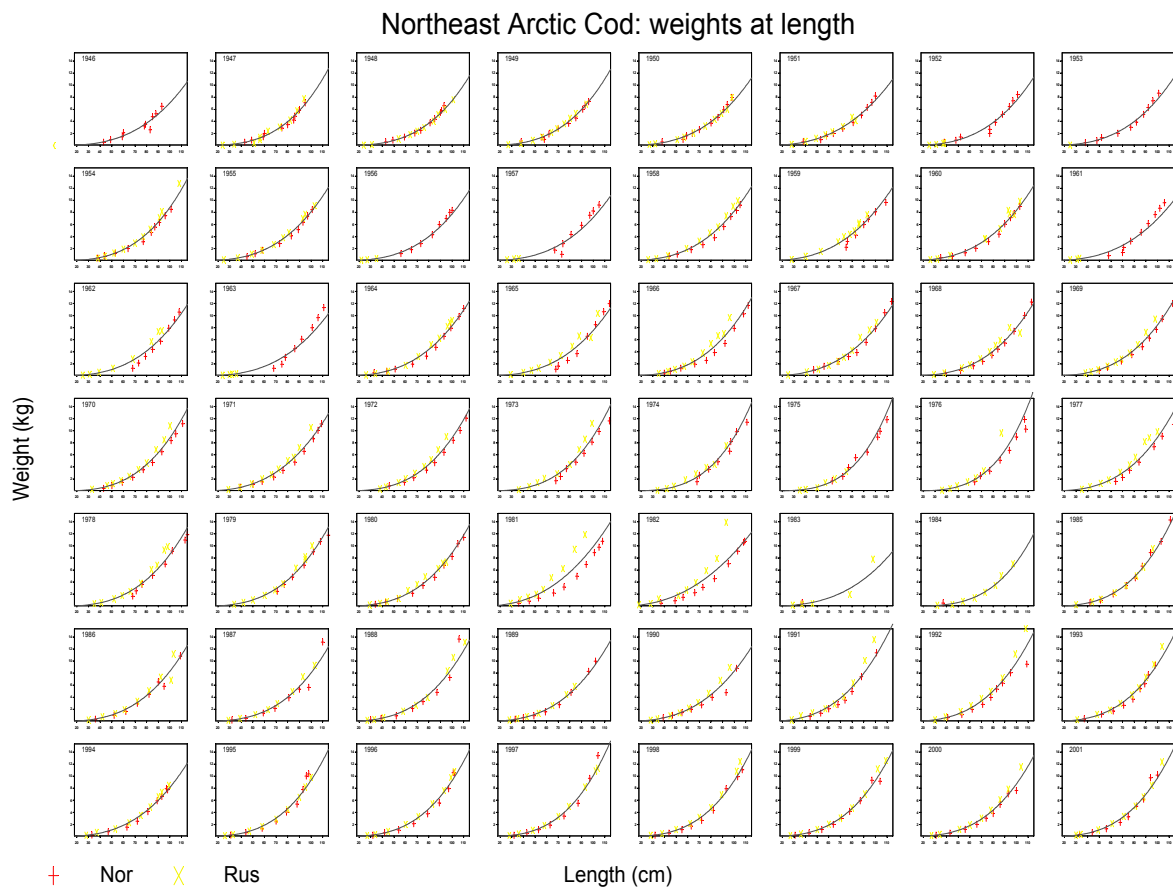
Figure 4.15　　　Year-specific weight/length relationships for Northeast Arctic cod. Graphical output produced in StockAN (see Section 5.17 and Appendix C). The years run from 1946 in the top left to 2001 in the bottom right.
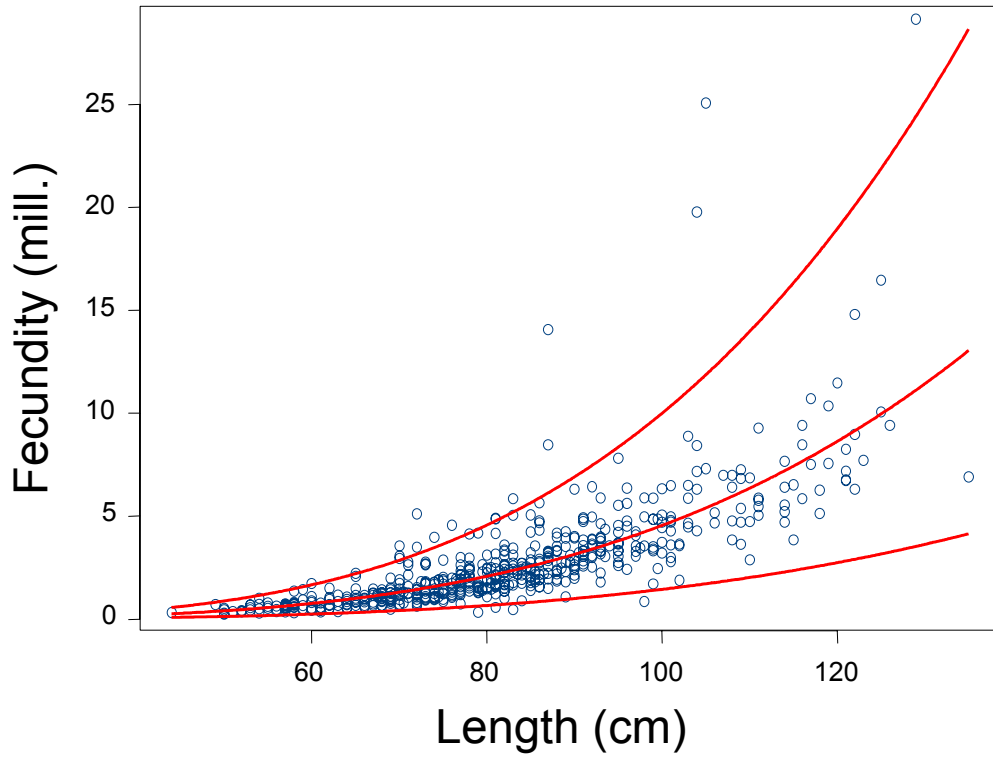
Figure 4.16   Fecundity/length relationship for Northeast Arctic cod. Circles represent observations and the solid lines represent model predictions made by Eq. 4.4 for minimum, mean and maximum values of Kn.
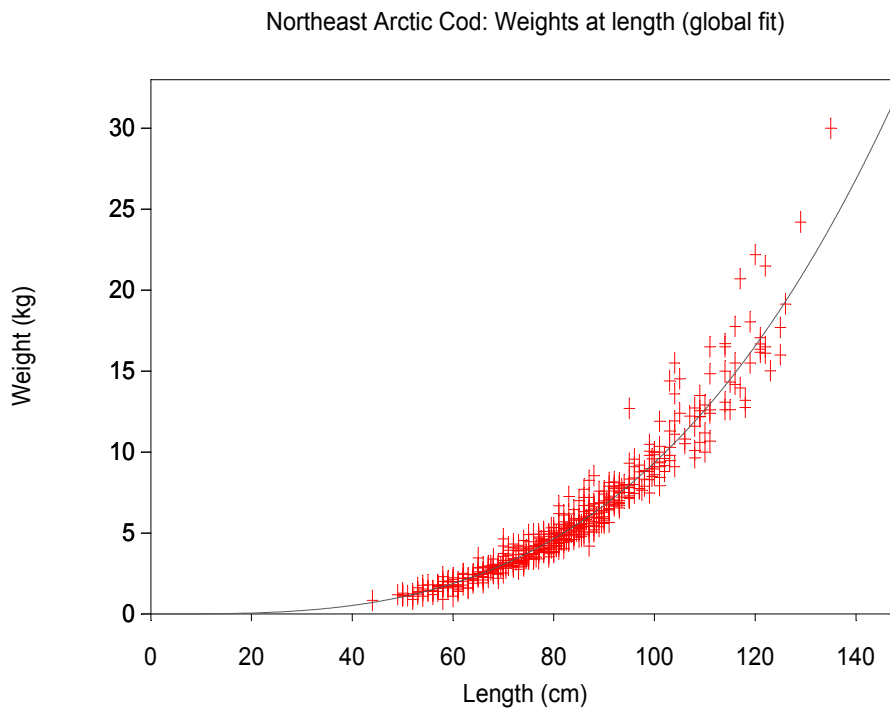
Figure 4.17: Estimates of weight and length for the time period 1946 to 2001 used to estimate Eq. 4.5. Graphical output produced in StockAN (see Section 5.17 and Appendix C).
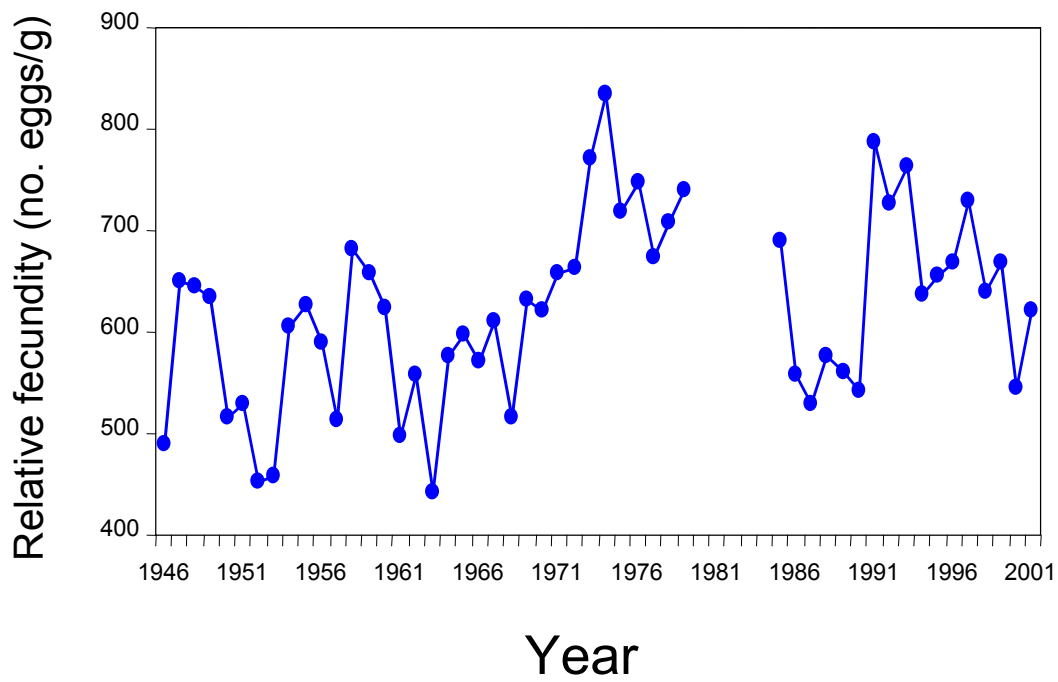
Figure 4.18   Time series of relative fecundity (Total egg production/SSB*0.5) for Northeast Arctic cod. Observations for 1980 to 1984 are missing due to data quality problems in those years.
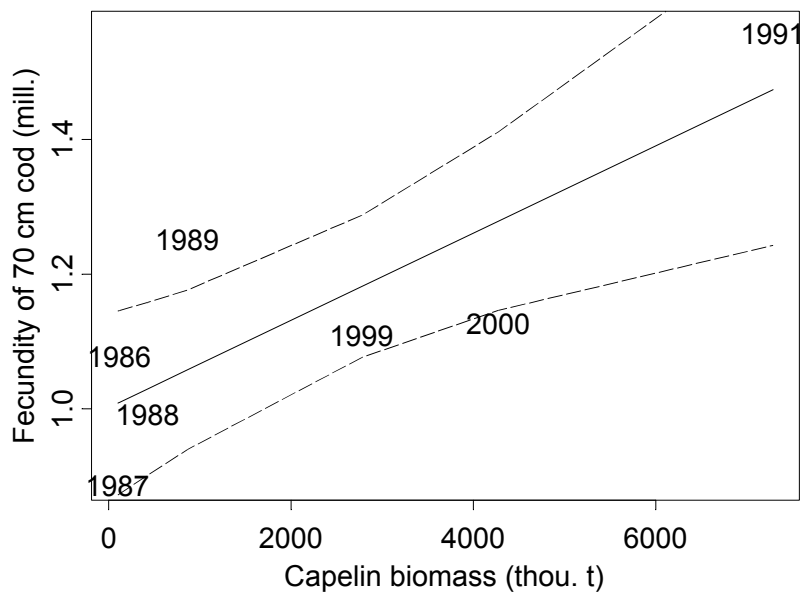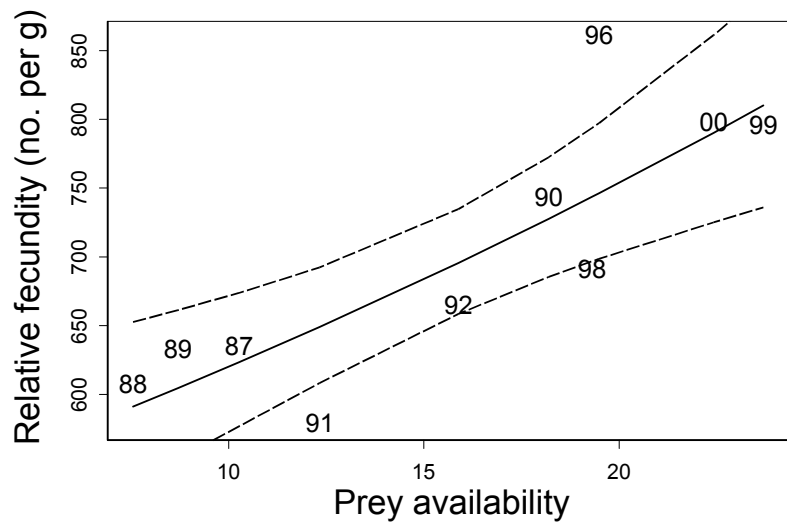
Figure 4.19: The relationship between the relative fecundity of Baltic cod (no. eggs per gram total body weight) and prey availability (total sprat + herring age 0–2 biomass) expressed per unit adult cod biomass. Observations (labelled by year), modeled relationship (solid line) and 95% confidence intervals (dashed line) are shown. Fecundity relationship is from Kraus *et al*. (2002); B) The relationship between capelin stock biomass and the fecundity of a 70 cm Northeast Arctic cod. Fecundity relationships for 1986–1989 and 1991 are from Kjesbu *et al.,* (1998). Fecundity relationships for 1999 and 2000 are courtesy of A. Thorsen and O.S. Kjesbu (Institute of Marine Research, Bergen, Norway). Observations are labelled by year. A simple linear regression line is shown as the solid line ($r^2 = 0.66$, $p = 0.02$) along with 95% confidence intervals.

4.6 A process-based egg production model

Assuming that fecundity models have been developed, the next step is a more detailed analysis of spatial and temporal patterns of egg production within a single spawning season. Such highly resolved information can be then used as input to models investigating the spatial and temporal trajectory of egg and larval drift and development. As part of an EU-funded collaboration (STEREO) daily reproductive output of Atlantic cod was modelled over an entire spawning season for a range of age/size-structured populations. These simulated populations were created under different stock-recruitment and fishing pressure scenarios. An individual-based modelling approach was used to link empirical relationships with flexible reproductive parameters to quantify and qualify the effects that variation in individual female condition and egg quality can have on stock reproductive potential (SRP) and the temporal distribution of reproductive output within the contrasting age/size-structured populations. Spatial elements are also considered by allowing fish to aggregate and be fished at different intensities by size and by assuming that different spawning locations can give rise to different egg survival rates. The egg production model (EPM) and results of scenario testing are described briefly below.

4.6.1 The EPM model

The motivation behind the design of this model was three-fold. Firstly, a generic model of egg production was produced that could be used for a wide range of serial spawning species with only changes to parameter values needed between species and simple requirements for input. For input, the model only needs the length, weight and expected weight at a given length for either each individual fish or for age/size groups of fish, which share those characteristics. Secondly, the model was mechanistic and state-oriented such that flexible reproductive life history traits (i.e., fecundity, the number and size of batches, date of initial spawning, etc.) are all modelled as functions of the individual's state. The model was composed of four modules (described below) which could be run separately such that the effects of each functional relationship on reproductive output can be examined at different levels of complexity: individual, individual spawning period, seasonal spawning period and population level. Thirdly, the model was used to run strategic, deterministic simulations to quantify the relative differences in SRP and temporal distributions of reproductive output across contrasting age/size structured populations, condition factors and egg quality relationships using 'ideal' individuals (a mean value for each age/size group) as input.

The first module contains the equations that are only functions of the state (length and weight) of an individual fish (Figure 4.20). These functions produce the condition, the level of pre-spawning atresia, the maximum potential fecundity, the maximum egg size, the number of batches, the proportion sexually mature and the proportion of first time spawners. The second module contains the equations, which are functions of the state and the temporal aspects of the spawning period of an individual fish. This module calculates the changes in variables such as egg size, numbers of eggs per batch, seasonal atresia and inter batch duration which can change over an individual's spawning period. The third module calculates the calendar date for the starting of spawning for a positive incremental proportion of individuals as a function of their state and date. How long each individual continues to spawn from that date onward and on what dates the batches are released are determined by the outcome of state driven relationships in module 2. Therefore, on any given day of the spawning season, a range of fish of different states can be releasing eggs and the temporal pattern of spawning produced is based entirely on the range of states (lengths) and number of individuals at those states in the current simulation model. The fourth module is the calculation of the daily summation of reproductive output for each of the three different methods used to calculate egg survival. This accounting module can also be used to explore the number of eggs of a given size released that day or the number of females of a given state or states spawning on that date. The model also sums over the entire spawning period to produce the SRP for each simulated population under each scenario.

4.6.2 Results of simulations

The simulation results indicate that the loss of older/larger individuals from populations that have been subjected to heavy fishing pressure can cause the SRP to fall by 48%, shift the timing of peak spawning by 2 weeks, and shorten the spawning period by 4 weeks. This is the result when the populations are allowed to maintain a constant SSB – meaning that the change in SRP are solely due to the effect of changes in population structure. If egg quality is a function of either the size of an egg or the spawning history of it's parent then the estimates of losses in SRP can fall by an additional 18 to 26%, respectively. In those populations that not only loose older/larger fish but also show substantial loses in SSB, the decrease in SRP can be up to 98% with a 40% decline in the length of the spawning season. Female condition can change the SRP drastically. If fish are in very low condition there is nearly complete reproductive failure (a drop of 93% of SRP). Even just a 10% decline in condition can cause a 15% drop in SRP. When fish are in excellent condition (surplus of 30%) the SRP can rise by 16%, compared to same population when fish are in mean condition.

When spatial issues are considered such that fish of different sizes use separate spawning sites and that different spatial locations are assigned differences for egg survival, the changes in fishing pressure (on just the medium- and large-sized fish) from 0.6 to 0.1 can increase the SPR up to 56.7% (a mean of 53.2% across all 6 populations). This suggests that even in heavily fished populations a reduction of fishing during the spawning season can lead to a very large proportional increase in reproductive potential and likelihood of higher recruitment.

