Advisory Committee on Fishery Management **ICES CM 1997/Assess:15**

REPORT OF THE

COMPREHENSIVE FISHERY EVALUATION WORKING GROUP

ICES, Headquarters
25 June - 4 July 1997

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

1.1 Participants

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1.2 Terms of reference

It was decided at the 84th Annual Science Conference in 1996 (C. Res. 1995/2:14:14) that;

The **Comprehensive Fishery Evaluation Working Group** [WGCOMP] (Chairman: Dr G. Stefánsson, Iceland) will meet at ICES Headquarters from 25 June to 4 July 1997 to:

a) continue the development of tools for the comprehensive evaluation of fisheries;

b) suggest and evaluate methods for medium-term projections which take into account harvest control laws;

c) continue the comprehensive evaluation of the following fisheries:
   i. North Sea flatfish,
   ii. Norwegian spring-spawning herring,
   iii. North Sea herring,
   iv. Icelandic haddock,
   v. Southern Gulf of St. Lawrence cod;

d) evaluate the implications for assessment and management of the stability or trends in catchabilities from surveys and commercial CPUE data in demersal fisheries, using the North Sea and Faroe Plateau roundfish stocks as examples;

e) report on the reliability of catch forecasts in those circumstances when commercial catches and/or catch rates are subject to significant errors.

The Working Group will report to the 1997 Annual Science Conference. The report will be made available to the Multispecies Assessment Working Group at its meeting in August 1997

In addition, the working group received requests to consider the Barents Sea cod, Globec issues, the report of the ITQ study group and efficiency of survey gear, and a request from the European Commission and Norway on North Sea herring.

1.3 Structure of the report

This report of the second meeting of the Comprehensive Fishery Evaluation Working Group (COMFIE) develops further some of the main issues raised at and since the first meeting of the Working Group, emphasizing the relationship between biological reference points and their use in order to attain management objectives.

In accordance with terms of reference (a) and (b) described above, the Working Group considered various theoretical and practical issues relating to the comprehensive evaluation of fisheries with an emphasis on the evaluation of harvesting strategies using medium-term simulations of different form. In order to undertake medium-term simulations or other evaluations of the effect of fishing some harvest control laws must be assumed or under evaluation. Many harvest control laws are based on biological reference points and hence Section 2 describes the estimation of such reference points and estimation of the associated uncertainty.

The implication of implementing the precautionary approach to fishing and the relationship between the precautionary approach and biological reference points was considered in some detail in the first report of this Working Group and this topic is revisited in Section 3 of this report.

Several harvest control laws are considered in Section 4 with an emphasis on the evaluation of their performance under different scenarios, using both simulated and real data, with various different models of the population dynamics.

All models are simplifications of reality and some important deviations from model assumptions are considered in Section 5. As indicated in term of reference (e), these include errors in commercial catches or catch rates.

Sections 6-11 describe the state of affairs and proposed development of comprehensive evaluations of several fisheries (Terms of Reference (c) and additions to this). Some of these have proceeded quite far whereas others are still in their early stages.

Section 12 deals with other issues delegated to the Working Group.

1.4 Overview of a Comprehensive Fishery Evaluation

In its 1996 report, COMFIE described the following steps to be considered in preparation of a comprehensive fishery evaluation (CFE):

1. interpret management objectives and viable management actions;
2. identify existing data;
3. conduct exploratory analyses;
4. determine the feasibility of management procedure evaluation;
5. construct appropriate models of the fishery system;
6. evaluate and compare the performance of alternative management procedures;
7. recommend steps that would lead to improvements in the CFE;
8. produce full documentation of the CFE;
9. produce information required for decision making.

