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Report of the Workshop on Implementing the ICES F_{MSY} framework

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International Council for the Exploration of the Sea

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Executive Summary

WKFRAME met for 4 days in late March to provide some technical guidelines to assist ICES expert groups in the implementation of the ICES MSY concept in advice for 2011. The workshop was attended by scientists from the ICES community, stakeholders from the fishing Industry and environmental interest groups, as well as representatives from one of ICES clients (EC). The primary area addressed by the group was to provide technical guidelines for the estimation of an exploitation rate based MSY target or if necessary a proxy, which should include; criteria for selection of proxies for F_{msy} and criteria for advice when catch forecasts are not available. While the workshop focused on the technical issues related to defining F_{msy} proxies, the discussions touched on other issues related to the implementation of an MSY based advice. These issues which include: the role of management plans in relation to MSY based advice, the function and definition of the $B_{trigger}$ in the ICES implementation of an MSY advice, the definition of F_{msy} as a target or limit reference point, and the inclusion of estimation or implementation errors in the MSY target. The effects of multi species/predator prey interactions on F_{msy} targets, requires further consideration. In relation to these issues, for the purposes of generating ICES advice for 2011, practical approaches are proposed by ACOM. With regard to the estimation of F_{msy} proxies, the general approach advocated by WKFRAME is to explore the data through a range of methods with different assumptions, to identify the range of plausible candidates. The workshop suggested that EG's explore the sensitivity of the estimates of these candidates to uncertainty and assumptions in the model parameters, and finally, where possible, to check the response of the stock to fishing at any proposed target in the long term (through simulation). Technical guidelines in terms of methods, sensitivity analyses and things to look out for are detailed in chapter 2 of the report. With regard to the criteria for advice when there is no forecast; the workshop suggests that F advice in relation to putative F_{msy} targets should be framed in terms of moving exploitation rates towards the target, rather than specifying a harvest in relation to the current stock status and/or expected short term development of the stock. Thus advice arising from circumstances where there is no short term forecast, has to be seen in the context of a "soft" evaluation of stock status relative to crudely estimated proxies. There are no new methods or techniques proposed in this report, and indeed the most basic equilibrium based methods are those used in the early years of fisheries science. The implementation of guidelines suggested in this report, require some degree of "expert judgement" and (in the cases of simulation) a caution against over interpretation of the results. This leads ultimately to a conclusion that the move to MSY based advice has to be seen as a stepwise process, which will require data exploration and sensitivity analysis by the EG's, and a willingness from both ICES and its clients to work with recursively updated targets.

1 Introduction

The goal of "maximum sustained yield" has played a prominent role in the governance of fisheries for decades. It is grounded in theoretical models of the production (i.e., weight of recruits + growth of individuals- weight lost to natural mortality) of a fish population. The model relates production to population size, and it specifies a unique value of MSY at equilibrium population size that corresponds to a constant level of fishing mortality. This deterministic equilibrium theory is useful for framing the concept of MSY, but it is unrealistic and unworkable in practice.

Fisheries and fish populations exist within very dynamic systems. The production function is affected by fishing practices and fisheries management (e.g., minimum fish size regulations), as well as natural environmental variability and species interactions. Actual production functions are always changing such that equilibriums defined from deterministic theory, are rarely coincident with real world point estimates.

Therefore, the concept of MSY is widely interpreted as the maximum long term average catch that can be achieved under prevailing conditions (including both the state of the ecosystem and size selectivity of the fishery). MSY is considered to be achieved by a fishing mortality (F_{msy}) that produces a high long term average yield while the stock fluctuates around the stock size where production is at or close to the maximum. A strategy for achieving MSY can be expressed as a harvest control rule where F is a fixed target which may also be a function of stock size. This is the form of the ICES MSY framework.

The issue of whether the F_{msy} reference point should be treated as a target or a limit is not investigated thoroughly by this report. From a scientific perspective, in addition to the dynamic nature of production functions and fisheries, a strategy for achieving MSY also needs to consider the uncertainty in estimates of the parameters of the function (e.g., F_{msy}) and estimates of the variables of the MSY harvest control rule (e.g., current population size). Since the loss in long term average yield is usually greater from overshooting F_{msy} than undershooting, a conservative approach to selecting F_{msy} to address estimation uncertainty is usually desirable. The amount of "conservativeness" applied depends on how the F_{msy} reference point is applied in management and what tolerance for risk to declining SSB is required. Ideally, the trade-offs between the ways uncertainty is taken into account in the estimation of parameters of the harvest control rule, and the ways uncertainty is taken into account in the estimate of catch that results from applying the control rule, should be investigated in the context of management plan evaluation. However, there are many cases where this is not practical. In such cases, a practical approach is to be conservative in the estimation of parameters (i.e., F_{msy}) and to apply deterministic or median estimates of the catch resulting from the harvest control rule. An opinion stated at the meeting was that the EC would assume that the management risk was included in the framework used by science. This implies that the EC consider that the F_{msy} reference point can be used as a target, and that measurement error and uncertainty must therefore be taken into account in its derivation. It also suggests that the EC are asking ICES to assume the risk tolerance.

Detailed guidelines on how to evaluate MP's with respect to MSY are also not given in this report. This issue deserves further consideration, but it could be generally stated that the averaged F expected to be realised through the implementation of a management plan, should be consistent with the F_{msy} estimate for the stock and that projected average catches should be similar (see chapter 3).

There are a range of approaches which can be implemented to biological and fishery data with a view to exploring potential candidates for F_{msy}. The general approach advocated by WKFRAME is to explore the data through a range of methods with different assumptions. This does not mean that a straight average across a number of approaches should be adopted. In the first instance the approach is to identify the range of plausible candidates, to explore the sensitivity of the estimates of these candidates to uncertainty and assumption in the model parameters. And finally, where possible, to check the response of the stock to fishing at any proposed target in the long term (through simulation). The response of the stock will depend primarily on the stock recruit function applied, and there should be a thorough exploration of the most appropriate stock and recruitment relationship. Any stock and recruit function used in a simulation should be both statistically and biologically plausible. The approaches outlined in this report are intended to cover a variety of data availability situations, and use methods from very basic deterministic equilibrium yield analysis through to stochastic simulation procedures. However WKFRAME notes that there is some potential to propose poorly considered values for F_{msy} without careful evaluation. Thus, in all cases it is expected that any analyses are accompanied by circumspection with regard to; the data quality, model fit, and assumptions; which should be explicitly declared. A basic recommendation is therefore that any proposed F_{msy} target should be accompanied by a sensitivity analysis to ensure that the recommended target is robust.

2 Guidelines

Before any data is used in an exploration, an evaluation of the quality of this information should be made. While information can be gleaned from almost any data source, the focus should be data which are reliable. In this respect a categorical decision could be taken on the utility of the data, or a weighting of the data based on quality could be considered. In either event any data which on which the advice is based should be identified in the stock annex. Thus a stock annex should exist whether there is an analytical assessment or not.

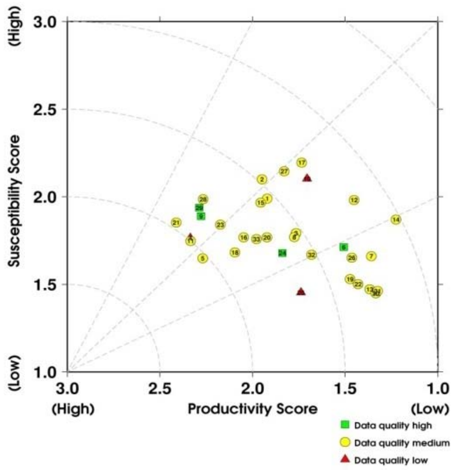
2.1 Where there is only catch data

Overall, information on growth, mortality, and maturity are the basic biological data required for making demographic and population inferences in terms of yield per recruit and spawning per recruit analysis. Where no progress can be made on reference points from a YPR analysis, EG's should concentrate on what measurable metrics are possible.

If data is extremely limited, such that even catch data are not separate by species, or are incomplete, basic data on species productivity (fecundity, natural mortality etc which may be by inference) coupled with susceptibility to fishing could be used to inform a vulnerability analysis. For example in the USA a stock's vulnerability is defined as a combination of its productivity (which depends upon its life history characteristics) and its susceptibility. Productivity is defined as the capacity of the stock to produce MSY and to recover if the population is depleted and susceptibility is defined as the potential for the stock to be impacted directly or indirectly by the fishery. Productivity indicators would include;

1. Population growth rate (r)
2. Maximum age
3. Maximum size
4. von Bertalanffy growth coefficient (k)
5. Natural mortality
6. Fecundity
7. Reproductive biology (i.e. parental investment)
8. Recruitment pattern
9. Age at maturity
10. Mean trophic level

An example plot of a vulnerability analysis from the Hawaiian longline fisheries from the swordfish is shown below:



This type of plot requires a scoring of the productivity and susceptibility metrics, but is able to highlight the potentially vulnerable species in "data poor" fisheries, on which scientific research and management action would need to be focused. Further detail on vulnerability analysis as applied in the USA under National Standard 1 is given in Patrick *et al* (2009).

Where there are indications of low productivity, there will be an effect on the time period for recovery, and this needs to be taken into account in relation to the consequences of overexploitation. Thus where data is restricted to mixed species landings, an effort should be made to identify vulnerable species in the mix. Metrics on grouped data would mask the trends in individual species, but that's what you have in these situations. An approach could also be taken to evaluate the information on those species for which you have data, and if it is reasonable, to assume that these are representative of others of which you have limited/no information. In the cases of mixed species landings, some useful information may also be gleaned from surveys, i.e. these should have proper species ID's and length data, so even length distributions and max length over time. Where age info is also available you could compute an age ratio metric.

Where catch data reflect initial high catches followed by a decline, a method called depletion corrected average catch (DCAC) can be used, to advise on a catch corrected for an initial windfall caused by fishing a previously unexploited biomass. This method basically corrects average catch for expected declines in the population given (an assumed) natural mortality and an approximated decline in abundance (which can come from any abundance index) and (an assumed) relationship between F_{msy} and M (low productivity scalar). This method provides a correction which is useful in stocks with slow growth which may be vulnerable. However when M is 0.2 or greater and the assumed relationship between F_{msy} and M is about 1, there is little difference between the application of the method and straightforward average catch. The method is easily implemented on a spreadsheet; however exploration of this method is more useful with some sensitivity analysis to the assumed parameters. This is implemented in the NOAA NFT toolbox which is available at http://nft.nefsc.noaa.gov.

Without an age structure, a production model, or better still a biomass dynamic model e.g. ASPIC (where there is no equilibrium assumption) may be applicable. The model output contains F_{msy} and B_{msy} estimates as well as the time series of F and SSB, and thus can be used to inform the selection of an F_{msy} target.

2.2 Where there is age or length structure data

A YPR can be used to explore the expected yield under equilibrium conditions, of growth, maturity and natural mortality, for a given or assumed fishery pattern, across a range of exploitation levels. YPR requires age structured data which can come from an assessment output (can be the converged part of a VPA and does not have to be "an accepted assessment"), or even from population length frequency data with assumptions or estimates of growth (k, t_0 L_{inf}), selection (age at first capture, fit with a selection function) and maturity (length at 50% maturity with a fitted maturity ogive). Given such basic data requirements there are very few exploited fish stocks that can be considered data poor.

With regard to weight and maturity data: Weights at age & maturities change with time and are affected by density dependence. If a time series is available, choose a recent year average option to cope with any detectable trends, or use longest year averages where no changes are observed. The objective is a sufficient year range to smooth out short term noise or measurement error but short enough to take account of contemporary trends.

With regard to the selection pattern, where limited data are available, try to estimate an Lc50 and then an assumed oldest age, hence an ogive can be fitted. If a time series of F estimates are available from an assessment and there is stability in the selection pattern, then a sufficient year range can be used to smooth out short term noise or measurement error but the time series should be short enough to take account of contemporary trends. If the relative Fs are changing significantly, you should investigate if this is driven by real changes in fishery selection - which could potentially caused by variation in discard patterns over time. A selection pattern needs to be used in the YPR and the resulting curve is sensitive to the vector used. So the pattern used should reflect the contemporary situation. Another consideration is if fishery regulations are expected to change selection, if so the sensitivity to of the YPR to putative changes in selection should be examined. YPR analysis based on assessments which use only landings but from stocks with significant discards will give an F_{MSY} target that may be too high (see Section 2.3). This needs to be noted. However while decreases in exploitation to such a target will be in the correct direction; increases of exploitation under these circumstances should only be done with consideration of accuracy of the MSY target. The default approach here is to assume that the exploitation in the fishery is that which you wish to continue with. However just because the YPR may have a well defined maximum, such a shape to the YPR may be as a result of a suboptimal exploitation pattern taking fish at a small size, there are other plausible alternatives, based on different selection which would give different a different F_{msy} and approaches other than a single stock basis, could be considered in context of multi species fisheries (e.g. Maximum Economic Yield) (Bjornsson and Hjorleifsson working document)

The YPR is sensitive to the natural mortality, so a sensitivity analysis should be done across a range of plausible values. However the kind of scaling which happens to the equilibrium yield also happens to a certain extent to the assessment SSB, when the same value (scalar or vector) is used. What is important to establish here is the sensitivity of the amount by which you have to move F between the assessed F and the target. If this ratio is significantly affected then the basis for the M value used requires some justification.

$F_{0.1}$ can be determined from this type of analysis, and there may or may not be a well defined peak in the YPR to define F_{max}. If there is clear peak at low F in the YPR analysis, and there is no evidence of recruitment dependence on biomass, then a check should be made that the equilibrium biomass implied by this target F is within the observed range of SSB, under this condition F_{max} may be appropriate. Where F_{max} is undefined and equilibrium biomass at $F_{0.1}$ lies within the historic range of SSB $F_{0.1}$ might be considered as a 'lower bound' to the range of F suitable for F_{msy}, as it is assumed to be low risk. However, this does not take into account any curvature in the S/R function near that SSB[1] , thus it is preferable to carry out a risk analysis including the S/R function (see section 2.4). F targets which imply equilibrium SSB's outside the historic range should be looked at carefully, however it should be noted that where exploitation has historically been very high, this situation does not necessarily denote biological implausibility. The critical issue here is the fit to the S/R function, and more detail on this is given in section 2.4.

The YPR function may not be stable over time especially with regard to F_{max} and $F_{0.1}$, in such circumstances there needs to be further examination of the time series to determine if either of these points could be suitable candidate for a long term reference point. (see section 2.4 & Case studies in chapter 4). The problem could be related to a very long time series with large scale temporal variability in the magnitude of recruitment. If there is a justification for a change in productivity, the S/R pairs should reflect the productivity regime to which the F_{msy} target would apply; this may necessitate truncating the time series.

Spawner biomass per recruit analysis should be routinely evaluated in addition to YPR; an advantage of SPR based proxies is that they take into account directly the reproductive capacity of the stocks. Several studies have provided range values for guidelines on percentage for spawner per recruit ratios (in reference to unexploited stocks) expected for different life history types of exploited stocks. There is not a single level of % SPR that is optimal for all stocks and the proposal for F_{msy} should include some consideration of life history. Values in the range of F20% to F30% (% SPR relative to SPR at F=0) have been characteristic of recruitment overfishing (Rosenberg *et al*. 1994). Initial studies show that values of F30% to F40% could be used as proxies for F_{msy} (Goodyear 1993, Mace and Sissenwine 1993). These studies suggested F20% as a minimum threshold for avoiding recruitment overfishing for stock with average resilience (Mace and Sissenwine 1993). Further studies by Clark (1991, 1993) concluded that F35% and higher were robust proxies for F_{msy}, considering uncertainty in stock-recruitment functions and or recruitment variability. This value may be a useful guide for the ICES stocks. Evaluations of long lived species with relatively low productivity such as rockfish (Sebastes spp) in the Pacific west coast, concluded that higher SPR values (50% to 60%) were required to maintain sustainability exploitation of these stocks. Spawner per recruit curves should be provided in all cases, particularly if stock-recruitment data is non-informative or in cases when the range of historic data for spawning biomass covers only a period of high exploitation.

2.3 The impact of discards on estimating F_{msy}

For some fisheries discarding is banned or is known to be negligible, in these cases landings and catches can be considered equal and the standard YPR and S/R calculations described elsewhere in this document will give acceptable estimates of F_{msy} or a

[1] "that SSB" refers to the SSB realised under equilibrium conditions of fishing at $F_{0.1}$

proxy. The presence of a significant discarded (or slippage or highgrading) component of catch in a fishery has two important influences on the selection of an appropriate F_{msy}. Firstly in the definition of what constitutes the Yield in the context of MSY, and secondly the calculation of the F to give the maximum yield.

The choice of Y as catches or landings is a matter for policy: if Yield is considered to be that which is removed from the stock F_{msy} should be based on maximising catch; if Yield is considered to be the utilised component from the stock, the amount contributing to economic or social benefit, then Yield should be taken as landings and F_{msy} calculated accordingly to maximise the landings.

Where discards are known to occur, sufficient information is available to make some acceptable estimates which are then included in the assessment, ICES standard YPR analysis software can deal with discarding as a 'fleet' and estimate F dependence accordingly. Similarly if simulations in FLR or HCS (see case studies in chapter 4) are carried out discarding can be explicitly included and the landings (or catches) evaluated according to the policy choice. The EG may additionally like to consider if additional technical measures to change discarding rates (spatial, temporal or gear related) would be of relevance to managers in deciding on an MSY objective.

Where discarding is known to occur, believed to be significant, but insufficient data is available to estimate these adequately and they are not included in the assessment a standard YPR analysis will give a biased estimate of F_{msy}. While the assessment may very reasonably be considered adequate to give catch advice (based on an assumption of stable discard selection) the results from the YPR assume that recruitment to the fishery is independent of F, however, due to discarding 'recruitment' to the landed component is an inverse function of F. Thus the benefits of reducing F will be underestimated resulting in a YPR estimate of F_{msy} that is too high. To evaluate the importance of discarding as a first approximation the dependence of 'recruitment' to landings will depend on the sum of $F_{discard}$ over all ages in the fishery. (It should of course be recognised that in practice discarding may change in other ways with F or could be reduced further by other policy changes as discussed above). For the assessments based only on landings the EG should compare F_{msy} values for landings and catch for other fisheries on the same species where discard data is available and compare these to the F_{msy} landings based values The EG could then modify or comment on the appropriateness of the calculated values accordingly.

2.4 Where there is data to fit a stock recruit relationship

Where an assessment can provide a plausible set of stock and recruit pairs, the process of trying to find an appropriate F_{msy} estimate should be based on raising the yield per recruit analysis to a stock recruit relationship.

The fit to the Stock Recruit Relationship requires analysis (i.e. you should not assume a relationship and fit without circumspection). The things you need to look at are time variability (i.e. the robustness of the fit over time), as well as the precision of S/R coefficients. You could chose default function based on some statistical criteria for a measure of fit (e.g. AIC, BIC), but the fit needs to have biological plausibility[2]. For example if the maximum in a dome shaped model is way out of the range of the observed biomass, there may be a problem. Alternatively Bayesian methods may help by using informed priors on the model parameters. As a simple alternative a Hockey

[2] What is meant by biological plausibility is not simply the observed range of stock biomass, as this may reflect a long history of an over exploited stock.

stick (restricted to a recent period that you consider relevant to the contemporary productivity) can be used.

WKFRAME discussed a workflow for the process of fitting stock and recruit models and the estimation of F_{msy} or proxies for it based on the fit to the data and suggested the following approach.

1) Fit a stock and recruit model and review how well the parameters are defined:

a) if well defined, F_{msy} could be estimated from the combination of the model fit and a YPR

b) if poorly defined a hockey stick model may be to determine F_{msy}

2) Selection of the hockey stick model, with constant recruitment above a threshold level, results in F_{msy} being defined by either the YPR estimate of F_{max} or if F_{max} is undefined, the slope of the hockey stick model F_{crash}.

a) If F_{max} is not well defined $F_{0.1}$, F35% F40% SPR could be considered as a proxy for F_{msy}

b) If F_{max} is well defined and below F_{crash}, F_{max} can be considered as a proxy for F_{msy}

Where there is a potential conflict between risk to productivity and confidence in the estimates of F_{msy}, a greater understanding of the implications of fishing at the putative target F can be obtained by stochastic simulation. Such simulations can incorporate biological uncertainty in S/R, growth and maturation and in the fishery through variability in selection. With this approach the population vector, as used in the YPR, with the weights maturity ogive and selection is projected under the target F, with recruitment drawn from the stock recruit relationship. Measurement error should not be included at this point, i.e. you should use a fixed F and introduce variability in the biological parameters. From the simulation output you can get a distribution of SSB values which should give the range of expected stock size when fishing under the F_{msy} estimate. Examining the distribution of this SSB relative to the observed historical range, should help to identify problems. The distribution of SSB estimates as a function of F can be compared with B_{pa} and B_{lim}, to examine the risk to recruitment impairment. If the equilibrium and range of biomass implied by fishing at an estimate of F_{msy} has a low probability of reaching B_{lim}, this analysis is not critical and should not be a high priority, though may be informative. For situations where the biomass or range of biomass implied by fishing at an estimate of F_{msy} give substantial probability of encountering B_{lim} or B_{pa}, stochastic simulation is of interest to provide information on risk to B_{lim} and to advise on an appropriate trigger biomass.

There are many input specifications which need to be carefully considered at this stage. Where simulations are done, the guidelines in SGMAS 2008 report should be considered (chapter 5.2 of ICES 2008 ACOM: 24). This report provides some basic ideas of when different levels of complexity are required; for example the distribution of the errors in the simulation can have a big effect on the outcome ($B_{trigger}$).

2.5 Btrigger

$B_{trigger}$ should be selected as a biomass that is encountered with low probability if F_{msy} is implemented. The selection of the $B_{trigger}$ is likely to be an iterative process. If F_{msy} is chosen correctly and implemented then the probability of encountering B_{lim} should be very low. If the SSB is below this level it is (by definition) out of expected range, and thus a suitable trigger to initiate action. In addition to this, the appropriate trigger should include implementation error. Although B_{pa} is proposed as a default trigger biomass in the ICES MSY framework, it is not a logical candidate in the long term as it is derived from a error model basis around B_{lim}.

2.6 The role of estimation or implementation error of an Fmsy target

As is the case with management plans, estimation errors and implementation failure play a role in translating a theoretical MSY target into an appropriate management rule. In the USA as the overriding criteria for managers is maintaining the stock above a minimum biomass these types of error are used to develop an appropriate buffer and the target F_{msy} is reduced accordingly. This approach is specifically dependent on the USA framework. However, as both measurement error and implementation errors can result in exploitation at suboptimal F, the final choice of the target used by managers should take into account these potential errors. In many cases the change in yield at exploitation away from the theoretically value of F_{msy} is expected to be asymmetrical, with yield declining more slowly with lower F and more quickly with higher F. In addition the risk of SSB<Blim is also asymmetrical and will rise if F is higher, this combination usually implies that an appropriate F target is lower than the error free theoretical value. Where possible it is recommended that assessment and implementation errors be estimated from history (possibly from the ICES quality sheets) and explicitly included in the analysis. It is important that the approach used to include (or not) error distributions is explicitly addressed in the EG report and the influence of this on proposed F_{msy} values included with the analysis.

2.7 Translating the reference points and stock status information into advice

The ICES MSY framework described in ICES (2010) applies directly to situations where you have a target F and have an assessment with a forecast. However the Concept document further states "The framework should be applicable to a range of situations ranging from stocks for which there is little information to stocks with full analytical assessments and forecasts." In the former case WKFRAME considers that EG's may be able to use YPR and SSB/R analyses to propose a proxy F_{MSY} reference point, however, without an accepted assessment and forecast, there will be no direct translation of the target F into quantitative advice. Under these circumstances WKFRAME suggests that advice should be generated (in relation to the putative targets) which is aimed at moving the exploitation rate towards the target, by specifying an applicable longer term catch rather than specifying an exact harvest rate in relation to the current stock status and expected short term development of the stock. The text below outlines some approaches which may be useful under these circumstances.

The advice arising from these circumstances has to be seen in the context of a "soft" evaluation of stock status relative to estimated proxies.

- There needs to be a consideration of the spatial and temporal history of the fishery: i.e., is it an emerging fishery? Is it spatially discrete (e.g. seamounts) can serial depletion occur? How do the data series relate to these dimensions? These considerations are very important when interpreting trends.
- A broad range of metrics should be monitored as a guidance for a change in exploitation (catches, Effort etc, or an exploitation metric e.g. catch/survey cpue) levels. Those metrics may include both values and trends in a wide variety of indicators. Even if information is fragmentary, it should be put forward if it is considered useful for advice.

- This approach may not yield a well founded basis for advice in year 1 but if a sustained effort is made to improve the precision of metrics which are found by experience to be informative, then with experience a functional series of metrics can be developed over time.

The default EC rule (CEC 2009) has a design along these lines, but with a fixed magnitude of change according to the trend in the abundance indicator. Within this kind of framework, it is necessary to establish the range of indicator values and trends to be expected with a fishing mortality near a putative target at a proxy for F_{MSY}.

Such information can be gleaned from:

- Catch curves analysis
- Length and/or age distributions relative to equilibrium conditions
- CPUE from the whole or segments of the fleet
- Survey indicators
- Area distributions
- Environmental drivers.

For all these, some insight of how indicators relate to the stock abundance and /or exploitation level is needed. This includes the relationship (which can be a continuous functional relation or semi quantitative -good, medium, poor), as well as the strength of the link - i.e. variance of error terms. This approach can be formalised with statistical process control (Trenkel & Rochet 2009, Scandol 2005, Mesnil & Petitgas 2009).

Simulations can be done on a relative level, with a population that has life history parameters that are representative for the population in question. In such simulations, if recruitment variability is poorly known, one may look at a range of recruitment variability, perhaps also variability of weights and maturities, and explore how such variations (in biological parameters) propagate to variations in indicators (noisy survey or CPUE data, length/age distributions etc.). This will give a range (at least in relative terms) of indicator values, and trends in indicator values, and in addition demonstrate how quickly the population measures may be expected to change, at the proxy F_{msy} (derived from Yield/recruit analysis). This range should give some guidance to when and how much to change TAC advice.