Results as such supports the view that predictions of recruitment can no longer be based solely as a function of SSB. More careful analysis of the population structure as well as annual dynamics of condition factors and exploration of functional relationships between female characteristics and egg quality are needed to assess and predict survival and the probability of recruitment levels
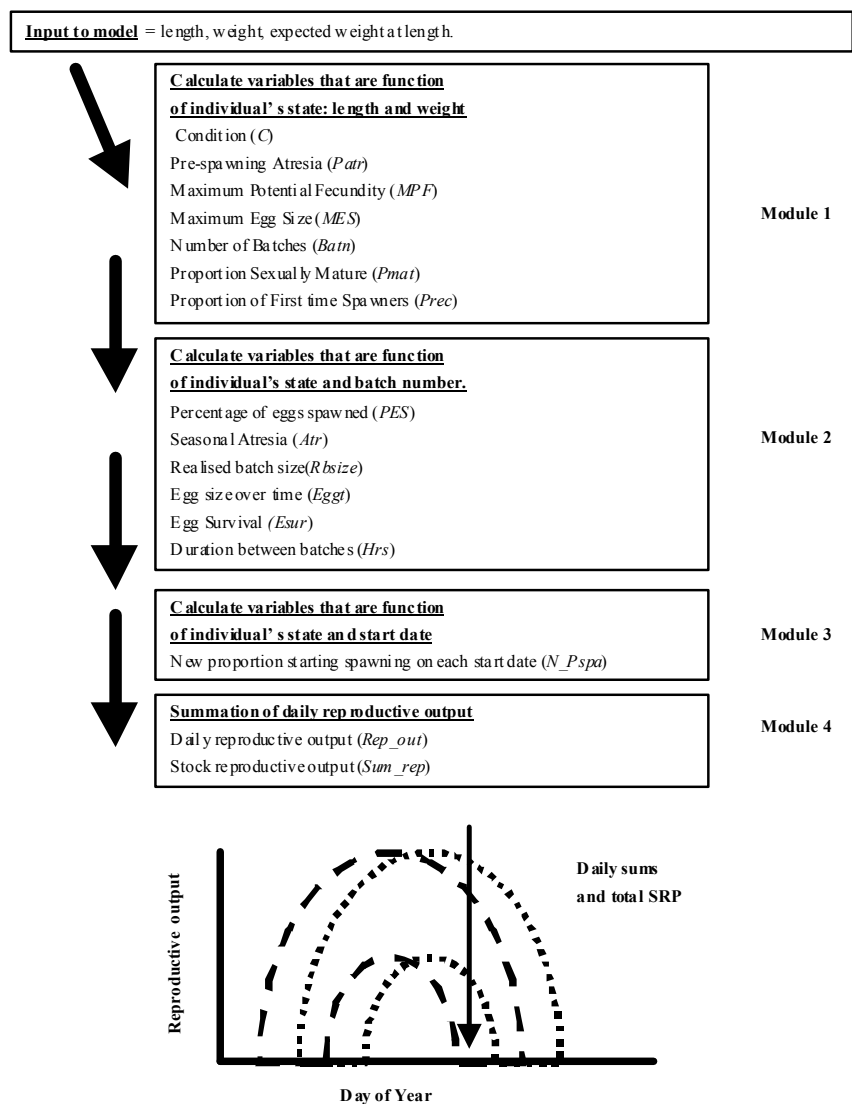

Figure 4.20   Flowchart of the STEREO EPM.

4.6.3   Application of the EPM to the estimation of realized total egg production

This modelling study should be viewed as a first attempt to bind together many of the more important variable life history characteristics that drive variation at the population level, for all aspects of reproductive potential, e.g., realized

fecundity and offspring viability. The model is currently being used to reconstruct historical variation in Iceland cod and North Sea haddock egg production both within and between years. It will also be explored for Northeast Arctic cod. Using this approach it may be possible to explore the consequences for recruitment of both variable egg production both temporally and spatially.

4.7 Future work

There is a strong need to collect individual fish lengths and weights, but also other biological data that would allow us to assess fish condition more precisely (e.g., liver, stomach or gonad weights) and to find tractable ways to analyse lipid or protein content in fish. Furthermore, the evaluation of fish condition should take into account any temporal (seasonal and interannual) and spatial (habitat) differences in condition as well as possible physiological (e.g., reproductive status) and fishery (e.g., mesh sizes or gear type) effects. For those species presenting a strong allometric growth, condition indices based on morphometric data could be used.

Given the need to predict variability in maturity and fecundity, the potential of condition indices as an explanatory variable be explored in more detail for a range of stocks.

5 IMPLEMENTATIONS OF PROCESS-BASED MODELLING APPROACHES IN PROJECTIONS

5.1 Introduction

ToR c) required the SG to "implement process-based models in a new projection methodology and compare the results to the methodology currently used." Due to delays in the production of new projection methodologies, the SG was unable to fully address this ToR. It is envisaged that the development of projection methodologies will be a process of continual improvement. In the meantime, this section discusses several aspects germane to such development, and points out areas which are likely to create difficulties.

5.2 Projection methodologies

A key question to be addressed is that of projection methodology. The most common practice within current working groups is to project drivers such as weights and maturities forward at the level of the final year, or a short-term recent average. Where variations and trends exist within the drivers, this approach is clearly inadequate.

In extant implementations, random variation in drivers has been addressed by bootstrapping. Non-parametric bootstrapping of residuals from stock-recruit models is used in WGMTERM to provide estimates of recruitment in line with historical observations. Whilst this is an improvement over projection at a constant level, there are often temporal trends in residuals which are not conserved within the projection (e.g., a series of consecutive large recruitments are predicted when none are observed in the historical dataset). ARMA (autoregressive moving average) modelling of residuals has been employed in the StockAn/RecAn/MedAn suite (see Sections 2.17 and 12) in order to account for temporal patterns in drivers: however this is not the only approach which may be suitable. One alternative may be to implement mixed-effects models in which different parameters can simultaneously be treated as either fixed (without error) or random. Alternatively, time-series descriptions of population state-space vectors which perform historical assessment and forward projection simultaneously may be implemented with Kalman filters or Bayesian MCMC approaches. Such approaches are complex and time-consuming to implement. Work in these areas is planned, but is unlikely to be completed before the next SG meeting.

5.3 Software design issues

5.3.1 Type of implementation

A single implementation of process-based projection models is unlikely to be sufficient. Assessment Working Group members need programmes that are robust, consistent and straightforward to use. There is little time within the confines of a Working Group for experimentation with process-model formulation, and perhaps more importantly, ACFM must know the precise basis and methodology behind each projection which they are asked to consider, and be able to replicate the results. These points suggest a centrally-managed package, with tight version control and regular, well-tested and verified updates. Conversely, process modellers trying to evaluate the effect of different models and methodologies in a management framework require programmes that are flexible, open-source and easily modified.

The requirements of the two groups likely to make use of the software are therefore very different. However, it is intended that both will be addressed by developing parallel implementations. The first, the StockAn/RecAn/MedAn

suite, is being written in FORTRAN, and consists of centrally-managed code, suitable for Working Group use. This software will be modularised as far as possible, in order to simplify expansion and modification. The second will be available as a script for the R language (http://www.r-project.org/). R is a freeware version of the S language, which is also used as the basis of S-PLUS. R has similar functionality and syntax to S-PLUS (so that the code is fairly straightforward to modify for those experienced in the latter), and provides a suitable programming environment for process modellers seeking to test hypotheses and methodologies.

5.3.2 PA reference points

Reference points are only revisited periodically, so it would be inappropriate for any new projection software to determine reference points by default. The range of alternative measures of spawning potential will depend upon the input data available, thus increasing the complexity of the programming and utilisation of any comprehensive projection software. However, any software should certainly be able to estimate the *probability* of going beyond PA reference points.

5.3.3 Data structures

Data may be available for use in projection modelling in a wide range of formats, and this diversity of data types creates problems for the construction of a single forecasting tool for all stocks. In order to use the same suite of functions on all stocks, a flexible internal data structure would be required which could be produced by aggregation or disaggregation to a common level. Neither of these approaches is ideal, as aggregation could mask potentially important factors (such as sex-disaggregated growth) for which data had specifically been collected. Alternatively, holding data at the most disaggregated level would necessitate the use of artificial keys, for which there is little or no information, in order to split aggregate data types down to the common level. The likely scenario is that the single projection tool will require a suite of forecasting approaches to be programmed for different levels of data aggregation.

5.4 Environmental drivers of variation in forecasts

The key deliverable from ToR c) of SGGROMAT is the production of projection software which incorporates more biological realism. Much attention was devoted during the SG meeting to discussion on the advantages and disadvantages of the use of physical environmental variables in historical modelling and forecasts for this purpose. There is no *a priori* scientific justification for limiting the models implemented in a software package to either biotic or abiotic factors, and the choice *in the first instance* should be driven purely by resource restrictions in time and manpower. That is, the initial implementation effort should prioritise those factors which will yield the most benefit for the effort. In the majority of ICES stocks these factors will be biotic, for the following reasons:

1. Projection models are used to advise fisheries management. The actions of management affect biotic factors such as stock structure, spawning-stock biomass and prey availability, not abiotic factors such as temperature or salinity.

2. The current population structure of a stock will persist for some time at least, since a proportion of the fish alive today will survive into the future. This residual stock dynamic signal can be used in forecasting: for example, a large year-class at age 2 has a good chance of remaining large in subsequent ages.

It is clear that analysis of the interactions between fish stocks and their physical environment must be encouraged to continue. There are already particular examples where a lag or lead-in time in the forecast would permit the rapid inclusion of such data, such as Northeast Arctic cod and American plaice, which recruit at ages 3 and 5 respectively, giving at least that many years worth of environmental data to be incorporated. There are also examples where environmentally-driven process-modelling is in an advanced state of development, such as Baltic Sea cod, and the results of such work may influence software development.

5.5 Multispecies/feeding modelling.

In instances where there are large changes in growth, it may be important to include feeding activities in the projection model. At the simplest level this could be the input of prey forecasts to the predator's projection model. This approach is taken with Icelandic cod where the biomass of capelin is included (see Section 5.7). This approach assumes only "bottom-up" regulation where the prey availability is assumed to be independent from predator abundance.

In contrast to this, MSVPA/MSFOR (Multispecies Virtual Population Analysis and Forecasting respectively) uses predator abundance to modify prey abundance through predation mortality. Food intake and growth are assumed to be constant in the MSVPA and changes in biomass of prey will therefore not affect the growth of their predators.

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Models for variable growth and maturity have now been implemented in 4M (the latest version of MSVPA/MSFOR). Average (historical) growth is modified by departures from average food availability. Maturity is modelled either with an analogue of the growth model, or by assuming a constant maturity-weight relationship and using modified weights. Either approach should behave in a similar way (ICES 2001b). Food intake is modelled as a function of body weight, food conversion efficiency (to somatic growth), proportion mature, a factor for body weight lost due to spawning, and the food conversion efficiency for spawning products. Thus the parameter requirements of this approach are considerable. The approach has been tested using data from the Baltic Sea (ICES 2001b) but is not used by the relevant assessment working group. Even this relatively complex approach to the forecasting of growth ignores the potential effects of different nutritional qualities of prey items.

It may be argued that for predators with varied diets (e.g., cod in temperate waters), or where little data on prey species are available (e.g., annelids and ophiuroids), the addition of multispecies effects to the forecasting of growth and maturity/fecundity might be an arduous task with little return.

The projection of feeding for those species living in simpler ecosystems (e.g., Barents Sea) is a more tractable proposition in terms of model complexity and parameter estimation. It remains the case that many forage species (e.g., capelin, sprat and sandeel) are short-lived with recruit-driven dynamics. MSFOR predictions were found to be most sensitive to the assumed future recruitment (ICES 2001b). If feeding-based growth of their predators is to be sucessfully modelled and forecast, effort must be directed to the understanding and prediction of such species (see Section 5.6.1).

5.6   Case study regarding predictability in the Barents Sea

The ability to use biotic or abiotic drivers of change in growth and reproductive potential in forecasts is dependent on the predictability of those drivers – if a certain factor is not predictable to any extent, its use in forecasting is rather curtailed. The predictability of two such factors (one biotic, one abiotic) in the Barents Sea is contrasted below.

5.6.1   Barents Sea capelin

Barents Sea capelin is a main prey item for Northeast Arctic cod. The abundance of Barents Sea capelin has shown large fluctuations, from 0.1 to 7.3 million tonnes as measured by an acoustic survey on 1+ fish (ICES CM 2002/ACFM:19). These fluctuations have had significant impact on cod growth (Mehl and Sunnanå, 1991) as well as on cod fecundity (Kjesbu et al., 1998). Thus, it is important to be able to predict capelin abundance. 1-year projections of capelin abundance are now routinely made available to the Arctic Fisheries Working Group. The Northern Pelagic and Blue Whiting Fisheries Working Group plans to include medium-term projections of capelin stock size in the annual assessment of Barents Sea capelin. Capelin recruitment is strongly influenced by the abundance of 1+ herring in the Barents Sea (Gjøsæter and Bogstad, 1998). Thus, capelin recruitment may be predicted 1 year ahead and the possibility of capelin collapse may be predicted 2–3 years ahead, with potential implications for forecasting of the predatory cod population.

5.6.2   Temperature in the Barents Sea

Prediction of Barents Sea temperature is complicated by the fact that variation is governed by processes of both external and local origin that operate on different time scales. The volume flux and temperature of inflowing Atlantic water masses as well as heat exchange with the atmosphere is important in determining the temperature of the Barents Sea. Thus, both slowly moving advective propagation and rapid barotropic responses due to large-scale changes in air pressure must be considered. The major changes in Barents Sea climate take place during the winter months. The variability in the amount of heat flowing in with Atlantic water masses from the south is particularly high during this season. Furthermore, variability in low-pressure passages and cloud cover has a strong influence on the winter atmosphere-ocean exchange.

This seasonal difference is reflected in the merit of simple six-month forecasts of Kola-section temperature based on linear regression models. The tendency is that persistence across the spring and summer months is higher than for other seasons, allowing for reasonably reliable forecasts from spring until autumn (Ottersen et al., 2000). Such half-year forecasts are now routinely made available to the Arctic Fisheries Working Group (ICES 2002c) and Northern Pelagic and Blue Whiting Fisheries Working Group (ICES 2002d).

Assuming that temperatures in the Barents Sea fluctuate periodically, it is possible to do medium-term forecasts by means of statistical methods. Such forecasts are also made available to the working groups mentioned above. However, the precision of such forecasts is not high. Ottersen et al. (2000) showed that historically about 25% of the variability in the time series was explained by forecasts as those given by Anon. (2002b).

5.7 Process-based models presently used in predictions

Below, some examples of process-based models currently used in predictions made by ICES assessment Working groups are given. Note that this is not intended to be a complete overview of all such models presently in use.

- Weight-at-age of capelin in the Iceland-Greenland-Jan Mayen area is predicted using a process-based model where the weight at age is inversely related to the abundance at age (Gudmundsdottir and Vilhjálmsson, 2002; ICES 2002d). The relationship used is given by:

$$w_a = P_{1,a} - P_{2,a} N_{total}$$

  where w_a is the mean weight of age a fish in the fishable stock in August-December, N_{total} is the total adult stock in numbers, and $P_{1,a}$ and $P_{2,a}$ are age-specific estimated parameters. This equation is used for ages 2 and 3.

- For Barents Sea capelin, the assessment and prediction uses a length-dependent maturation model as well as a model for natural mortality due to predation by cod (Gjøsæter et al., 2002; ICES 2002d). The maturation model is given by:

$$pm(l) = \frac{1}{1 + e^{4P_1(P_2 - l)}},$$

  where $pm(l)$ is the proportion of fish at length l which will become mature, and P_1 and P_2 are again estimated parameters. P_2 is the length at which 50% of the fish will mature, and P_1 is the slope of $pm(l)$ when $l = P_2$. The capelin abundance by age and length groups is estimated by an acoustic survey, and thus the abundance of maturing fish can be calculated from the survey estimate and the maturation function. The spawning stock is calculated by predicting the maturing stock six months ahead in time (October-April), using a model for predation by cod to calculate natural mortality.

- The mean weight at age of Icelandic cod is predicted using capelin abundance as an explanatory variable (Steinarsson and Stefánsson, 1996; ICES 2002e).

- For Irish Sea haddock, mean weight at age is predicted using a model for growth in length, which includes a year-class effect (ICES 2003). The mean weights-at-age of Irish Sea haddock are very variable in the older age groups, due to the low numbers in the catches. There is a trend in weight at age, so combining data from groups of years would result in a bias, as would using a constant. The mean weights are thus predicted using a model of the length data: $L_t = Yearclasseffect * L_\infty (1 - e^{-k(t - t_0)})$ and then converting to length using Weight = 0.0000039* L $^{3.2536}$. A small bias is introduced by calculating mean weights from mean lengths, but it will be consistent between years. The resultant stock weights were used in the ICES assessment of Irish Sea haddock. Whilst they show well the year effect in changes in growth, they would not be suitable for analysis of condition, as they assume a constant length to weight relationship.

It should be noted that the first three process models, which all consider cod and/or capelin, have been in use in Working Group projections for a number of years. It is unknown to what extent the performance of these process models in predictions has been evaluated.

5.8 Age- and length-structured models

The StockAn/RecAn/MedAn suite (see Section 2.17 and Section 12) includes models of length- and weight-dependent processes by switching between numbers at age and numbers at length using age-length keys. In addition, weight-length relationships are used. However, the models are still based on standard assessment data on weights-at-age and maturity-at-age, and estimated numbers-at-age. The three programs are built on to the standard assessment methodology, rather than being replacements for it.

An alternative approach is to explicitly model the stock development by using a model where the state variables are the number and individual weight of the fish in each age-length group. Within the EU project dst[2] (Anon., 2001b; 2002a), the Gadget modelling framework has been developed. Gadget is a computer program combining mathematical models of population biology with statistical estimation techniques. Gadget allows for a quite complex model structure: the population models may be multi-species, multi-area and multi-fleet age- and length structured models where processes as maturation, spawning, growth, fishing mortality, and natural mortality are modelled. A stock may be divided into

several sub-stocks (mature/immature, female/male, juvenile/adults etc.) with separate population dynamics. Data from surveys, commercial catches, stomach samples, and tagging experiments distributed on length and/or age groups may be used when fitting the model to observations. The model can, however, also be run as a self-contained model without data from observations.

The rationale for building such a model to study the dynamics of marine populations in boreal systems is given by Stefánsson and Pálsson (1998), while the model framework is described in detail by Stefánsson and Pálsson (1997). In these papers the term BORMICON is used to describe the modelling framework. Gadget is a newer version of this modelling framework and is a superset of both the Fleksibest (Frøysa et al., 2002) and BORMICON models.

In an age and length-structured model, the state variable is a matrix giving the number of fish for each age and length group. Processes like growth, maturation, fecundity, recruitment, fishing mortality and natural mortality can be modelled as functions of size (length, weight) instead of/in addition to as functions of age. Fitting a Gadget-type model to observations is a rather complex task, involving both choice of model structure (stocks, sub-stocks, number of age and length groups, time step etc.), choice of functional forms for growth, maturation, recruitment, predation/natural mortality and fishing mortality, and choice of likelihood functions for fitting the model to observations.

Gadget has now been implemented for a number of stocks in the Barents Sea, Icelandic waters, West of Scotland and Celtic Sea. For Northeast Arctic cod, Gadget (Fleksibest) is used by the Arctic Fisheries Working Group as a supplementary model to the XSA. Assessment and predictions using Gadget (Fleksibest) and XSA are compared in the 2002 Arctic Fisheries Working Group report (ICES 2002c). For Northeast Arctic cod, it seems appropriate to include the same process-based models in Gadget and MedAn and compare predictions made using the two methodologies.

5.9 Environmental scenarios in forecasts

Some general points associated with difficulty of forecasting environmental factors in the context of medium-term stock projections are covered in Section 5.4. However, while it may not be possible to forecast such environmental factors with appropriate precision in the medium term, this does not necessarily preclude the use of environmental factors in projections. If such factors are important drivers of e.g., growth and/or recruitment, and if they are not accounted for in the projection period then there is an implicit assumption that they are constant at some average value, depending how the projection models are parameterised. By including such factors in the projection model, the assumptions about the future environmental conditions are made explicit.

Once this step is taken, the next requirement is to decide what assumptions will be made about the future environment. A pragmatic approach is to use sequences of values from the observed time-series. This approach has the advantages that it preserves any time-series and covariance information in the data, and restricts values to the range of previous observations. The actual sequences used will depend upon the context of the projections, but for the purpose of providing management advice it would be appropriate to provide projections based on a relatively limited number of environmental scenarios. These might for instance include illustrative runs assuming 'good', 'average' and 'poor' environmental conditions, with perhaps one of these indicated as a 'most likely' scenario, based on e.g., recent conditions or climate modelling. The sequences of environmental data used in each scenario would then use a fixed starting year from the historical data, so that the periods used corresponded e.g., to 'good' environmental conditions based on historical experience. Using this approach, projections run for each environmental scenario with a range of levels of fishing mortality can be used to explore management strategies which should be robust to future environmental conditions.