Because each step potentially involves a large number of components, work on several steps should proceed simulaneously. For example, step 2 should include in-depth examination of both the socio-economic and biological basis for the management of the fisheries under consideration. The review of the biological basis alone would minimally cover:

- management procedures currently in place, and their consequences
- scope of feasible management actions available for the fishery
- stock structure of the species involved
- main predator-prey relationships
- main environmental relationships as they affect recruitment and growth

- distribution of the stock with respect to the distribution of the fishery
- spawning areas
- juvenile areas and rearing areas
- migration patterns by size/age-groups
- influence of density on growth and/or distribution
- variability in recruitment and its main causes
- stock-recruitment relationship
- fleet composition, the fisheries in which they are involved, their interactions and their selectivities
- robustness of various stock assessment approaches (including statistical catch at age analysis)
- possibility of a catastrophe (e.g. what happened for these stocks in the past, or for stocks with similar characteristics elsewhere).

Assessment working groups would normally either provide these reviews or be closely involved in them.

2 BIOLOGICAL REFERENCE POINTS

2.1 Background

Biological reference points have been discussed in several reports of the "Methods Working Group" (Anon 1983, 1984, 1993) and in the previous Comfie report (Anon 19996). Caddy and Mahon (1995) review the literature on reference points and provide commentary on various problems related to their implementation. Reference points are most commonly stated in terms of fishing mortality rates or biomass. In this section, we provide a brief overview of the biological reference points which are discussed in later sections of this report. These reference points are commonly derived from analyses of yield per recruit (Y/R) and spawning stock biomass per recruit (SSB/R), and from age-structured production models.

$F_{0.1}$: fishing mortality rate at which the slope of the yield per recruit curve as a function of fishing mortality is 10% of its value near the origin.

F_{max}: fishing mortality rate which corresponds to the maximum yield per recruit as a function of fishing mortality.

F_{low}: fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 10th percentile of the observed R/SSB.

F_{med}: fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the median observed R/SSB.

F_{high}: fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 90th percentile of the observed R/SSB.

$F_{x\%}$: fishing mortality rate on an equilibrium population with a SSB/R of x% of the SSB/R for the corresponding unfished population.

B_{MSY}: biomass corresponding to maximum sustainable yield as estimated from a production model

F_{MSY}: fishing mortality rate which corresponds to the maximum sustainable yield as estimated by a production model.

F_{crash}: fishing mortality which corresponds to the upper intersection of the yield and fishing mortality relationship with the fishing mortality axis as estimated by a production model.

F_{loss}, the replacement line corresponding to the Lowest Observed Spawning Stock (LOSS).

$B_{50\%\ R}$, the level of spawning stock at which average recruitment is one half of the maximum of the underlying stock-recruitment relationship.

$B_{90\%\ R,\ 90\%\ Surv}$: level of spawning stock corresponding to the intersection of the 90th percentile of observed survival rate (R/S) and the 90th percentile of the recruitment observations.

Estimates of these quantities may be conditional on the stock-recruitment relationship assumed.

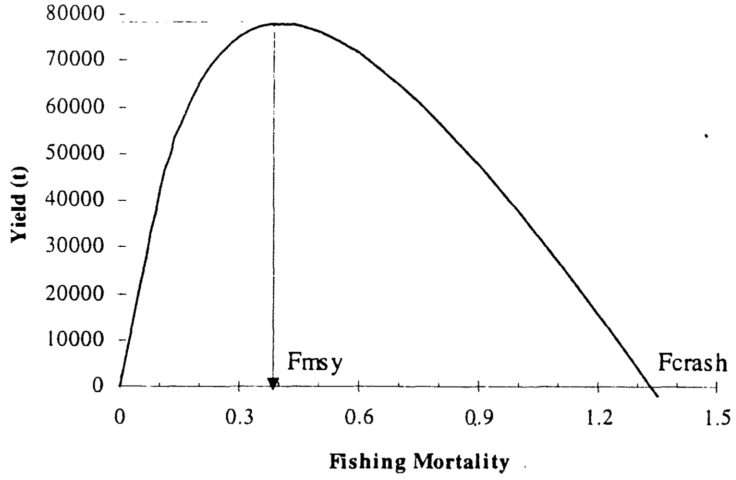


Figure 2.1 Equilibrium yield as a function of fishing mortality determined from an age-structured production model.