Such studies can be adapted to a wide range of information bases, and done without detailed information about all factors that go into a standard harvest rule simulation. As with any simulations, there should be careful consideration at the input specification, and the level of assumption and precision in the input data, applied to the interpretation of the results (i.e. do not over interpret the results). Some points to consider include:

- Occasional large year classes may disrupt indicators. The dynamic response of the stock to a large year class can be outlined through simulations as described above.
- Growth and maturation parameters will be corrupted if the ageing is wrong. This may be a quite severe problem for some stocks. Without ages, length or staged based methods (stock synthesis, flexibest, gadget, collie-Sissenwine etc) may be of some utility where they are considered robust.
- Stocks with a developing fishery require special consideration.

Stock reduction analyses (i.e. modified DeLury method) can be used on catch data and abundance indices to infer stock sizes that would have given rise to the catches given the observed changes in abundance. From this you can work back to reference points. However there is no "magic bullet" here, in terms of insight to either stock productivity, or current stock status. It can however, with an appropriate time series, provide some insight into how recruitment and stock size may have changed over time in response to the catches. A good example of a stochastic implementation of this method is given in Walters *et al* (2006).

Handling of stocks with limited data will often require strong assumptions. Common sense instead of over interpreting should help to avoid some stumbling blocks. Careful consideration of the impact of assumptions (that have to be made) e.g. sensitivity analyses, is always necessary. Finally, while appropriate proxies for MSY exploitation levels may be derived from biological information with a (assumed) selection pattern, some measure to infer exploitation rate is required to advise on harvest levels appropriate to MSY.

2.8 Documentation process

Any information used for the estimation of F_{msy} should be clearly documented, this should be at least in the WG report, but should ultimately end up in the stock annex. This information includes the methodology as well as the data.

There needs to be an explicit statement of the assumptions used as part of the documentation process.

2.9 Available software

There are plenty of "off the shelf" packages that can compute YPR and SSB/R, with varying degree of flexibility for different types of input data. Routines for exploring SRR's (with fit diagnostics), raising the YPR estimates to a SRR, and simulating the stock with error are available at various levels of completion. In most cases these routines were developed specifically for this meeting, and require further error checking. As a process ICES should have some involvement with warehousing and providing a point of access to this code. The idea here is to provide the facility to develop and build on what has been done (& error checked) before. A list of the software used in the case studies in this report is given in the Software folder of the WKFRAME sharepoint site http://groupnet.ices.dk/WKFRAME2010/Software/Forms/AllItems.aspx .

2.10 Useful diagnostic plots

There are a range of fishing mortality reference levels that EG's may consider as being suitable proxies for F_{msy}, examples are $F_{0.1}$, F_{max}, F35%SPR. WKFRAME considered that in order to allow managers a comparison of the various estimates, the format in which the PA reference levels were compared within the PASoft package could be useful (see Figure 2.10.1, Table 2.10.1).

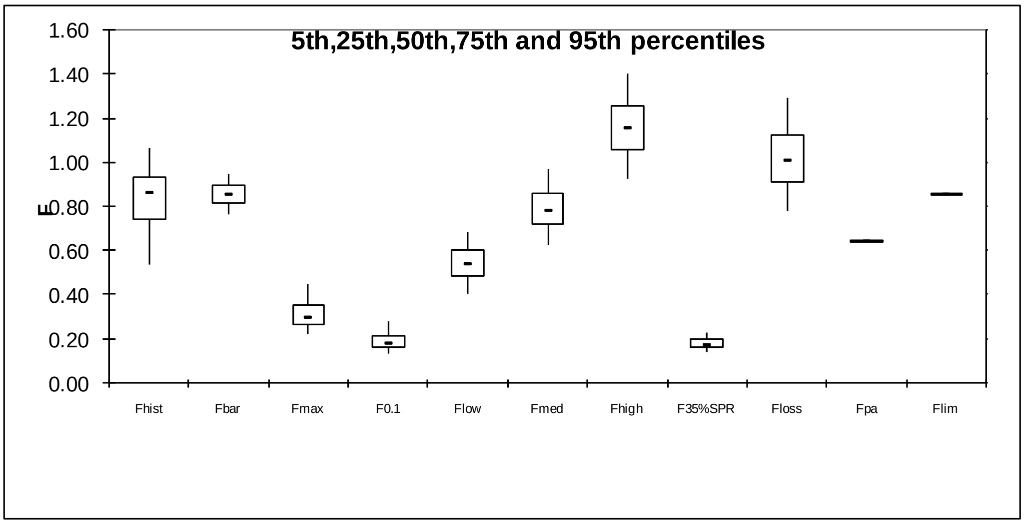


Figure 2.10.1 Estimates of the fishing mortality reference levels, historic and current fishing mortality rates and potential F_{msy} estimates and/or proxies

Table 2.10.1 Estimates of the fishing mortality reference levels, historic and current fishing mortality rates and potential F_{msy} estimates and/or proxies with confidence intervals based on parametric bootstrap.

	Fhist	Fbar	Fmax	F0.1	F35%SPR	Flow	Fmed	Fhigh	Floss	Fpa	Flim
95th %ile	1.06	0.95	0.45	0.28	0.23	0.68	0.97	1.41	1.29	0.65	0.86
75th %ile	0.93	0.90	0.35	0.22	0.20	0.60	0.86	1.25	1.12	0.65	0.86
Median	0.87	0.86	0.30	0.19	0.18	0.55	0.79	1.16	1.01	0.65	0.86
25th %ile	0.74	0.82	0.27	0.16	0.16	0.49	0.72	1.06	0.91	0.65	0.86
5th %ile	0.54	0.76	0.22	0.13	0.14	0.41	0.63	0.92	0.78	0.65	0.86

Fhist - the historic time series; Fbar - the current fishing mortality rate; Fmax, F0.1, F35%SPR - YPR proxies; Flow, Fhigh, Fmed, Floss - nonparametric stock and recruit reference levels.

Current F and lines to indicate the relative position of F_{lim} and F_{pa} and the replacement lines from the SR would be useful in the discussion about suitable proxies. Similar plots of the SSB and yield resulting at the equilibrium level from stock and recruit plots or at the geometric mean level of recruitment if no relationship is considered appropriate would allow comparison of the current status with that resulting from prolonged exploitation at the estimated fishing mortality rate. Wherever a proxy is proposed the equilibrium SSB at the target from a simulation, with percentiles indicating some lower fractile of the distribution would provide guidance to the putative level of $B_{trigger}$ relative to the current position of Bpa.

3 Further considerations

3.1 Evaluation of management plans in relation to MSY

The role of management plans in relation to the MSY objectives is being discussed between ICES and its clients. A broader range of performance criteria may be expected for the evaluation of management plans in relation to the MSY objective. In order to decide on some of these criteria there needs to be a continuing dialogue with managers and stakeholders. Notwithstanding this, the distribution of average Fs implied by the MP and the F_{msy} target should be very similar.

3.2 Multi species considerations

There are many problems associated with the estimation of F_{MSY} in a multi species context. The F_{MSY} of a prey species depends on the status of the predator stocks, for example. Often feedback loops (e.g., sprat predation on cod eggs in the Baltic) further complicate the picture. The Working Group on Multi species Assessment Methods (ICES WGSAM 2008) came to following conclusions regarding MSY:

a) The high yields predicted at low F by single-species models are almost certainly unrealistic, as these will be 'eroded' by predation pressure and density-dependent growth reductions.

b) Multi-species models indicate that the MSY is achieved at different fishing mortalities compared with single-species approaches.

c) It is impossible to attain the high yields predicted by single-species models for all stocks simultaneously, because achieving BMSY for one species may result in stock declines for other species that are prey and/or competitors.

d) System-wide analyses suggest that the optimum strategy to maximize yield (harvested biomass) usually involves the depletion of top predators.

e) Management objectives need to be very clear – to maximize overall yield (Protein production), to maximize economic returns or to prevent the loss of any species (biodiversity objectives). These objectives are almost certainly mutually incompatible.

f) Predators might provide other 'services' in ecosystems which could be impacted if system-wide strategies are pursued to maximize yield.

Despite these difficulties the ecosystem approach to fisheries calls for taking into account species interactions. To be able to maximize yield in a multi species context a wider range of objectives are needed. There are conservation objectives (e.g., all stocks should have full reproductive capacity), but society has to decide what kind of fisheries they want in the future. Currently we are not able to define a compatible set of targets for the multispecies assemblage in most of the ICES eco-areas, though some progress has been made for the simpler species assemblages of the Baltic and Barents Seas, this work should be continued and developed, and brought into management targets when applicable.

Adopting a single species MSY approach implies changes in Biomass in most of the ICES areas. Currently we cannot identify which part of these changes are compatible or not with one another. However, single species MSY targets are considered to be a practical option for the way forward. In this context it is important to maintain a close watch on species interactions and to account where possible for the responses of different species when considering long term targets. Monitoring and understanding the development in each of the ICES areas is an important role for the WG on Mutispecies Assessment Methods (WGSAM) and other groups related to ecosystem research. In especially, current estimates of predation mortalities could be provided from multi species models on a regular basis.

3.3 Further work on Stock recruit relationships

The SRR fit can be improved through the inclusion of information on other processes than have been considered. The Stock Recruitment Relationship (SRR) plays a central role in the identification of Fmsy (Needle 2002), and of other key biological reference points (e.g. Myers *et al*. 1997; Myers & Mertz 1998). However, SRR is still rather poorly understood, as is shown in the low goodness of fit of this relationship for most if not all stocks (Hilborn & Walters 1992; Needle 2002). In many cases, the SSB metric alone explains only partly the variability in recruitment, this can result in high uncertainty in the determination of Biological reference Points (Rothschild & Fogarty 1989; Myers & Mertz 1998; Needle 2002).

Consequently, there is extensive research going on aiming to improve the understanding and predictability of the processes underlying recruitment success, including for instance factors influencing survival of early life stages, like climate (Cushing 1982; Rijnsdorp et al. 2009; Ottersen *et al*. 2010) and prey availability (Sundby 2000), and also life-history traits (Rickman *et al*. 1998; Denney 2002), differing dynamics of meta-population components (Secor *et al*. 2009), spawners age and size composition (Marshall *et al*. 1998; Cardinale & Arrhenius 2000) or other factors. These processes are often complex and interacting and various hypotheses have been put forward to explain fluctuations in recruitment (see Ottersen *et al*. 2010 for an overview).

There is thus a clear scope for potentially improving the modeling of Recruitment dynamics and thus refine the MSY estimate. To this regard, meta-analysis can be useful to borrow strength from a broader dataset, and thus reveal large scale patterns, test general hypotheses and reduce uncertainty in parameter estimates of SRR models (Myers & Mertz 1998; Myers 2001; Mantzouni *et al*. 2010).

WKFRAME recommends that a sensitivity study to any analysis using SRR, should explore new scientific methods and/or observations, as they become available.

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4 Case studies

The case studies presented below outline a number of approaches and highlight some of the issues encountered when exploring appropriate references for long term equilibrium fishing mortality rates. In Case study 1 you can see an approach used for a data limited situation, which is essentially a sensitivity analysis of a YPR conducted using the NFT toolbox. In Case study 2 AD model builder software has been used to develop a series of routines to estimate F_{msy} and explore some aspects of the uncertainty in the estimates. The routines were developed to read in standard .sen and .sum files from assessment outputs and there are choices in the S/R fit to the data as well as the specification of the procedure for uncertainty estimations. An example using these tools with North Sea cod is then given. The worked example highlights the difficulties in fitting an appropriate SRR given the spread of the stock and recruit points. In this case the beta parameter can be shown to be poorly estimated for both Ricker and Beverton and Holt fits. The smoothed hockey stick provides a more statistically robust fit to the data, at the cost of an assumption of no relationship between stock size and recruitment above the breakpoint. In Case study 3 an example is given of a simulation tool (HCS10) which will facilitates the stochastic analogue of a YPR function by screening over a range of F's given an implementation of a S/R relationship and a specification of "noise" in terms of magnitude and distribution on several parameters. An example of a diagnostic plot is given which is very useful in illustrating the yield change, risk to biological productivity, and uncertainty for a range of fishing mortalities which cover the default proxies for F_{msy} (such as $F_{0.1}$ and F_{max}). In case study 4 a more elaborate example of a similar approach is shown which is implemented using a series of FLR routines. For the example of North Sea herring, the effect of different of S/R functions as well as noise in the biological parameters of the stock is explored. The plots show the resulting effect (of the S/R function and uncertainty in biology) on the estimate of F_{msy} (and its probability distribution) and on the perception of risk to stock productivity (B_{pa} and B_{lim}) from a point estimate of F_{msy}. This kind of analysis is very informative to illustrate the effect uncertainty, related to both model specification (in the S/R fit) and biological "noise", to the perception of risk based on a point estimate of F_{msy}. The analysis highlights the need to consider these effects in the selection of an F_{msy} reference point. Case study 5 is an exploration of the potential effect of the time series on estimates of $F_{0.1}$ and F_{max} from a deterministic equilibrium function (YPR). Using the example of North Sea Cod, this case study highlights the effects of large scale temporal variability in the population dynamics, on the estimation of $F_{0.1}$ and F_{max}. This example also highlights the need for circumspection in the use of stock recruitment functions. In the final case study there is a comparison of 2 North Sea flatfish stocks (Plaice and Sole) using the approach in Case study 4. In the case of Plaice the example highlights the challenges faced when the S/R data have very little dynamic range, such that the fit to any S/R relationship is compromised by a lack of observations to show the response of the stock productivity to SSB size. In the case of sole, again the S/R data show a limited dynamic range, but this time the YPR is very flat topped, making the estimate of F_{max} very sensitive to the data.

These examples are likely not to be unique in terms of trends and variability in population dynamic observations, and thus probably represent the kind of challenges to be faced by Expert Groups in evaluating appropriate F_{msy} reference points. There is no "one size fits all" approach to overcome these problems, many of which may be related changes in stock productivity and possibly selection over time. As stated above, in these cases WKFRAME advocates data exploration and a rationalisation of the results of different model fits to expert knowledge of biological productivity and fishing patterns, and putative changes in these over time.

4.1 Case Study 1-Dankert Skagen & Mauricio Ortiz

A data limited situation with Redfish

YPR and SPR analysis were conducted for *Sebastes mentella* in Subareas I – II, a rockfish species. This species is long lived (maximum age 75), ovoviviparous, and inhabits pelagic and epibenthic habitats from 300-1400m in the North Atlantic. *Sebastes mentella* is exploited by fisheries in the NE Atlantic for which weight and maturity at age information is available. There is no accepted ICES stock assessment. The input data for this example were the age vectors of selectivity at age (assumed to be similar to maturity at age), maturity at age, weight at age and natural mortality (constant by age at 0.1). The input data were the same as that used by WKPOOR2 (ICES 2009) in a recent study for a somewhat different purpose. The present analyses were performed with the program YPR version 2.7, which is part of the NOAA Fisheries Toolbox available at http://nft.nefsc.noaa.gov/. Table 1 and Figure 1 show the deterministic point estimates of YPR and SPR values for this species under the current selectivity pattern. The F values correspond to the F multiplier (F apical) for all ages. Maximum yield per recruit is attained at F multiplier values around 0.66, however at this level of fishing mortality the spawning stock is expected to be only 11% of the unexploited stock. At F_{01} the SSB is expected to be 35% of the unexploited biomass level, and the reduction in YPR compared to the F_{max} is about 18% or 0.08 kg per recruit.

Table 1

Reference Point	F	YPR	SSB per R	Biomass per R	Mean Age	Mean Generation time	Expected Spawnings	%SPR
F Zero	0	0	1.7898	2.42913	10.50379	24.87919	2.87014	100.0%
F01	0.1455	0.08342	0.63673	1.23064	7.07563	17.09902	1.16686	35.6%
Fmax	0.6613	0.10151	0.19185	0.69947	5.62176	13.11568	0.36728	10.7%
F at 40%SPR	0.1209	0.07859	0.71606	1.31654	7.31409	17.71023	1.29879	40.0%

Figure 1

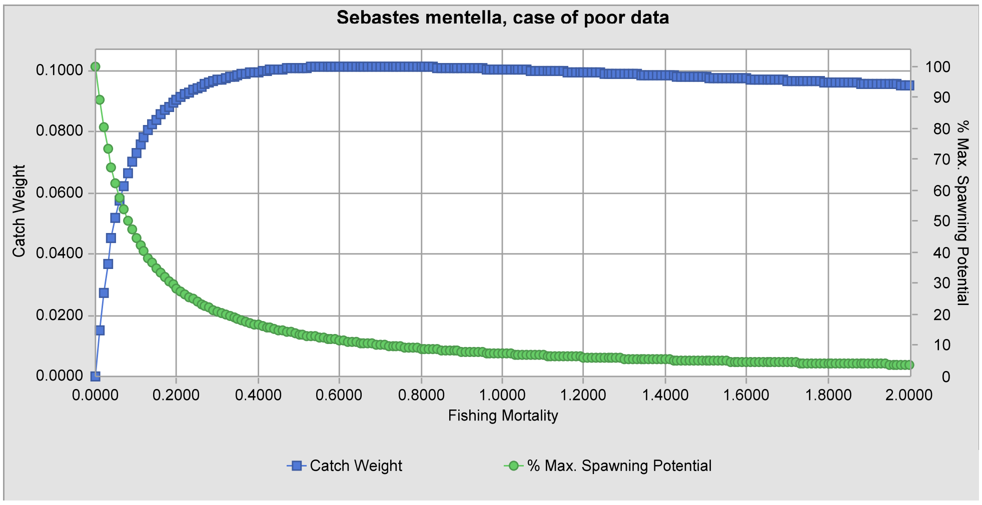
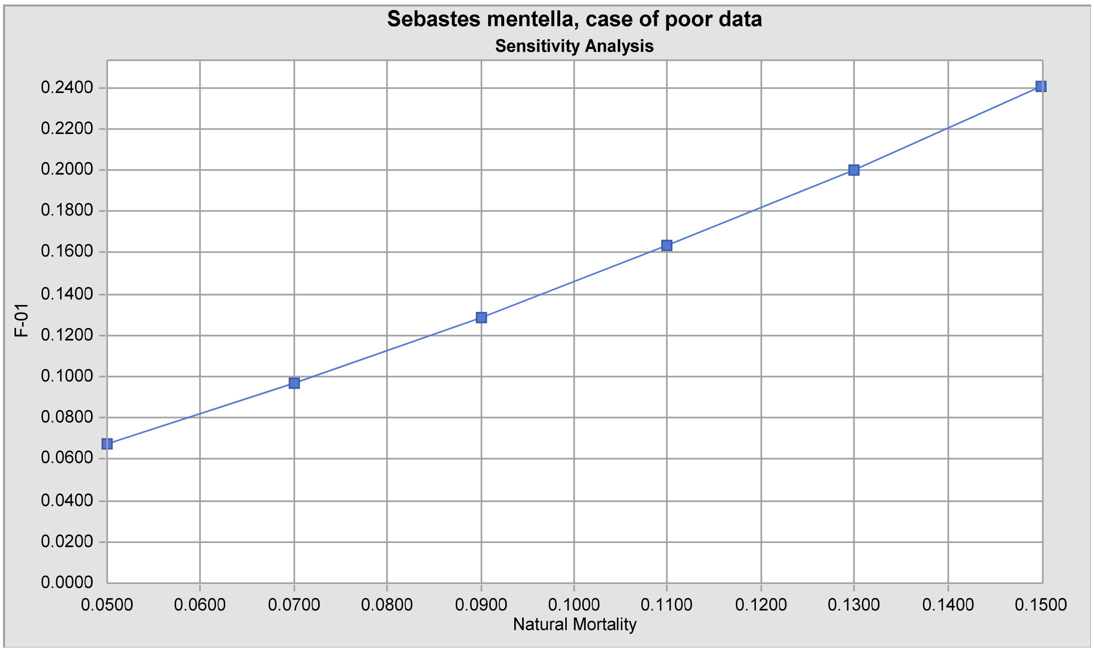
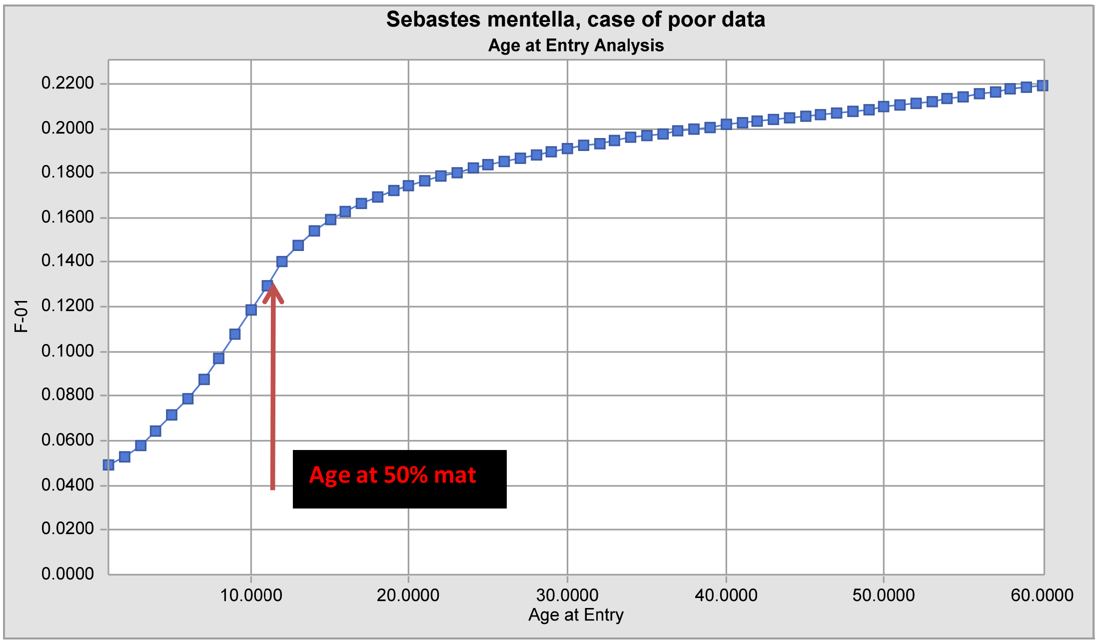


Figure 2 shows the sensitivity analysis of YPR for *Sebastes mentella* in reference to the assumption value of natural mortality. The default value of M was 0.1, if this value is lower it is expected that the productivity per recruit increases (large fraction of recruits survive), delaying the exploitation toward older age classes (i.e. lower fishing mortality with the same exploitation pattern), therefore the estimate of exploitation at F_{01} of F40%SPR decreases. The sensitivity analysis covered a range of M from 0.05 to 0.15.

Figure 2



Similar sensitivity analysis were done for YPR as function of age at entry (to the fishery). This analysis would be similar to examining potential changes in the selectivity pattern. Figure 3 shows the expected F_{01} value for first age at entry or full selectivity. If the selectivity shift towards younger age classes, the expected exploitation level would need to be reduced, this in response to growth overfishing. It is also noted that the age of 50% maturity for *Sebastes mentella* is about 11 year-old, if the selectivity shifted toward older age classes, the level of exploitation can be increased, however after age 12-14 this species has almost reached its asymptotic size, making it very difficult for a fishing gear to size select exclusively older (mature) age classes.



In summary, in cases of "data poor" species, if age structure information is available in most cases YPR and SPR analysis can be performed. This analysis should provide YPR based estimators such as F_{01} or F_{max}. However it is prudent to check the corresponding SPR estimates for these reference points, and it is recommended that the reproductive capacity of the stock be at least above 30% SPR at F=0. The bounds for F_{MSY} proxies should be evaluated in function of the YPR and SPR curves. The YPR curve left of the plateau can be used as low bound (F_{01} proxy) and a prescribed percent SPR as upper bound. This example illustrates why it is informative to carry out sensitivity analysis, particularly to assumptions regarding natural mortality, selection pattern, growth (density dependence) and maturity.

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4.2 Case Study 2-José De Oliveira, Timothy Earl, Chris Darby

Estimating F_{msy} using AD model builder

AD Model Builder (admb-project.org) is a highly efficient, freely available software for implementing non-linear statistical models. One of the principal advantages of this software is the ability to carry out automatic differentiation which speeds up the convergence of any model fit and calculates the derivatives as accurately as if the analytical derivatives were implemented. It also produces several different estimates of the uncertainties of model parameters and selected derived quantities.

Staff from CEFAS (José De Oliveira, Timothy Earl & Chris Darby) have put together a suite of programmes in AD model builder to estimate Fmsy and some components of its uncertainty from the outputs of a standard ICES stock assessment. The index file from the Lowestoft-format input files is used to get the proportion of F and M before spawning; alternatively these can be specified in an argument to the convertSumSen.r function (as a list). The ICES *.sum and *.sen files are converted with an R function (convertSumSen.r) to two files: srmsy.dat and out.dat. The former file is the input file to srmsy.tpl, the program which calculates Fmsy assuming a particular stock recruit function. Another program, srsmsysim.tpl, calculates the uncertainty associated with those elements of the assessment which are described in the *.sen files as well as the uncertainty around the stock recruit relationship.

The steps required to run these routines are as follows:

1) Convert sum and sen files to srmsy.dat and out.dat files, using the function convertSumSen.r. This also delivers an internal R object (a list).

   e.g.: stock = convertSumSen(hadiv.sen)

2) Ensure that the files srmsy.dat and out.dat produced from convertSum-Sen.r are in the same directory as srmsy.tpl.

3) Determine which stock recruit relationship you want to use. There are a variety of pieces of software which can do this.

4) Check the stock recruit function code on row 4, column 5 of the srmsy.dat. This can currently be coded as: 1 = Ricker; 2 =Beverton-Holt; 3 = Smooth Hockey Stick e.g. 1963 2008 0 8 2 0 0 will fit a Beverton-Holt model.

5) Run srmsy.tpl in AD model builder: compile, link and run it.

6) The output is a text file, simpar.dat, with a single row of data in columns; the F-related quantities are multipliers on the input F (see point 10).

7) To calculate the uncertainty using srmsysim.tpl, compile and link this file (first time you use it only), then run srmsy.tpl again (no need to re-compile it), but change row 4, column 6, of the input file (srmsy.dat) from 0 to 1.

   e.g. 1963 2008 0 8 2 1 0.

8) To specify which uncertainty components are included, make row 4, column 7, of the input file (srmsy.dat) 0 for recruitment variability only; and 1 for both recruitment variability and steady-state vector uncertainty.

   e.g. 1963 2008 0 8 2 1 1 for both recruitment variability and steady-state vector uncertainty.