As an alternative to using individual scenarios in this way, a similar approach can be used to incorporate the observed environmental variability into projections. Instead of using a fixed starting year from the historical time series for all runs, this can be randomised so that a different sequence of values is used in each simulation. The net result of this may be similar to the implicit assumption of constant, average conditions in the future which applies if environmental factors are disregarded, but it should provide more realistic estimates of the uncertainty which results from environmental variation.

Some example medium-term projections for Eastern Baltic cod for different environmental scenarios are given in Figure 5. 1. These use a recruitment model which incorporates the effect of oxygen conditions on egg survival and food availability on larval survival. The results are presented here for illustration only as at this stage the recruitment model used is regarded as exploratory, and hence is not documented here. The projections illustrate the effects of fishing at the precautionary fishing mortality F_{PA} (0.6), under poor, good and random environmental conditions. In this case the "poor" environment corresponds to the period of low oxygen and low food availability experienced since the early 1990s, which resulted in a series of poor year classes. The "good" environment sequence starts in 1976 when there was a period of high oxygen availability and food availability when some very large year classes were produced. At present

the stock is well below the precautionary biomass value B_{PA} (240,000t) and it can be seen that fishing at F_{PA} has a high probability of leading to rapid recovery to this level if good environmental conditions are experienced. Conversely, if the environment remains poor, the stock has a very low probability of recovering to this level. Under the assumption of random environment, fishing at F_{PA} leads to a probability of around 50% that the stock will reach B_{PA} in ten years.

It is necessary to add a number of caveats to these conclusions. The work presented here is based on cod in the Baltic Sea. The Baltic is a relatively simple system. This means that it is comparatively straightforward to study, and the processes influencing cod recruitment are relatively well understood. Even so, the use of this information in stock projections is still at an early stage, and there are a number of problems still to be addressed. In other areas with more complex ecosystems, it is much more difficult to identify the key processes in recruitment and growth and hence incorporate them in projections.

Furthermore, the use of environmental information in projections intended for management advice raises a number of issues. Such advice would need clear and careful presentation. Advice to managers typically involves presenting the consequences of a number of different management options. If environmental options (which cannot themselves be managed) are incorporated, this increases the number of scenarios to be presented multiplicatively. It also raises the possibility that under certain environmental scenarios it may not be possible e.g., to return SSB above B_{PA}. This may also undermine the credibility of such precautionary reference points, not least because the ICES implementation of the precautionary approach assumes that there is a fixed level of SSB below which recruitment is impaired. If environmental effects on recruitment are significant then this link is much less clear.

5.10 A case study investigating growth and maturity in medium-term projections

As an investigation of the sensitivity of medium-term projection results to methods of projecting growth and maturity, projections were run for Eastern Baltic cod using a fixed fishing mortality but different growth and maturity assumptions. The medium-term projections run also included a recruitment model which incorporates environmental effects, but as this is at an exploratory stage, it is not documented here. All projections assume the same scenario for future environment. The starting populations, fishing mortalities etc. come from the assessment of the stock made by Baltic Fisheries Assessment Working Group in 2001 (ICES 2001c).

Two approaches to estimating future weights at age are implemented; a fixed value based on a mean over the last N years, and an approach based on selecting a random growth increment from the last N years. This latter approach is described in more detail as follows:

Estimates of weight at age in the catch at the youngest age are derived by randomly selecting a mean value from the observed values at that age over the last N years. For older ages the procedure is to randomly select a growth increment at the appropriate age from the last N years and add this to the most recent observation or estimate of the weight at age of the relevant year-class. Thus the estimated weight at age $a+1$ in year $t+1$ is based on the weight at age a in year t plus an increment (i.e., the difference between weight at age a and age $a+1$ in the same cohort) drawn randomly from the preceding N years. Weights at age in the stock are derived from the weights at age in the catch using the mean ratio between stock and catch weights at age over the last ten years.

For maturity at age, two approaches were used; a mean over the last N years, or values derived from the catch weight-at-age data. For this stock there is a clear sigmoidal relationship between weight at age and maturity (Figure 5.2) so a model of this form has been fitted to describe this relationship between weight at age and maturity. Catch weight at age data were used instead of stock weight at age data, as there is a longer time series of observations of catch weights available for this stock.

Four sets of projections were run as follows:

- Weights at age and maturities based on random growth increments, $N = 3$ years.
- Weights at age and maturities based on random growth increments, $N = 10$ years.
- Weights at age and maturities based on fixed mean values, $N = 3$ years.
- Weights at age and maturities based on fixed mean values, $N = 10$ years

An additional run was made with weights at age based on random growth increments taken over the last 3 years but with maturities fixed at the three-year mean to identify what proportion of the effect is due to maturity.

The SSB projections from the four main runs are given in Figure 5.3 and the 50 percentiles of SSB from the separate run are compared in Figure 5.4. The 50 percentiles of SSB from the additional run and the equivalent runs where both growth and maturity vary or are kept fixed are given in Figure 5.5.

The results show similar overall trends in SSB under different assumptions about growth and maturity, but rather different absolute values. Taking growth and maturity based on observations over the last ten years leads to a higher value of SSB at the end of the ten-year projection period than using observations from the last three years, and using fixed average values leads to a higher final SSB than using random increments. The effect of the number of years of observations used is greater than the difference between using fixed means and random increments. The results from the additional run using variable growth but fixed maturities indicates that assuming fixed maturities leads to higher estimates of SSB than if maturity varies with growth.

The main differences in results comes from using different time periods of observations. In this case the use of only the three most recent years leads to lower estimates of SSB as there has been a general tendency for reduced weight at age in recent years. This probably also leads to the lower values when the random increment approach is used, as the low weights at age of cohorts forming an important part of the starting population propagate through into the projection period. The fact that using growth increments selected from the ten year period leads to higher values than the recent period, indicates that the reduction in growth in recent years is apparent as reduced growth increments as well as initial weight at age.

The results from these analyses indicate that the choice of projection model for growth and maturity can have an important influence on the results of medium-term projections. Further work on this is clearly desirable, but provisionally it would appear that a cohort-based approach as used here (and also in WD2) would be preferable to using fixed values for weight at age and maturity in future years. Such an approach is able to account for the relative growth rate of individual cohorts present in the fishery and thus uses more information about recent growth than assuming a fixed mean.

The cohort approach used here appears to offer some advantages over the conventional approach of using fixed mean values for weight at age and maturity, and while such an approach may not be appropriate for all stocks, an approach along these lines may provide a useful default procedure for stocks for which more complex, process-based models are not available. It is possible to envisage related approaches, including selecting increments as a percentage, rather than absolute basis, selecting increments from the same year to model year effects in growth, or attempting to model time-series effects in growth increments, and these may be productive areas for future work.
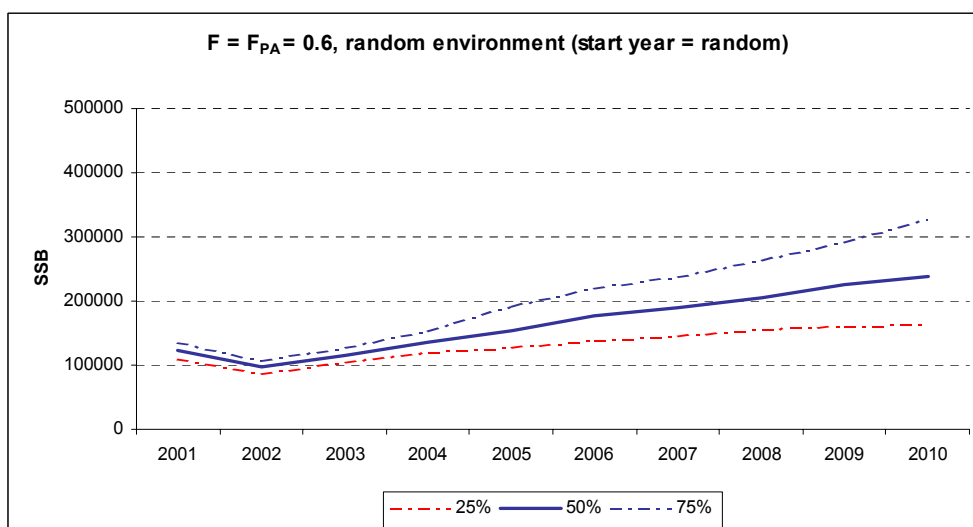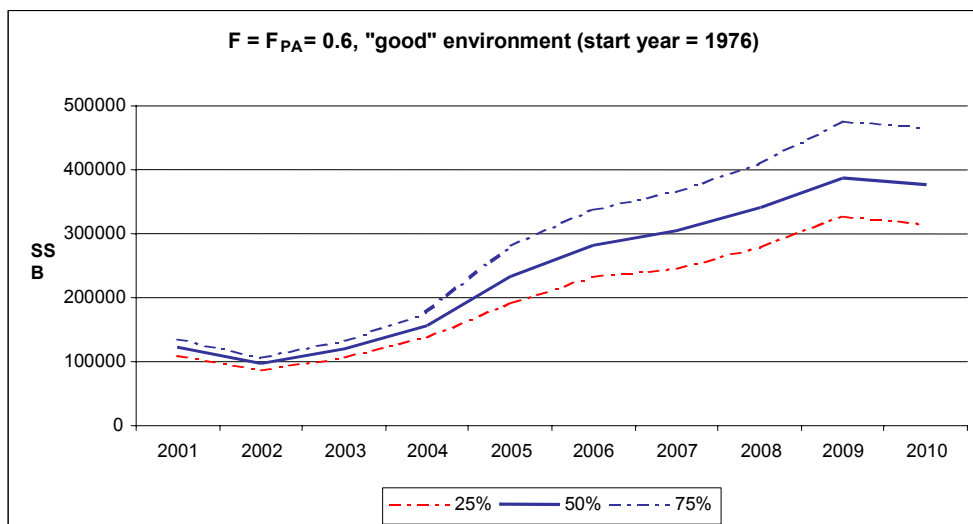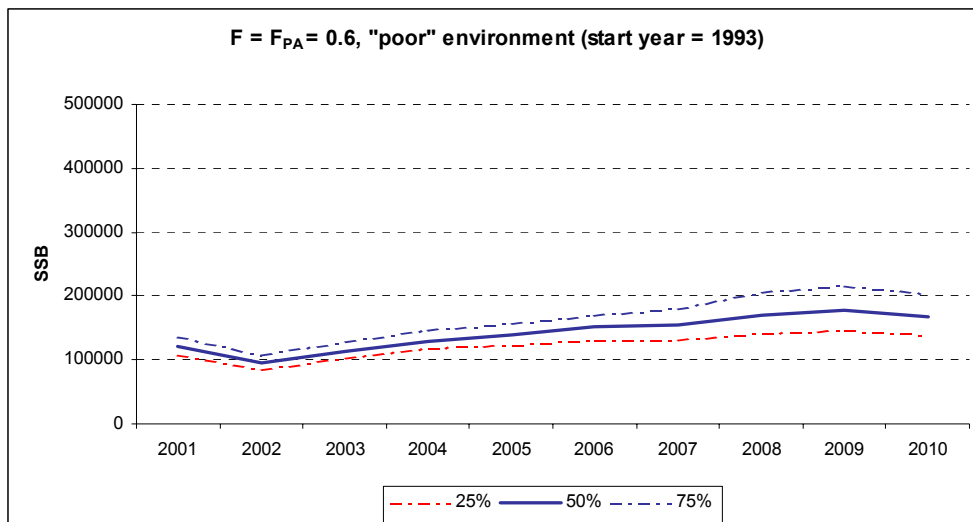
Figure 5.1. Medium-term projection of SSB for Eastern Baltic cod under different scenarios for the future environment.
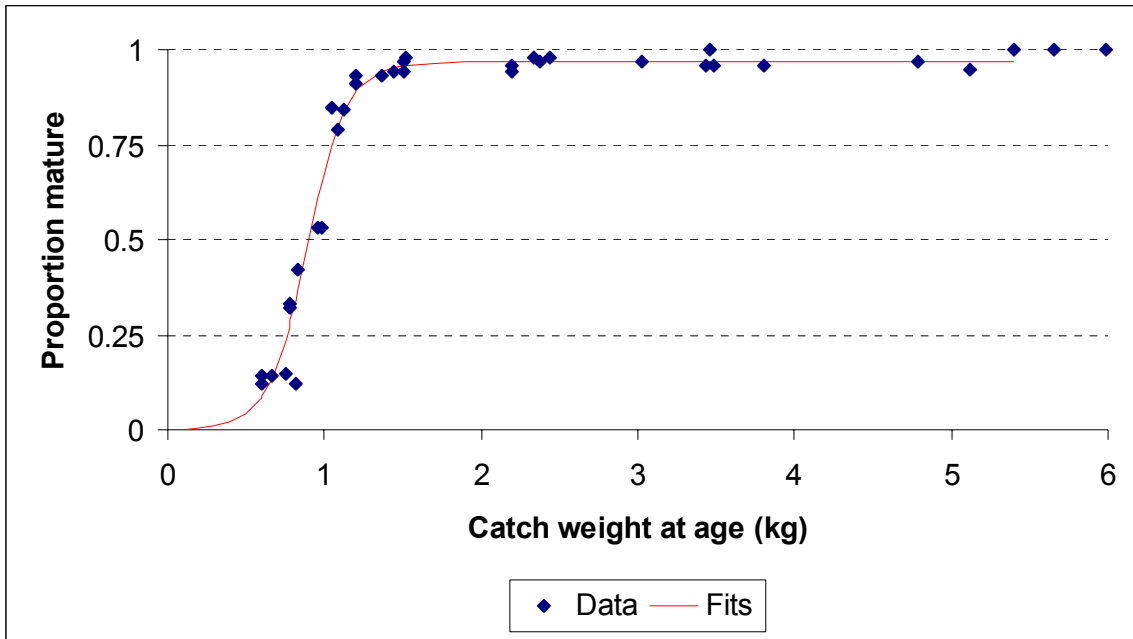
Figure 5.2   The relationship between catch weight at age and proportion mature for Eastern Baltic cod.

Random growth increments, 3 years
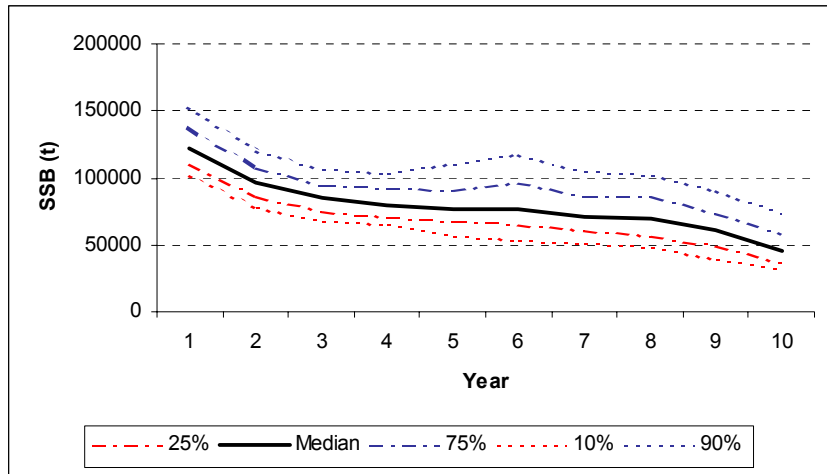
Random growth increments, 10 years
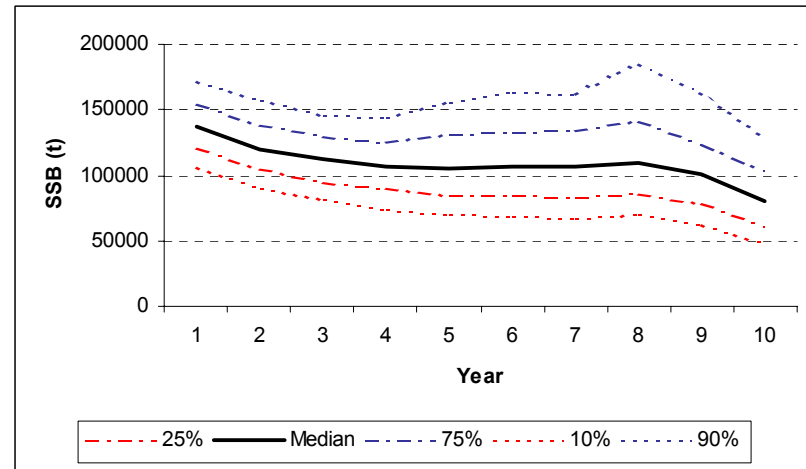
Fixed mean values, 3 years
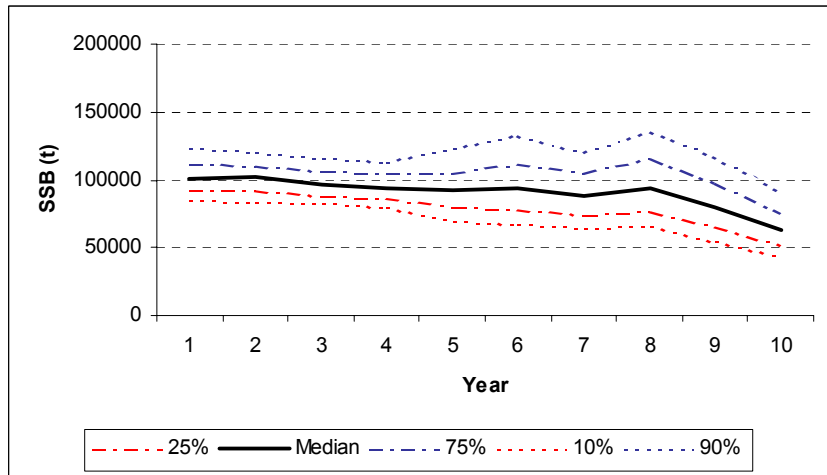
Fixed mean values, 10 years
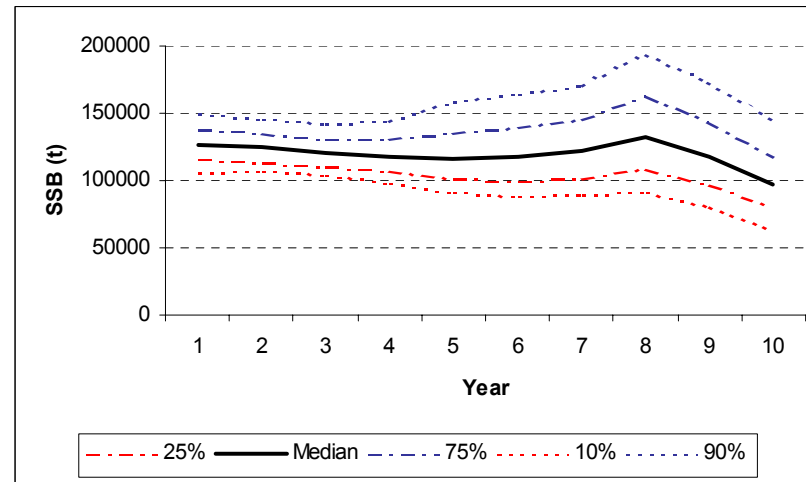
Figure 5. 3   Medium-term projections for SSB for Eastern Baltic Cod for fixed F (FSQ = 1.07) using different approaches to forecasting weight at age and maturity. The projections also incorporate environmental variability ("poor" environment, i.e., start year 1993)
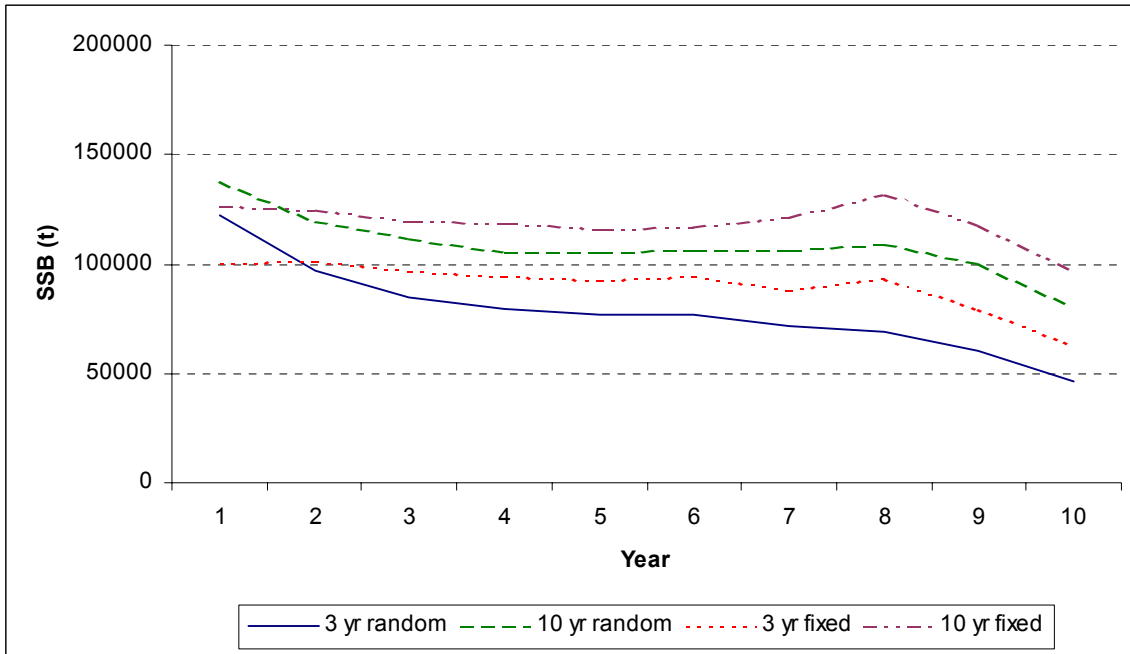
Figure 5.4   50-percentiles of SSB from medium term projections for Eastern Baltic cod using different approaches to forecasting growth and maturity
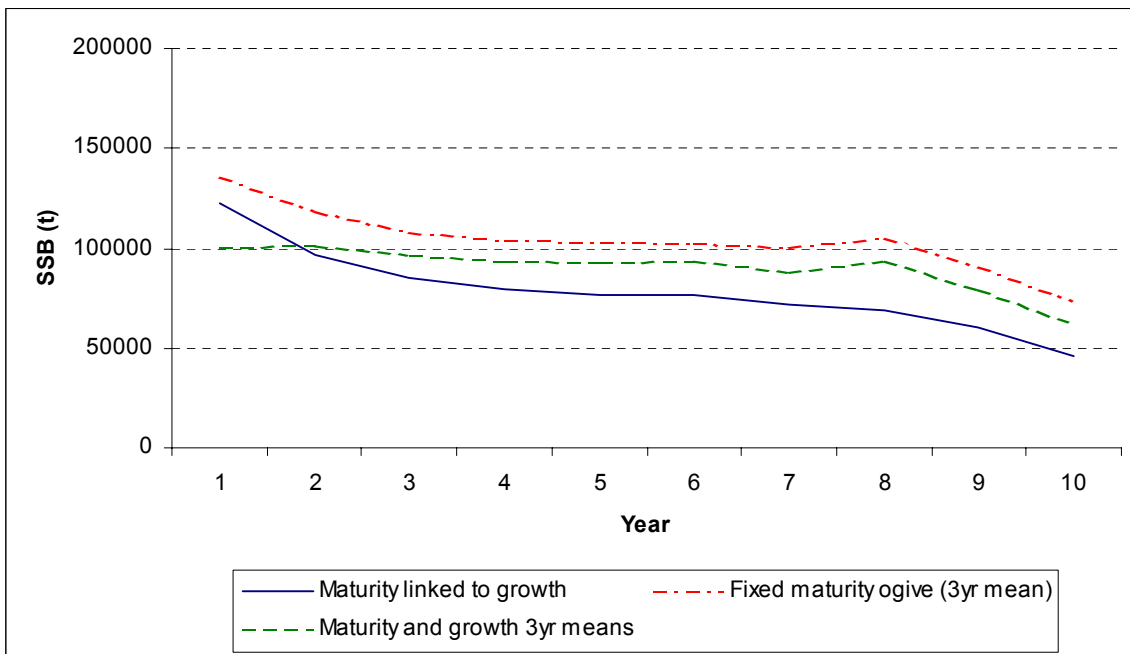
Figure 5.5   50-percentiles of SSB from medium term projections for Eastern Baltic cod using different approaches to forecasting maturity