In addition to these analytical reference points, the Minimum Biologically Acceptable Level (MBAL) refers to a critical value of spawning stock biomass. Issues related to the calculation and interpretation of MBAL have been discussed elsewhere (Anon 1991, Anon 1993).

2.2 Estimation

2.2.1 Basic considerations for computation

The estimates of most BRPs based on per-recruit computations can be quite sensitive to the range of ages used. The oldest age in the computations should be high enough so that very few individuals survive to that age under natural mortality only (it should generally not be the oldest age in recent catch history). Special consideration should also be given to reflect appropriately the life-history characteristics of the stock. For instance, total SSB is often used as a proxy for reproductive output. However, this may not be a good proxy in cases where the sex ratios change with exploitation, or when egg production is a nonlinear function of weight.

Consistency in the various measures used is also very important. For instance, in estimating quantities like F_{crash} and F_{MSY} based on age-structured models (see Shepherd 1982), it is necessary to combine equilibrium spawner-per-recruit computations and computations based on observed spawner-recruit data. In this case, "spawners" should measure the same quantity (e.g. midyear female spawning biomass, including the "plus" group). In addition, it is not possible to condense systematic changes in fishing mortality vectors (due to selectivity changes) into a single F value which contains no age-specific information. Thompson (in Mace *et al.*, 1996) suggested the spawning exploitation rate, SER, as a convenient way to put different F-vectors on equal footing in terms of their impact on the reproductive stock:

$$\text{SER} = \text{foregone reproduction due to fishing} = 1 - \frac{\sum_a N_a P_a e^{-F_a - M_a}}{\sum_a N_a P_a e^{-M_a}},$$

where P_a are age-specific per capita spawning rates. The SER measures directly how much reproduction is lost in a given year due to fishing at a given rate. It ranges between 0 and 1, is comparable between different selectivity vectors, and easily understood by non-scientists.

The group did not discuss in detail the question of how frequently BRPs should be computed. The answer to this may depend on the nature of their variability (e.g. due to systematic changes in selectivity or to density-dependent growth and reproduction) and on the management controls in place. These could be addressed through simulations as those described in section 4.

2.2.2 Variance estimates

In general, reference points cannot be expressed as simple functions of the assessment model parameters. Thus, practical difficulties arise in calculating variances. Given an appropriate error structure and data set, the simple models in Schnute and Richards (BP5) could be used as a basis for estimating reference points and their variance directly. However, the assumptions in these models are too simple for a detailed assessment of most ICES stocks. One exception is F_{crash} (Lewy and Lassen, WP2). Section 2.2.2.1 illustrates how the delta method can be used to examine the variability in some important equilibrium relationships. Section 2.2.2.2 illustrates the use of the more versatile bootstrap approach. With both these methods, the variance estimates are conditional on the methods assumed. Section 2.2.2.3 discusses other integrated approaches for handling uncertainty that would be very useful in the context of management advice. The WG did not explore the bias in the estimators. It is evident from the results that the expected value of the estimators is not always the population mean.

2.2.2.1 Delta method

The delta (Taylor series) method is a simple way to approximate the variance of a quantity which is a function of other quantities whose variances are known.

The reference points, F_{crash} and F_{MSY} and the coefficient of variation of F_{crash} were estimated for North Sea plaice, cod and herring using the deterministic approach described in Working Document 2 and assuming a Ricker and a Beverton and Holt stock-recruitment model.