9) Ensure that the file sim.dat is in the same directory as the tpl files. It is a space separated file with three numbers: a random seed (change this for a different suite of random numbers, if desired); 1 (the starting iteration

number – don't change this); final number of iterations (adjust this as appropriate).

e.g. 21 1 100

10) The output from srmsysim is an overwritten version of text file simpar.dat with (iterations +1) rows, and columns for:

i. n (iteration index: 0 - number of iterations, where 0 is the deterministic calculation)
ii. a (alpha from stock recruit relationship)
iii. b (beta from stock recruit relationship)
iv. sigr (recruitment variability)
v. scor (serial correlation)
vi. fcrash
vii. fmax
viii. f01
ix. fmsy
x. msy
xi. bmsy
xii. msypr
xiii. bmsypr
xiv. msyr (MSY/Bmsy)
xv. fnFcrash (function to solve for Fcrash – should be zero or close)
xvi. fnFmax (function to solve for Fmax – should be zero or close)
xvii. fnF01 (function to solve for F0.1 – should be zero or close)
xviii. dYdF (derivative at Fmsy – should be zero or close)
xix. nll (negative log likelihood)
xx. AIC

In summary:

	Preparing data files	Running ADMB code
Programs	convertSumSen.r	srmsy.tpl srmsysim.tpl (compile and link these only once)
Input	*.sum *.sen Lowestoft-format input files	srmsy.dat sim.dat (change options in these – see below)
Output	srmsy.dat out.dat	screen output simpar.out admb output files srmsy.* (ignore srmsysim.*)

Key inputs:

srmsy.dat:

Ropt = choice of stock-recruit function (1=Ricker, 2=Beverton-Holt, 3=smooth hockey stick

simopt = whether to include uncertainty beyond the original fit to the stock-recruit data (0=perform single fit only, 1=use a parametric bootstrap to re-generate recruit data and re-fit the chosen stock-recruit function – this number of simulations can be set in the sim.dat file)

senopt = whether to include uncertainty in recruitment only (=0), or uncertainty in both recruitment and steady-state vectors (=1)

sim.dat:

A file that contains three numbers: 1st is the seed, 2nd is the number 1 (don't change this), 3rd is the number of simulations required. This file is used during the running of srmsy.tpl when simopt=1, so if the program is aborted prior to completion, these three numbers have to be re-set.

North Sea cod - ADMB implementation

The Cefas ADMB module was used to estimate Fmsy and potential proxies for the North Sea cod stock. The model applied assumes a single species harvest scenario with no density dependent variation in growth and mortality rates at high stock abundance.

Input data

Input data was taken from the most recent assessment. Landings and discard mortality rates were included within the over all selection pattern used to estimate population dynamics but only landings values were used to calculate the maximum yield. Weights, maturity and natural mortality at age were taken as the average over the most recent three years.

Stock and recruitment

Ricker, Beverton-Holt and the smooth hockey stick stock and recruitment curves were fitted to the data and the diagnostic output evaluated (Tables 1 & 2 and Figure 1 - 5) to determine the appropriate function for the estimation of Fmsy or its proxies.

Figures 1a, 1b, 1c illustrate the uncertainty inherent in the estimation of the stock and recruitment curves. MCMC re-sampling was used to derive alternative fits of the stock and recruit curve based on the variance and covariance structure of the parameters estimated from the initial model fit. The left hand curves in each figure illustrate the confidence intervals from X/1000 re-samples from the MCMC chain; where X (recorded in the legend) represents the number of successful samples in which the bounds of the fit are not violated. The right hand figures present curves plotted from the first 100 re-samples for illustration.

Figures 2a, 2b, 2c present the range and correlation of the fitted slope (alpha) and biomass (beta) parameters for each stock and recruit function, the figures on the left as estimated using a transformation to increase orthogonality, on the right as defined for the original formulations of each of the curves. The transformation reduces the correlation between the parameters allowing an improved estimate for both the Ricker and Beverton Holt curve parameters.

Figure 3 presents for the fit of the Ricker curve:

a) box plots of the estimated Fmsy fishing mortality with proxies for Fmsy, based on the yield per recruit definitions of Fmax, F0.1, F35% and F40% SPR, and also Flim, Fpa and F in the final year, for comparison;

b) the equilibrium landings versus fishing mortality plot based on the fitted stock and recruit plot and the selection and weight at age data. The left hand figure illustrates the percentiles from re-sampling the MCMC chain with the assessment data points, the right hand figure the first 100 successful re-samples of the estimated relationship;

c) the equilibrium SSB versus fishing mortality relationship for the fitted stock and recruit plot, selection, weight and maturity at age data, with the historic data values.

Figures 4 and 5 present similar plots to those in 3a - 3c for the Beverton Holt and smooth hockey stick functions; Tables 2(a) - (c) present the estimated values for each of the stock and recruitment curves.

Yield per recruit

a) Figures 6a, 6b and 6c present the yield per recruit output from the model:

b) The estimates of Fmax, F0.1, F35% and F40% SPR with Flim, Fpa and the final year F.

c) The human consumption yield per recruit at specified levels of fishing mortality.

d) The spawner biomass per recruit at the specified level of fishing mortality.

Table 2(d) presents the yield pre recruit estimates.

Summary for North Sea cod

All model fits illustrate that for North sea cod, as fishing mortality approaches Fcrash the stock declines to zero at equilibrium, at low mortality rates there is a substantial rebuilding of SSB and yield well above the historic estimates although the absolute long term values are poorly defined.

The slope at the origin of the stock and recruitment curve from which Fcrash is derived is well estimated for all three curves (CVs around 20%, Table 2). However, one of the stock recruit parameters used to derive Bmsy and MSY is poorly defined for both the Ricker and Beverton-Holt curves. This can be seen in the wide range of the distribution of the percentiles and large CVs (Tables 2a and 2b). Given the uncertainty in the parameter estimates from the fit on the Ricker and Beverton-Holt models, the Fmsy estimates derived from these curves cannot be used for cod in the North Sea.

The smooth hockey stick recruitment model parameter estimates are well defined and can be used as a basis for determining Fcrash and for scaling the estimate of MSY. The level of recruitment above the breakpoint in the smooth hockey stick is constant; consequently the Fmax value becomes the proxy for Fmsy as long as it is defined and lower than Fcrash, which is the case for North Sea cod.

The models used do not included uncertainty due to ecosystem effects and multi-species interactions affecting growth, maturity and natural mortality. Therefore the variability estimated at low fishing mortality rates is likely to be under-estimated and the potential yields over estimated.

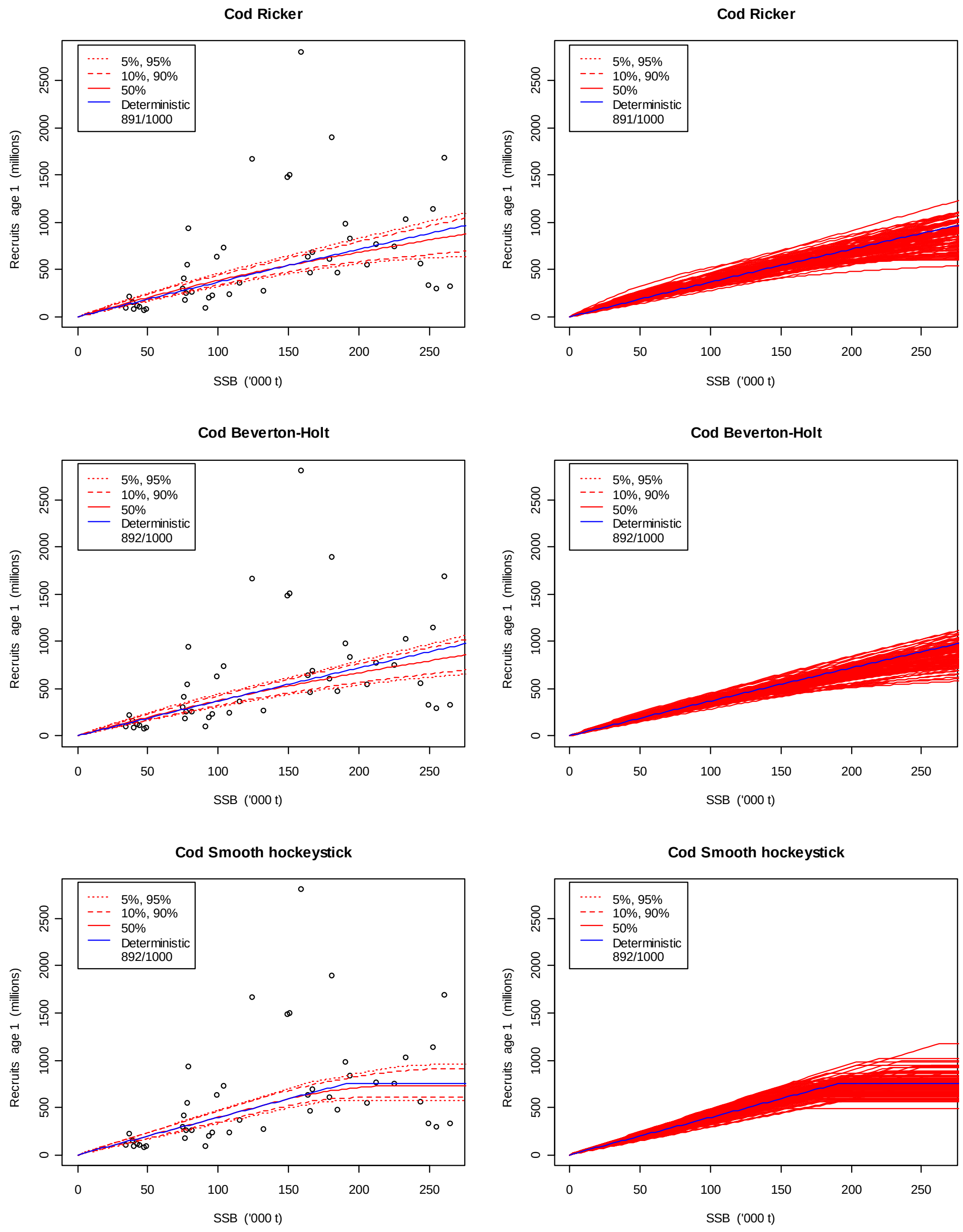

Figure 1 (a) Ricker, (b) Beverton-Holt and (c) smooth hockey stick curves fitted to the North Sea cod stock and recruitment estimates. The 95th, 90th, median, 10th, and 5th percentiles derived from MCMC re-sampling are illustrated in red; the deterministic estimates in blue. The bottom row in the legends indicates the number of successful re-samples (where bounds are not violated).

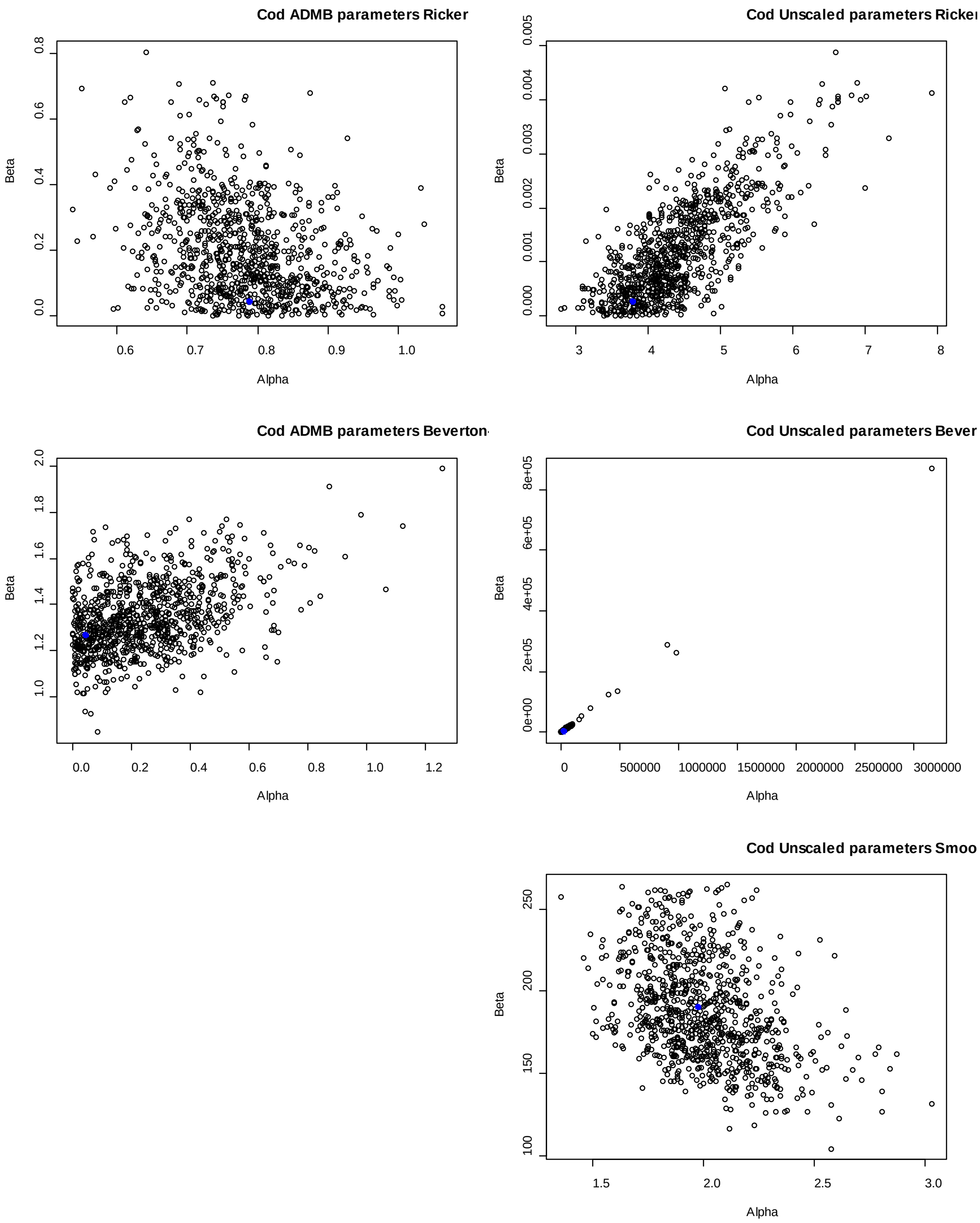

Figure 2: MCMC pair re-samples from (a) Ricker, (b) Beverton-Holt and (c) smooth hockey stick parameter estimates for curves fitted to the North Sea cod stock and recruitment estimates. The plots illustrate the correlation between and variability in the estimates on the original and transformed scales used to increase orthogonality (right and left hand side plots respectively).

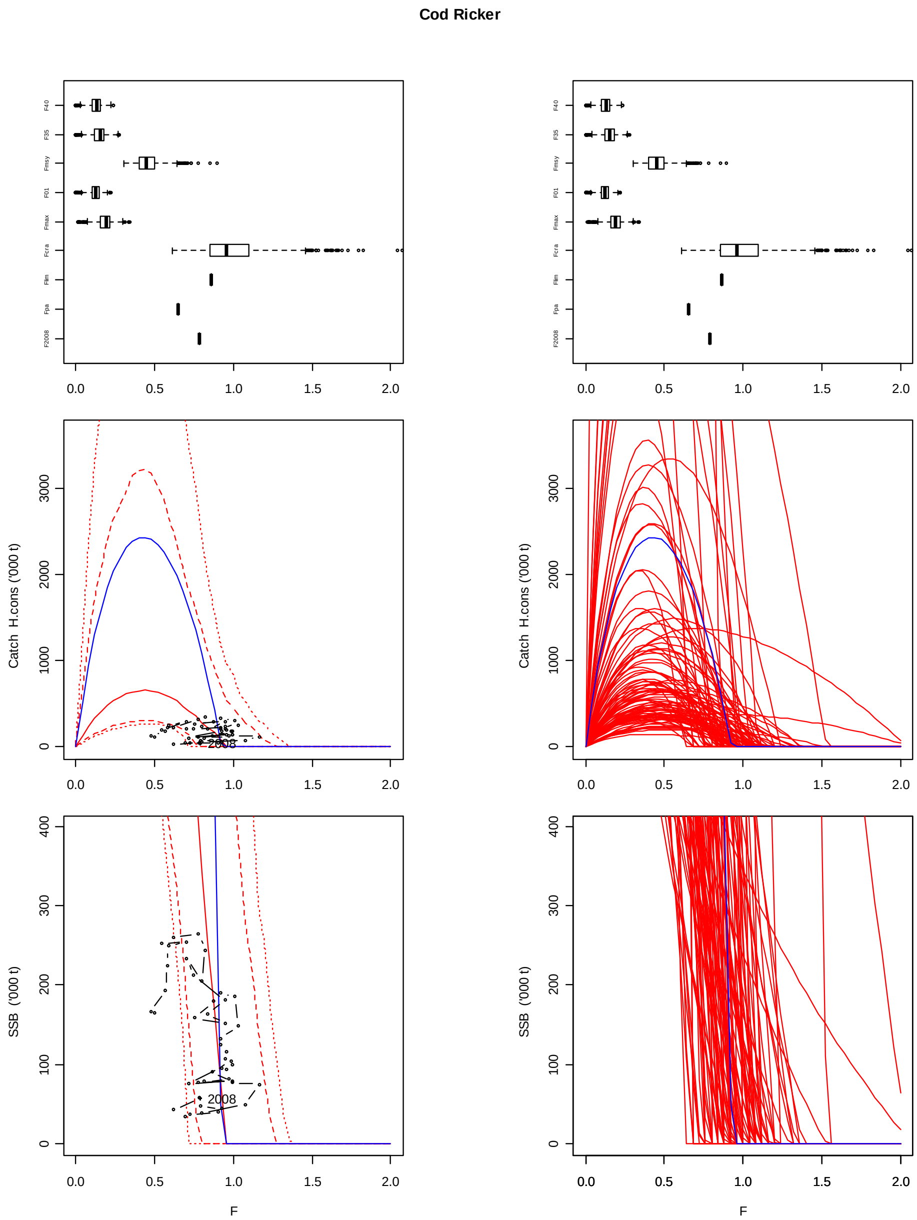

Figure 3: North Sea cod Ricker stock and recruitment model estimates. (a) Box plots of Fmsy and Fcrash with proxies for Fmsy based on the yield per recruit: Fmax, F0.1, F35% and F40% SPR also Flim, Fpa and F in the final year; (b) equilibrium landings versus fishing mortality; (c) equilibrium SSB versus fishing mortality. The left hand figures illustrate the percentiles from the successful MCMC re-samples, plotted with the assessment data points, the right hand figures 100 illustrative re-samples.

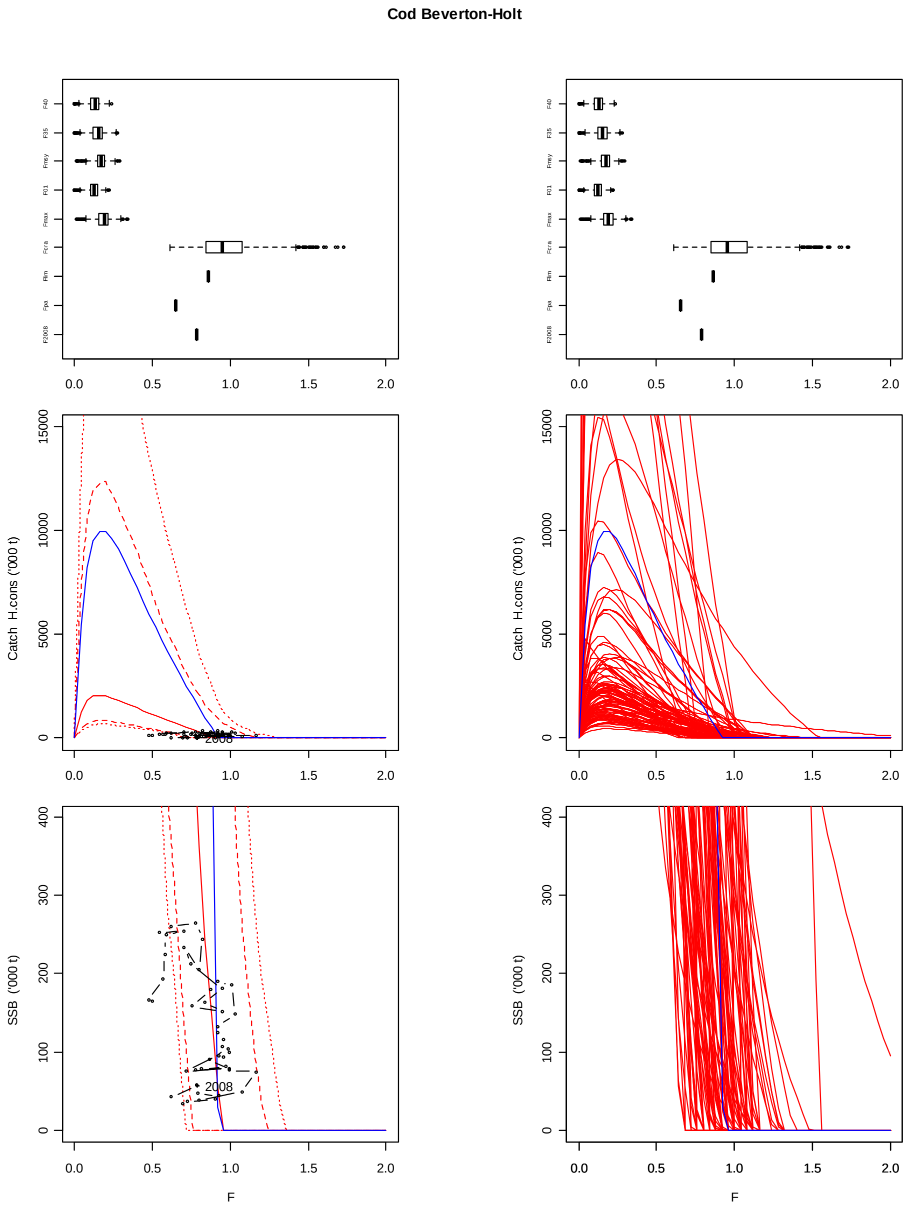

Figure 4: North Sea cod Berverton-Holt stock and recruitment model estimates. (a) Box plots of Fmsy and Fcrash with proxies for Fmsy based on the yield per recruit: Fmax, F0.1, F35% and F40% SPR also Flim, Fpa and F in the final year; (b) equilibrium landings versus fishing mortality; (c) equilibrium SSB versus fishing mortality. The left hand figures illustrate the percentiles from the successful MCMC re-samples, plotted with the assessment data points, the right hand figures 100 illustrative re-samples.

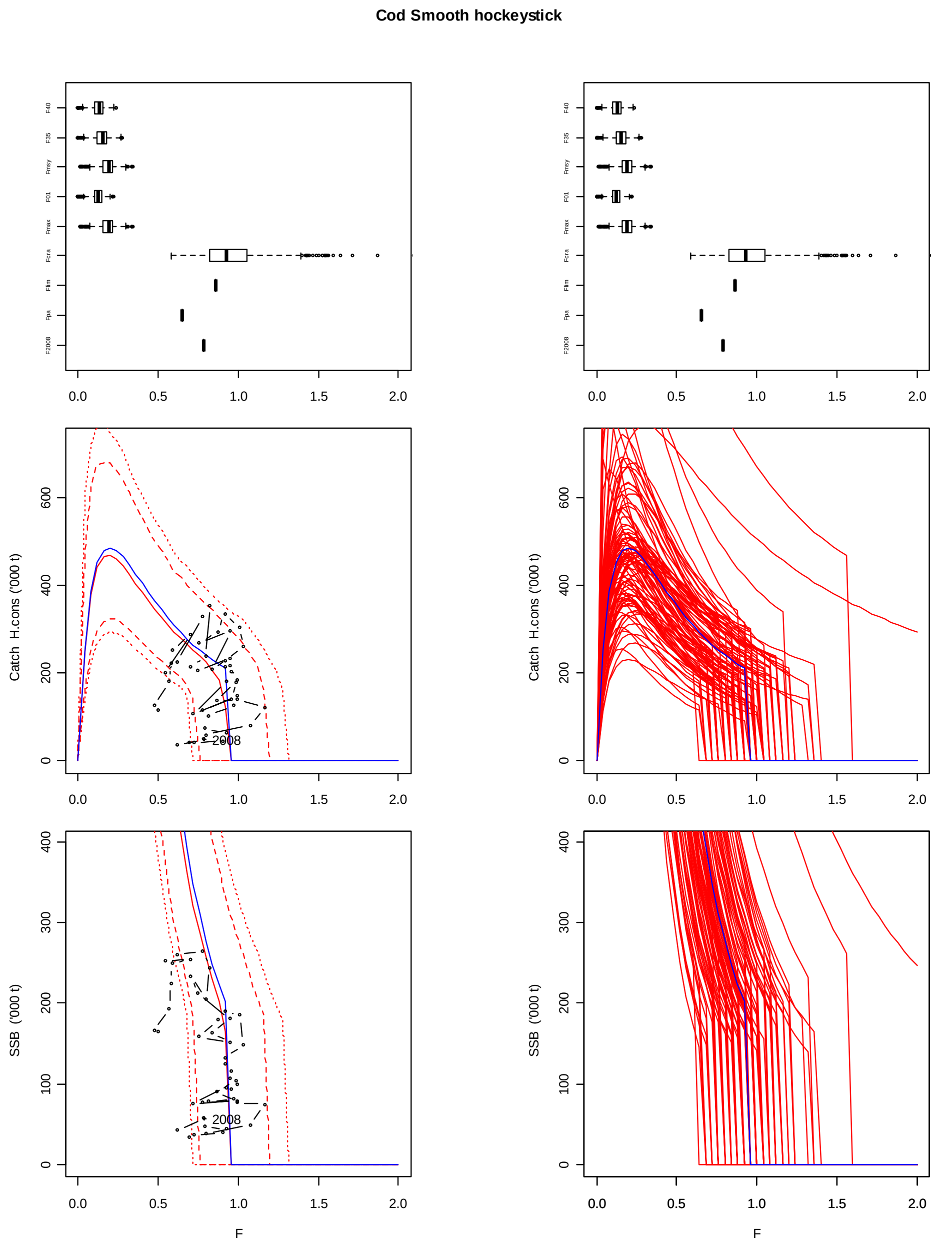

Figure 5: North Sea cod smooth hockey stick stock and recruitment model estimates. (a) Box plots of Fmsy and Fcrash with proxies for Fmsy based on the yield per recruit: Fmax, F0.1, F35% and F40% SPR also Flim, Fpa and F in the final year; (b) equilibrium landings versus fishing mortality; (c) equilibrium SSB versus fishing mortality. The left hand figures illustrate the percentiles from the successful MCMC re-samples, plotted with the assessment data points, the right hand figures 100 illustrative re-samples.