6 CONCLUSIONS

The tasks for which SGGROMAT was convened, namely the summarising of data availability, the formulation of appropriate process models, and the implementation of models in projection software, have not yet been completed although a promising start has been made. Indeed, it now appears that the ToRs for the first SGGROMAT meeting were rather ambitious. A short meeting such as this one is not the place for extensive hypothesis testing and programming, but rather for reviewing and assessing the work that has been done and formulating proposals and plans for the work still to be done. SGGROMAT appears to be a good forum within which to accomplish these tasks, and momentum has been built within the Study Group to carry the required tasks forward.

6.1 Precautionary approach reference points

In the current advisory framework used within ICES, a precautionary approach (PA) to fisheries management has been framed in terms of reference points for SSB and F. The SG recognises that SSB has the potential to be a misleading proxy for spawning potential, and as such questions the validity of reference points based upon SSB. There are, however, several arguments in favour of retaining SSB reference points for the time being;

- The concept of SSB is a relatively simple one and is easily explained to a wide variety of stakeholders.

- SSB reference points are already used in management and legal frameworks (EU-Norway agreements).

- SSB can be determined for all analytically-assessed stocks, whereas the calculation of more complex measures of reproductive potential is only possible for a sub-set of stocks

That said, it should not be assumed that stakeholders would not accept alternative indices of reproductive potential where the use of SSB reference points can be demonstrated to pose a significant risk to stock recovery potential. Once suitable candidates for spawning potential have been agreed upon, sensitivity analyses should be undertaken to investigate the likely consequences of managing to reference points based on SSB or alternative indices.

6.2 Intersessional programme to apply the findings of the Study Group

ToR d) calls for the SG to "agree on an intersessional programme to apply the findings of the Study Group." The intention behind this ToR was to formulate a timetable for collating data, implementing models in software, and encouraging the use of the software in the 2003 round of ICES assessment Working Groups. This ToR seems now to have been overly optimistic. The work on all three aspects of the SG's remit (data collation, model formulation, implementation) is at a much earlier stage than had previously been anticipated. For this reason it would be premature to attempt to apply the SG's findings to the ICES assessment process in 2003.

More generally, plans of work have been put in place to enable each of ToRs a), b) and c) to be addressed intersessionally, and these are discussed in the relevant Sections of this report.

7 LINKS TO OTHER GROUPS

The findings of several recent meetings are relevant to the deliberations of SGGROMAT, namely:

- the ICES Working Group on Recruitment Processes;
- the ICES Working Group on Cod and Climate Change;
- the ICES Working Group on Transport Processes in Cod;
- the ICES Working Group on Methods of Fish Stock Assessments;
- the DFO Workshop on implementing data from the AZMP in stock assessment.

The outcomes of this meeting will be useful for several forthcoming meetings, namely:

- the ICES Study Group on Biological Reference Points for Northeast Arctic cod (SGBRP: January 2003);
- the ICES Working Group on Methods of Fish Stock Assessments (WGMG: January 2003);
- the ICES Study Group on Precautionary Reference Points for Advice on Fishery Management (SGPRP: February 2003);
- the NAFO Working Group on Reproductive Potential (the date of which yet to be fixed);
- the ICES assessment Working Groups which begin with Herring (March 2003);

- the ICES Study Group on Age-Length Structured Assessment Models (June 2003);
- the ICES Study Group on Multispecies Assessments in the North Sea (August 2003).

Several of these meetings would ideally have a completed projection package available to them, although at the moment it seems unlikely that this will be achievable for 2003 (particularly the forecast module).

8 RECOMMENDATIONS

8.1 Second SGGROMAT meeting

The SGGROMAT recommends that the Resource Management Committee makes the following recommendation:

The **Study Group on Growth, Maturity and Condition in Stock Projections** [SGGROMAT] (Co-Chairs: C. L. Needle, UK and C. T. Marshall, Norway) will meet at a location to be decided during six days in early December 2003 to:

a)   review progress in summarising data availability for the stocks identified in the first SGGROMAT meeting;

b)   evaluate extant projection methodologies which incorporate process-based growth, maturity, condition and fecundity models, and propose modifications where necessary;

c)   review and compare currently-available projection software and sensitivity analyses of their likely effects on fisheries management.

The SGGROMAT report will be available for perusal by the Resource Management Committee (who parents the Group), along with the Living Resources, Oceanography, and Baltic Committees, and ACFM. The report will be brought to the attention of the Working Group on Methods of Fish Stock Assessments (WGMG) and the ICES Study Group on Precautionary Reference Points for Advice on Fishery Management (SGPRP).

SGGROMAT would recommend further that the Working Group on Recruitment Processes [WGRP] pursue process studies in such a way that outcomes and results can be used in projection models.

8.2 Provision of meta-data

The ToR a) for this SGGROMAT meeting called for the creation of tables of data sources (i.e., meta-data) for a wide variety of stocks. A plan of action to address this task has been formulated, and certain key individuals have agreed to participate in the meta-data collation process. However, undertaking such a task is labour-intensive, and relies heavily on the good-will and time-availability of members of staff at national fisheries science laboratories. The end-product of all this endeavour will be of enormous value, not only to those involved in its collation, but to the whole ICES community. Therefore, SGGROMAT recommends that ICES staff become actively involved in this work, by contacting the relevant members of SGGROMAT (the co-chairs, in the first instance) and identifying ICES data sources which should be included in the final tables.

8.3 Routine collection of condition information

Considering that fish condition influences fish productivity in multiple ways (recruitment, adult mortality, growth, fecundity, maturation, etc), condition data should be routinely collected from the fishery and from surveys. SGGROMAT recommends that the International Bottom Trawl Survey Working Group and the Baltic International Fish Survey Working Group consider ways in which this could be achieved.

8.4 Working documents and presentations

SGGROMAT recommends that the ICES secretariat combines the working documents and computer presentations from the meeting on the same CD as the final report, using preferably a separate directory. This has been done for the herring assessment Working Group, and has proved to be extremely useful.

9 REFERENCES AND WORKING DOCUMENTS

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9.2 Working Documents

WD 1: Bogstad, B. and Howell, D. Use of age- and length-structured models: A way of incorporating more biological knowledge in population models.

WD 2: Brander, K. Predicting weight at age in cod.

WD 3: Dickey-Collas, M., Armstrong, M. J. and Gerritsen, H. D. Trends in growth and maturity in Irish Sea cod, whiting, haddock and herring.

WD 4: Filin, A. A. Simulation of cod growth in the Barents Sea as an element of medium-term projection of its stock dynamics

WD 5: Heino, M. Estimating age- and size-dependent maturation probabilities.

WD 6: Heino, M., Vinje, F., Dieckmann, U. and Godø, O. R. Establishing growth indices in fish stocks: application to Northeast Arctic cod.

WD 7: Kraak, S. Dutch data sets on North Sea plaice.

WD 8: Kraak, S. Other Dutch data sets.

WD 9: Lloret, J. and Rätz, H-.J. Use of condition indices as indicators of habitat quality.

WD 10: Morgan, M. J., Healey, B. P. and Shelton, P. A. An approach to examining factors affecting recruitment: a work in progress.

WD 11: Simmonds, E. J. A method for calculation of optimum mean weights-at-age for use in the assessments and predictions: an example using North Sea herring data.

10   TABLES OF REPRODUCTIVE POTENTIAL

10.1 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 and larval production can be evaluated for different stocks. The tables, including information about available data and their sources, will be listed on the NAFO web-site 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 four tables: 1) Available Data; 2) Data Basis, Format and Quality; 3) Studies of Reproductive Potential; and 4) Data Sources. The first table provides an overview of the availability of basic information to estimate the reproductive potential of a given stock. The table is on a yearly scale and includes basic variables only. 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 the address of persons and laboratories is given. An example of a completed table is provided, i.e., witch flounder in NAFO Sub-areas 5 and 6 (Gulf of Maine-Georges Bank).

The listed variables are intended to primarily cover aspects related to maternal and paternal influences on the 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 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.

The availability of data and information to estimate reproductive potential varies tremendously, from hardly any data existing for some species or stocks while others are data-rich with studies of reproductive potential and recruitment processes at an advanced level. However, tables recording data-poor stocks may prove to be as valuable as data-rich as they may draw attention to specific variables and research fields where information is needed in order to estimate the stock reproductive potential. The availability of data has thus not been a criterion in the selection of species to be included. The species/stocks identified by the Working Group mainly include commercially exploited, demersal species, which were allocated to 4 levels according to priority. Level 1 includes all species managed by NAFO as well as those managed by member states but brought to NAFO for review at those states' request. Level 2 includes species associated with Terms of Reference 3 and 4 of the Working Group, i.e., methods to estimate reproductive potential and potential applications in stock assessment and management. Level 3 includes cod stocks not contained in Levels 1 and 2, and Level 4 comprises additional species which contributors have volunteered to include.

10.2 Guidelines to fill in tables

The template file (Table Templates - Reproductive Potential - updated 20010703.dot) is protected, and should be opened as read only. The file includes four tables, 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., witch flounder in NAFO Sub-areas 5 and 6 (Gulf of Maine-Georges Bank), 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 - area - management code.doc" (as in the example: "Witch flounder - Northwest Atlantic - NAFO Subareas 5 and 6.doc"). Be aware not to apply save as "document template" as it saves the form, but not the information filled into the form. Do not protect the document, the NAFO Working Group will do this after updating document properties.

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 2–4 will be updated automatically, e.g., 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 submission of data to the NAFO Working Group 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. These persons are normally also the contact persons for the stock in case of questions regarding table contents (the names and addresses of contact persons will be listed below).

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 and potentially estimate the viable egg and larvae production. This implies that highest priority should be given to inclusion of quantitative measures or relationships 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: √ is selected in the form field if proper information about a given variable is available. Option 3: (√) 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 √ or (√) 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 to record specific information about variables.

Table 2

The text fields in the header to be filled in include information about Reproductive Strategy, Timing of Spawning, Optimal Time for Maturity Sampling and Recommended Method for Fecundity Analysis 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 depend on the type of reproductive strategy, which also relates to the methods recommended for fecundity analyses. 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 more 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 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 factors and parameters" at the end of the table – specifying under "Notes …" the kind of information; if sub-categories are incomprehensive, the information can similarly be entered under "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 data, methods and contents', additional information about the particular data source can be added. The help function (F1) provides general 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 e.g., estimates of egg or larvae production may be available. This information should be included in Table 3. The headers will be filled in automatically. The table lists different subject-related categories to include information about the reproductive potential

as well as about processes affecting stock reproduction. 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. The table repeats the variables and subjects specified in Tables 2 and 3. This may imply that single references applying to more subjects or categories have to be repeated. This structure, however, makes it very easy to overview the sources available for each category. For each variable or subject, the reference numbers applying to the proceeding tables as well as the data sources should be filled in, i.e., full literature reference or the name and postal address of contact persons.

DATA ON REPRODUCTIVE POTENTIAL

TABLE 1: AVAILABLE DATA

COMMON NAME: _____   SPECIES: _____

AREA: _____   STOCK: _____

CREATED BY: _____   UPDATED: _____

Data status									
Year	Stock size	Stock composition	Age	Sex ratio	Maturity	Fecundity	Weight	Condition	Additional data
2001									
2000									
1999									
1998									
1997									
1996									
1995									
1994									
1993									
1992									
1991									
1990									
1989									
1988									
1987									
1986									
1985									
1984									
1983									
1982									
1981									
1980									
1979									
1978									
1977									
1976									

						Data status				
Year	**Stock size**	**Stock composition**	**Age**	**Sex ratio**	**Maturity**	**Fecundity**	**Weight**	**Condition**	**Additional data**
1975									
1974									
1973									
1972									
1971									
1970									
1969									
1968									
1967									
1966									
1965									
1964									
1963									
1962									
1961									
1960									

DATA ON REPRODUCTIVE POTENTIAL

TABLE 2: DATA BASIS, FORMAT AND QUALITY

COMMON NAME:

AREA:

STOCK:

REPRODUCTIVE STRATEGY: **REF. NO.:**

TIMING OF SPAWNING: **REF. NO.:**

OPTIMAL TIME FOR MATURITY SAMPLING: **REF. NO.:**

RECOMMENDED METHOD FOR FECUNIDTY ANALYSIS:

       REF. NO.:

[**Blank table to be placed here**]

Data basis, format and quality					
Variables	**Year range**	**Data basis (A/L/W)**	**Data origin**	**Sampling frequency**	**Notes on data, methods and contents**	**Ref. No.**
Stock size						
Stock composition						
Age determination						
Sex ratio						
Maturity:						
A. Ogives (E)						
B. Skip of spawning						
C. Spawning probability						
D. Other						
Fecundity:						
A. Estimation						
B. First time vs. repeat spawners						
C. Atresia						
D. Other						
Weight:						
A. Commercial fisheries data						

Data basis, format and quality					
Variables	**Year range**	**Data basis (A/L/W)**	**Data origin**	**Sampling frequency**	**Notes on data, methods and contents**	**Ref. No.**
B. Survey data					
C. Other					
Condition:					
A. Fulton					
B. HSI					
C. Energy					
D. Other					
Egg viability:					
A. Egg quality					
B. Fertilisation success					
C. Egg mortality					
D. Other					
Larval viability:					
A. Hatching success					
B. Larvae quality					
C. Mortality					
D. Other					
Spawning time					
Contamination					
Environmental key factors					
Other factors or parameters					

DATA ON REPRODUCTIVE POTENTIAL

TABLE 3: STUDIES OF REPRODUCTIVE POTENTIAL

COMMON NAME:

AREA:

STOCK:

Estimation of reproductive potential			
Subject	**Brief description**	**Year range**	**Ref. No.**
Potential or realised egg production			
Viable egg and larvae production			
Critical life stages			
Environmental influences			
Stock recruitment relations			
Other studies			

DATA ON REPRODUCTIVE POTENTIAL

TABLE 4: DATA SOURCES

COMMON NAME:

AREA:

STOCK:

Data sources		
Variables	**Ref. No.**	**Data sources** (literature reference or contact person)
Stock size		
Stock composition		
Age determination		
Sex ratio		
Maturity:		
A. Ogives (E)		
B. Skip of spawning		
C. Spawning probability		
D. Other		
Fecundity:		
A. Estimation		
B. First time vs. repeat spawners		
C. Atresia		
D. Other		
Weight:		
A. Commercial fisheries data		
B. Survey data		
C. Other		
Condition:		
A. Fulton		
B. HSI		
C. Energy		
D. Other		
Egg viability:		
A. Egg quality		
B. Fertilisation success		

Data sources		
Variables	**Ref. No.**	**Data sources** (literature reference or contact person)
C. Egg mortality		
D. Other		
Larval viability:		
A. Hatching success		
B. Larvae quality		
C. Mortality		
D. Other		
Spawning time		
Contamination		
Environmental key factors		
Estimation of reproductive potential:		
A. Potential or realised egg production		
B. Viable egg and larvae production		
C. Critical life stages		
D. Environmental influences		
E. Stock recruitment relations		
Other references		