F_{crash} was estimated by $F_{crash} = T^{-1}(1/\alpha)$,

where $T(F)$ is the spawning stock biomass per recruit in the equilibrium:

$$T(F) = \sum_{a=0}^{A-1} w_a mat_a e^{-T_a^M - FT_a^E} + w_A mat_A e^{-T_A^M - FT_A^E} / (1 - e^{-M_A - FE_A}),$$

where

$T_a^M = \sum_{i=0}^{a} M_i$ and $T_a^E = \sum_{i=0}^{a} E_i$., as stock sizes in this method refer to the <u>end</u> of the year.

F_{MSY} is found by solving numerically for the fishing mortality that maximizes the equilibrium yield:

$$Y^{eq}(F) = R^{eq}(F) \times V(F),$$

R^{eq} is the equilibrium recruitment, which equals $\frac{\ln(\alpha T)}{\beta T}$ and $\frac{\alpha T - 1}{\beta T}$ for the Ricker and Beverton and Holt stock-recruitment models respectively and where $V(F)$ is the equilibrium yield per recruit:

$$V(F) = \sum_{a=0}^{A-1} e^{-T_{a-1}^M - FT_{a-1}^E} \frac{FE_a}{M_a + FE_a} (1 - e^{-M_a - FE_a}) w_a + e^{-T_{A-1}^M - FT_{A-1}^E} \frac{FE_A}{M_A + FE_A} w_A.$$

and where w_a indicates the mean weight at age, mat_a indicates the maturity at age, M_a indicates natural mortality at age, E_a indicates the exploitation pattern (fishing mortality in the current year divided by the average fishing mortality over selected age groups), and F indicates the average fishing mortality over the selected age groups.

The variance of F_{crash} has been approximated by the delta method including the variability of estimated α. The reference points have been estimated using input data for predictions from Anon. (1996a and 1996b). The results are shown in the table below:

Stock	S-R model	F_{crash}	cv of F_{crash}	F_{MSY}	$F_{current}$
North Sea Plaice	Beverton and Holt	0.88	0.77	0.36	0.46
Cod in IV and IIIa	Ricker	0.78	0.12	0.48	0.81
Cod in IV and IIIa	Beverton and Holt	0.85	0.23	0.21	0.81
North Sea herring	Ricker	0.65	0.10	0.36	0.63
North Sea herring	Beverton and Holt	0.68	0.16	0.17	0.63

The delta method can also be used to approximate the variance of equilibrium yield, recruitment and spawning biomass, conditional on a given F vector. Let $[S/R]_F$ and $[Y/R]_F$ be the equilibrium spawner-per-recruit and yield-per-recruit values obtained with F. The formulae below are for a Ricker-type S-R relationship, but similar ones could also developed for other parametric forms. Given estimates of a and b in the S-R relationship and of their variance-covariance matrix, the quantities of interest are:

$$S_F = \frac{\ln(a[S/R]_F)}{b},$$

$$V(S_F) = \frac{V(a)}{a^2b^2} + \frac{V(b)(\ln(a[S/R]_F))^2}{b^4} - \frac{2COV(a,b)\ln([a[S/R]_F)}{ab^3},$$

$$R_F = \frac{S_F}{[S/R]_F},$$

$$V(R_F) = \frac{V(S_F)}{[S/R]_F^2},$$

$$Y_F = R_F[Y/R]_F,$$

$$V(Y_F) = V(R_F)[Y/R]_F^2.$$

The variances of the per-recruit quantities can also be incorporated via the delta method, when available.

Data for North Sea plaice were used as an example. Section 2.2.2.2.3 explains the data sets used. Estimates of the parameters of the stock recruitment relationship and their variances and correlation were as follows for two data sets used:

Quantity	WG SSB estimates	Alternative SSB est.
a	6.3863	10.8298
SE(a)	2.4678	3.1132
b	0.004648	0.007355
SE(b)	0.001067	0.001147
corr(a,b)	0.9879	0.9802
d.f.	36	36