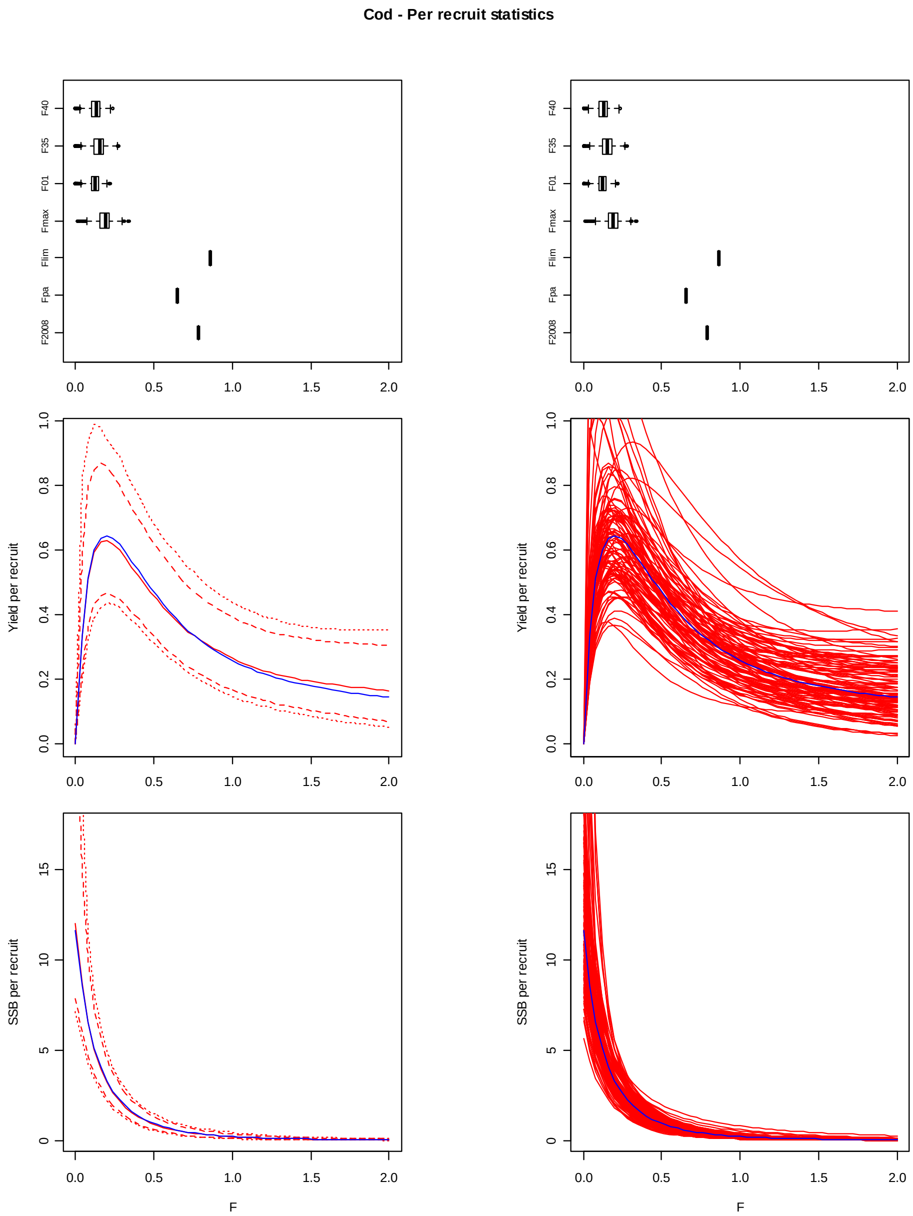

Figure 6: North Sea cod yield per recruit estimates: (a) box plots of the proxies for Fmsy: Fmax, F0.1, F35% and F40% SPR also Flim, Fpa and F in the final year; (b) yield per recruit (kg); (c) SSB per recruit (kg).

Table 1: The input file and model fit summary for the estimation of the North Sea cod biomass and fishing mortality reference levels derived from the fit of three stock and recruit relationships and the yield per recruit Fmsy proxies.

Stock name	Sen filename	pf	pm	Number of iterations	Simulate variation in Biological parameters	SR relationship constrained
North Sea Cod	.\data\cod\cod_vMcm_late.sen	0	0	1000	TRUE	TRUE

Table 2: The estimates of the North Sea cod biomass and fishing mortality reference levels derived from the fit of three stock and recruit relationships and the yield per recruit Fmsy proxies. Estimates are based on the successful MCMC re-samples, indicated in the legends of Figure 1.

(a) Ricker

	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta
Deterministic	0.925	0.427	5795	2438	0.788	0.044	3.779	0.0003
Mean	0.993	0.459	6392	2660	0.781	0.202	4.417	0.0012
5%ile	0.716	0.349	526	269	0.649	0.017	3.458	0.0001
25%ile	0.854	0.402	865	402	0.725	0.083	3.939	0.0005
50%ile	0.957	0.450	1477	673	0.777	0.175	4.323	0.0011
75%ile	1.098	0.500	2932	1347	0.829	0.299	4.782	0.0018
95%ile	1.366	0.605	15072	6154	0.926	0.492	5.733	0.0030
CV	0.206	0.173	6.88	6.11	0.106	0.739	0.160	0.7393

(b) Beverton-Holt

	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta
Deterministic	0.923	0.175	58826	10023	0.045	1.268	16739	4458
Mean	0.982	0.166	73905	9698	0.249	1.346	15171	4125
5%ile	0.713	0.084	3845	682	0.020	1.136	1327	252
25%ile	0.847	0.146	7429	1291	0.105	1.242	2140	464
50%ile	0.953	0.171	13569	2139	0.216	1.325	3499	824
75%ile	1.078	0.193	32585	4552	0.354	1.441	7196	1885
95%ile	1.355	0.230	201361	22328	0.570	1.618	37957	10382
CV	0.207	0.270	5.33	7.16	0.738	0.112	7.7	7.9

(c) Smooth hockeystick

	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta
Deterministic	0.942	0.195	2561	486	0.430	1.418	1.973	190
Mean	0.952	0.186	4275	504	0.435	1.401	1.998	188
5%ile	0.699	0.088	1400	296	0.360	1.073	1.652	144
25%ile	0.823	0.159	1988	391	0.401	1.227	1.842	165
50%ile	0.929	0.191	2514	475	0.432	1.361	1.983	183
75%ile	1.052	0.216	3382	576	0.466	1.557	2.140	209
95%ile	1.302	0.265	8052	818	0.516	1.830	2.369	246
CV	0.198	0.285	1.96	0.34	0.116	0.165	0.116	0.165

(d) Per recruit

	F35	F40	F01	Fmax	Bmsypr	MSYpr	Fpa	Flim
Deterministic	0.162	0.138	0.131	0.195	3.409	0.647	0.65	0.86
Mean	0.146	0.124	0.121	0.186	5.793	0.677		
5%ile	0.040	0.032	0.039	0.088	2.011	0.439		
25%ile	0.121	0.103	0.101	0.159	2.732	0.540		
50%ile	0.153	0.130	0.125	0.191	3.448	0.644		
75%ile	0.179	0.153	0.145	0.216	4.491	0.766		
95%ile	0.218	0.185	0.177	0.265	10.598	1.030		
CV	0.351	0.355	0.333	0.285	1.972	0.306		

4.3 Case Study 3-Dankert Skagen

Using a harvest rule simulation tool for calculating deterministic and stochastic equilibrium yield and SSB as function of F

When evaluating harvest rules, a standard procedure is to simulate a stock in the medium term, where the fishery is according to the harvest control rule applied to a managers' perception of the stock. Many such simulation tools exist. Some obtain the perceived stock by performing an assessment on noisy data derived from the true simulated stock, others just assume that the assessed stock deviates from the true stock according to a specified probability distribution. In all cases, the simulation is stochastic, with recruitment, weights at age, maturity at age, selection at age, assessment error and implementation error as stochastic variables. Recruitment is typically according to a specified stock-recruit relation.

Such tools are straightforward to adapt to the present purpose of finding a value of F or a range of F-values that lead to a (near) maximum long term yield with low risk of impaired recruitment due to depletion of the stock. All routines and data needed for calculating deterministic yield and SSB per recruit are at hand, and combining the yield and SSB per recruit with the deterministic part of the stock recruit function is straightforward. In addition, one will obtain the stochastic relation between a fixed F and yield and SSB directly, by simulating a harvest rule with fixed F and no assessment or implementation error, for a suitable range of F-values.

The simulation program HCS has been used to explore and evaluate several harvest rules in the past (e.g. mackerel and Blue whiting). It has developed gradually; the most recent update from 2010 is termed HCS10. This program was used recently to explore candidate FMSY values for a range of stocks (Skagen, WD to WKFRAME) and by HAWG for the same purpose for most herring stock covered by that group. The program has not been formally published but a full description of the program, as well as the source code, are available from the author (dankert.skagen@imr.no) .

The program consists of a population model that generates yearly true stock numbers at age, an observation (assessment) model that transfers the stock numbers into noisy, 'observed' numbers, a decision rule through which a TAC is derived according to the observed stock (projected forward if relevant) and an implementation model that translates the TAC into actual removals. These removals are then input to the population model for the next time step.

The program is run as a bootstrap, with the following stochastic elements:

- Initial numbers
- Recruitments
- Observation noise
- Implementation noise

Weights and maturities have fixed values, which can be modified according to the total biomass to imitate density dependence.

The biological properties can be input as values at age, or generated according to a von Bertalanffy growth model and logistic selection at age. Stock numbers at the start of the simulation can be entered or obtained by 'priming' a population with a fixed fishing mortality. This may make the program more feasible in data-poor situations, where one at best can simulate a generic stock with realistic properties.

The standard stock-recruit functions (Hockey stick, Beverton-Holt and Ricker) are implemented with normal or lognormal noise, with options for truncation. In addition, there are facilities for simulating periodic recruitments and occasional very big year classes.

Deterministic yield and biomass as function of F is generated routinely. The output includes Fmax and F0.1. For a range of fishing mortalities, Yield, SSB in absolute values and in percent of virgin biomass, as well as the mean age in the spawning stock are output.

The program is constructed to automatically screen over specified ranges for a large number of management rule parameters. For the present purpose, it was used to run a stochastic simulation for a range of fishing mortalities. That gives a stochastic analogue to the deterministic yield per recruit. The results after 50 year projection were taken as a proxy for the equilibrium state.

The program is relatively fast, the analysis described here will take 10 - 15 minutes computing time. The output is easily transferred to spreadsheets. The HAWG also developed R-scripts to generate figures from the output files.

Example: Wester Baltic spring spawning herring – from HAWG (ICES 2010)

Weights, maturities, natural mortality and selection at age were taken from the input to short term prediction by the 2009 HAWG. The recruitment model was a hockey stick based on recruitments for year classes 2003 – 2007, to represent the current, lower productivity regime. The recruitment variation was lognormal with CV taken from the same recruitments. The breakpoint at 110 000 t as suggested for Blim by HAWG.

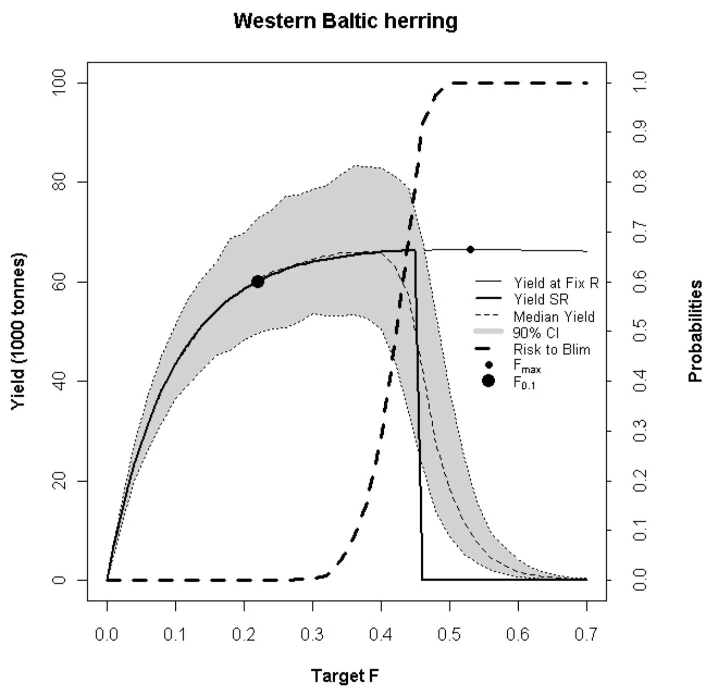

Figure 5.1: Western Baltic spring spawning herring. Yield per recruit and equilibrium distribution of catches, calculated with HCS10.

Yield at fixed R: Conventional yield per recruit raised to the plateau level of recruitment.

Yield SR: Yield per recruit at equilibrium level of recruitment according to the stock-recruit function.

Percentiles of catch in year 50 of projections (10th, 50th and 90th) are indicated.

Risk to Blim: Probability of SSB < Blim (110 000 tonnes) in year 50 of the projections.

4.4 Case Study 4-John Simmonds

A Diagnostic tool for displaying stock history and simulated equilibrium exploitation, and an example using North Sea herring

The objective

To provide a single page display to compare historic exploitation, and stochastic equilibrium exploitation with estimates of risk of SSB<Blim and probability of F=Fmsy. Uncertainty is optionally included in the modelling.

The basis

Simulated recruitment based on a fitted S/R relationship from a year based data period set by user. Number of iterations (stocks) selected by user – (100). Number of years to project to equilibrium (100). This longer period is required near F crash where equilibrium can be more difficult to find – 30 years is sufficient elsewhere. Selected F steps to scan over (0 to 1 in steps of 0.05) (The settings given in brackets takes around 5 minutes to compute)

Available uncertainty

Option 1 S/R uncertainty

a) Choice of model type

b) Fixed fitted model

c) Var/Cov parametric bootstrap of S/R estimated coefficients

Option 2 Growth and maturation

d) Fixed mean Maturity, stock and catch weights mean from a selected year range of data

e) Maturity, stock and catch weights bootstrapped together from a selected year range of data

Option 3 Variation in Fishery

f) Fixed mean selection over a selected year range of data

g) Selection bootstrapped from a selected year range of data

Technical Basis

FLR S/R routine

FLR Forward projection routines.

Displayed Metrics

Distribution of Catch in terminal year (100)

Distribution of SSB in terminal year (100)

Distribution of simulated Recruitment in years contribution to terminal year 91-100 (user defined)

Distribution of F at which maximum catch is obtained in terminal year (100)

Risk of SSB<Blim or Bpa in terminal year

Distribution of SSB/recruit relative to SSB/recruit a F=0

Example analysis based on North Sea herring

Some exploration to show effect of S/R function on NS herring – comparing Beverton Holt and Ricker for two periods 1975-2008 (post crash) and 2002 to 2008 (recent reduced recruitment). Stock Recruit model fits are given in Figures 1,3,5,7 Stochastic equilibrium, SSB, catch and recruitment compared with historic values are shown in Figures, 2,4,6,8 along with estimates of risk to SSB<Blim and <Bpa,the estimated pdf of Fmsy and the for comparison the exploitation F rule for the existing management plan.

The results are sensitive to recruitment assumptions but the management plan seems to appropriate for recent recruitment.

Figures 9-12 show the changes in estimates of the pdf of Fmsy for the Ricker S/R relationship for differing varying components in the simulation. Figure 9 gives the mean yield per recruit, a deterministic result showing a single value. Figure 10 shows the impact of the inclusion of just stochastic recruitment, which gives Fmsy as a spread of values symmetrically around the mean. Figure 11 shows the impact of addition of uncertainty in the functional form of the S/R relationship, through bootstrap using var/cov of the fit, this gives increased uncertainty at high F. Figure 12 includes variability from the last 10 years in weights at age, maturity and selection in the fishery.

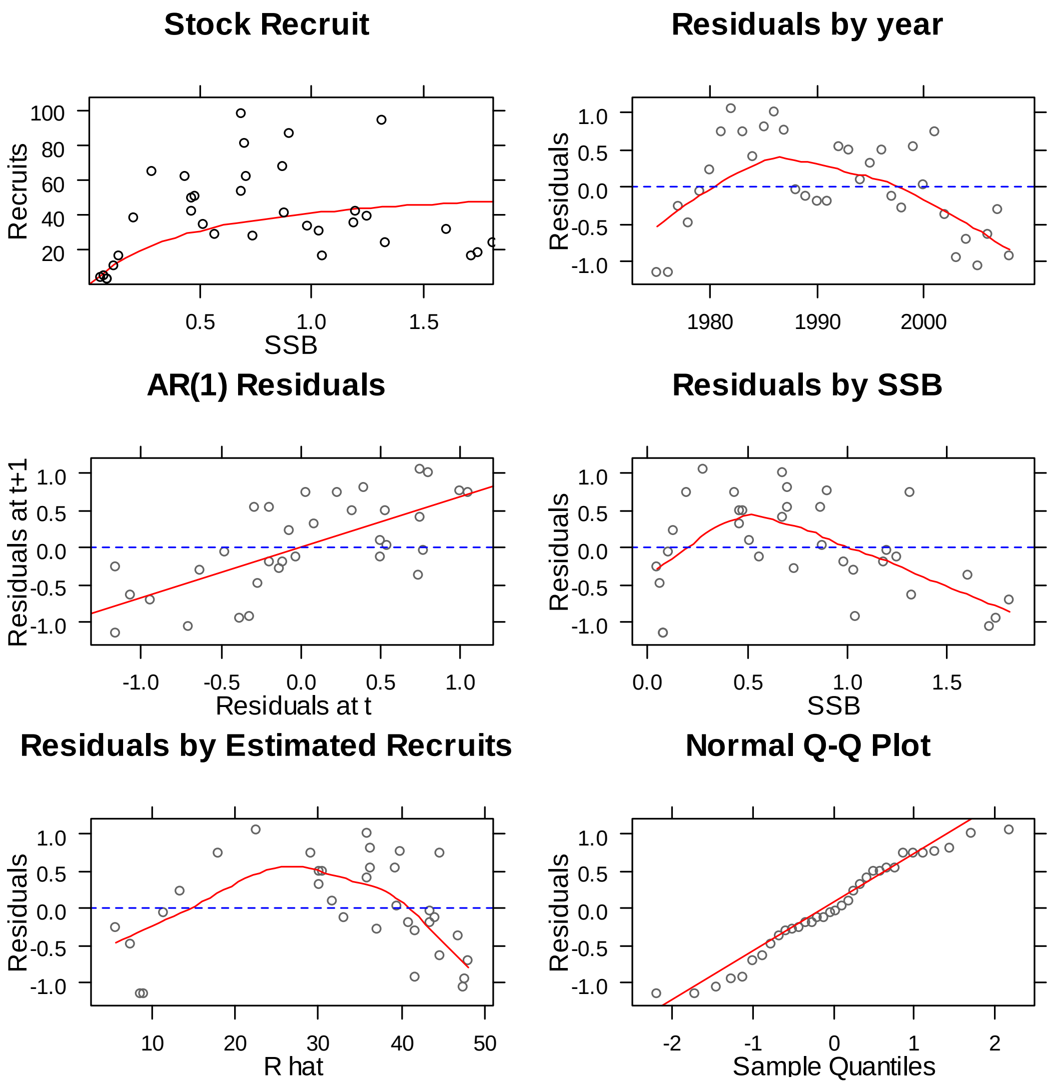

Figure 1: Beverton-Holt S/R model fitted to NS herring S/R data 1975-2008. Year trends are observed particularly in the last few years. Slope are the origin is well defined.

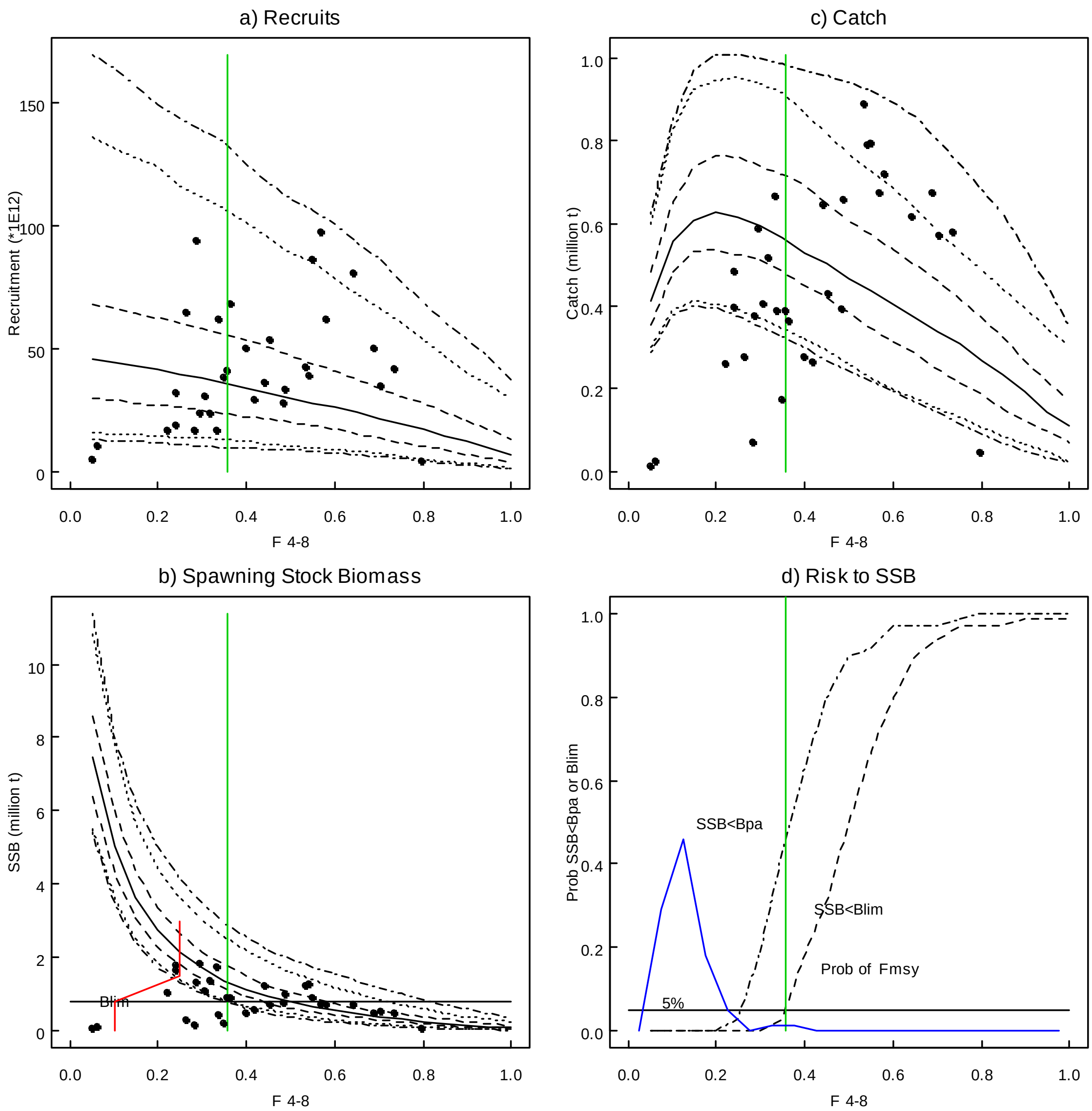

Figure 2: Equilibrium results for NS herring recruitment 1975 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Ricker. A) Recruitment, b) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) c) Catch, d) Risks and Fmsy. Green grid line is at the F for a 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. The blue line shows the pdf of F=Fmsy

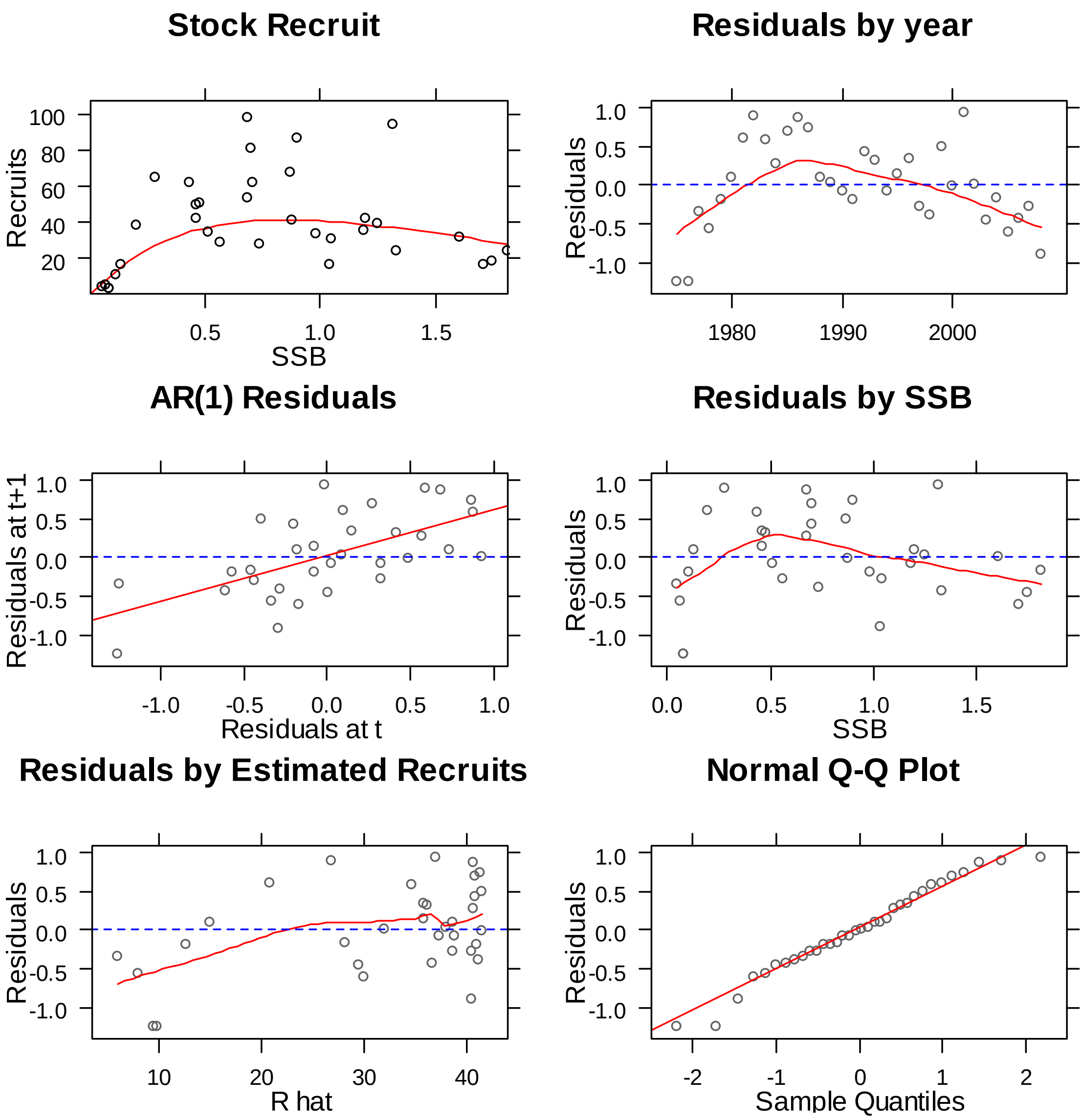

Figure 3: Ricker S/R model fitted to NS herring S/R data 1975-2008. Year trends are observed particularly in the last few years. Slope are the origin is well defined.