11 DATA AVAILABILITY ON STOCK REPRODUCTIVE POTENTIAL: POTENTIAL STOCKS TO REVIEW

Category A: Assessed stocks in the North Sea, Barents Sea, Baltic Sea, Irish Sea

Group	Species	Stock	Area	rea code	Assessment WG	Chair
Baltic Sea						
F	Flounder	Baltic flounder 24–25	Baltic Sea	ICES SD 24–25	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
G	Cod	Eastern Baltic cod*	Baltic Sea	ICES SD 25–32	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
G	Cod	Western Baltic cod	Baltic Sea	ICES SD 22–24	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
P	Herring	Central Baltic herring	Baltic Sea	ICES SD 25–29, 32	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
P	Herring	Bothnian Sea herring,	Baltic Sea	ICES SD 30	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
P	Herring	Bothnian Bay herring	Baltic Sea	ICES SD 31	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
P	Herring	Gulf of Riga herring	Baltic Sea	Part ICES SD 28	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
P	Herring	Spring spawning herring 22–24, IIIa (Rügen herring)	Baltic Sea, Kattegat, Skagerrak	ICES SD 22–24, Div. IIIa	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@i Mrno
P	Sprat	Baltic sprat	Baltic Sea	ICES SD 25–32	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
North Sea						
F	Plaice	English Channel (east)	English Channel (east)	ICES Div. VIId	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
F	Plaice	North Sea plaice	North Sea	ICES Subarea IV	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
F	Plaice	Skagerrak & Kattegat	Skagerrak & Kattegat	ICES Div. IIIa	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
F	Sole	English Channel	English Channel (east)	ICES Div. VIId	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
F	Sole	North Sea sole	North Sea	ICES Subarea IV	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
G	Cod	North Sea cod*	North Sea, Skagerrak, Kattegat, English Channel (east)	ICES Subarea IV, Div. IIIa, VIId	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl

Group	Species	Stock	Area	rea code	Assessment WG	Chair
G	Haddock	North Sea haddock*	North Sea, Skagerrak & Kattegat	ICES Subarea IV, Div. IIIa	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
G	Norway pout	North Sea, Skagerrak & Kattegat	North Sea, Skagerrak & Kattegat	ICES Subarea IV, Div. IIIa	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
G	Saithe	North Sea, West of Scotland, Rockall, and Skagerrak & Kattegat	North Sea, West of Scotland, Rockall, and Skagerrak & Kattegat	ICES Subarea IV, VI and Div. IIIa	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
G	Whiting	North Sea whiting	North Sea and English Channel (east)	ICES Subarea IV, Div. VIId	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
O	Sandeel	North Sea	North Sea	ICES Subarea IV	WG on the Assessment of Demersal Stocks in the North Sea and Skagerrak	M. A. Pastoors martin@rivo.wag-ur.nl
P	Herring	North Sea autumn spawners	North Sea	ICES Div. IV, VIId, IIIa	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@i Mrno
P	Sprat	North Sea	North Sea	ICES Div. IV	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@i Mrno
Irish Sea						
F	Plaice	Irish Sea plaice	Irish Sea	ICES Div. VIIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
F	Sole	Irish Sea sole	Irish Sea	ICES Div. VIIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
G	Cod	Irish Sea cod	Irish Sea	ICES Div. VIIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
G	Haddock	Irish Sea haddock	Irish Sea	ICES Div. VIIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
G	Whiting	Irish Sea whiting	Irish Sea	ICES Div. VIIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
P	Herring	Irish Sea, autumn spawners	Irish Sea (North)	ICES Div. VIIa (N)	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@i Mrno

Barents Sea

Group	Species	Stock	Area	Area code	Assessment WG	Chair
F	Greenland Halibut	NEA	Barents/ Norwegian Sea	ICES Div. I-II	Arctic Fisheries WG	S. Mehl sigbjoern.mehl@i Mrno
G	Cod	NEA Cod*	Barents Sea	ICES Div. I-II	Arctic Fisheries WG	S. Mehl sigbjoern.mehl@i Mrno
G	Cod	Norwegian Coastal Cod	Barents Sea	ICES Div. I-II	Arctic Fisheries WG	S. Mehl sigbjoern.mehl@i Mrno
G	Haddock	NEA Haddock	Barents Sea	ICES Div. I-II	Arctic Fisheries WG	S. Mehl sigbjoern.mehl@i Mrno
G	Saithe	NEA Saithe	Barents/ Norwegian Sea	ICES Div. I-II	Arctic Fisheries WG	S. Mehl sigbjoern.mehl@i Mrno
P	Capelin	Barents Sea	Barents Sea	ICES Div. I	Northern Pelagic and Blue Whiting Fisheries WG	A. Gudmundsdottir asta@hafro.is
P	Herring	Norwegian spring spawning	Barents/ Norwegian Sea	ICES Div. I, II, V	Northern Pelagic and Blue Fisheries Whiting WG	A. Gudmundsdottir asta@hafro.is
R	Deep-water redfish	NEA (*Sebastes mentella*)	Barents/ Norwegian Sea	ICES Div. I-II	Arctic Fisheries WG	S. Mehl sigbjoern.mehl@i Mrno
R	Golden redfish	NEA (*Sebastes marinus*)	Barents/ Norwegian Sea	ICES Div. I-II	Arctic Fisheries WG	S. Mehl sigbjoern.mehl@i Mrno

Category B: Assessed stocks in other ICES areas than priority A

Group	Species	Stock	Area	Area code	Assessment WG	Chair
F	Greenland halibut	Greenland	Greenland, Iceland, Faroes	ICES V, XIV	North-Western WG	E.Hjörleifsson einarhj@hafro.is
F	Megrim	Southern Shelf Megrim (*Lepidorhombus whiffiagonus* & *Lepidorhombus boscii*)	Celtic Sea and Bay of Biscay	ICES Div. VIIb,c,e-k, VIIIa,b,d	WG on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim	V. Trujillo valentin.trujillo@vi .ieo.es
F	Megrim	Northern Shelf	West of Scotland, Rockall	ICES Div. VI	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marin e.ie
F	Plaice	Celtic Sea Plaice	Celtic Sea	ICES Div. VIIf and g	WG on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co .uk
F	Plaice	Western Channel Plaice	Western Channel	ICES Div. VIIe	WG on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co .uk
F	Sole	Bay of Biscay Sole	Bay of Biscay	ICES VIII a and b	Working Group on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co .uk

Group	Species	Stock	Area	Area code	Assessment WG	Chair
F	Sole	Celtic Sea Sole	Celtic Sea	ICES Div. VII f and g	Working Group on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co.uk
F	Sole	Kattegat-Skagerrak sole	Kattegat, Skagerrak	ICES Div. IIIa	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
F	Sole	South of Ireland Sole	South of Ireland	ICES Div. VIIh-k	Working Group on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co.uk
F	Sole	Western Channel Sole	Western Channel	ICES Div. VIIe	Working Group on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co.uk
G	Cod	Celtic Sea cod	Celtic Sea	ICES Div. VII e – k	WG on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co.uk
G	Cod	Greenland	Greenland	ICES Div. XIV +NAFO 1	North-Western WG	E.Hjörleifsson einarhj@hafro.is
G	Cod	Icelandic cod*	Iceland	ICES Div. Va	North-Western WG	E.Hjörleifsson einarhj@hafro.is
G	Cod	Kattegat cod	Kattegat	ICES Div. IIIa	Baltic Fisheries Assessment WG	M. Plikshs Maris@latfri.lv
G	Cod	West of Scotland	West of Scotland	ICES Div. VIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
G	Haddock	Iceland	Iceland	ICES Div. Va	North-Western WG	E.Hjörleifsson einarhj@hafro.is
G	Haddock	Rockall	Rockall	ICES Div. VIb	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
G	Haddock	West of Scotland	West of Scotland	ICES Div. VIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
G	Hake	Northern Hake	Combined	ICES Div. II-VIII	Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim	V. Trujillo Valentin.trujillo@vi.ieo.es
G	Saithe	Iceland	Iceland	ICES Div. Va	North-Western WG	E.Hjörleifsson einarhj@hafro.is
G	Whiting	Southern shelf whiting	Celtic Sea	ICES Div. VIIe-k	Working Group on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co.uk
G	Whiting	West of Scotland	West of Scotland	ICES Div. VIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie
O	Anglerfish	Northern Shelf	North Sea, Skagerrak & Kattegat, West of Scotland, Rockall	ICES div.IV, VI IIIa	WG on the Assessment of Northern Shelf Demersal Stocks	R.A. Officer rick.officer@marine.ie

Group	Species	Stock	Area	Area code	Assessment WG	Chair
O	Anglerfish	Southern Anglerfish (*Lophius piscatorius*)	Celtic Sea, Bay of Biscay	ICES Div. VIIb-k, VIII a,b,d	WG on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim	V. Trujillo valentin.trujillo@vi.ieo.es
O	Anglerfish	Southern Anglerfish (*Lophius budegassa*)	Celtic Sea, Bay of Biscay	ICES Div. VIIb-k, VIII a,b,d	WG on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim	V. Trujillo valentin.trujillo@vi.ieo.es
P	Anchovy	Bay of Biscay, Iberian Region (north)	Bay of Biscay, Iberian Region (north)	ICES Subarea VIII	WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy	D. Skagen dankert.skagen@iMrno
P	Anchovy	Iberian Region (east)	Iberian Region (east)	ICES Subarea IXa	WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy	D. Skagen dankert.skagen@iMrno
P	Blue whiting	"Atlantic blue whiting"	Northeast Atlantic	ICES Div. I-IX, XII, XIV	Northern Pelagic and Blue Whiting Fisheries WG	A. Gudmundsdottir asta@hafro.is
P	Capelin	Iceland-East Greenland-Jan Mayen area	Iceland-East Greenland-Jan Mayen area	ICES Div. V, XIV, Div IIa	Northern Pelagic and Blue whiting Fisheries WG	A. Gudmundsdottir asta@hafro.is
P	Herring	Celtic Sea & VIIj	Celtic Sea	ICES Div. VIIg, VIIj	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@iMrno
P	Herring	Icelandic summer spawning	Iceland	ICES Div. Va	Northern pelagic & Blue whiting Fisheries WG	A. Gudmundsdottir asta@hafro.is
P	Herring	Ireland autumn-spring spawners	NW Ireland	ICES Div. VIa (S), VIIb,c	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@iMrno
P	Herring	West of Scotland, autumn spawners	West of Scotland	ICES Div. VIa (N)	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@iMrno
P	Horse mackerel	North Sea horse Mackerel	Central and southern North Sea, eastern Skagerrak & Kattegat, English Channel (east)	ICES Div. IIIa (excluding western Skagerrak) Ivbc, VIId	WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy	D. Skagen dankert.skagen@iMrno
P	Horse mackerel	Southern Horse Mackerel (Iberian Region)	Iberian Region	ICES Div. VIIIc and IXa	WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy	D. Skagen dankert.skagen@iMrno
P	Horse mackerel	Western horse mackerel	Norwegian Sea, western Skagerrak, northern North Sea, Faroes, West of Scotland, Irish Sea, West of Ireland, Celtic Sea, Bristol Channel, English Channel (west), Bay of Biscay	ICES Div. Iia, IIIa (western part), Iva, Vb, VIa, VIIa-c, VIIe-k and VIIIabde	WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy	D. Skagen dankert.skagen@iMrno

Group	Species	Stock	Area	Area code	Assessment WG	Chair
P	Mackerel	Northeast Atlantic	Northeast Atlantic	ICES Subareas IV, Vb, VI, VII, VIII	WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy	D. Skagen dankert.skagen@iMrno
P	Sardine	Iberian Region	Iberian Region	ICES Div. VIIIc and IXa	WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy	D. Skagen dankert.skagen@iMrno
P	Sprat	Kattegat-Skagerrak	Kattegat-Skagerrak	ICES Div. IIIa	Herring Assessment WG for the Area South of 62° N	E. Torstensen Else.torstensen@iMrno
R	Deep-water redfish	Irminger pelagic fishery	Irminger Sea	ICES Div. XII, Va, XIV	North-Western WG	E.Hjörleifsson einarhj@hafro.is
R	Deep-water redfish	Greenland, Iceland, Rockall	Greenland, Iceland, Rockall	ICES Div. V, VI, XIV	North-Western WG	E.Hjörleifsson einarhj@hafro.is
R	Golden redfish	(*Sebastes marinus*)	Greenland, Iceland, Irminger, Rockall	ICES Div. V, VI, XII, XIV	North-Western WG	E.Hjörleifsson einarhj@hafro.is

Category C: Assessed stocks in other areas

Group	Species	Stock	Area	Area code	Assessment body	Contact person
Northwest Atlantic						
F	American plaice	West Greenland	NW Atlantic	NAFO SA 1	NAFO	H. Siegstad/H. Raetz helle@natur.gl / raetz.ish@bfa-fisch.de
F	American plaice	Southern Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4T	Canada	R. Morin morinb@dfo-mpo.gc.ca
F	Atlantic halibut	Scotian shelf/southern Grand Bank	NW Atlantic	NAFO Div. 4VWX3NOPs	Canada	K. Zwanenburg zwanenburgk@mar.dfo-mpo.gc.ca
F	Greenland halibut	Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4RST	Canada	R. Morin morinb@dfo-mpo.gc.ca
F	Winter flounder	Southern Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4T	Canada	R. Morin morinrb@dfo-mpo.gc.ca
F	Witch flounder	Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4RST	Canada	D. Swain swaind@dfo-mpo.gc.ca
F	Yellowtail flounder	Southern Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4T	Canada	G. Poirier poirierg@dfo-mpo.gc.ca
G	Haddock	Grand Bank	NW Atlantic	NAFO Div. 3LNO	Canada	E. Murphy murphye@dfo-mpo.gc.ca

Group	Species	Stock	Area	Area code	Assessment body	Contact person
G	Silver Hake	Scotian Shelf	NW Atlantic	NAFO Div. 4VWX	Canada	M. Showell showellm@mar.dfo-mpo.gc.ca
O	Atlantic wolffish	West Greenland	NW Atlantic	NAFO SA 1	NAFO	H. Siegstad/H. Raetz helle@natur.gl / raetz.ish@bfa-fisch.de
O	Thorny Skate	Grand Banks	NW Atlantic	NAFO 3LNOPs	Canada/unregulated outside 200 miles	D. Kulka kulkad@dfo-mpo.gc.ca
P	Capelin	Northeast NF Shelf/northern Grand Bank	NW Atlantic	NAFO 2J3KL	Canada	J. Carscadden carscaddenj@dfo-mpo.gc.ca
P	Herring	White Bay- Notre Dame Bay	NW Atlantic	NAFO Div. 3K	Canada	J. Wheeler wheelerj@dfo-mpo.gc.ca
P	Herring	Bonavista Bay-Trinity Bay	NW Atlantic	NAFO Div. 3L	Canada	J. Wheeler wheelerj@dfo-mpo.gc.ca
P	Herring	Conception Bay-Southern Shore	NW Atlantic	NAFO Div. 3L	Canada	J. Wheeler wheelerj@dfo-mpo.gc.ca
P	Herring	St. Mary's Bay-Placentia Bay	NW Atlantic	NAFO Div. 3L 3Ps	Canada	J. Wheeler wheelerj@dfo-mpo.gc.ca
P	Herring	Fortune Bay	NW Atlantic	NAFO Div. 3Ps	Canada	J. Wheeler wheelerj@dfo-mpo.gc.ca
P	Herring	Southern Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4T	Canada	G. Poirier poirierg@dfo-mpo.gc.ca
P	Herring	SW Nova Scotia/Bay of Fundy	NW Atlantic	NAFO Div. 4VWX	Canada	R. Stephenson stephensonr@mar.dfo-mpo.gc.ca
P	Herring	Offshore Scotian Shelf	NW Atlantic	NAFO Div. 4VWX	Canada	R. Stephenson stephensonr@mar.dfo-mpo.gc.ca
P	Herring	Coastal Nova Scotia	NW Atlantic	NAFO Div. 4VWX	Canada	R. Stephenson stephensonr@mar.dfo-mpo.gc.ca
P	Herring	SW New Brunswick	NW Atlantic	NAFO Div. 4VWX	Canada	R. Stephenson stephensonr@mar.dfo-mpo.gc.ca
P	Herring	West Coast of Newfoundland	NW Atlantic	NAFO Div. 4R	Canada	F. Gregoire gregoiref@dfo-mpo.gc.ca
P	Herring	Quebec north shore	NW Atlantic	NAFO Div. 4S	Canada	F. Gregoire gregoiref@dfo-mpo.gc.ca
R	Redfish spp.	West Greenland	NW Atlantic	NAFO SA 1	NAFO	H. Siegstad/H. Raetz helle@natur.gl / raetz.ish@bfa-fisch.de
R	Redfish spp.	Unit 1	NW Atlantic	NAFO Div. 4RST-3P4Vn(Jan-May)	Canada	B. Morin morinb@dfo-mpo.gc.ca

Group	Species	Stock	Area	Area code	Assessment body	Contact person
	USA STOCKS TO COME					
Mediterranean Sea						
G	Hake	*(Merluccius merluccius)*	Balearic	GFCM 1, 2, 3, 5, 6	General Fisheries Commission for the Mediterranean	Luis Gil de Sola (IEO Málaga)
G	Hake	*(Merluccius merluccius)*	Gulf of Lions	GFCM 7	General Fisheries Commission for the Mediterranean	Arnauld Souplet (Ifremer Sète)
O	Angler	*(Lophius piscatorius)*	Balearic	GFCM 1, 2, 3, 5, 6	General Fisheries Commission for the Mediterranean	Luis Gil de Sola (IEO Málaga)
O	Angler	*(Lophius piscatorius)*	Gulf of Lions	GFCM 7	General Fisheries Commission for the Mediterranean	Arnauld Souplet (Ifremer Sète)
O	Axillary seabream	*(Pagellus acarne)*	Balearic	GFCM 1, 2, 3, 5, 6	General Fisheries Commission for the Mediterranean	Luis Gil de Sola (IEO Málaga)
O	Axillary seabream	*(Pagellus acarne)*	Gulf of Lions	GFCM 7	General Fisheries Commission for the Mediterranean	Arnauld Souplet (Ifremer Sète)
O	Black-bellied angler	*(Lophius budegassa)*	Balearic	GFCM 1, 2, 3, 5, 6	General Fisheries Commission for the Mediterranean	Luis Gil de Sola (IEO Málaga)
O	Black-bellied angler	*(Lophius budegassa)*	Gulf of Lions	GFCM 7	General Fisheries Commission for the Mediterranean	Arnauld Souplet (Ifremer Sète)
O	Common pandora	*(Pagellus erythrinus)*	Balearic	GFCM 1, 2, 3, 5, 6	General Fisheries Commission for the Mediterranean	Luis Gil de Sola (IEO Málaga)
O	Common pandora	*(Pagellus erythrinus)*	Gulf of Lions	GFCM 7	General Fisheries Commission for the Mediterranean	Arnauld Souplet (Ifremer Sète)
O	Red mullet	(*Mullus barbatus*)	Balearic	GFCM 1, 2, 3, 5, 6	General Fisheries Commission for the Mediterranean	Luis Gil de Sola (IEO Málaga)
O	Red mullet	(*Mullus barbatus*)	Gulf of Lions	GFCM 7	General Fisheries Commission for the Mediterranean	Arnauld Souplet (Ifremer Sète)
O	Striped red mullet	(*Mullus surmuletus*)	Balearic	GFCM 1, 2, 3, 5, 6	General Fisheries Commission for the Mediterranean	Luis Gil de Sola (IEO Málaga)
O	Striped red mullet	(*Mullus surmuletus*)	Gulf of Lions	GFCM 7	General Fisheries Commission for the Mediterranean	Arnauld Souplet (Ifremer Sète)

Category D: Stocks with marginal fishery or landings only

Group	Species	Stock	Area	Area code	Assessment body	Chair/contact
Northeast Atlantic						
F	Brill	Baltic brill	Baltic Sea	ICES SD 22–32	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Dab	Baltic dab	Baltic Sea	ICES SD 22–32	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Flounder	Flounder 22	Baltic Sea	ICES SD 22	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Flounder	Flounder 26	Baltic Sea	ICES SD 26	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Flounder	Flounder 28	Baltic Sea	ICES SD 28	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Flounder	Botnian Sea flounder	Baltic Sea	ICES SD 29–30	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Flounder	Flounder 32	Baltic Sea	ICES SD 32	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Plaice	Baltic plaice	Baltic Sea	ICES SD 22–32	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Turbot	Baltic turbot	Baltic Sea	ICES SD 22–32	Baltic Fisheries Assessment WG	Maris Plikshs Maris@latfri.lv
F	Plaice	South of Ireland Plaice	Northeast Atlantic	ICES Div. VIIh-k	Working Group on the Assessment of Southern Shelf Demersal Stocks	S. Flatman s.flatman@cefas.co.uk
G	Blue ling	Arctic and Atlantic Ocean	Northeast Atlantic	ICES Subareas I to XII and XIV	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno