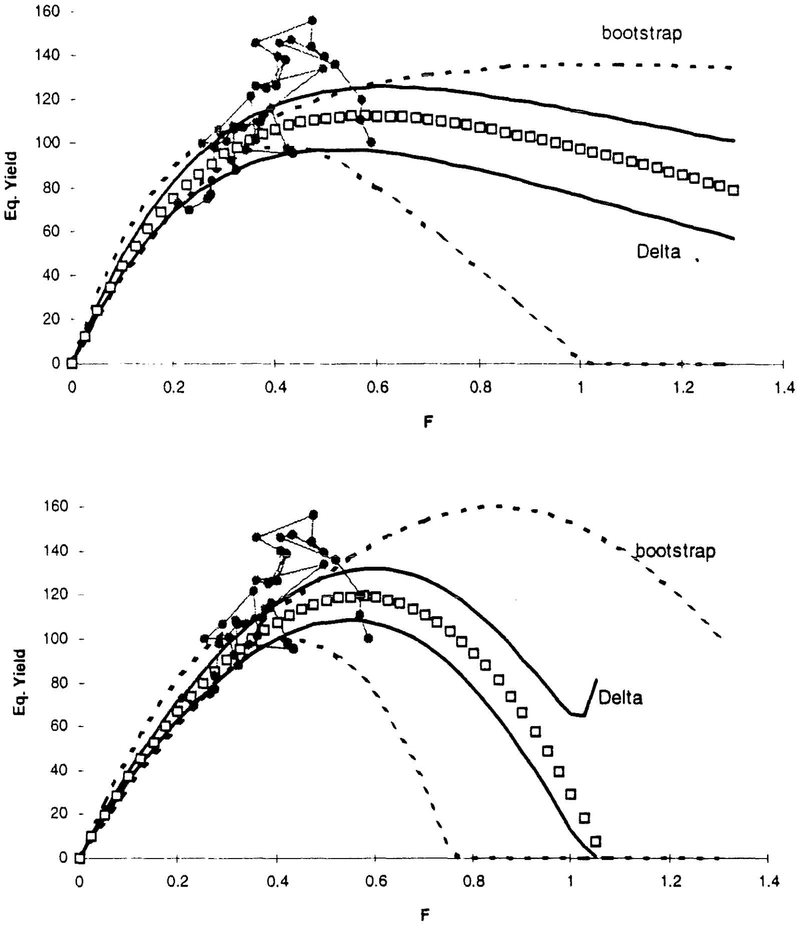


Figure 2.2.1 Equilibrium yield (squares) and approximate 95% confidence intervals for North Sea plaice. The top figure uses the Working Group's maturity data for computing SSB and SSB per recruit; the bottom one uses an alternative set of maturities. The dashed lines are the limits based on percentiles of 100 bootstraps (see next section). The solid lines are from the delta method. Also shown are the nonequilibrium trajectories estimated by the WG.

Figure 2.2.1 shows 95% confidence limits for equilibrium yield against F corresponding to the two fits, assuming that errors estimated by the delta method are lognormally-distributed. The bootstrap limits were computed directly from the individual fits. The results suggest that the delta method can provide a reasonable approximation around the range of observed values. Extrapolation beyond that range (to higher Fs) suggests that the bootstrap approach provides more conservative (higher) estimates of variance.

2.2.2.2 Bootstrapping

Bootstrapping is a resampling technique commonly used to estimate parameter variance. The procedure is to randomly resample the original data, with replacement, to generate pseudo-replicate data sets of the same size as the original dataset. The same estimation procedure is applied to the replicate data as to the original data, and the variance of the replicated estimates is used as an estimate of the variance of the original parameter estimates. The variance estimates are conditioned on the estimation model and are non-parametric. The qualities of bootstrap estimates of several BRP (F_{msy}, F_{crash}, B_{msy}, $F_{0.1}$, F_{med}) are discussed in this section.