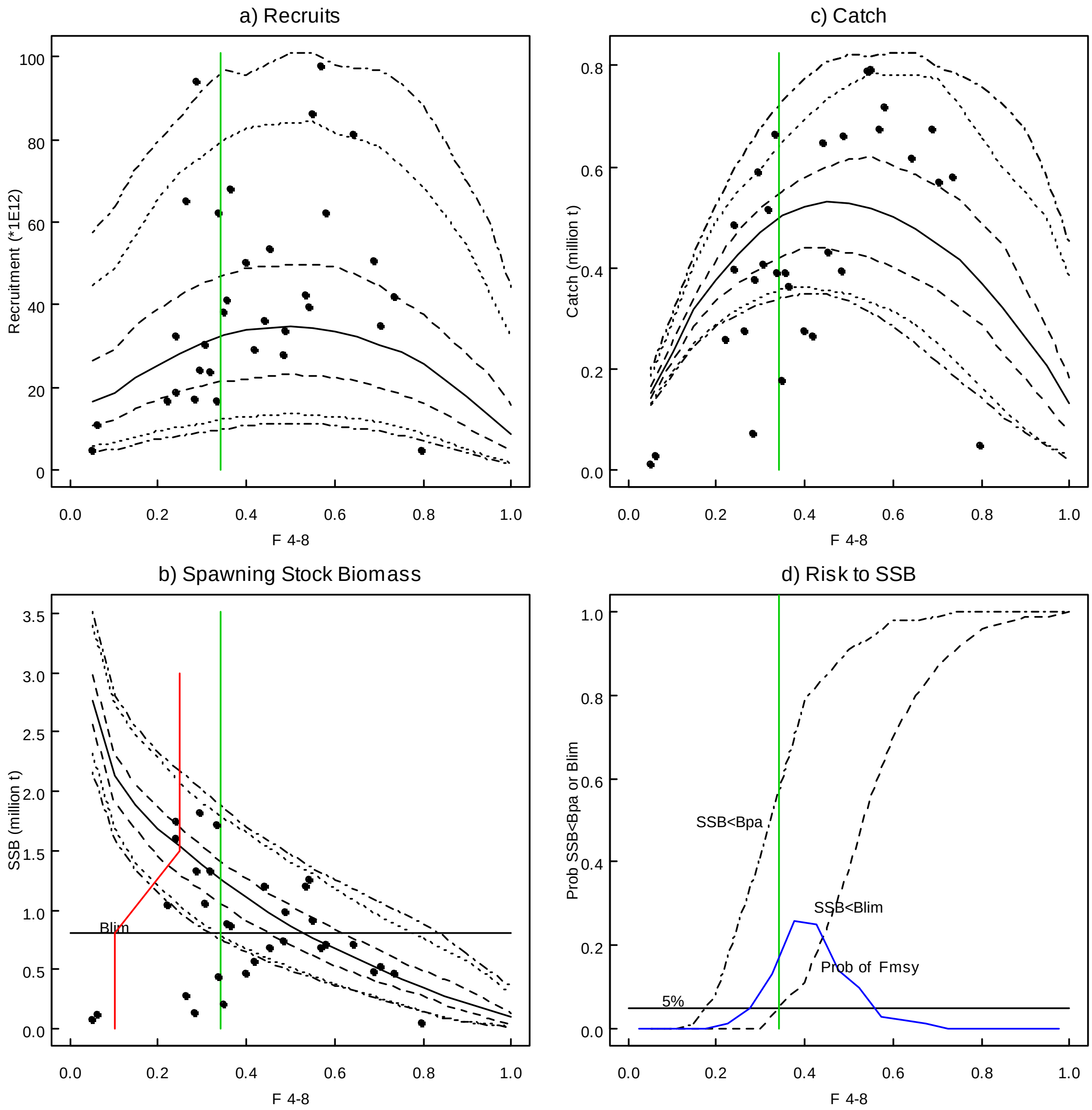

Figure 4: Equilibrium results for NS herring recruitment 1975 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Beverton Holt. A) Recruitment, b) Catch, c) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) d) Risks and Fmsy. Green grid line is at the F for a 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. The blue line shows the pdf of F=Fmsy

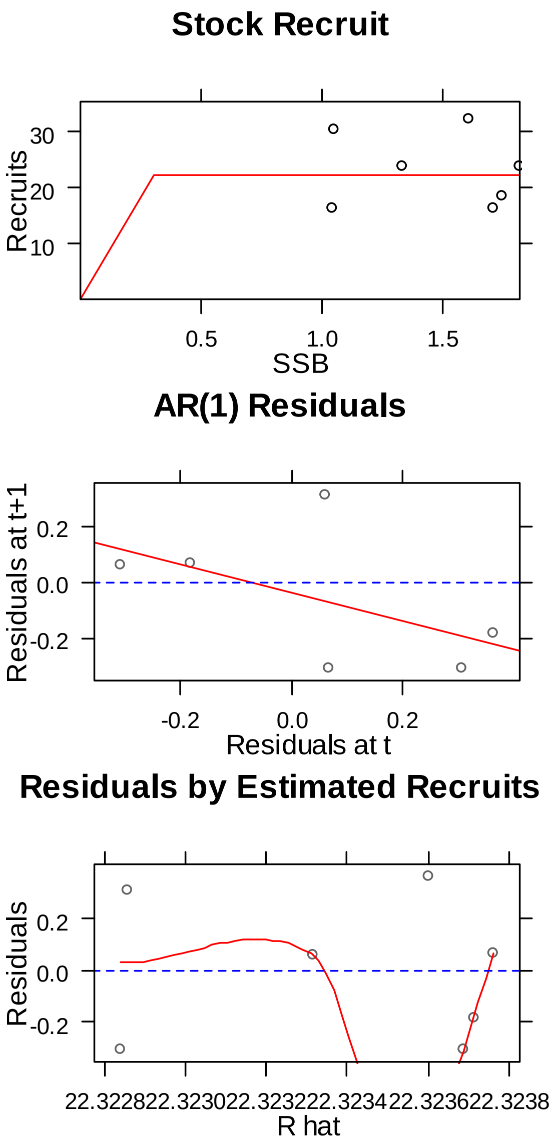

Figure 5: Beverton-Holt S/R model fitted to NS herring S/R data 2002-2008. Year trends are observed particularly in the last few years. Slope are the origin is well defined.

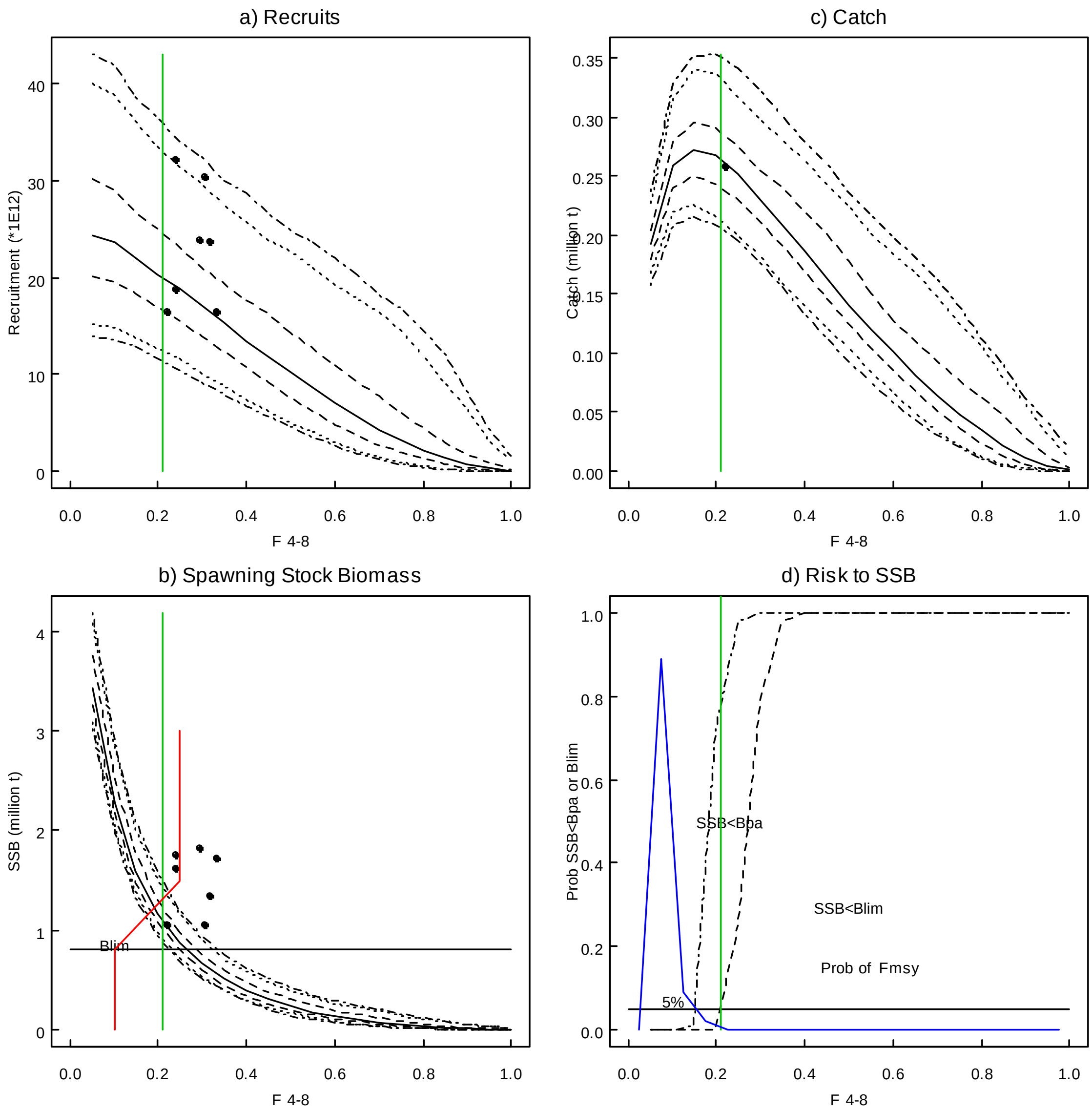

Figure 6: Equilibrium results for NS herring recruitment 2002 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Beverton Holt. A) Recruitment, b) Catch, c) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) d) Risks and Fmsy. Green grid line is at the F for a 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. The blue line shows the pdf of F=Fmsy

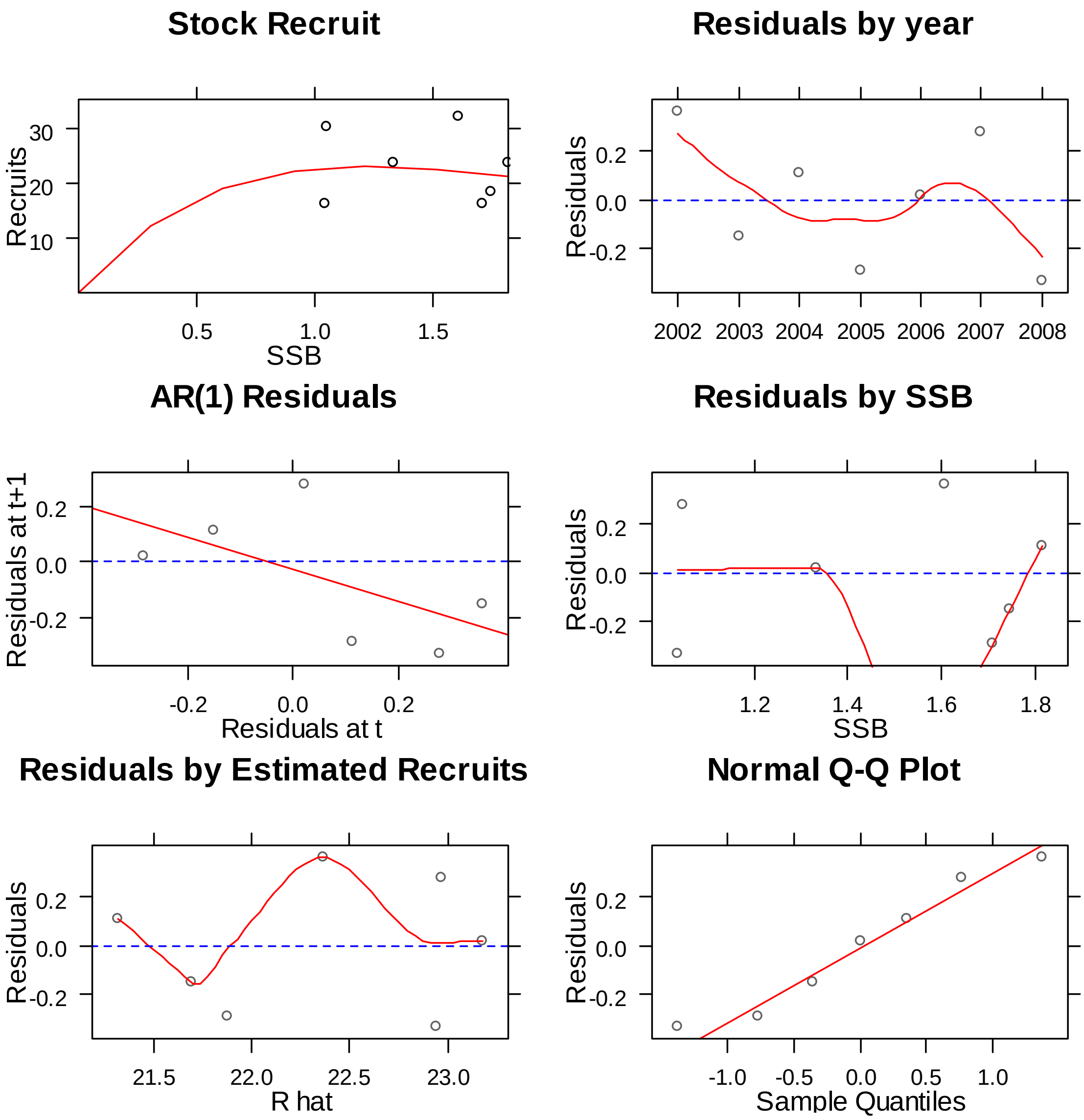

Figure 7: Ricker S/R model fitted to NS herring S/R data 1975-2008. Year trends are observed particularly in the last few years. Slope are the origin is well defined.

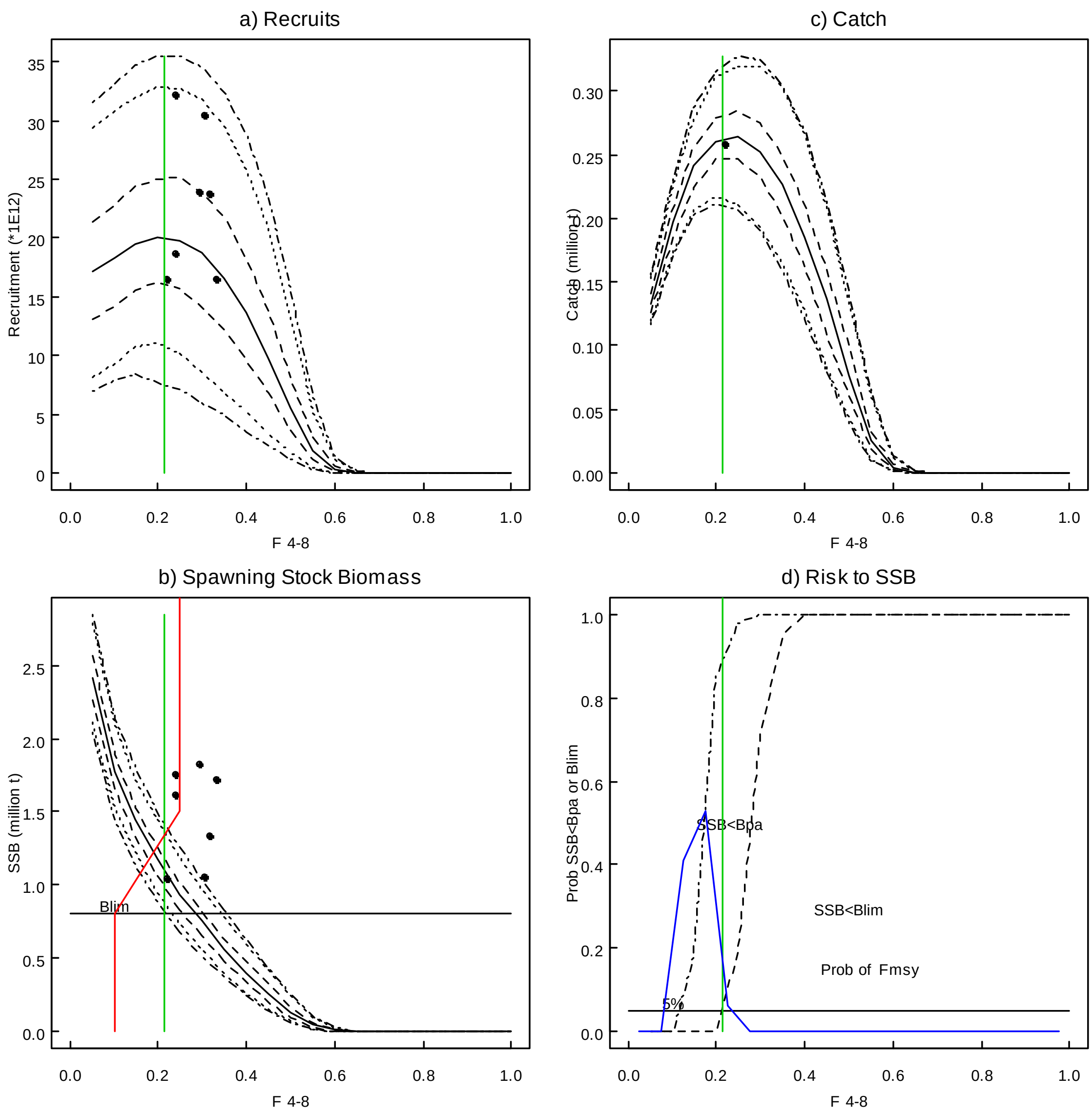

Figure 8: Equilibrium results for NS herring recruitment 1975 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Beverton Holt. A) Recruitment, b) Catch, c) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) d) Risks and Fmsy. Green grid line is at the F for a 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. The blue line shows the pdf of F=Fmsy

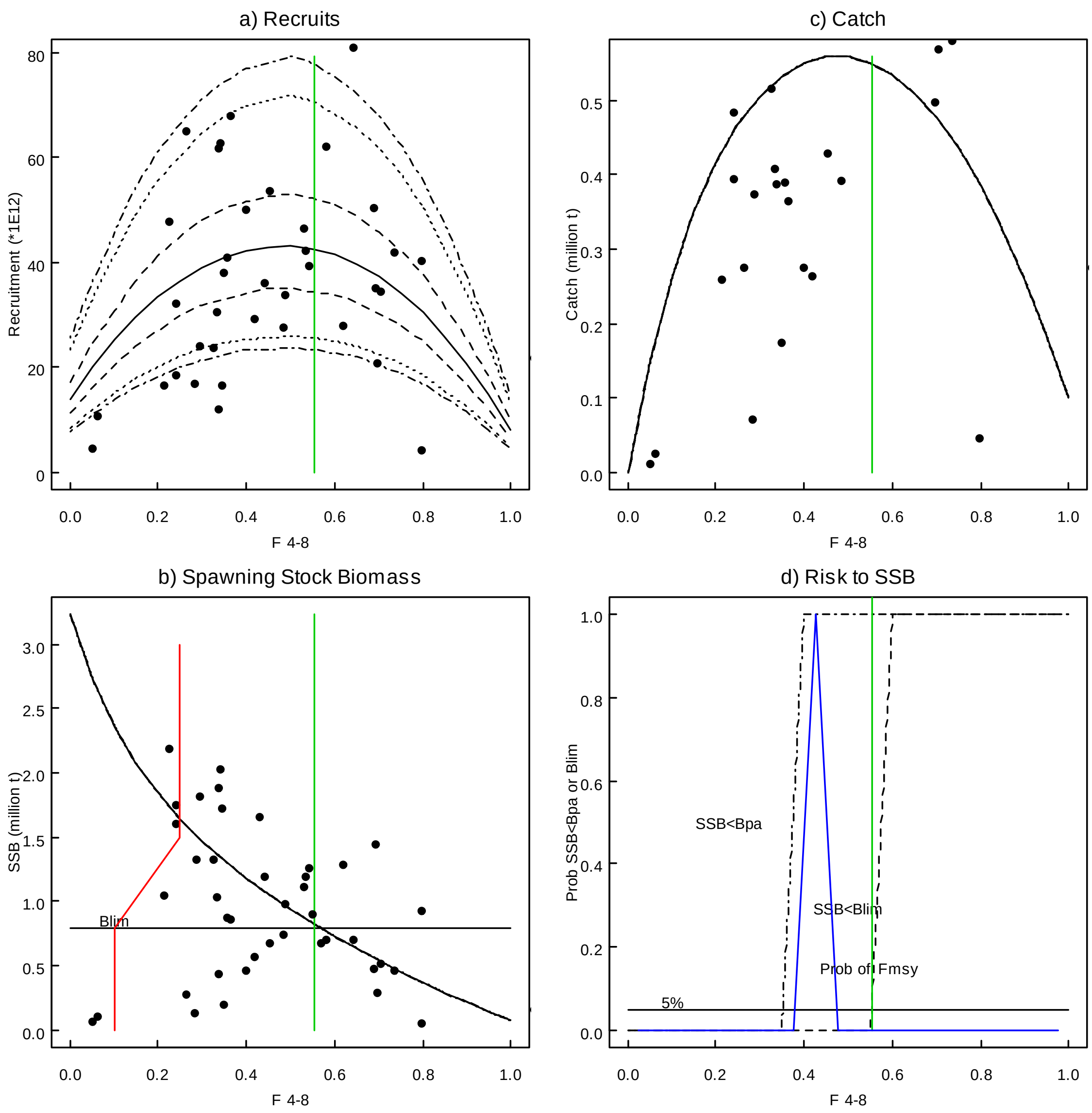

Figure 9: Results with no uncertainty for NS herring recruitment 1975 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Ricker. A) Recruitment, b) Catch, c) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) c) Risks and Fmsy Green grid is F for 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. Blue line pdf of F=Fmsy

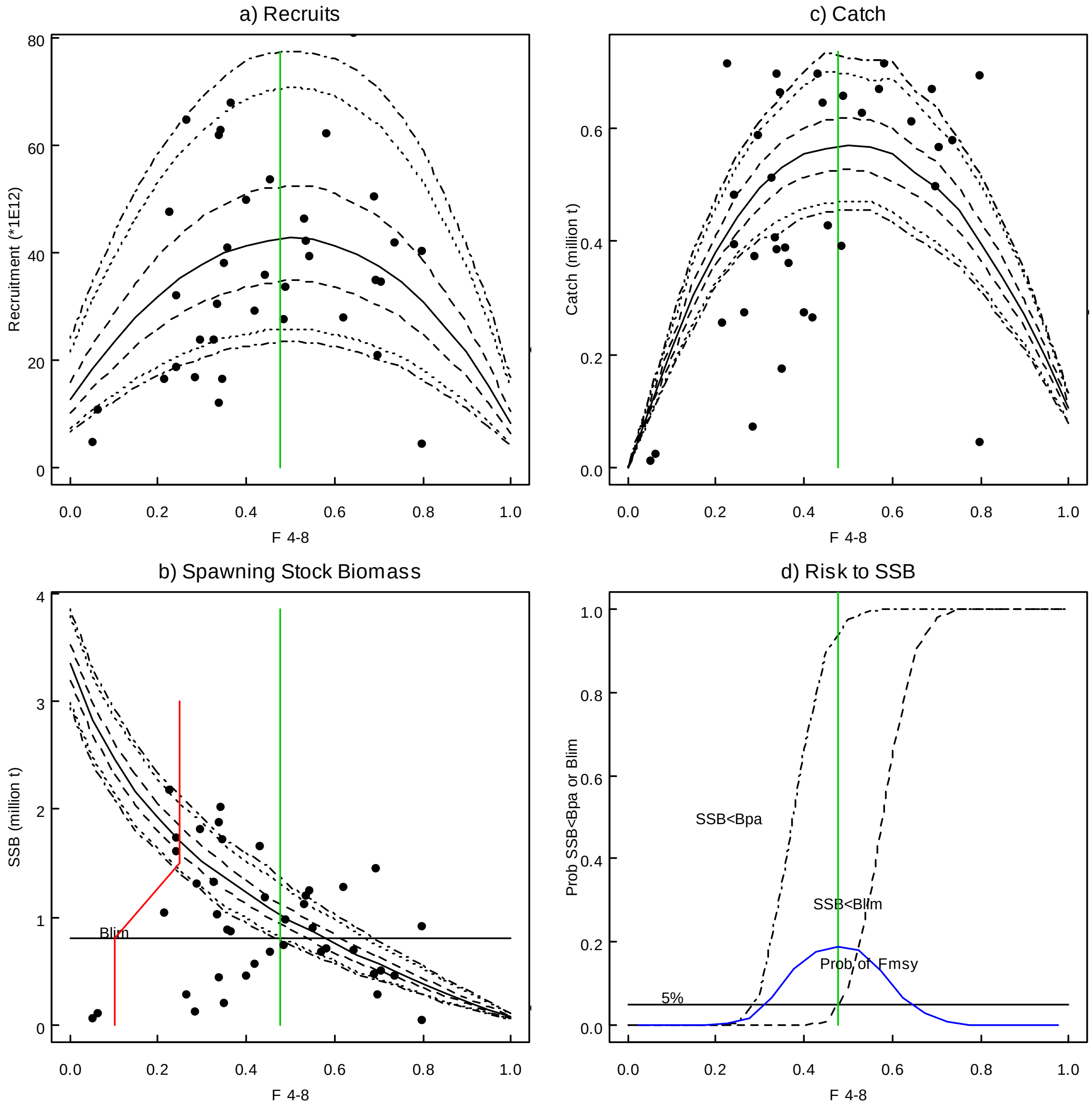

Figure 10: Results with only stochastic recruitment for NS herring recruitment 1975 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Ricker. A) Recruitment, b) Catch, c) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) d) Risks and Fmsy. Green grid line is at the F for a 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. The blue line shows the pdf of F=Fmsy