Group	Species	Stock	Area	Area code	Assessment body	Chair/contact
G	Ling	Norwegian Sea, northern North Sea, Faroes, Iceland, Rockall, West of Scotland, Irish Sea, West of Ireland, Celtic Sea, English Channel	Northeast Atlantic	ICES Div. IIa, IVa, subareas V, VI and VII	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno
G	Tusk	Norwegian Sea, northern North Sea, Faroes, Iceland, Rockall, West of Scotland	Northeast Atlantic	ICES Div. IIa, IVa, Subareas V, VI	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno
O	Black scabbard-fish	Iceland, Rockall, West of Ireland, Bay of Biscay, Iberian Region	Northeast Atlantic	Mainly ICES subareas V, VI, VII, VIII, IX	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno
G	Greater forkbeard –*Phycis blennoides*	Rockall, West of Ireland, Bay of Biscay, Iberian Region	Northeast Atlantic	Mainly ICES subareas VI, VII, VIII, IX	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno
P	Greater silver smelt	Norwegian Sea, Baltic, Iceland, Rockall, West of Ireland	Northeast Atlantic	Mainly ICES div. IIa, III, V, VI, VII	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno
O	Orange roughy	Iceland, Rockall, West of Ireland, Irminger Sea	Northeast Atlantic	Mainly ICES subareas V, VI, VII, X, XII	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno
O	Red / Blackspot seabream	Azores deep, Rockall, West of Ireland, Bay of Biscay, Iberian Region	Northeast Atlantic	Mainly ICES subarea X, some VI, VII, VIII, IX	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno
O	Round-nose grenadier	Baltic, Iceland, Rockall, West of Ireland, Irminger Sea	Northeast Atlantic	ICES Subareas III, V, VI, VII, XII	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno

Group	Species	Stock	Area	Area code	Assessment body	Chair/contact
O	Deepwater sharks	Rockall, West of Ireland, Bay of Biscay, Iberian Region, Irminger Sea	Northeast Atlantic	Mainly ICES subareas VI, VII, VIII, IX, X, XII	WG on Biology and Assessment of Deep Sea Fisheries Resources	Odd Bergstad oddaksel@iMrno

Northwest Atlantic

Group	Species	Stock	Area	Area code	Assessment body	Chair/contact
G	White Hake	Scotian Shelf / Georges Bank	NW Atlantic	NAFO Div. 4VWX5Z	Canada	A. Bundy bundya@mar.dfo-mpo.gc.ca
G	White Hake	Southern Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4T	Canada	T. Hurlbut hurlbutt@dfo-mpo.gc.ca
G	White Hake	Grand Bank/St. Pierre Bank	NW Atlantic	NAFO Div. 3LNOPs	Canada	D. Kulka Kulkad@dfo-mpo.gc.ca
O	Lumpfish	Southern Newfoundland	NW Atlantic	NAFO Div. 3P	Canada	D. Stansbury stansburyd@dfo-mpo.gc.ca
O	Monkfish	Grand Bank/Southern Newfoundland	NW Atlantic	NAFO Div. 3LNOPs	Canada	D. Kulka kulkad@dfo-mpo.gc.ca
O	Monkfish	Scotian shelf/northwest Georges Bank	NW Atlantic	NAFO Div. 4VWX5Zc	Canada	D. Beanlands beanlandsd@mar.dfo-mpo.gc.ca
O	Northern wolffish	Newfoundland	NW Atlantic	NAFO SA 2+3	Canada	D. Kulka kulkad@dfo-mpo.gc.ca
O	Porbeagle shark	Eastern Canada/USA	NW Atlantic	NAFO Subarea 3–6	Canada	S. Campana campanas@mar.dfo.mpo.gc.ca
O	Spotted wolffish	Newfoundland	NW Atlantic	NAFO SA 2+3	Canada	D. Kulka kulkad@dfo-mpo.gc.ca

Group	Species	Stock	Area	Area code	Assessment body	Chair/contact
O	Spotted wolfish	West Greenland	NW Atlantic	NAFO SA 1	NAFO	H. Siegstad/H. Raetz helle@natur.gl / raetz.ish@bfa-fisch.de
O	Thorny skate	West Greenland	NW Atlantic	NAFO SA 1	NAFO	H. Siegstad/H. Raetz helle@natur.gl / raetz.ish@bfa-fisch.de
O	Wolffish	Scotian shelf/Georges Bank/Gulf of St. Lawrence	NW Atlantic	NAFO SA 4 + Div. 5YZe	Canada	J. McRuer mcruerj@mar.dfo-mpo.gc.ca
P	Capelin	Southern Grand Bank	NW Atlantic	NAFO Div. 3NO	NAFO	K. Gorchinsky
P	Capelin	Gulf of St. Lawrence	NW Atlantic	NAFO Div. 4RST	Canada	J-L. Beaulieu beauliewjl@dfo-mpo.gc.ca

*completed by the NAFO Working Group on Reproductive Potential

12 STOCKAN AND RECAN OUTPUTS

12.1.1 Northeast Arctic cod

StockAn outputs for Northeast Arctic cod are given in Figures A.1.1.1 – A.1.1.6, while example RecAn model fits are shown in Figures A.1.1.7 – A.1.1.8. Data sources are as detailed in Section 4.5.1.2.

12.1.2 North Sea stocks

StockAn outputs for weights-at-length modelling of North Sea cod, haddock, whiting and plaice are given in Figures A.1.2.1. – A.1.2.4 respectively. Data on numbers-at-age, mean weights-at-age, and proportion mature-at-age are taken from the 2002 report of the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES CM 2003/ACFM:02), while weights-at-length data are taken from the annual Q3 English groundfish survey as provided to the SG.

a.

b.

c.

d.
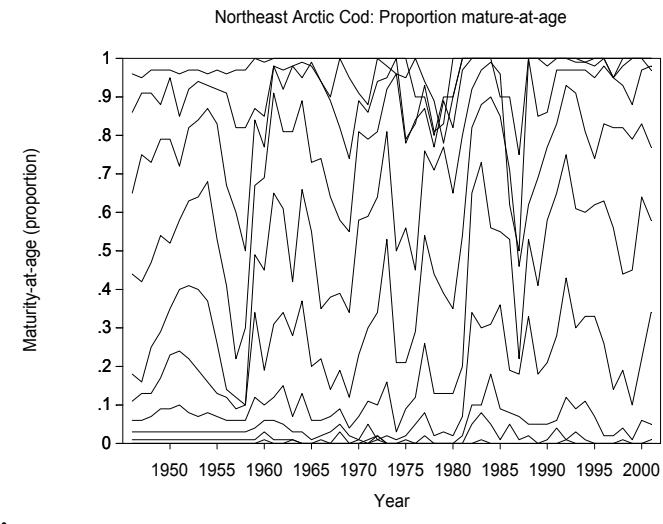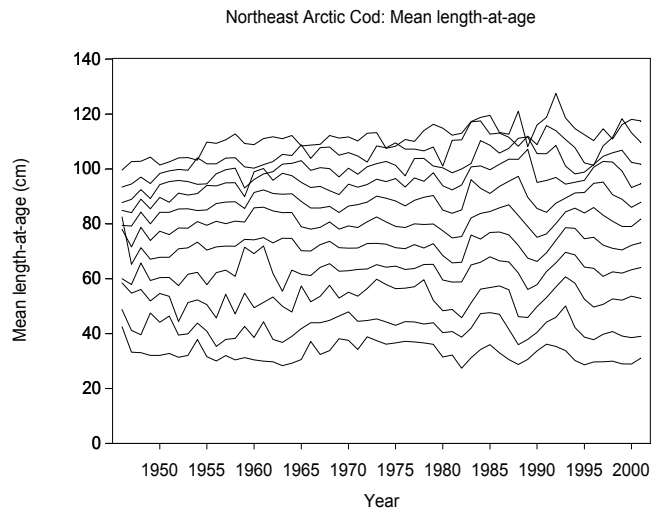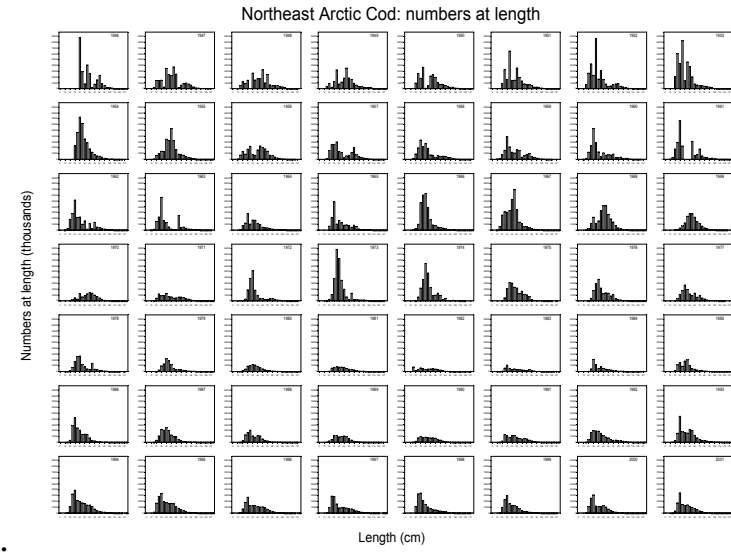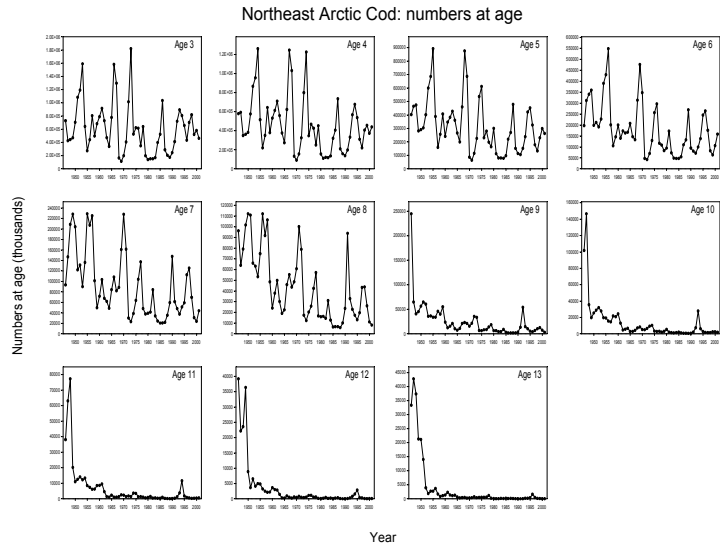
**Figure A.1.1.1.**   StockAn outputs for Northeast Arctic cod. Input data: a) numbers at age; b) numbers at length; c) mean length at age; d) proportion mature at age.
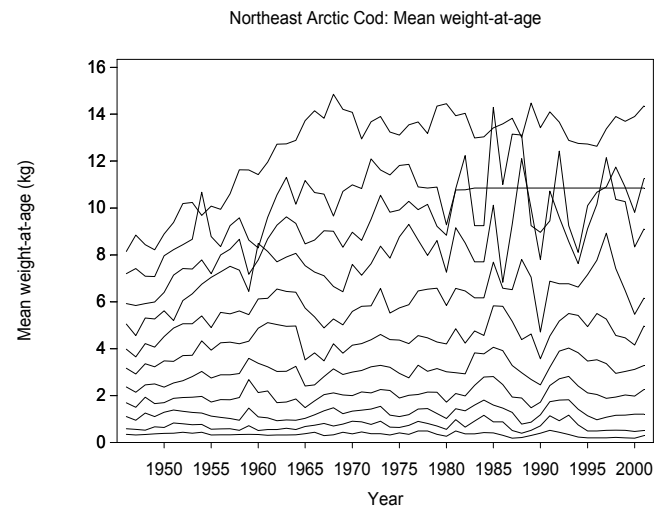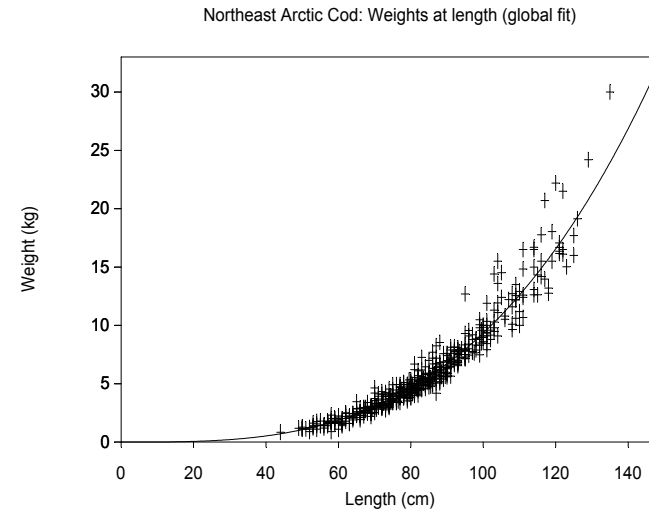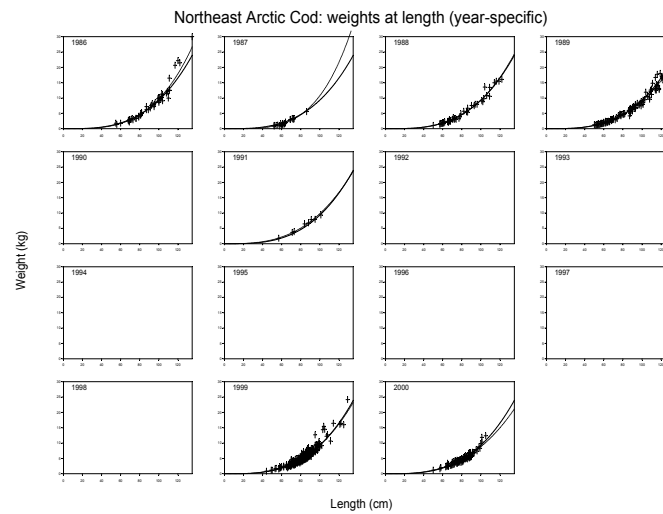
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Figure A.1.1.2. StockAn outputs for Northeast Arctic cod. a) Mean weights at age; b) weights against length from the fecundity dataset with fitted power model; c) as for b), but with years plotted separately
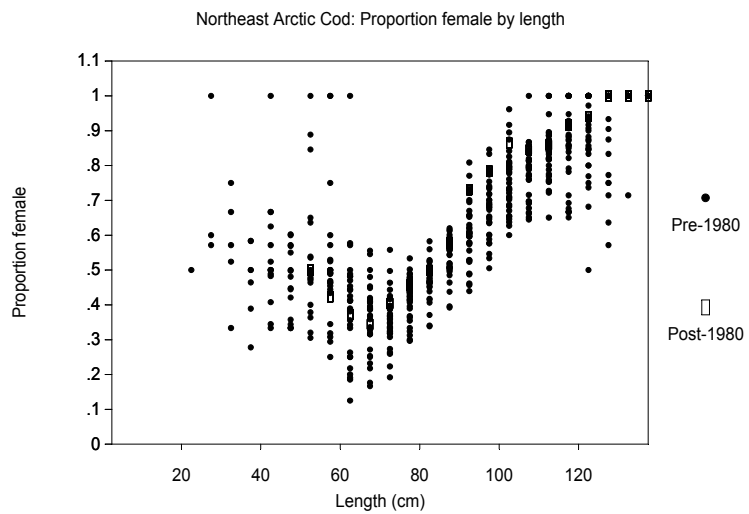
a.
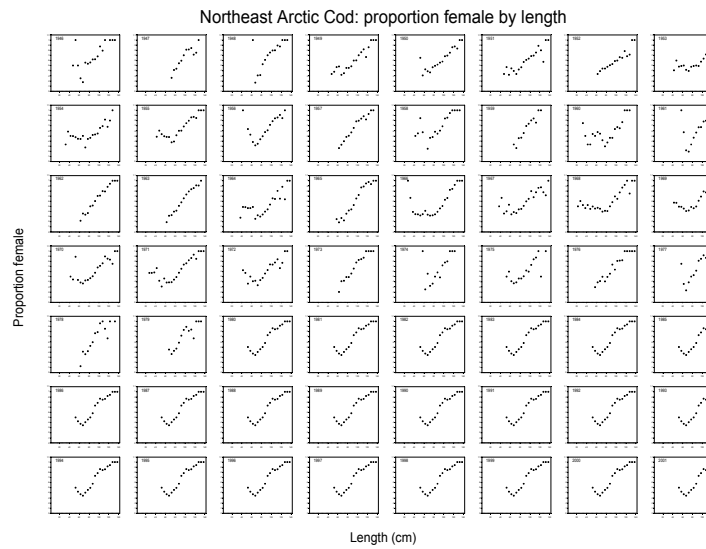
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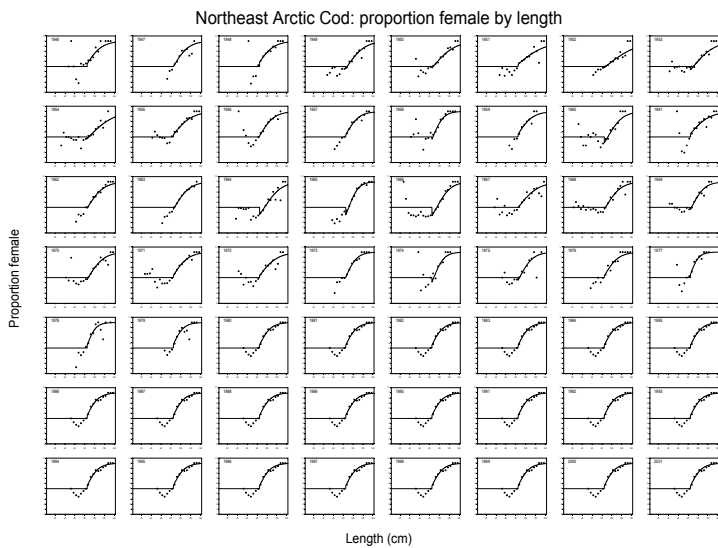
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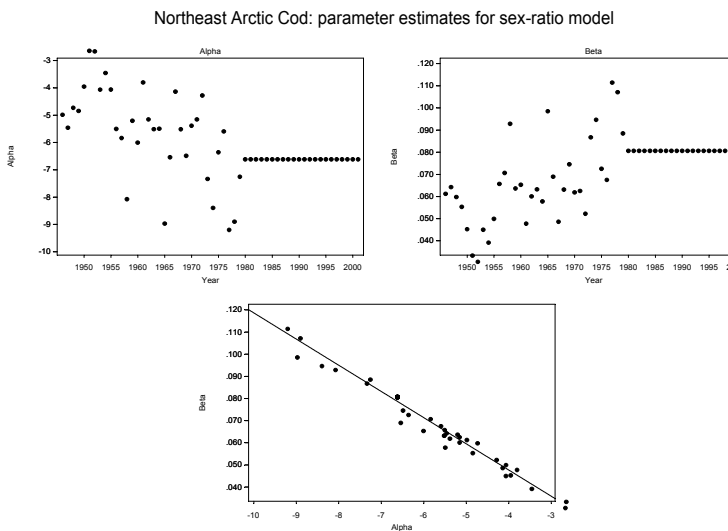
d.