2.2.2.2.1 Age-Structured Production Model

BRPs were estimated using an age-structured production model. Age-structured production analysis is an extension of yield per recruit (Y/R) and spawning biomass per recruit (S/R) analysis (Sissenwine and Shepherd (1987)). Yield per recruit analysis is used to estimate the amount of yield expected from a unit of recruitment as a function of fishing mortality, partial recruitment, and weight at age (details in Rivard 1982, section 5). One can also calculate S/R under the same conditions using a maturity-at-age ogive. The results are typically displayed as curves relating Y/R and S/R to F (step 1 in Figure 2.2.2). Where production modeling begins is by fitting a stock recruitment curve to the respective stock data (step 2 in Figure 2.2.2). The estimated curve is then used in combination with equilibrium S/R and Y/R computations as explained in Section 2.2.2.1 for the Ricker model. The sequence of computations is illustrated in Figure 2.2.2 as follows: Substituting S/R from spawning stock biomass per recruit analysis, one may estimate S_e for any F and use this to estimate R_e (step 3 in Figure 2.2.2). Equilibrium yield is then estimated using R_e * Y/R for that F (step 4 in Figure 2.2.2). Reference points include B_{MSY}, the biomass corresponding to maximum sustainable yield; F_{MSY}, the fishing mortality rate corresponding to MSY; and F_{crash}, the fishing mortality beyond which yield is 0.