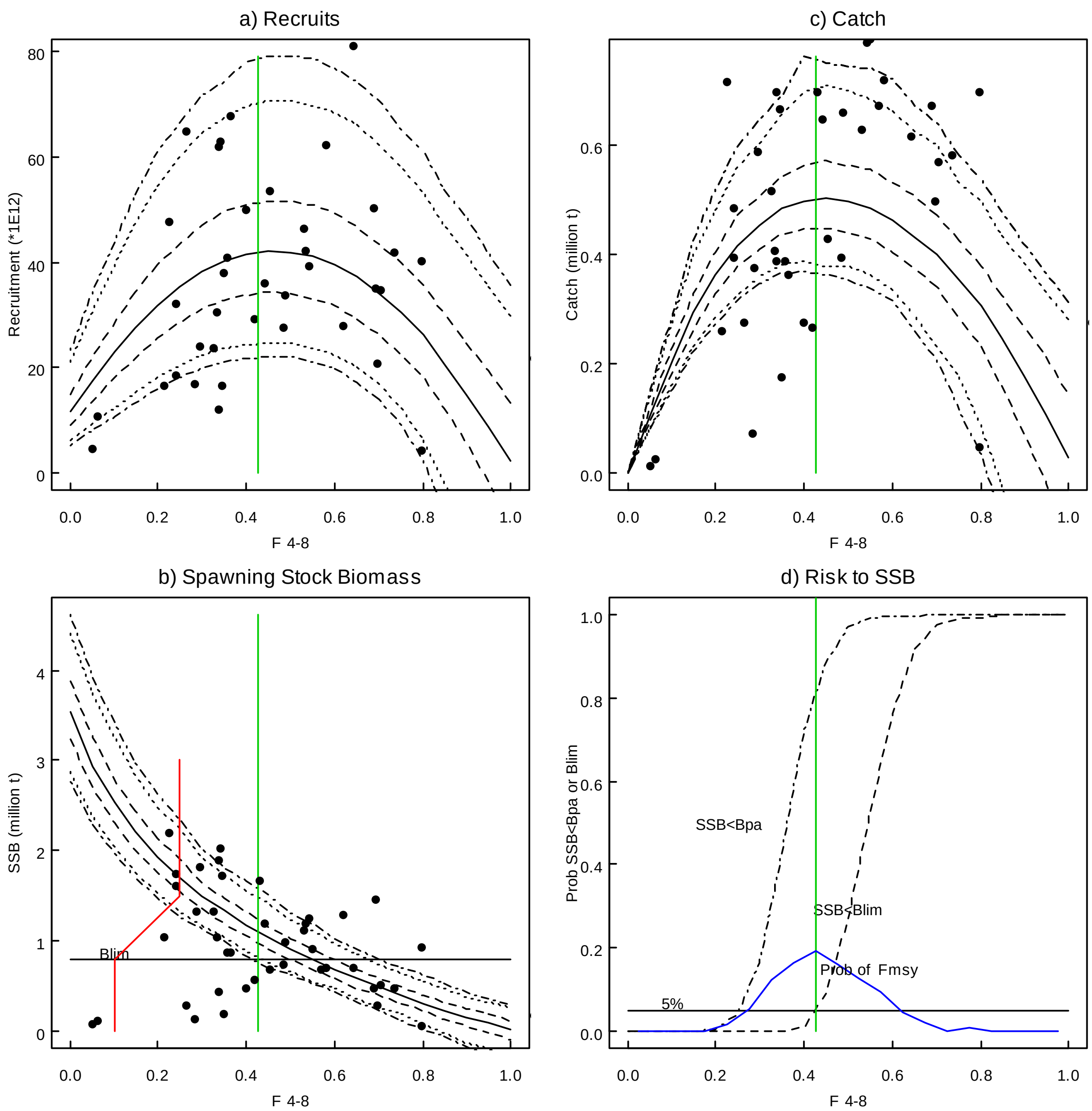

Figure 11: Results with Stochastic variable recruitment and uncertainty in S/R coefficients based on Var/Cov. for NS herring recruitment 1975 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Ricker. A) Recruitment, b) Catch, c) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) d) Risks and Fmsy. Green grid line is at the F for a 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. The blue line shows the pdf of F=Fmsy

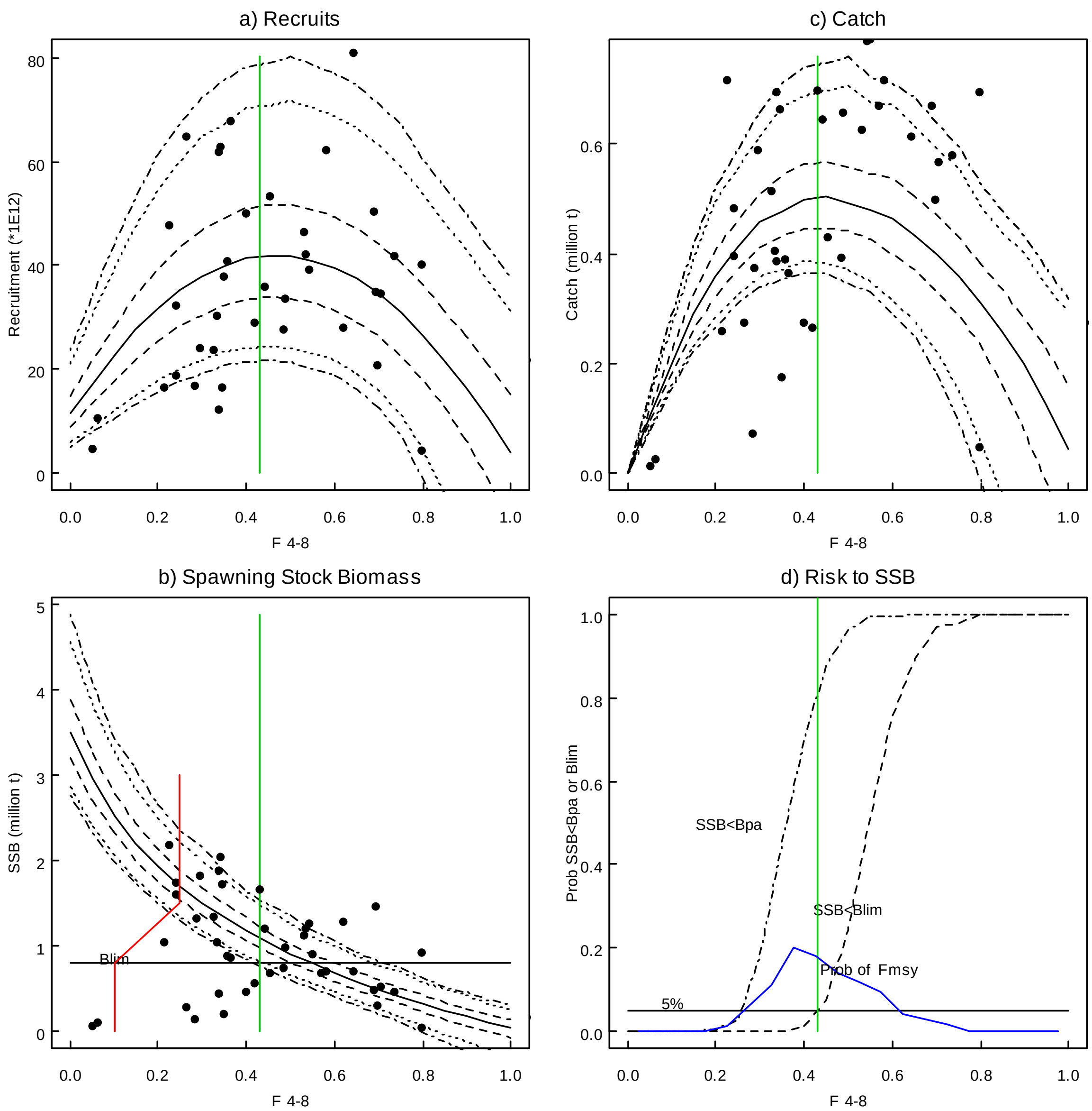

Figure 12: Results with Stochastic variable recruitment and uncertainty in S/R coefficients based on Var/Cov, growth, maturation and variation in selection in the fishery based on annual random draws for NS herring recruitment 1975 to 2008 with growth, maturation variability from 1999 to 2008. Recruitment model Ricker. A) Recruitment, b) Catch, c) SSB, points are observations, lines are quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) d) Risks and Fmsy. Green grid line is at the F for a 5% risk of SSB<Blim. Ogives show probability of SSB< Blim and Bpa. The blue line shows the pdf of F=Fmsy

4.5 Case Study 5–Coby Needle & Paul Fernandes

Temporal changes in F_{MSY} proxies

Estimates of FMSY can change systematically with changes in any one of the input variables associated with its calculation. These changes may be direct (e.g. changes in growth rates due to intraspecific competition e.g. Rijnsdorp & van Leeuwen 1996) or indirect (e.g. systematic changes in recruitment due to an environmental effect, e.g. Beaugrand *et al* 2003). Natural mortality may be affected by changes in the abundance of prey, predators or competitors, and other ecosystem effects (see Walters et al., 2005), or by changes in environmental quality where, for example, anthropogenic nutrient impacts can predominate over fishery effects in semi-enclosed seas (Caddy 2000). Long-term shifts in the life-history traits of fishes, particularly size and age at maturity, have been widely reported (Law 2000) and may be attributable to both environmental and genetic changes. Age at maturity has been observed to decrease in various fish stocks (Trippel 1995, Jennings *et al*. 1999, Yoneda & Wright 2004): in some cases this has been postulated to be as a compensatory response to a reduced stock size (Jørgensen, 1990). In many cases, such changes have come about as a result of fishing and the effects it has had on ecosystems and their communities (Jennings et al. 1999). Climate change is also likely to affect many of these factors (Brander, 2007) and has been postulated to have a direct effect on MSY (Cook and Heath 2005) although the effect is different for different species. Clearly the selection pattern of the fishery is also something that is subject to change over time (e.g. Enever *et al*. 2008).

In the case of North Sea cod, previous work has concluded that F_{msy} has changed over time. For example, Cook and Heath (2005) fitted time-varying stock-recruitment curves for this stock which incorporated an explicit temperature term, and used curves to generate estimates of F_{msy} that declined over the available assessment time-series. They assumed that this decline would be due to increases in temperature, but in this case identification of the causal driver is perhaps less important than the fact that fisheries managers need to be aware of potential changes in target reference points such as F_{msy}.

In this Case Study, we revisit the question of the estimation of F_{msy} for North Sea cod, but without explicit reference to temperature since the causal mechanism by which temperature can affect recruitment is not clearly defined. Figure 1 shows how F_{msy}, B_{msy} and MSY can be calculated for any given stock, using a combination of fitted stock-recruit, yield-per-recruit and SSB-per-recruit curves. The estimation proceeds as follows:

1. Draw a stock-recruit plot: that is, a curve illustrating the fitted relationship between recruitment R and spawning-stock biomass S. Denote this curve by $R = \mathbf{G}(S)$.
2. Draw a second plot, containing both yield-per-recruit and spawner-per-recruit curves. Denote these by $Y/R = \mathbf{H}(F)$ and $S/R = \mathbf{I}(F)$.
3. For any given F (say, F'), the corresponding point on the spawner-per-recruit curve is given by $S'/R' = \mathbf{I}(F')$.
4. Take the reciprocal, so that $R'/S' = 1/\mathbf{I}(F')$. This denotes the *slope* of a straight line on the stock-recruit plot, that passes through the origin and cuts the curve at $(S', \mathbf{G}(S')) = (S', R')$. Hence such a line on a stock-recruit plot does

not specify directly a particular fishing mortality rate, but the reciprocal of its slope does.

5. Iterate through multipliers $E_i \in [0.0, 2.0]$, and hence fishing mortalities (since $F_i = E_i \times F_{sq}$). For any E_i, $R_i / S_i = 1/\mathbf{I}(F_i) = 1/\mathbf{I}(E_i \times F_{sq})$. This is the slope of the line on the stock-recruit plot that intersects the stock-recruit curve at (S_i, R_i).
6. The yield-pre-recruit curve is written as $Y/R = \mathbf{H}(F)$. From this we can obtain yield $Y = R \times \mathbf{H}(F)$. For a given E_i, $Y_i = R_i \times \mathbf{H}(F_i) = R_i \times \mathbf{H}(E_i \times F_{sq})$. Plotting these for all i gives the yield curve $Y = \mathbf{J}(F)$, for which we can obtain F_{msy} by maximising:

$$F_{msy} = F \text{ such that } \frac{dY}{dF} = 0.$$

7. Note that the same procedure can be carried out for spawning biomass, so we can plot yield Y against spawner biomass S to estimate at what biomass yield is maximised.

Figure 2 demonstrated the results of this process for a North Sea cod example. Here we have used data on SSB, recruitment, exploitation pattern and growth from ICES (2009). We have used a Ricker stock-recruit curve $R = \alpha S \exp(-\beta S)$, firstly because it has traditionally been used to generate recruitment forecasts for this stock, and secondly because the underlying assumption in the model of cannibalism is reasonable for cod. It is not necessarily the best-fitting of the available stock-recruit models.

The analysis reported in Figure 2 indicates that the best estimate of F_{msy} for this stock is around 0.53, corresponding to B_{msy} of 450 kt and MSY of 375 kt. These values seem high when compared with the current biomass estimate of around 70 kt, and the $F_{\max}$ value of around 0.33. However, it is clear that the results are contingent on the assumed stock-recruit model. In this case the model indicates increasing recruitment beyond the range of observed SSB. The curve does turn eventually, but the equilibrium point on which estimates of MSY are based is far to the right for many values of F and the result of this is high estimates of F_{msy}, B_{msy} and MSY. It would be instructive to repeat the analysis for a range of different stock-recruit models to determine how sensitive results are to the choice.

We can estimate confidence limits for F_{msy} as follows. We use the variance-covariance matrix of the fitted Ricker model parameters to generate a bivariate normal distribution. We sample the Ricker α and β parameters from this distribution, which therefore maintain their correct variance and covariance characteristics. The sampled parameters generate a new stock-recruit curve, which in turn generates a new estimate of F_{msy} (and related quantities). Repeating this process 1000 times (for example) produces a distribution of F_{msy} from which 90% confidence intervals can be produced. We can also generate retrospective estimates of F_{msy} by repeating the process with the final year of the input data removed each time. Figure 3 summaries these two calculations for F_{msy}, giving a time-series of retrospectively-estimated F_{msy} values each with a 90% confidence interval. From the Figure, we can conclude for North Sea cod (given due caveats about sensitivity to stock-recruit models) that:

- F_{msy} has changed through time, from around 0.8 in the late 1980s to under 0.6 currently. This is a direct consequence of changing recruitment model fits, growth curves and exploitation patterns, without explicit recourse to an explicit environmental driver.
- F_{msy} is consistently much higher than the value commonly cited as a good proxy $(F_{0.1})$.
- F_{msy} is consistently lower than the historical estimate of *F*.

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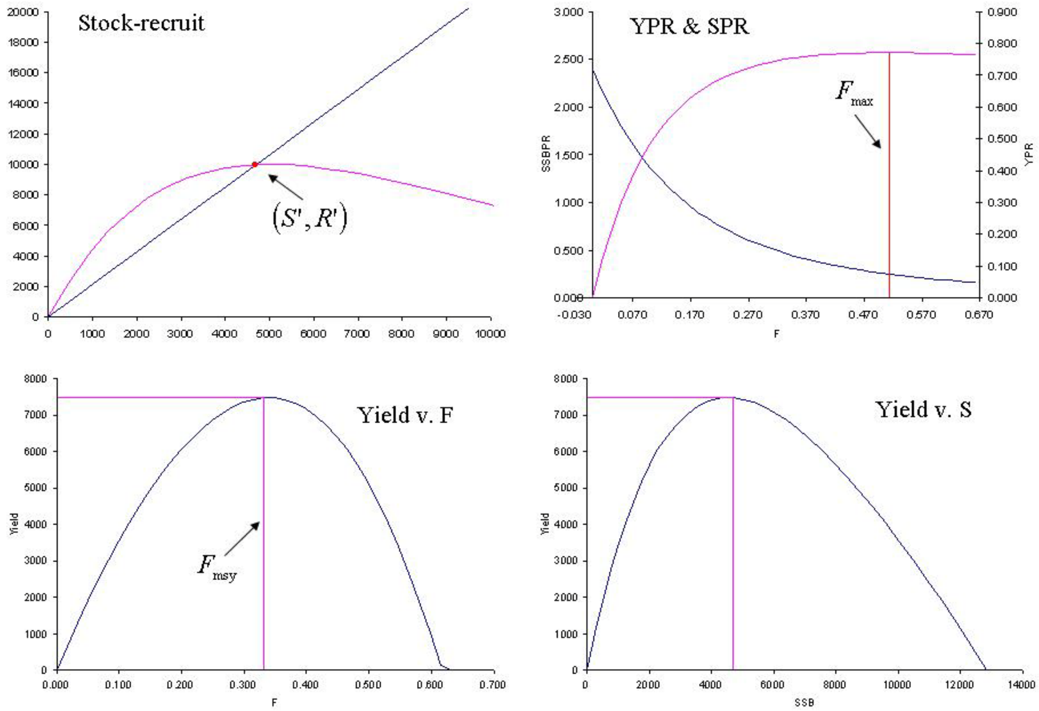

Figure 1: Graphs illustrating the estimation of F(msy), B(msy) and MSY.

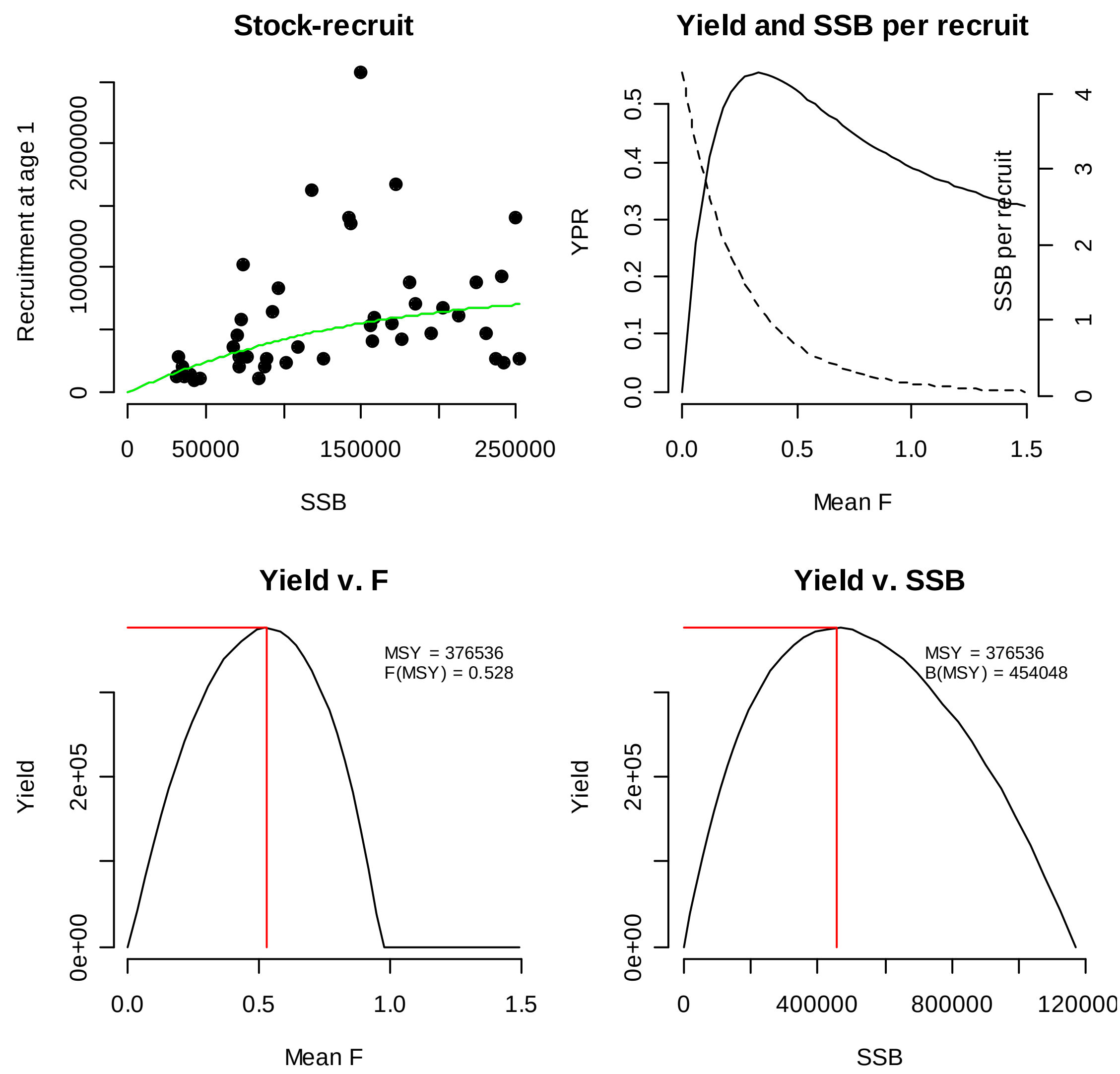

Figure 2: North Sea cod. Top left stock recruitment relationship and Ricker model fit. Top right, yield and SSB per recruit calculation. Bottom left, yield against F showing MSY (red line): F(msy) = 0.528. Bottom right, yield against SSB, showing MSY (red line): B(msy) = 454 048 t. MSY = 376 536 t.

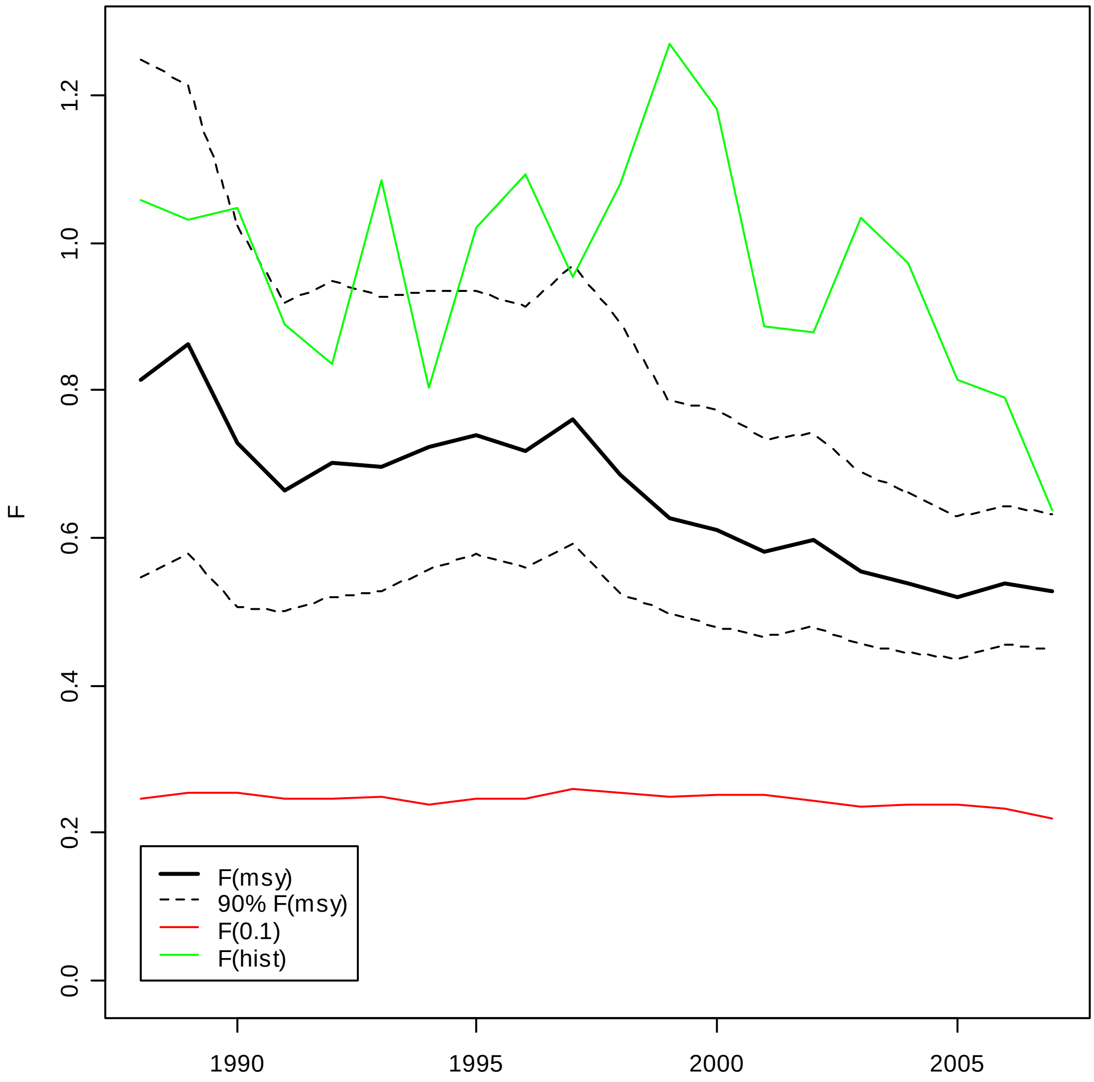

Figure 3: Retrospective calculations of F(msy) (with 90% confidence bounds), and F(0.1). The historical value as estimated by WGNSSK (ICES 2009) is also shown for comparison.