Figure A.1.1.3. StockAn outputs for Northeast Arctic cod. Proportion female at length.
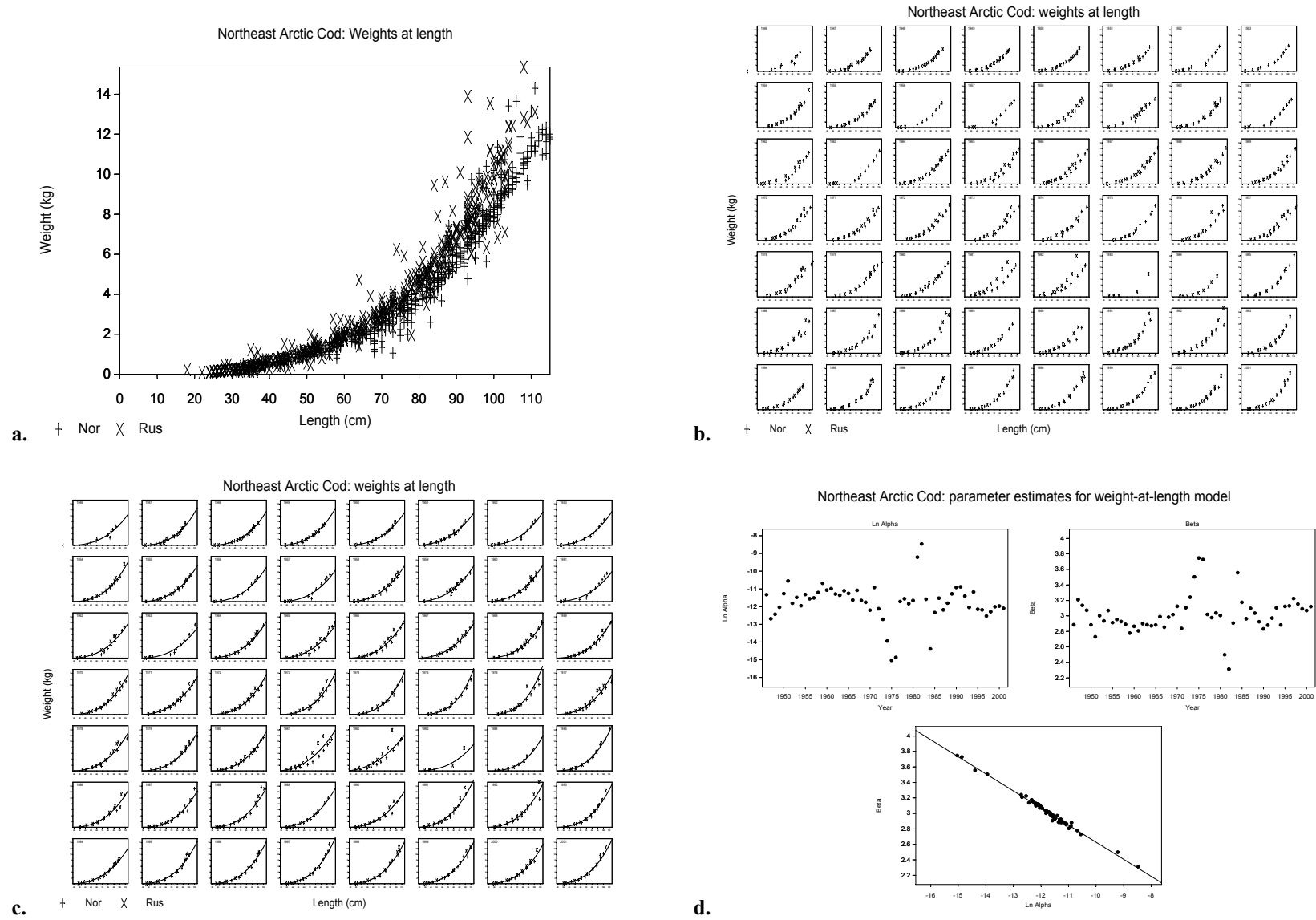
Figure A.1.1.4. StockAn outputs for Northeast Arctic cod. Weights at length.
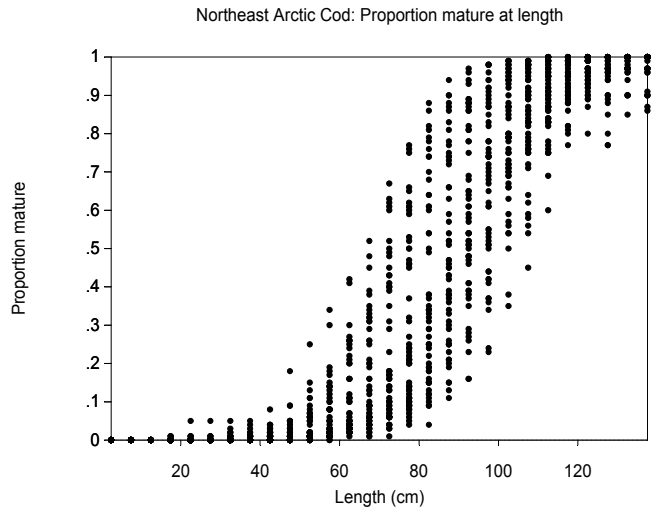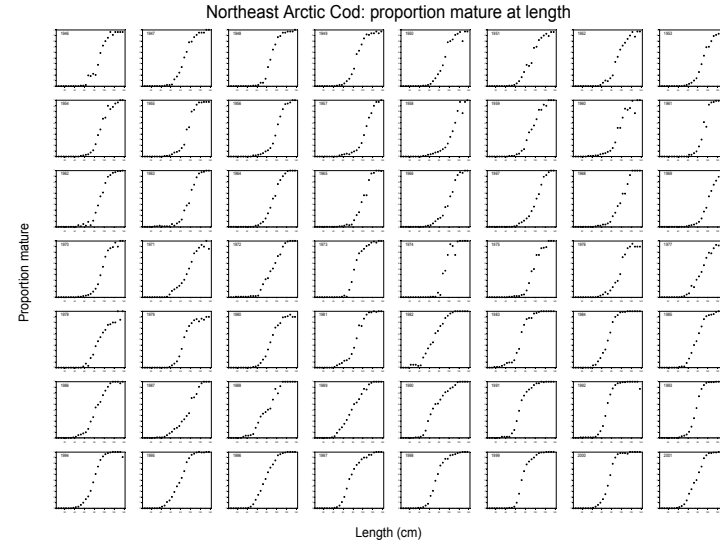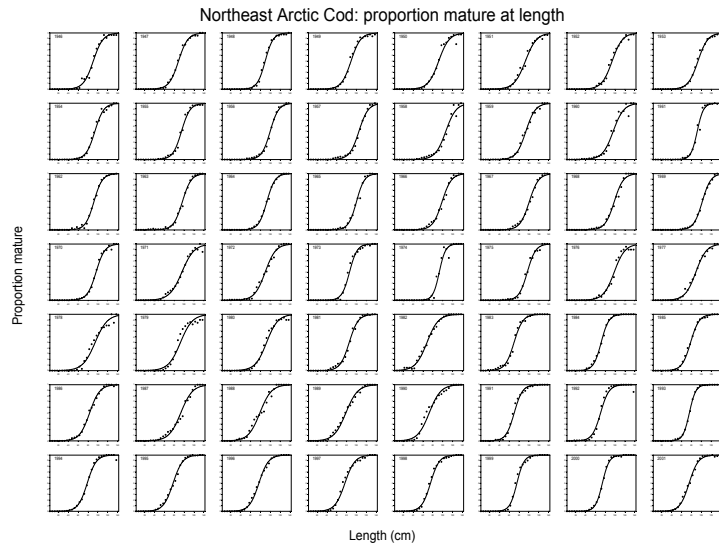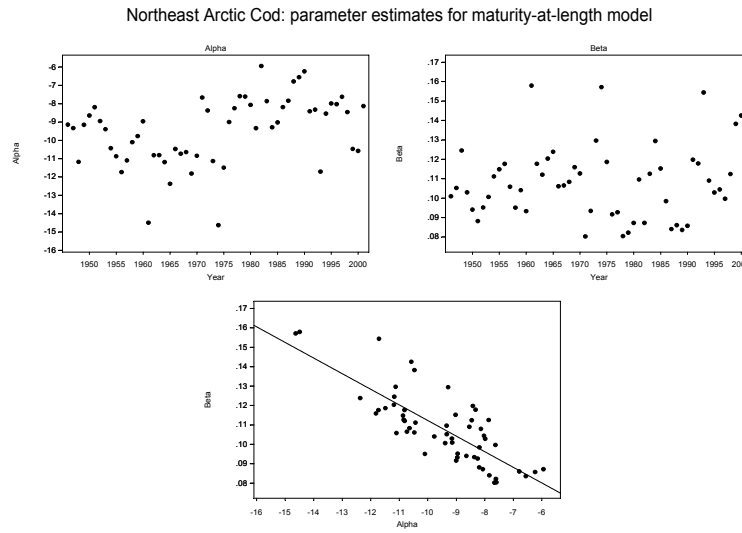
Figure A.1.1.5.   StockAn outputs for Northeast Arctic cod. Proportion mature at length.