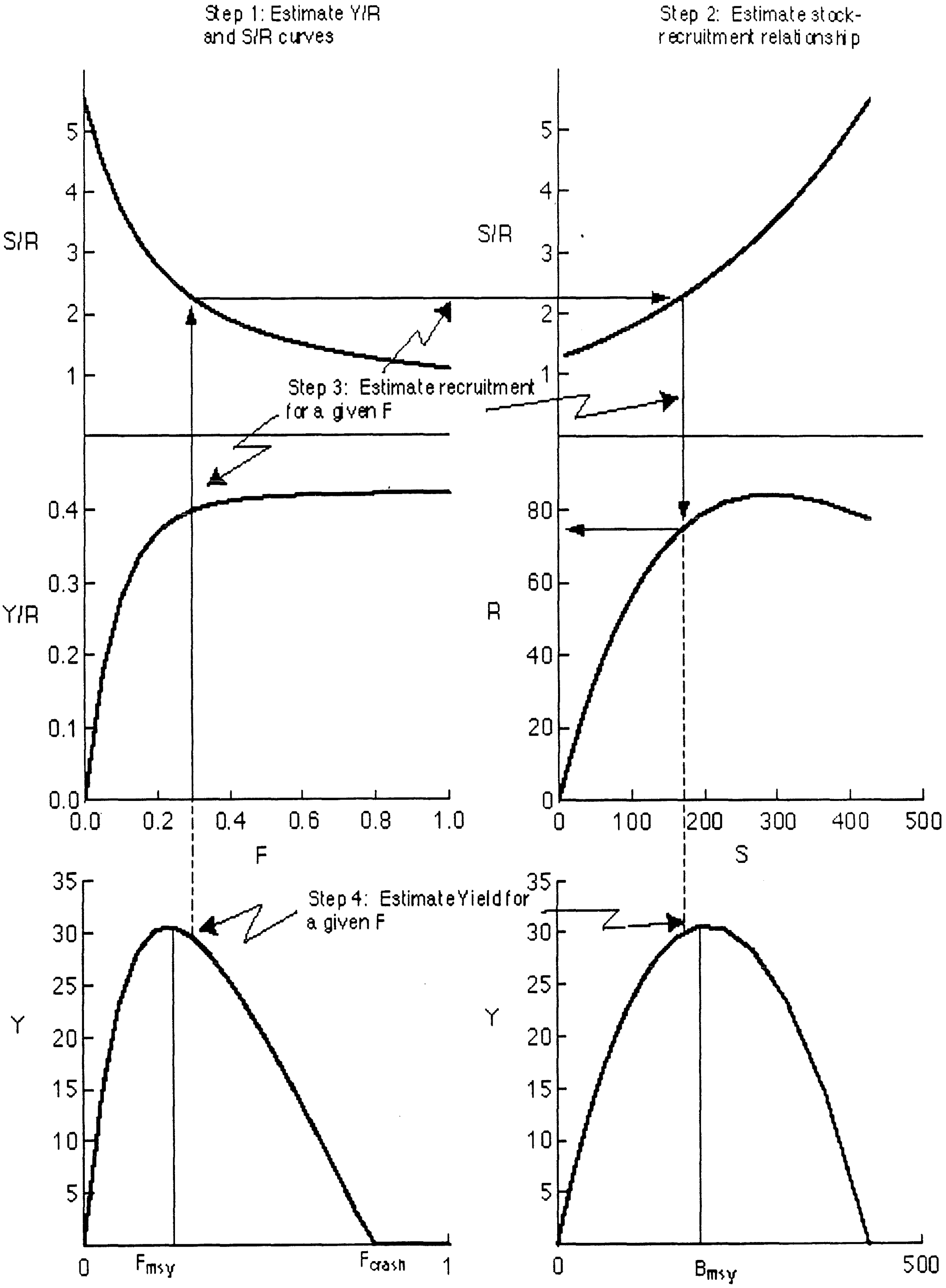


Figure 2.2.2: Family of curves describing yield (Y) per recruit (R), spawning stock biomass (S) per recruit, and yield as a function of fishing mortality (F). The steps to relate the curves are described in the text (based on Figure 1 of Sissenwine and Shepherd (1987)).

2.2.2.2.2 Resampling Methods

Two resampling options for the S - R data were examined. The first used the residuals from the fitted relationship. With this approach a non-parametric residual distribution conditioned on the selected model was assumed. The steps in the procedure were to

1 fit a S - R relationship to the data, assuming lognormal errors in R
2 resample residuals with replacement
3 add residuals to original predicted R to create a new set of R'
4 refit the S - R relationship
5 calculate reference points
6 return to 2
7 repeat the procedure "x" times

The second procedure involved resampling the observed S - R pairs. In this case there is no assumption regarding the residual distribution. The range and values of S used in the fit may vary from replicate to replicate. The procedure consists of

1. resample the observed S - R pairs, with replacement
2. fit the S - R relationship to the data, assuming lognormal errors in R
3. calculate the reference points
4. return to 1
5. repeat the procedure "x" times

The observed annual vectors of weight at age, F at age, and maturity at age were also resampled. In this case it was assumed that the annual values were independent from year to year. The procedure was always used in combination with resampling the S - R pairs in the comparisons described below. The procedure consisted of

1. randomly choose an annual vector of the variable of interest
2. calculate reference points
3. return to 1
4. repeat the procedure "x" times

2.2.2.2.3 Example for North Sea Plaice

Data from the North Sea plaice stock were used as an example. The analysis was exploratory and was not meant as a definitive estimate of these reference points. This would best be done by the assessment working group or as part of the comprehensive evaluation of the fishery where more in-depth knowledge of the biology and dynamics of the resource could be applied.

The input data consisted of the S - R data for the 1957-94 year classes, weight at age, F at age, and maturity at age from the 1957-66 period. When weight at age, F at age, and maturity at age were held constant in the production models, the median values at age for the 10 year period were used. The R values were taken from the assessment working group report (CM 1997/Assess:6). Two sets of S estimates were used, that from the assessment working group where a constant maturity ogive was used (referred to as WG), and a second series where annual maturity data were used (referred to as RV, see section 6.4.6.3). The working group is not advocating one over the other, but comparing results from these two sets of S was interesting in that the fit to the latter series was somewhat better (10% reduction in mse).