4.6 Case study 6-Jan Jaap Poos, Clara Ulrich, Alexander Kempf

Reference points for plaice and sole in the North Sea

Plaice

In 2005, the ICES ad hoc Group on Long Term Advice (AGLTA; ICES CM 2005/ACFM:25) concluded that "If the objective is to obtain a high long term yield in combination with a low risk to Blim, the preferred level of human consumption fishing mortality could be in the area of F_t=0.2 to F_t=0.3.". The EU long term management plan states that "The Scientific, Technical and Economic Committee for Fisheries (STECF) has advised that the precautionary biomass for the stock of plaice in the North Sea should be 230 000 tonnes, that the fishing mortality rate necessary to produce the highest yield from the stock of plaice in the North Sea in the long term is 0.3"

Using FLBRP package 1.0.0, in R version 2.10.1, an analysis of the yield per recruit reference points analysis with selectivity, natural mortality, and weight data taken to be the average of the observations and assumptions of the last five years (2004-2008) indicates that the Fmax is at 0.18, and reasonably well defined (Table 1 & Figure 1).

Table 1: Results from YPR analysis plaice in area IV.

YPR reference point	Fishing mortality (ages 2-6)
f0.1	0.13
fmax	0.18
spr.30	0.17

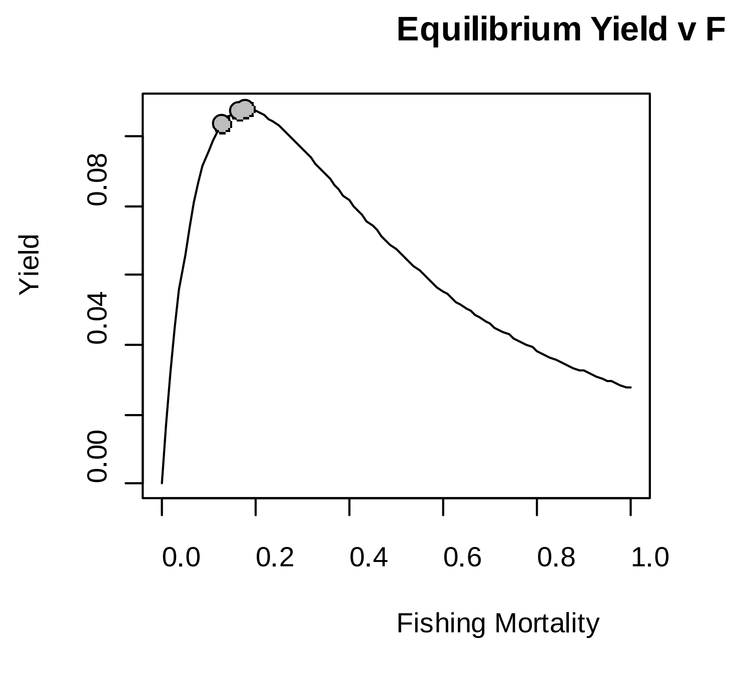

Figure 1: Results from YPR analysis plaice in area IV.

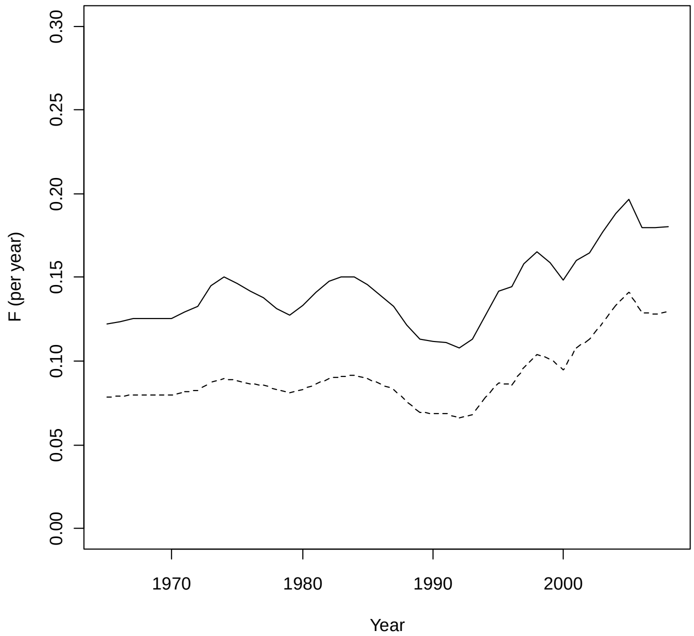

Figure 2: Times series for F_{max} (---) and $F_{0.1}$ (- - -) from YPR analysis for plaice in area IV.

The historic recruitment series does not indicate a very strong effect of spawning stock biomass on recruitment in the observed ranges. When estimating a segmented regression S/R relation using FLCore 3.0, no breakpoint is found within the observed biomass range (Figure 3). As a result the breakpoint is put at the lowest SSB estimate in the time series. A Ricker S/R model shows a dome shape with a very flat top, the maximum being within the range of SSB estimates (Figure 4). A Shepherd curve shows a very similar very flat topped dome (Figure 5). Because there are no SSB and recruitment estimates closer to the origin of the curve, there is no information in these data on the steepness of the curve in the origin. A Beverton and Holt curve was fitted to the data showed an extremely steep origin, and a flat curve at the asymptote through all observations. However there appears to be no information in the data from the assessment that provides information on the actual slope in the origin.

One feature that all fits share is that there are positive residuals in the 1980s. This indicates that there was strong recruitment in those years that is not explained by the stock-recruitment relation.

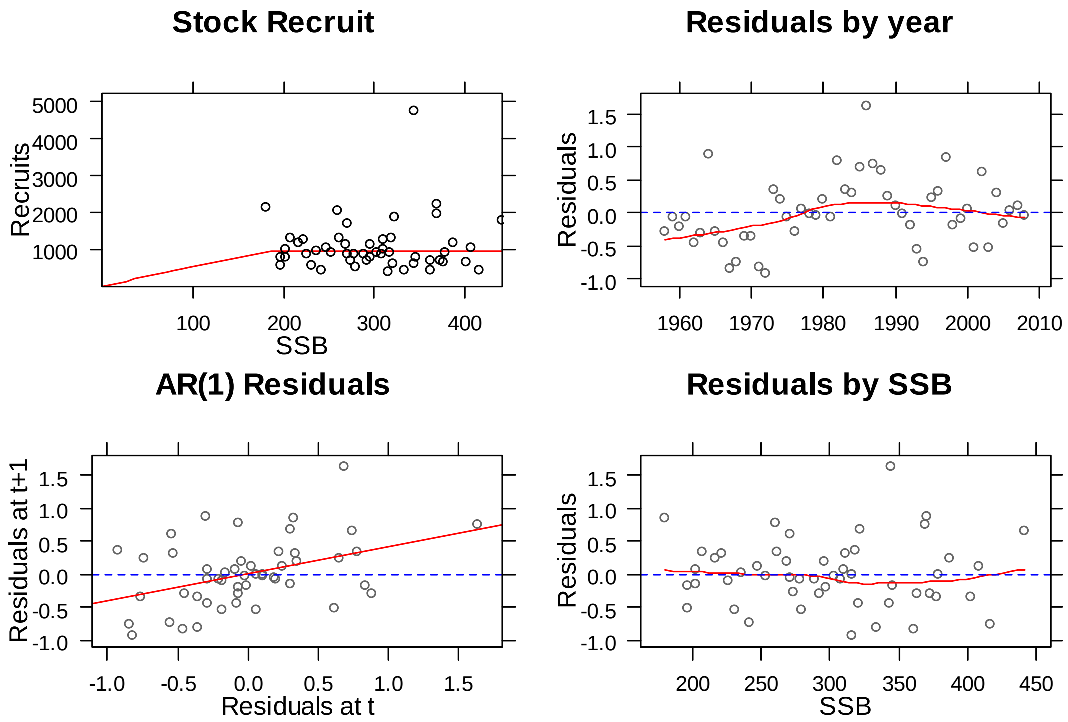

Figure 3: S/R analysis using a segmented regression model for plaice in area IV. Note that SSB is in 10E3 tons, and recruits are in 10E6.

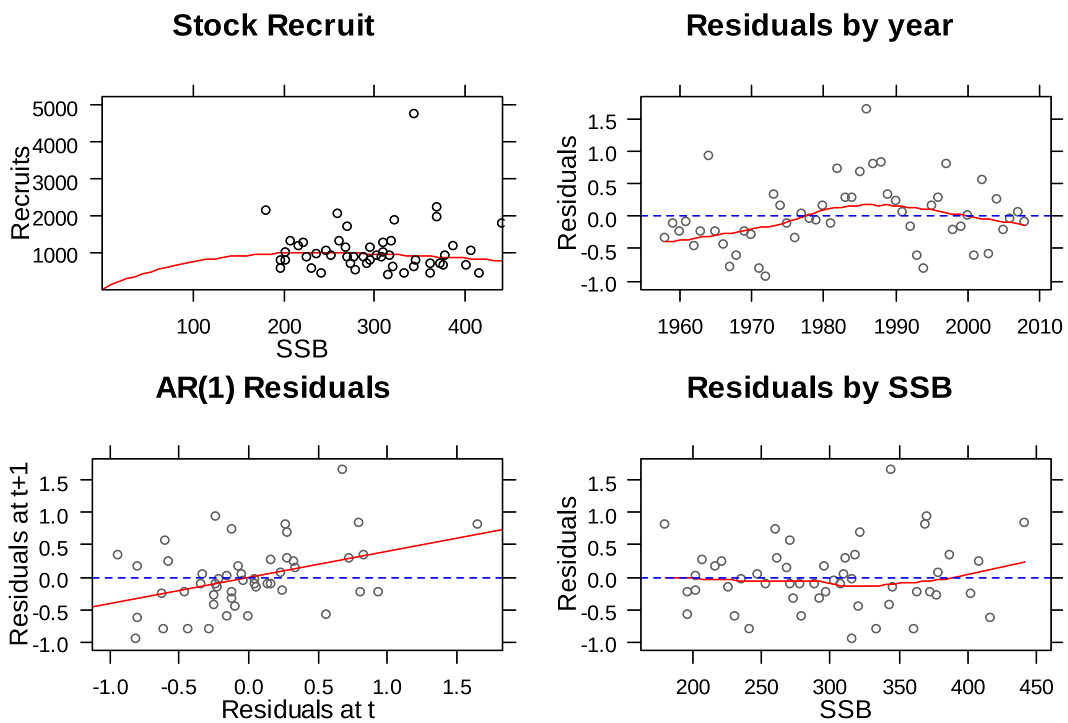

Figure 4: S/R analysis using a Ricker regression model for plaice in area IV. Note that SSB is in 10E3 tons, and recruits are in 10E6.

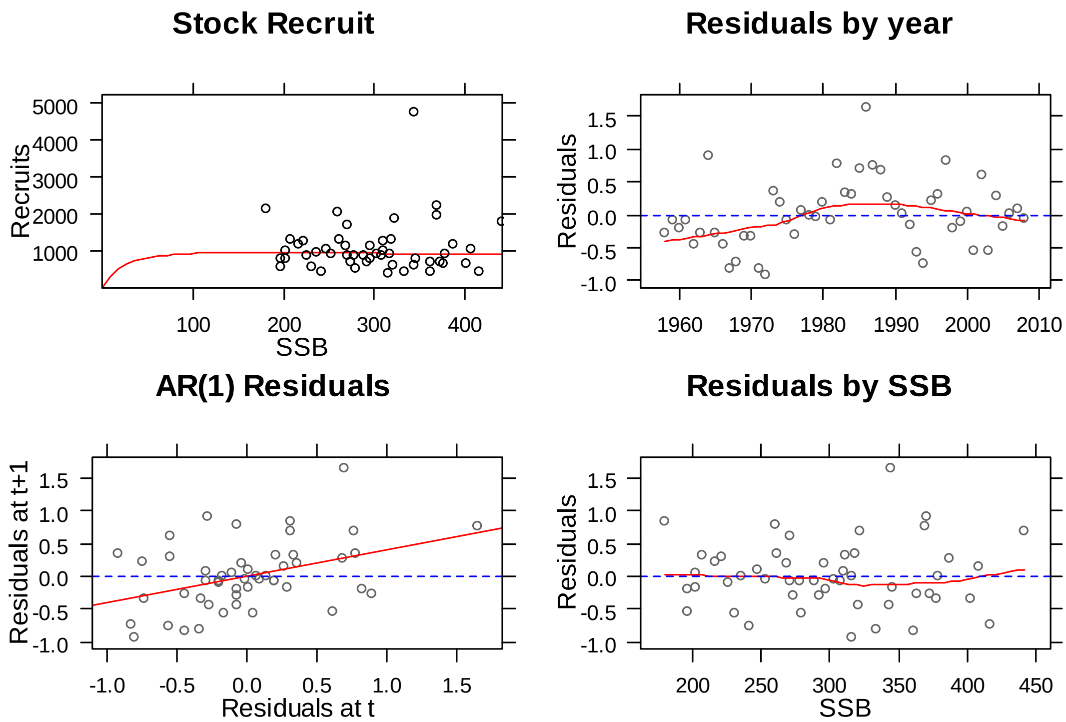

Figure 5: S/R analysis using a Shepherd regression model for plaice in area IV. Note that SSB is in 10E3 tons, and recruits are in 10E6.

When using the segmented regression to estimate a Yield curve from the YPR and S/R data (Figure 6). The F_{msy} estimate is at the deterministic F_{max} (0.18 year^{-1}) estimate, simply because in the region of F_{max}, the S/R curve is completely flat. However, the historic estimates of F, SSB, and yield show little correspondence to the equilibrium Y/R curve. The equilibrium SSB is far outside of the range of SSBs observed during the last 60 years for this stock.

The F_{msy} estimate is quite far from the F_{crash} estimate. It should be noted that this F_{crash} estimate depends entirely on the assumption for the breakpoint in the S/R relation, for which there is no information available in the assessment data.

To show the sensitivity of the deterministic F_{msy} estimate from the YPR and S/R on the assumptions on the S/R curve, an estimate using a Ricker curve is presented in Figure 7. Here, F_{msy} is estimated at 0.36, and F_{crash} is estimated at approximately 0.8 year^{-1}.

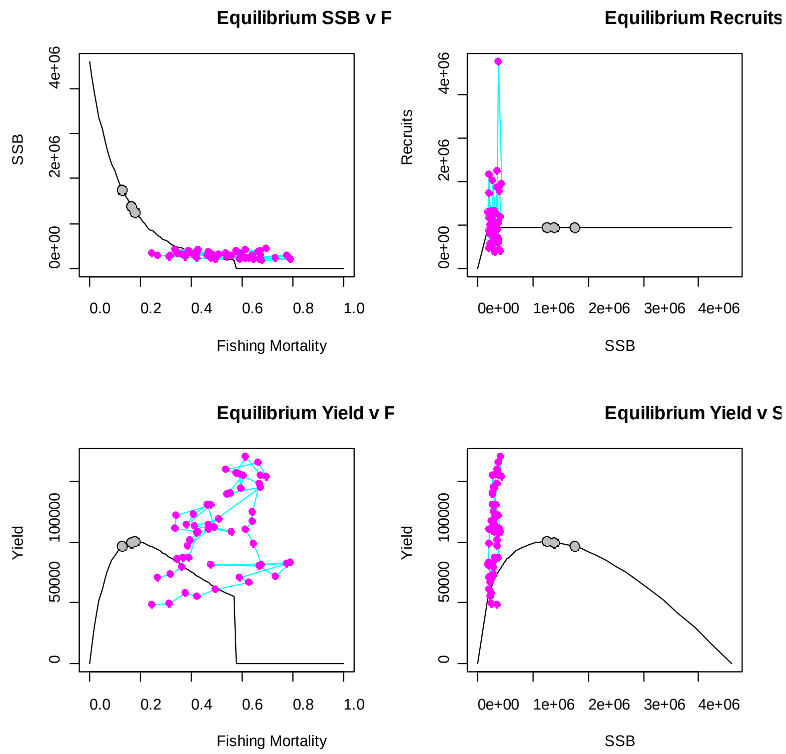

Figure 6: Results from equilibrium yield curve analysis for plaice in area IV, based on a segmented regression S/R curve.

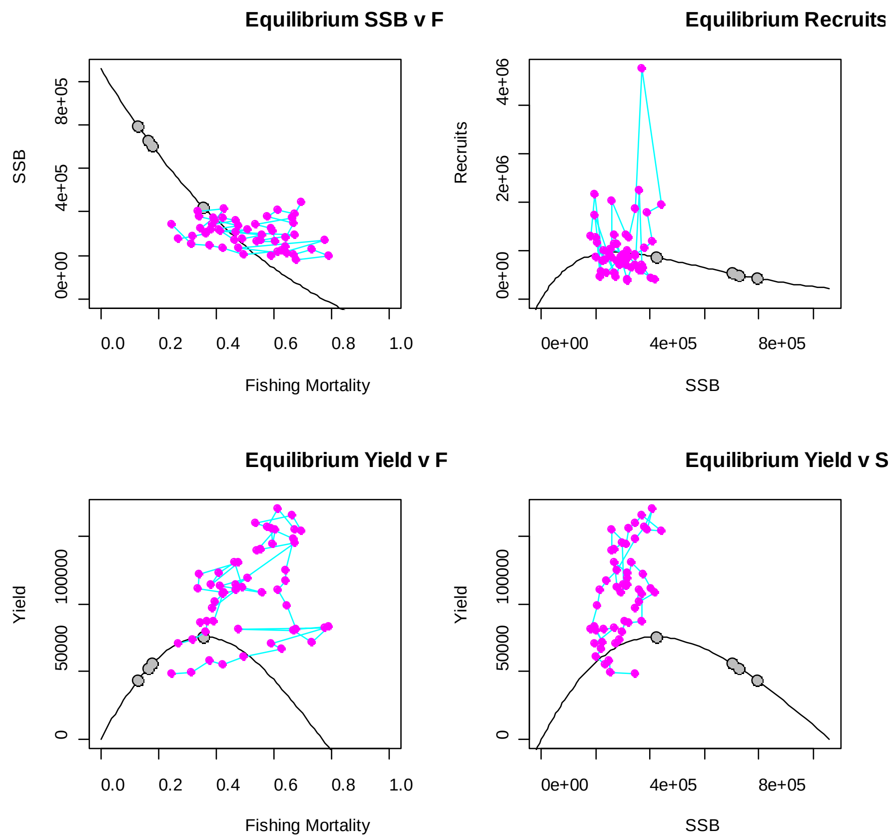

Figure 7: Results from equilibrium yield curve analysis for plaice in area IV, based on a Ricker S/R curve.

To show some of the sensitivity of the F_{msy} estimates to the input parameters coming from the stock assessment, a preliminary bootstrap analysis can be applied to plaice. Before doing so, the analysis was first adapted to use the landings rather than the catches as yield. Here we use the segmented regression S/R curve.

In the analysis, the selection, maturity and weight, and S/R data between 2003 and 2008 was bootstrapped, and for each of the bootstrapped values, the population was projected forward 100 years.

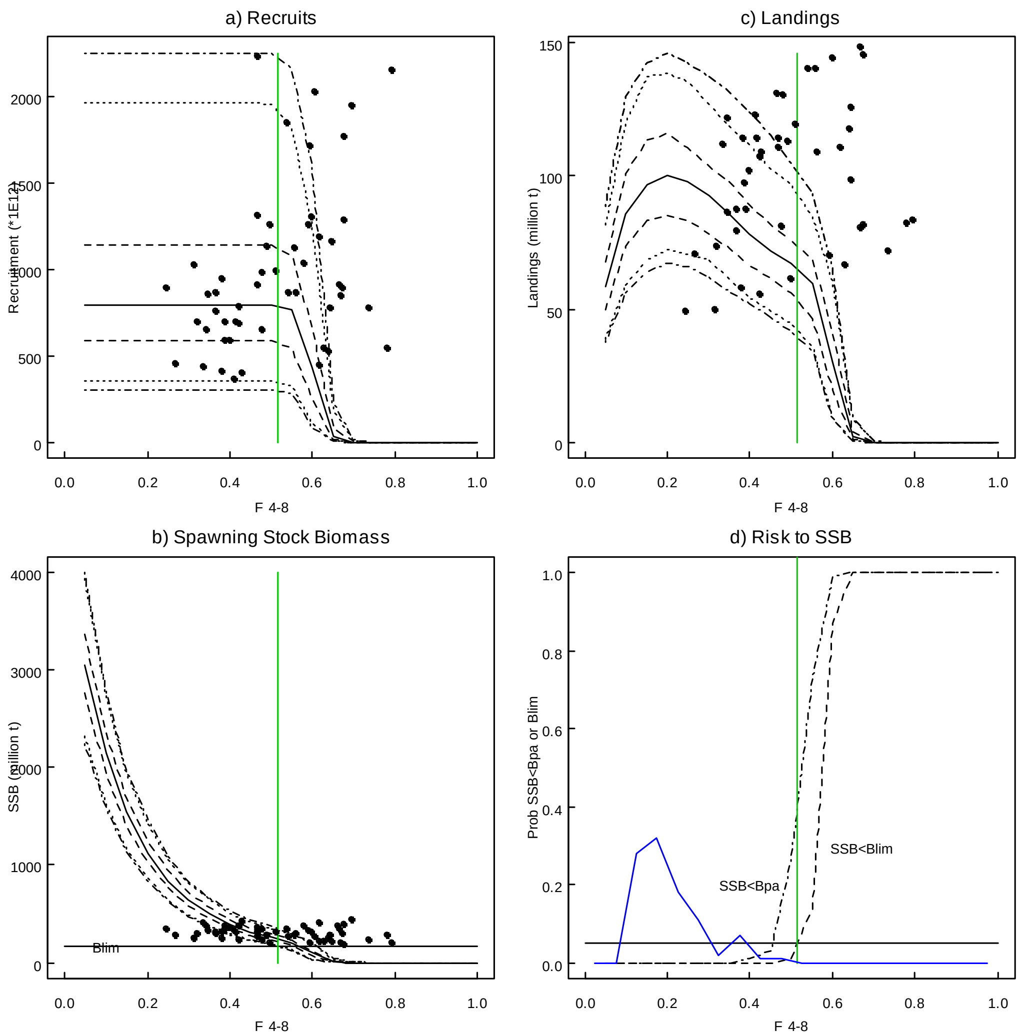

Figure 8: Results from bootstrap yield curve analysis for plaice in area IV, based on a Segmented regression S/R curve. The different black lines indicate the 0.025, 0.05, 0.25, 0.5, 0.75, 0.95, and 0.975 quantiles. In the bottom right corner, the two black dashed lines indicate the probability of falling below B_{pa} or B_{lim} The black horizontal line in the bottom left panel indicates the B_{lim} value for this stock. The black horizontal line indicates 0.05%. The green line indicated the F value where the probability of falling below B_{lim} = 5%. The black dots indicate the historic assessment outcomes. Finally, the blue line in the bottom right panel indicates the bootstrapped distribution for the F_{msy} estimate.

The bootstrapped Fmsy values range between 0.125 and 0.475 year^{-1}, the mode being at 0.175

Sole

The EU long term management plan states that “Advice from a committee of experts examining multiannual management strategies indicates that the highest yield of sole can be taken at a fishing mortality rate of 0,2 on ages two to six years.”

Using FLBRP package 1.0.0, in R version 2.10.1, an analysis of the yield per recruit reference points analysis with selectivity, natural mortality, and weight data taken to be the average of the observations and assumptions of the last five years (2004-2008) indicates that the F_{max} is at 0.59, but is poorly defined with a very flat top in the VPR curve (Table 2 & Figure 9).

Table 2: Results from YPR analysis plaice in area IV.

YPR reference point	Fishing mortality (ages 2-6)
f0.1	0.11
fmax	0.59
spr.30	0.14

The estimate of F_{msy} has changed from approximately 0.25 in the period up to 1995 to approximately 0.5 in the most recent years (Figure 10). $F_{0.1}$ has been stable throughout the entire time period for which assessment estimates are available, at approximately 0.1.

The historic recruitment series does not indicate a very strong effect of spawning stock biomass on recruitment in the observed ranges. When estimating a segmented regression S/R relation using FLCore 3.0, no breakpoint is found within the observed biomass range (Figure 11). As a result the breakpoint is put at the lowest SSB estimate in the time series. A Ricker S/R model shows a dome shape, the maximum being within the range of SSB estimates (Figure 4). Because there are no SSB and recruitment estimates closer to the origin of the curve, there is no information in these data on the steepness of the curve in the origin. A Beverton and Holt curve was fitted to the data showed an extremely steep origin, and a flat curve at the asymptote through all observations. However there appears to be no information in the data from the assessment that provides information on the actual slope in the origin.

One feature that all fits share is that there are positive residuals in the 1980s. This indicates that there was strong recruitment in those years that is not explained by the stock-recruitment relation.