Northeast Arctic Cod: Summary indices
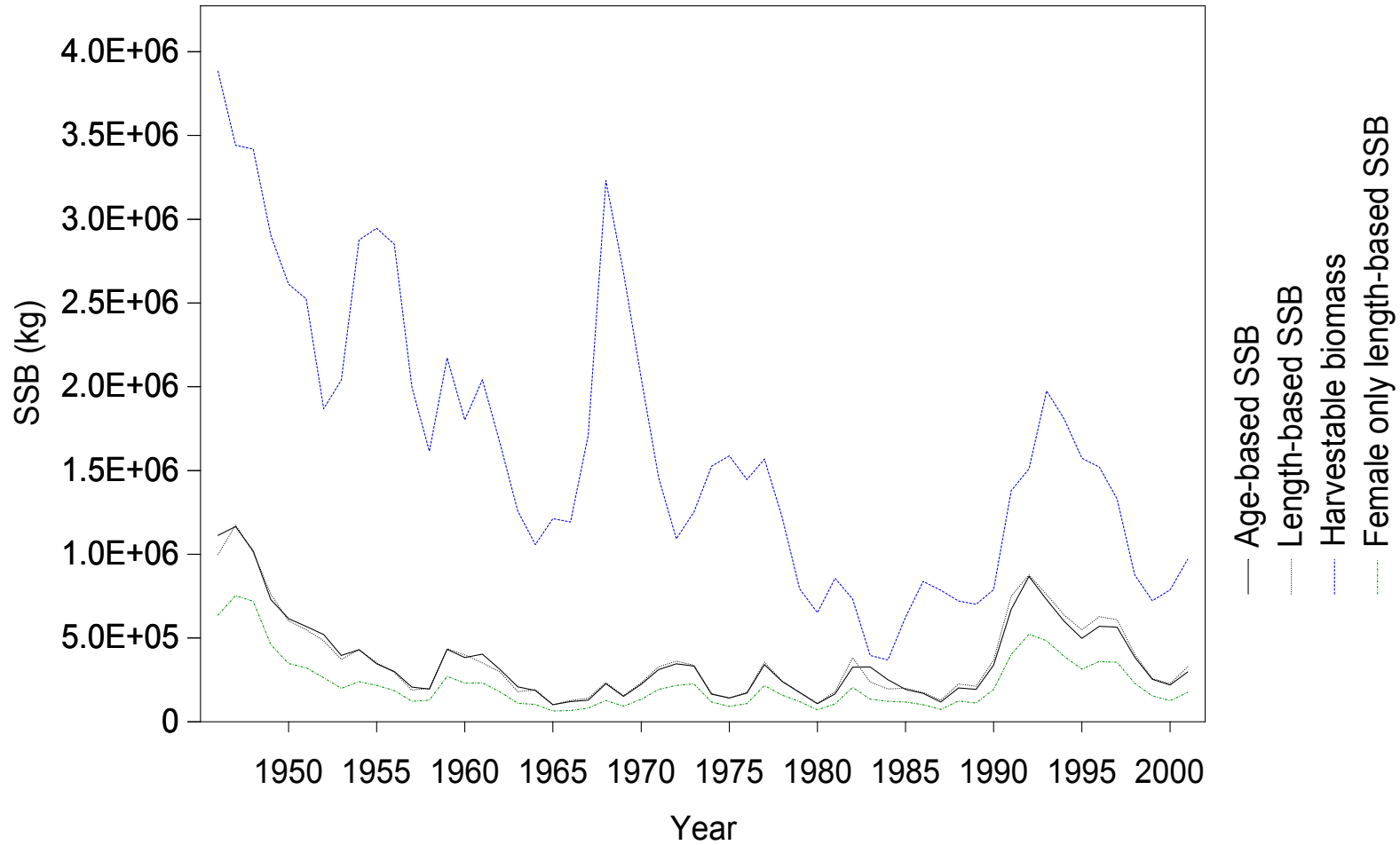
Figure A.1.1.6. StockAn outputs for Northeast Arctic cod. Summary indices
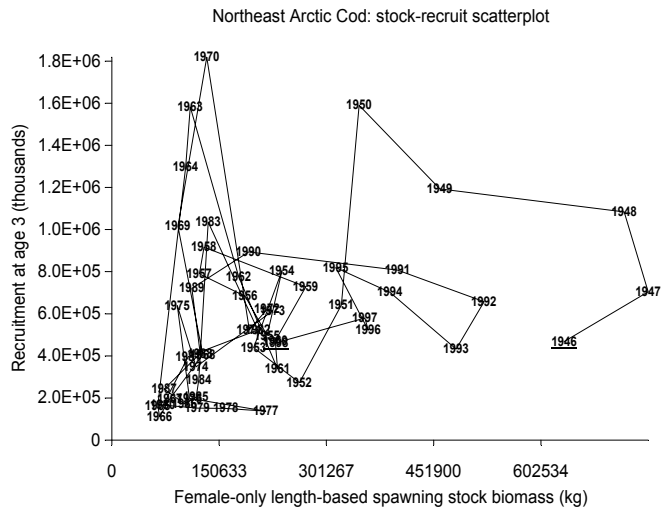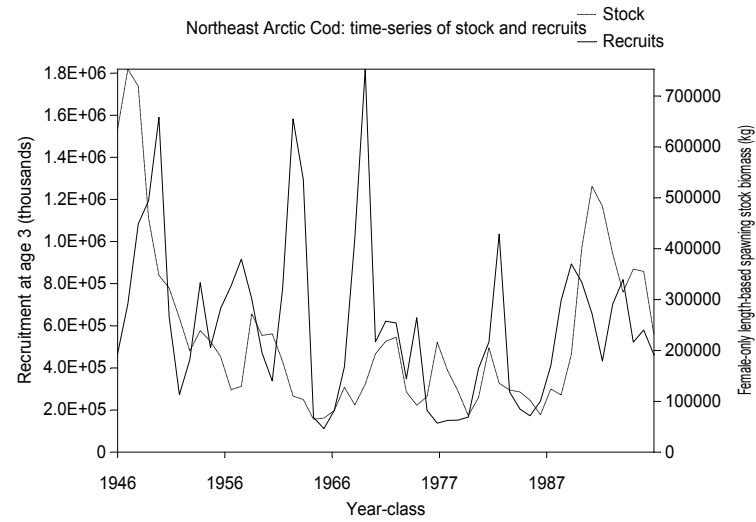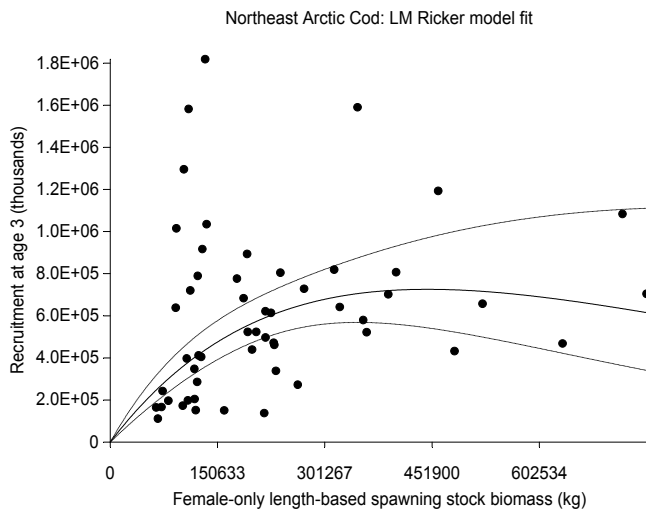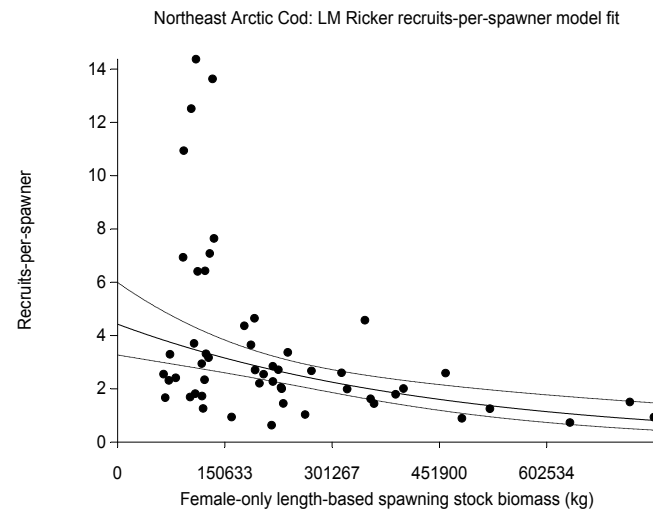
Figure A.1.1.7.   RecAn output for Northeast Arctic cod.
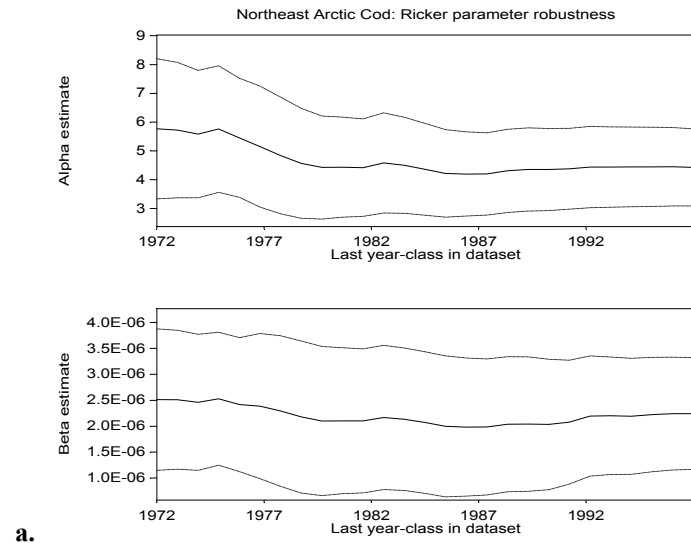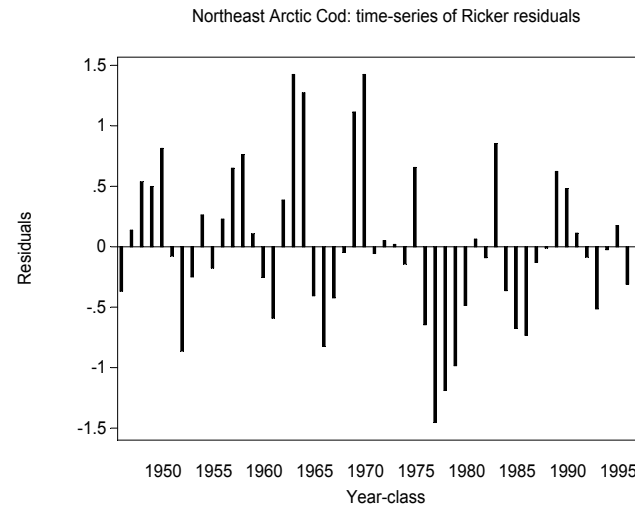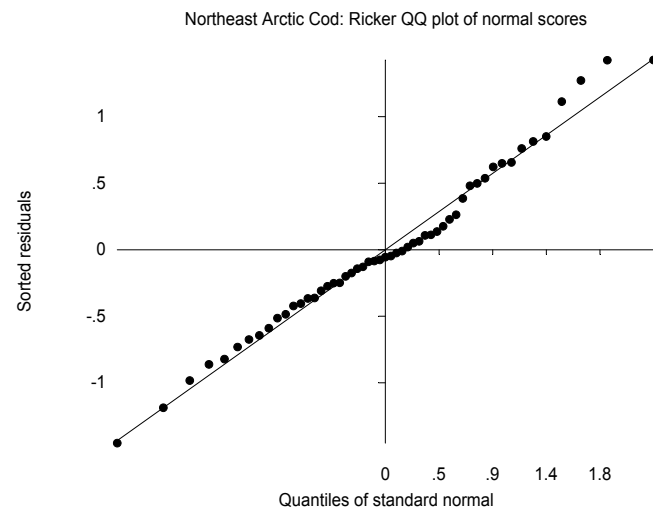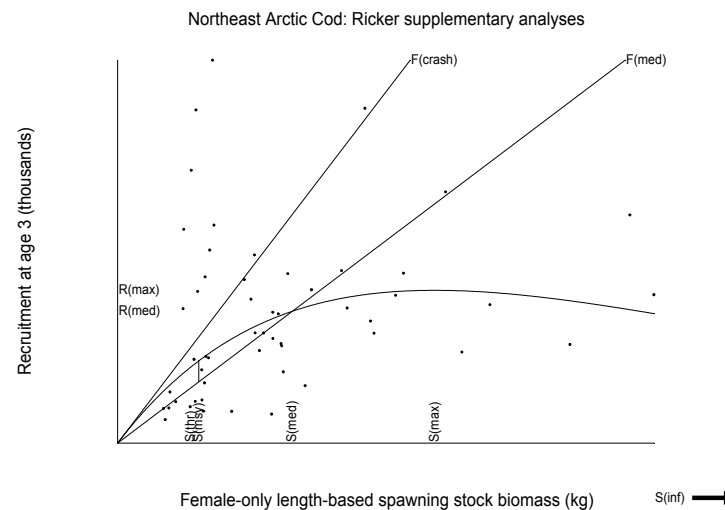
Figure A.1.1.8. RecAn output for Northeast Arctic cod.
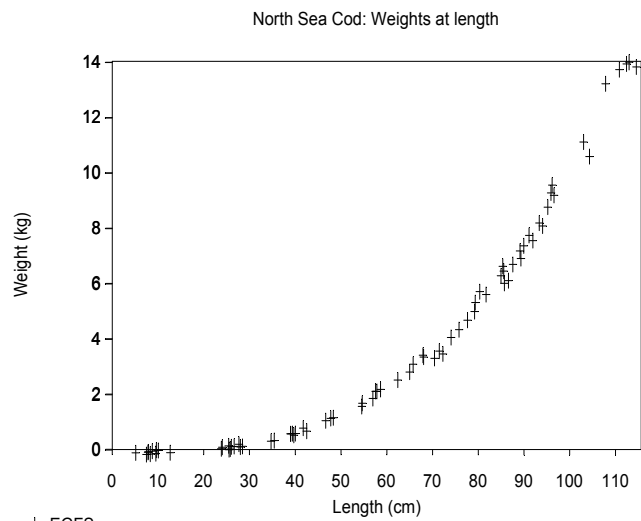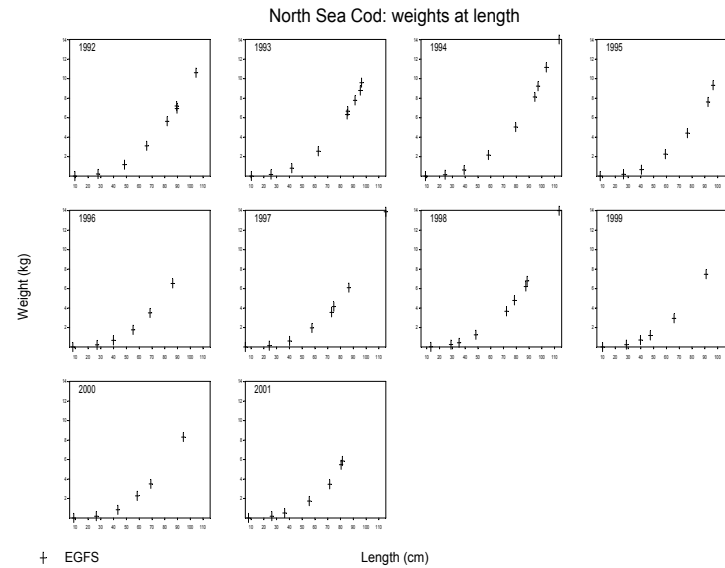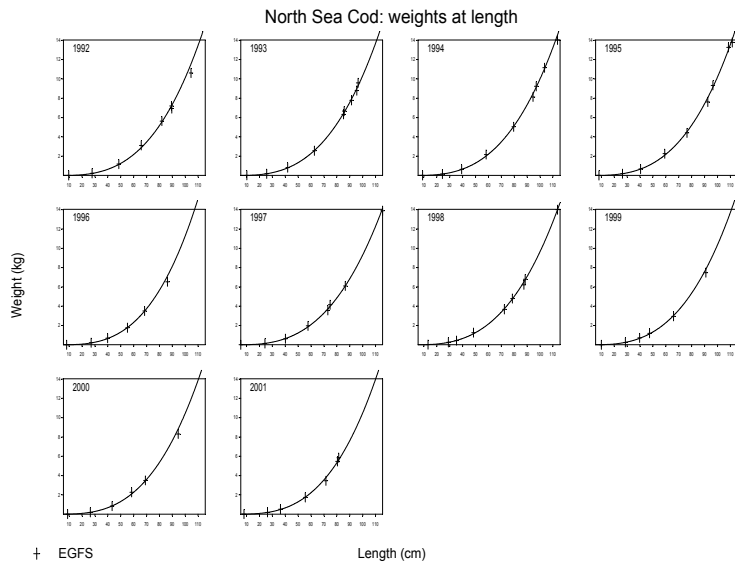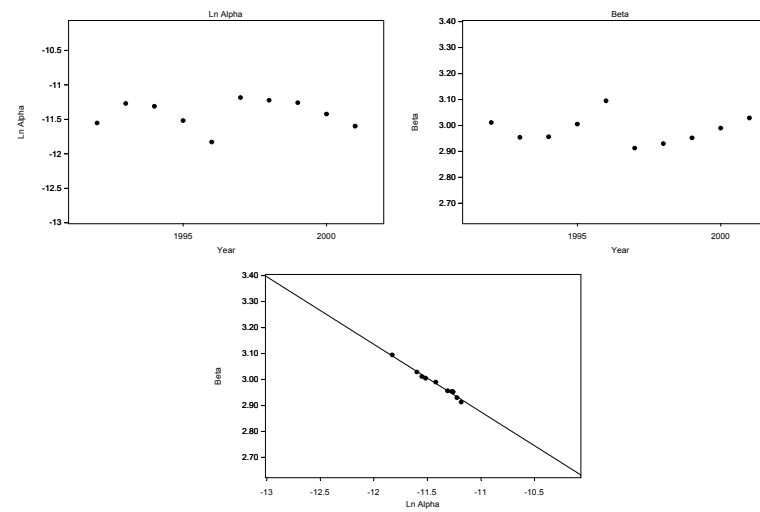
Figure A.1.2.1. StockAn-estimated weights-at-length data and model fits for North Sea cod, using data from the Q3 English groundfish survey. a) scatterplot including all years; b) separate scatterplots for each year; c) separate scatterplots for each year with model fit; d) time series and bivariate scatterplot of model parameter estimates.
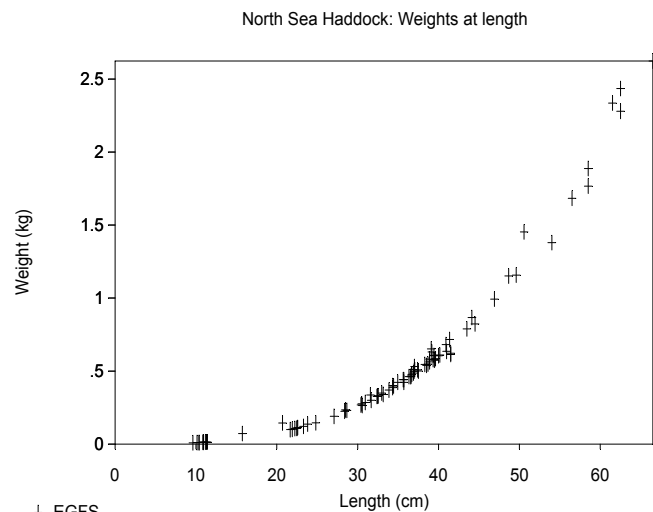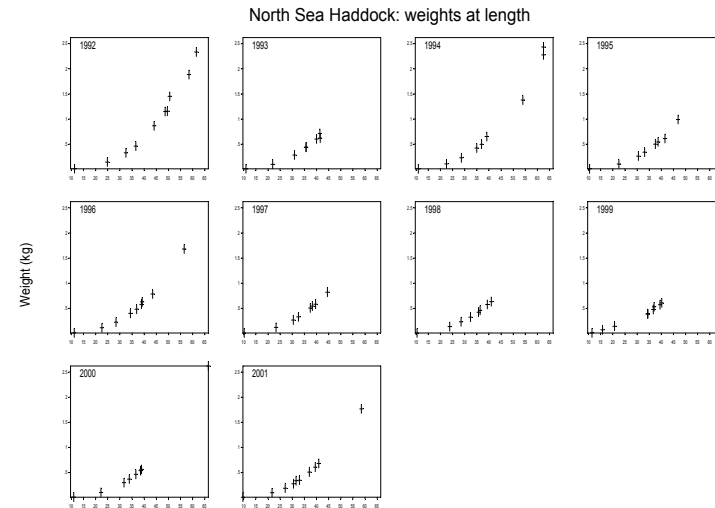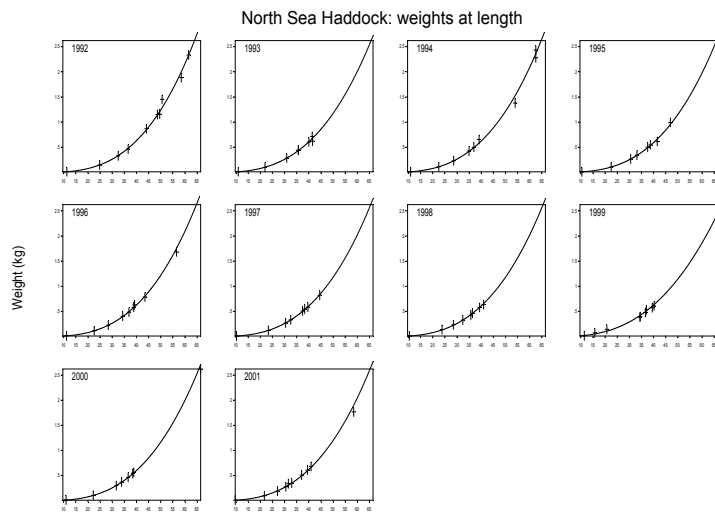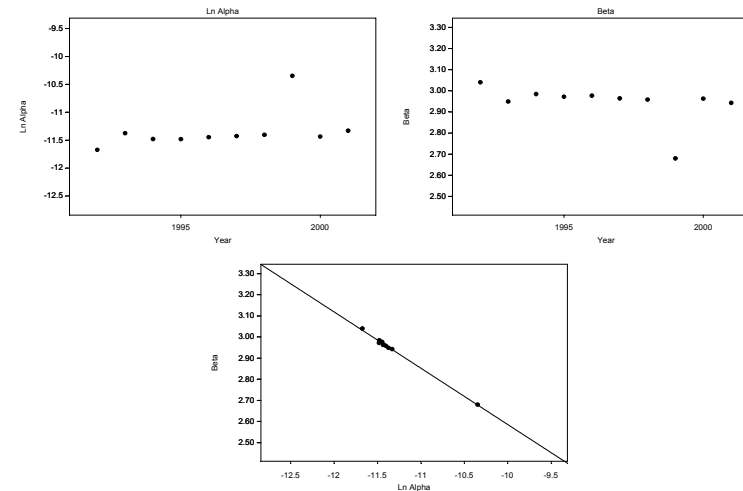
Figure A.1.2.2. StockAn-estimated weights-at-length data and model fits for North Sea haddock, using data from the Q3 English groundfish survey. a) scatterplot including all years; b) separate scatterplots for each year; c) separate scatterplots for each year with model fit; d) time series and bivariate scatterplot of model parameter estimates.
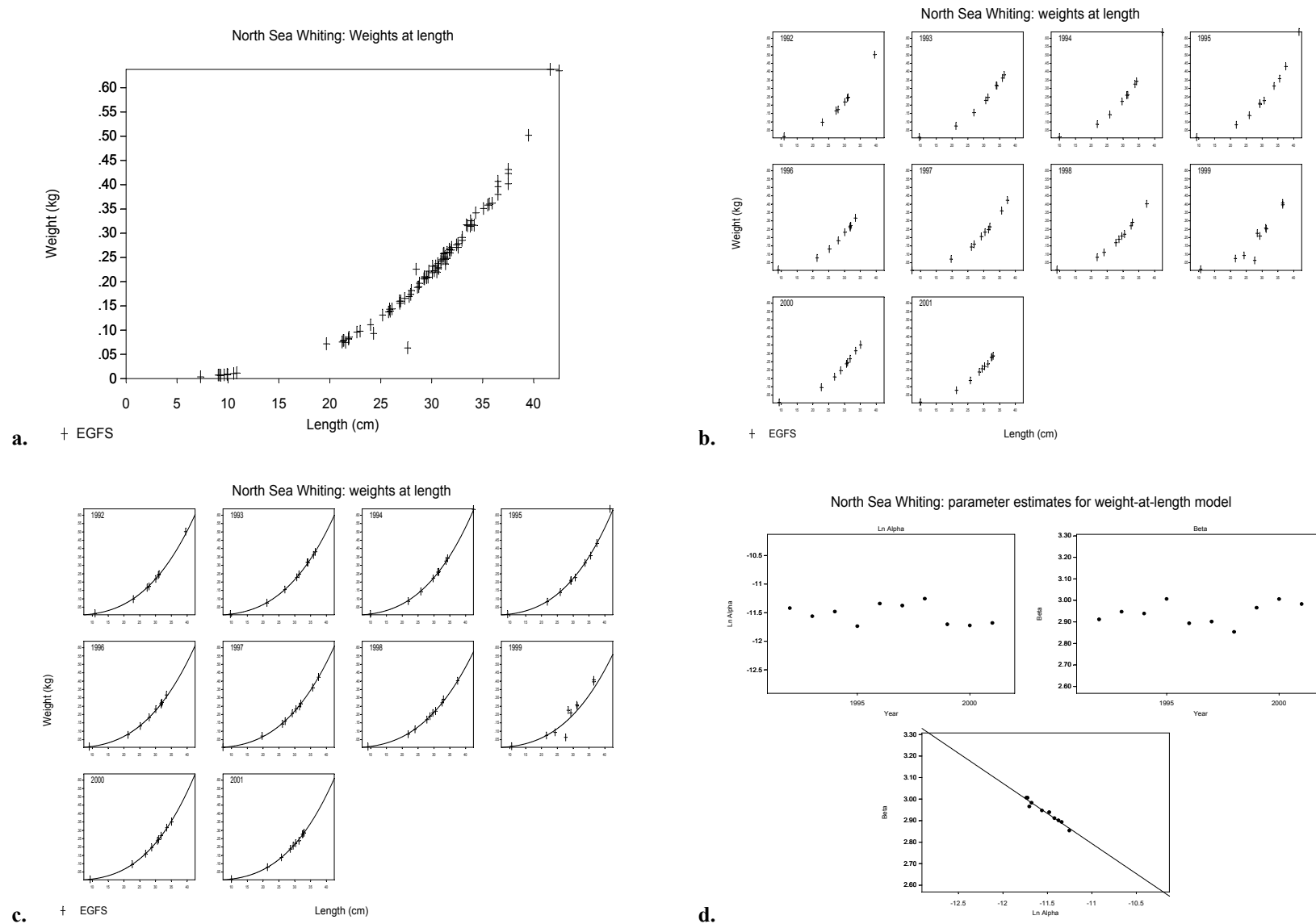
Figure A.1.2.3. StockAn-estimated weights-at-length data and model fits for North Sea whiting, using data from the Q3 English groundfish survey. a) scatterplot including all years; b) separate scatterplots for each year; c) separate scatterplots for each year with model fit; d) time series and bivariate scatterplot of model parameter estimates
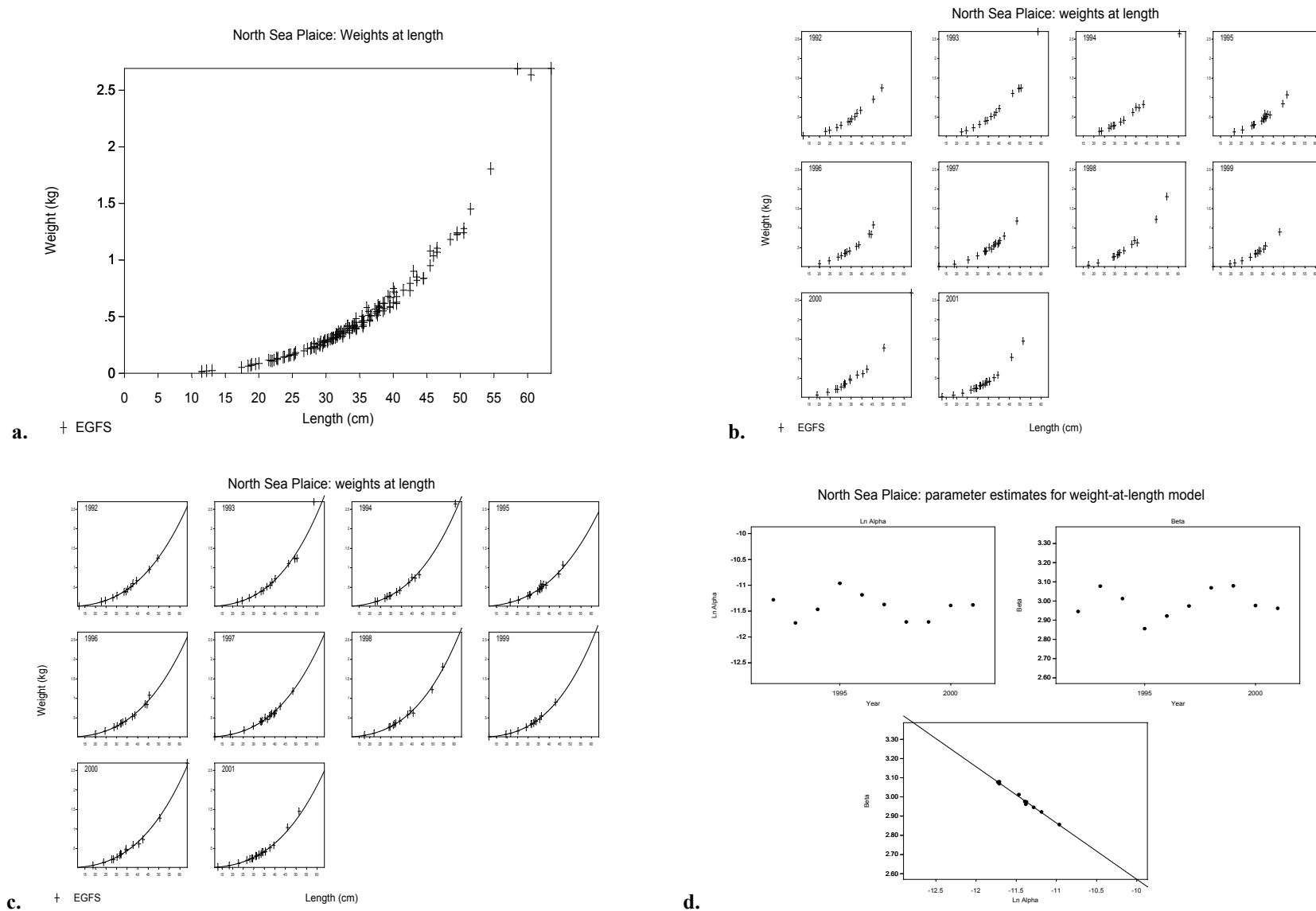
Figure A.1.2.4. StockAn-estimated weights-at-length data and model fits for North Sea plaice, using data from the Q3 English groundfish survey. a) scatterplot including all years; b) separate scatterplots for each year; c) separate scatterplots for each year with model fit; d) time series and bivariate scatterplot of model parameter estimates.