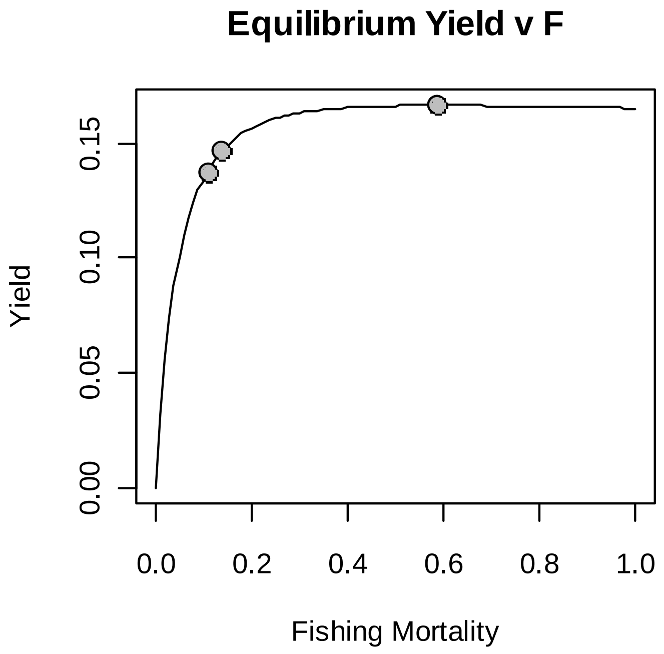

Figure 9: Results from YPR analysis sole in area IV.

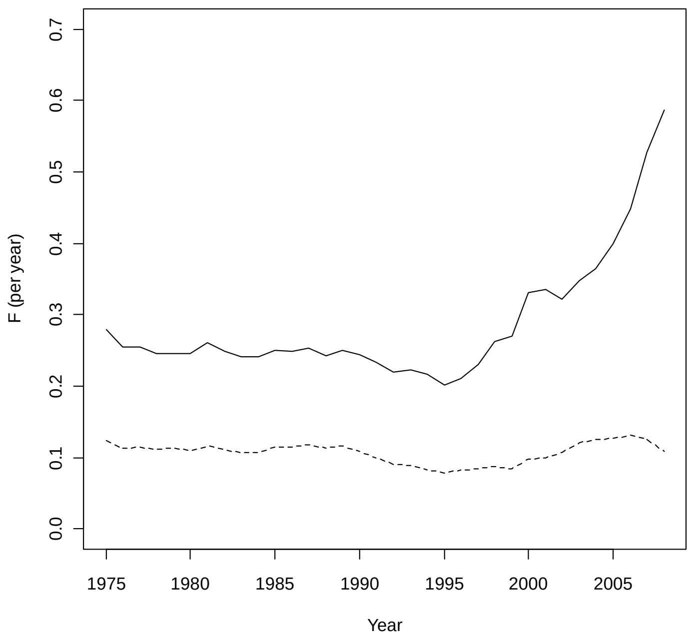

Figure 10: Times series for F_{max} (---) and $F_{0.1}$ (- - -) from YPR analysis for sole in area IV.

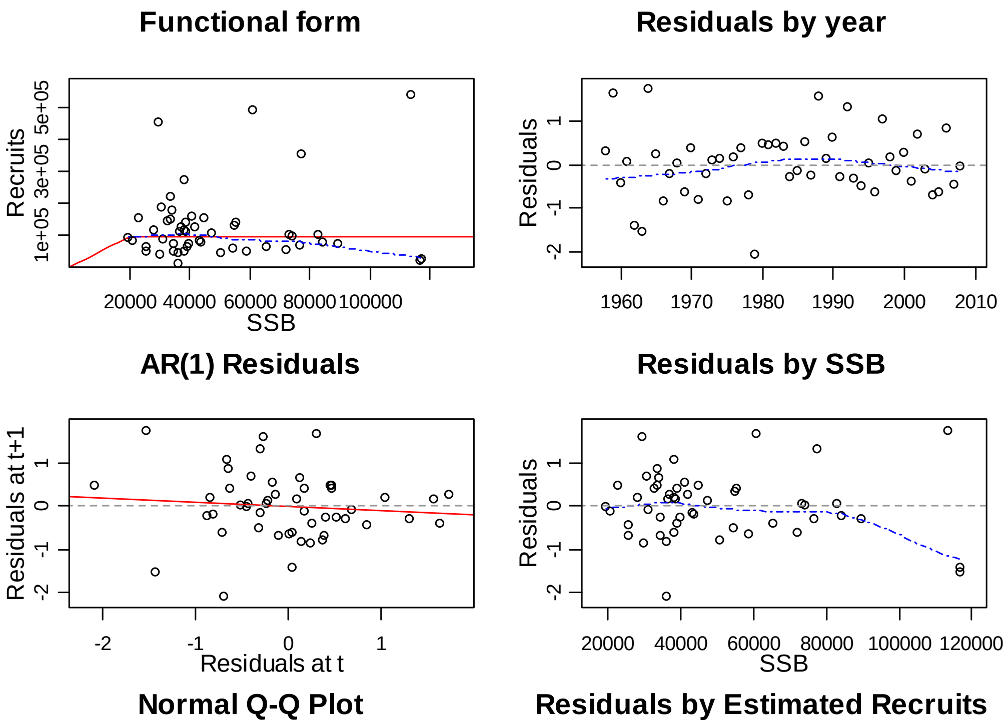

Figure 11: S/R analysis using a segmented regression model for sole in area IV.

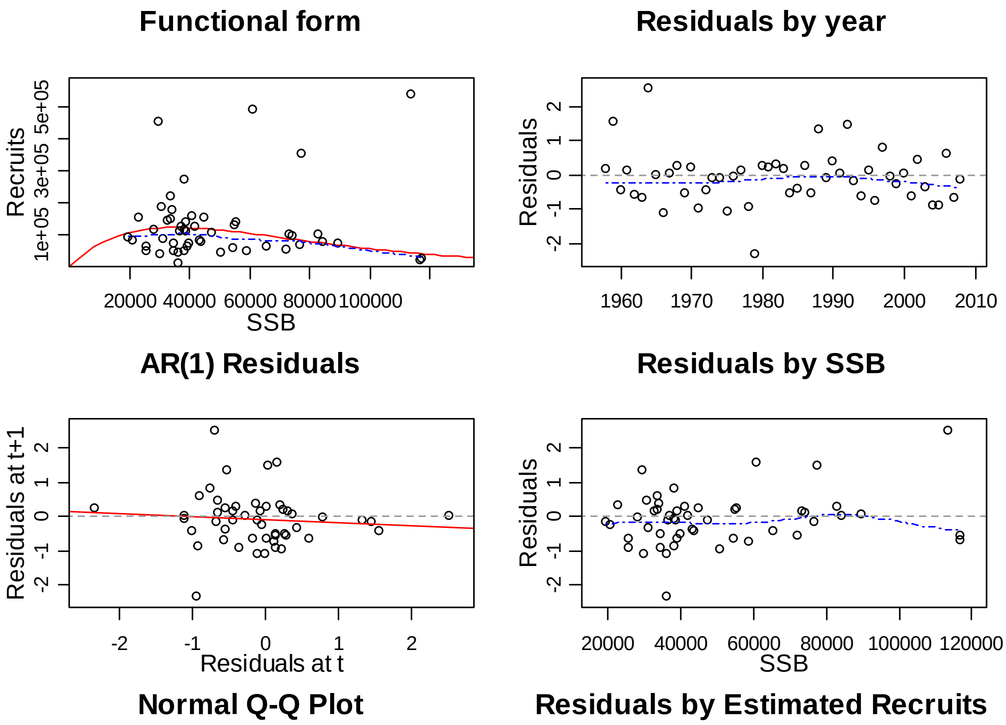

Figure 12: S/R analysis using a Ricker model for sole in area IV

When using the segmented regression to estimate a Yield curve from the YPR and S/R data (Figure 13), the F_{msy} estimate is close to the deterministic F_{max} (0.59 year^{-1}). However, the F_{msy} estimate is very close to the F_{crash} estimate. It should be noted that this F_{crash} estimate depends entirely on the assumption for the breakpoint in the S/R relation, for which there is no information available in the assessment data.

The historic estimates of F, SSB, and yield show little correspondence to the equilibrium Y/R curve. The equilibrium SSB is far outside of the range of SSBs observed during the last 60 years for this stock. One of the reasons for this is probably that the equilibrium analysis here estimates the yield curve based on the average recruitment, while the historic estimates stem also from the period when recruitment was high in the 1980s

To show the sensitivity of the deterministic F_{msy} estimate from the YPR and S/R on the assumptions on the S/R curve, an estimate using a Ricker curve is presented in Figure 14. Here, F_{msy} is estimated at 0.51, and F_{crash} is estimated to be higher than 1.0 year^{-1}.

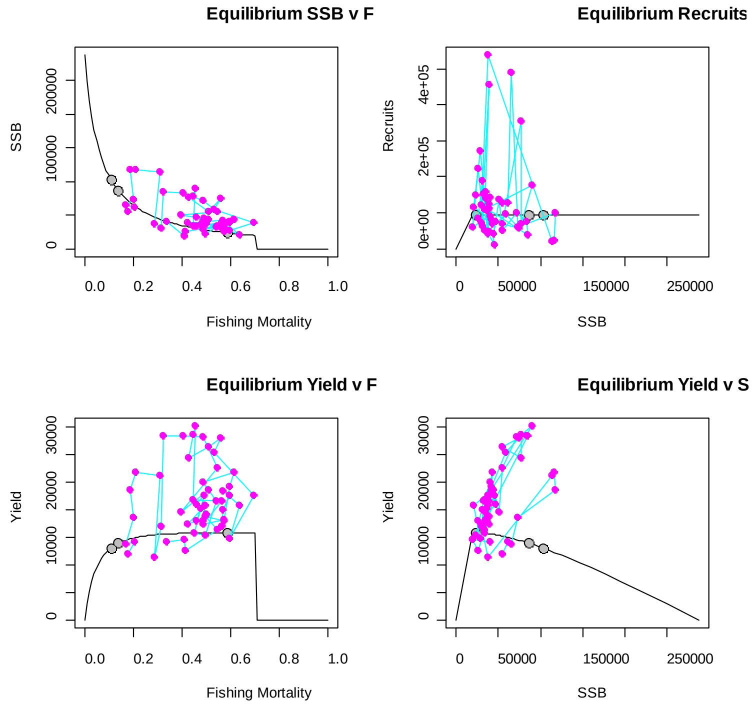

Figure 13: Results from equilibrium yield curve analysis sole in area IV, based on a segmented regression S/R curve.

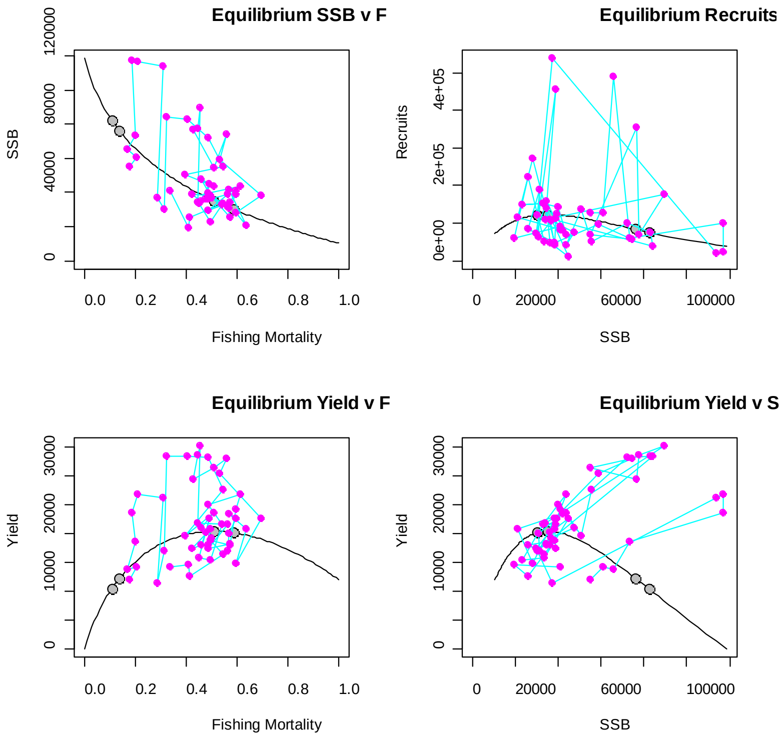

Figure 14: Results from equilibrium yield curve analysis sole in area IV, based on a Ricker S/R curve.

Annex 1: Bulleted Guidelines

General considerations

- Before any data is used in an exploration, an evaluation of the quality of this information should be made
- categorical decision could be taken on the utility of the data, or a weighting of the data based on quality could be considered
- any data which on which the advice is based should be identified in the stock annex
- a stock annex should exist whether there is an analytical assessment or not

Data limited (i.e. no age structure)

- Where no progress can be made on reference points from a YPR analysis, EG's should concentrate on what measurable metrics are possible
- basic data on species productivity (fecundity, natural mortality etc which may be by inference) coupled with susceptibility to fishing could be used to inform a vulnerability analysis
- Where there are indications of low productivity, there will be an effect on the time period for recovery, and this need to be taken into account
- evaluate the information on those species you can, if it is reasonable to assume that these are representative of others of which you have limited/no information
- Where catch data reflect initial high catches followed by a decline, a method called depletion corrected average catch (DCAC) can be used
- a production model, or better still a biomass dynamic model e.g. ASPIC (where there is no equilibrium assumption) may be applicable

With age or length structure data

- YPR requires age structured data which can come from an assessment output (doesn't have to be "an accepted assessment"), or even from population length frequency data with assumptions or estimates of growth (k, t0 Linf), selection (age at first capture, fit with a selection function) and maturity (length at 50% maturity with a fitted maturity ogive).
- Weights at age & maturities change with time and are affected by density dependence. If a time series is available, choose a recent year average option to cope with any detectable trends, or use longest year averages where no changes are observed. The objective is a sufficient year range to smooth out short term noise or measurement error but short enough to take account of contemporary trends.
- With regard to the selection pattern, where limited data are available, try to estimate an Lc50 and then an assumed oldest age, an ogive can be fitted. If a time series of F estimates are available from an assessment and there is stability in the selection pattern, then a sufficient year range can be used to smooth out short term noise or measurement error but short enough to take account of contemporary trends. If the relative Fs are changing significantly, you should investigate if this is driven by real changes in fishery selection - which could potentially caused by variation in discard patterns over time. A selection pattern needs to be used in the YPR and the result-

ing curve is sensitive to the vector used. So the pattern used should reflect the contemporary situation.

- Another consideration is if fishery regulations are expected to change selection, if so the sensitivity to of the YPR to putative changes in selection should be examined. YPR analysis based on assessments which use only landings but from stocks with significant discards will give an F_{MSY} target that may be too high.
- The choice of Yield as catches or landings is a matter for policy: if Yield is considered to be that which is removed from the stock F_{msy} should be based on maximising catch; if Yield is considered to be the utilised component from the stock, the amount contributing to economic or social benefit, then Yield should be taken as landings and F_{msy} calculated accordingly to maximise the landings.
- For the assessments based only on landings the EG should compare F_{msy} values for landings and catch for other fisheries on the same species where discard data is available and compare these to the F_{msy} landings based values The EG could then modify or comment on the appropriateness of the calculated values accordingly.
- The default approach here is to assume that the exploitation in the fishery is that that you wish to continue with. However just because the YPR may have a well defined maximum, such a shape to the YPR may be as a result of a suboptimal exploitation pattern taking fish at a small size, there are other plausible alternatives based on different selection which would give different F_{msy} targets and approaches other than a single stock basis, could be considered in context of multi species fisheries (MEY)
- The YPR is sensitive to the natural mortality, so a sensitivity analysis should be done across a range of plausible values. What is important to establish here is the amount by which you have to move F between the assessed F and the target. If this value is affected then the basis for the M value used requires some justification.
- $F_{0.1}$ can be determined from YPR and there may or may not be a well defined peak in the YPR to define F_{max}. If there is clear peak at low F in the YPR analysis, and there is no evidence of recruitment dependence on biomass, then a check should be made that the equilibrium biomass implied by this target F is within the observed range of SSB, under this condition F_{max} may be appropriate. Where F_{max} is undefined and equilibrium biomass at $F_{0.1}$ lies within the historic range of SSB $F_{0.1}$ might be considered as a 'lower bound' to the range of F suitable for F_{msy}, as it is assumed to be low risk. However, this does not take into account any curvature in the S/R function near that SSB[3] , thus it is preferable to carry out a risk analysis including the S/R function
- The YPR function may not be stable over time especially with regard to F_{max} and $F_{0.1}$, in such circumstances there needs to be further examination of the time series to determine if either of these points could be suitable candidate for a long term reference point. If there is a justification for a change in productivity, the S/R pairs should reflect the productivity regime

[3] "that SSB" refers to the SSB realised under equilibrium conditions of fishing at $F_{0.1}$

to which the F_{msy} target would apply, this may necessitate truncating the time series

- Spawner biomass per recruit analysis should be routinely evaluated in addition to YPR. There is not a single level of % SPR that is optimal for all stocks and the proposal for F_{msy} should include some consideration of life history. Further studies by Clark (1991, 1993) concluded that F35% and higher were robust proxies for F_{msy}, considering uncertainty in stock-recruitment functions and or recruitment variability. This value may be a useful guide for the ICES stocks. Spawner per recruit curves should be provided in all cases, particularly if stock-recruitment data is non-informative, or in cases when the range of historic data for spawning biomass covers only a period of high exploitation

Where there is data to fit a stock recruit relationship

- the process of trying to find an appropriate F_{msy} estimate should be based on raising the yield per recruit analysis to a stock recruit relationship
- The fit to the Stock Recruit Relationship requires analysis (i.e. you should not assume a relationship and fit without circumspection). The things you need to look at are time variability (i.e. the robustness of the fit over time), as well as the precision of S/R coefficients. You could chose default function based on some statistical criteria for a measure of fit (e.g. AICc ,BICc), but the fit needs to have biological plausibility[4]. For example if the maximum in a dome shaped model is way out of the range of the observed biomass, there may be a problem. Alternatively Bayesian methods may help by using informed priors on the model parameters. As a simple alternative a Hockey stick (restricted to a recent period that you consider relevant to the contemporary productivity) can be used.
- Where there is a potential conflict between risk to productivity and confidence in the estimates of F_{msy}, a greater understanding of the implications of fishing at the putative target F can be obtained by stochastic simulation. Such simulations can incorporate biological uncertainty in S/R, growth and maturation and in the fishery through variability in selection. Measurement error should not be included at this point, i.e. you should use a fixed F and introduce variability in the biological parameters. From the simulation output you can get a distribution of SSB values which should give the range of expected stock size when fishing under the F_{msy} estimate. Examining the distribution of this SSB relative to the observed historical range, should help to identify problems. The distribution of SSB estimates as a function of F, can be compared with B_{pa} and B_{lim}, to examine the risk to recruitment impairment.
- There are many input specifications which need to be carefully considered when doing a simulation, in this regard the guidelines in SGMAS 2008 report are a useful reference.

[4] What is meant by biological plausibility is not simply the observed range of stock biomass, as this may reflect a long history of an over exploited stock.

Btrigger

- $B_{trigger}$ should be selected as a biomass that is encountered with low probability if F_{msy} is implemented. The selection of the $B_{trigger}$ is likely to be an iterative process. If F_{msy} is chosen correctly and implemented then the probability of encountering B_{lim} should be very low. If the SSB is below this level it is (by definition) out of expected range, and thus a suitable trigger to initiate action. In addition to this, the appropriate trigger should include implementation error. Although B_{pa} is proposed as a default trigger biomass in the ICES MSY framework, it is not a logical candidate in the long term as it is based on an error model basis around B_{lim}.

The role of estimation or implementation error of an Fmsy target

- Where possible it is recommended that assessment and implementation errors be estimated from history (possibly from the ICES quality sheets) and explicitly included in the analysis. It is important that the approach used to include (or not) error distributions is explicitly addressed in the EG report and the influence of this on proposed Fmsy values included with the analysis.

Translating reference points and stock status into advice where the re is no forecast

- While you may be able to use Y/R and SSB/R analyses to propose a proxy F_{MSY} reference point, without an accepted assessment and forecast, they will be no direct translation of the target F into quantitative advice. The approach therefore should be the generation of advice (in relation to the putative targets) which is aimed at moving F towards the target, rather than specifying a harvest in relation to the current stock status and expected development of the stock. The advice arising from these circumstances has to be seen in the context of a "soft" evaluation of stock status relative to crudely estimated proxies
- There needs to be a consideration of the spatial and temporal history of the fishery.
- A broad range of metrics should be monitored as a guidance for a change in exploitation (catches, Effort etc, or an exploitation metric e.g. catch/survey cpue
- It is necessary to establish the range of indicator values and trends to be expected with a fishing mortality near a putative target at a proxy for F_{MSY}. Such information can be gleaned from;Catch curves analysis, Length and/or age distributions relative to equilibrium conditions, CPUE from the whole or segments of the fleet, Survey indicators, Area distributions, Environmental drivers.
- For all the above, some insight of how indicators relate to the stock abundance and /or exploitation level is needed. This includes the relationship (which can be a continuous functional relation or semi quantitative -good, medium, poor), as well as the strength of the link - i.e. variance of error terms. This approach can be formalised with statistical process control
- Simulations can be done on a relative level, This will give a range (at least in relative terms) of indicator values, and trends in indicator values, and in addition demonstrate how quickly the population measures may be expected to change, at the proxy F_{MSY} (derived from Yield/recruit analysis).

This range should give some guidance to when and how much to change TAC advice.

- Some points to consider for these kind of simulations are: Occasional large year classes may disrupt indicators, though he dynamic response of the stock to a large year class can be outlined through simulations. Growth and maturation parameters will be corrupted if the ageing is wrong. This may be a quite severe problem for some stocks. Without ages, length or staged based methods (stock synthesis, flexibest, gadget, collie-sissenwine etc) may be of some utility where they are considered robust. Stocks with a developing fishery require special consideration.
- Stock reduction analyses (i.e. modified DeLury method) can be used on catch data and abundance indices to infer stock sizes that would have given rise to the catches given the observed changes in abundance. From this you can work back to reference points. However there is no "magic bullet" here, in terms of insight to either stock productivity, or current stock status. It can however, with an appropriate time series, provide some insight into how recruitment and stock size may have changed over time in response to the catches. A good example of a stochastic implementation of this method is given in Walters et al (2006).
- Handling of stocks with limited data will often require strong assumptions. Common sense instead of over interpreting should help to avoid some stumbling blocks. Careful consideration of the impact of assumptions (that have to be made) e.g. sensitivity analyses, is always necessary

Documentation process

- Any information used for the estimation of Fmsy should be clearly documented, this should be at least in the WG report, but should ultimately end up in the stock annex. This information includes the methodology as well as the data.
- There needs to be an explicit statement of the assumptions used as part of the documentation process.

Available software

- Routines for exploring SRR's (with fit diagnostics), raising the YPR estimates to a SRR, and simulating the stock with error are available at various levels of completion. In most cases these routines were developed specifically for this meeting, and require further error checking. As a process ICES should have some involvement with warehousing and providing a point of access to this code.
- Code, manuals and references to other software is available in the software folder of WKFRAME sharepoint http://groupnet.ices.dk/WKFRAME2010/Software/Forms/AllItems.aspx

Diagnostic plots

- $F_{0.1}$, F_{max}, F35%SPR, and Current F, and maybe lines to indicate the relative position of Flim and F_{pa} and the replacement lines from the SR could be useful in the discussion about suitable proxies. Include information on SSB and Yield on this plot too.

- Wherever an F_{msy} estimate is proposed it may be useful to consider this in the context of other reference points (F_{lim} F_{pa}). Although the SSB MSY is not well determined, it may be useful to provide a distribution of the equilibrium SSB at the target from a simulation, with some lines indicating some lower fractile of the distribution as a putative $B_{tritgger}$, and the relative position of B_{lim}, B_{pa}.

Further considerations

The role of management plans in relation to the MSY objectives, is being discussed between ICES and its clients. A broader range of performance criteria may be expected for the evaluation of management plans in relation to the MSY objective. In order to decide on some of these criteria there needs to be a continuing dialogue with managers and stakeholders. Notwithstanding this, the distribution of average Fs implied by the MP and the F_{msy} target should be very similar.

Multi species considerations

- The F_{MSY} of a prey species depends on the status of the predator stocks
- The high yields predicted at low F by single-species models are almost certainly unrealistic
- Multi-species models indicate that the MSY is achieved at different fishing mortalities compared with single-species approaches
- It is impossible to attain the high yields predicted by single-species models for all stocks simultaneously, because achieving BMSY for one species may result in stock declines for other species that are prey and/or competitors.
- System-wide analyses suggest that the optimum strategy to maximize yield (harvested biomass) usually involves the depletion of top predators
- Management objectives need to be specified clearly, this has not been done so far in a multispecies context
- Predators might provide other ‘services’ in ecosystems
- Adopting a single species MSY approach implies changes in Biomass in most of the ICES areas. Currently we cannot identify which part of these changes are compatible or not with one another.
- However, single species MSY targets are considered to be the best option for the way forward. In this context it is important to maintain a close watch on species interactions and to account where possible for the responses of different species when considering long term targets

Annex 2: List of Participants

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Annex 3: Agenda

Monday 22nd March, All afternoon at EEA

14:00 Introduction & welcome

15:00 ToR's discussion & Report structure

16:00 Coffee

16:20 Presentations BM, DS, JS

17:45 Summary of Day 1 – any issues arising

18:00 Close

Tuesday 23rd March (at ICES)

Group 1 for data situations with at least an age structure; Subgroup chair John Simmonds

Group 2 for data situations with no age structure; Subgroup chair Mauricio Ortiz

09:00 Breakout group 1 North Sea room

Breakout group 2 Kattegat room

10:30 Coffee

11:00 Breakout group 1 North Sea room

Breakout group 2 Kattegat room

13:00 Lunch

14:00 Breakout group 1 North Sea room

Breakout group 2 Kattegat room

16:00 Presentation from Rick Methot via webex at North Sea room ICES followed by discussion

17:30 Summary of Day 2 – any issues arising

18:00 Close

Wednesday 24th March (at EEA)

09:00 Recap on day 2

10:30 Coffee

11:00 Case study work groups

13:00 Lunch

14:00 Case study work groups

16:00 Coffee

16:30 Report back from case study work groups

18:00 Close

Thursday 25th March (at EEA)

09:00 Recap on day 3

10:30 Coffee

11:00 Case study work groups

13:00 Lunch

14:00 Case study work groups

16:00 Coffee

16:30 Report back from case study work groups

18:00 Close

Friday 26th March All morning at EEA

09:00 Plenary discussions on where we have got in relation to ToR's

10:30 Coffee

11:00 Plenary discussions on where we have got in relation to ToR's

13:00 Summary of progress & Outstanding issues

14:00 Close