The choice of S and maturity has a large impact on the estimated equilibrium conditions. The pattern of F at age lies between the two maturity ogives (Figure 2.2.3) so that if the ogive used by the working group is true, the fish mature before entering the fishery whereas if the annual estimates are true, the fish enter the fishery before they mature. The annual estimate of S in the revised series are also lower than those estimated by the working group, and the fitted S - R relationship is steeper at the origin (section 6.4.6.3) resulting in a lower estimate of F_{crash} (F_{crash} = 2.4 for the "WG" series and F_{crash} = 1.0 for the "RV" series, Figure 2.2.4). The difference in F_{crash} estimates resulting from the two series of S estimates illustrates the degree of uncertainty in BRP estimates that may be associated with the basic input data, separate of the uncertainty associated with model fit.

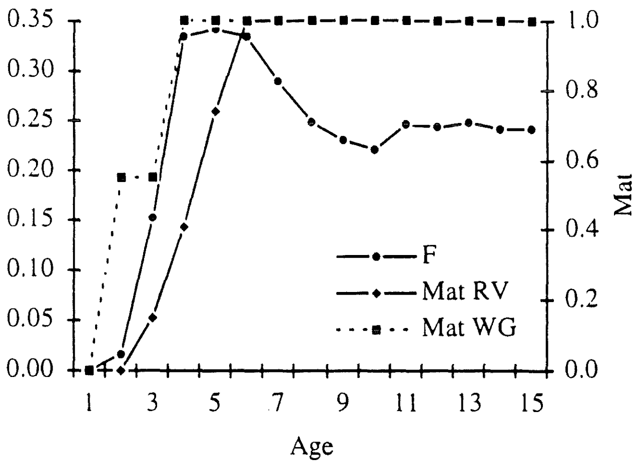


Figure 2.2.3: Comparison of maturity and F at age for North Sea plaice during 1957-66. The line "Mat WG" is the ogive used by the assessment working group and "Mat RV" is a revised ogive based on annual sampling. The selection pattern of F at age lies between the two so that if "Mat WG" is true, the fish mature before entering the fishery whereas if "Mat RV" is true, the fish enter the fishery before they mature.

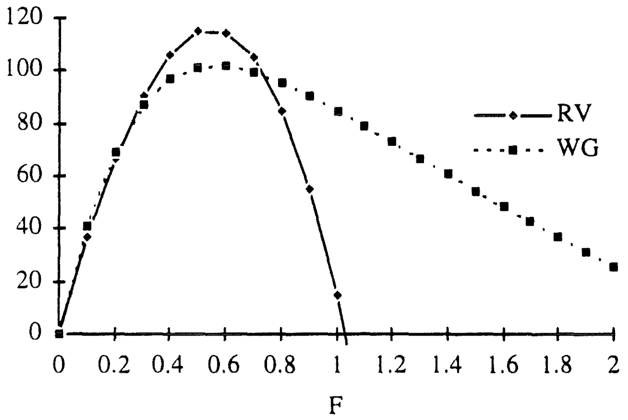


Figure 2.2.4: Equilibrium yield curves for North Sea plaice estimated from two series of stock biomass estimates. The curve "WG" was estimated from data provided by the assessment working group where a constant maturity ogive was used. The curve "RV" was based on annual maturity estimates. The latter has a much lower F_{crash} estimate than the former.

Bootstrapping results were compared for different series of S (WG or RV) and different resampling procedures (S - R pairs or residuals) (Table 2.2.1). 100 trials were used for the "WG" data and 50 trials were used for the "RV" data. The series of S used had a large effect on the CV of the F_{crash} and F_{msy} estimates. When the WG estimates were used the CV on F_{crash} was close to 80% and on F_{msy} close to 30%. When the RV series was used, the CVs were close to 17% on both. The S series had little effect on the CV of the B_{msy} estimates which were in the range of 15% - 23%. The resampling method used had little effect on the CVs. The point estimates of these BRP were close to the mean and median estimates from bootstrapping.

Bootstrapping provides a distribution of estimated BRPs and these may be used directly in estimating the probability that a given F or B is above or below the BRP. Selected percentiles of the distributions relevant to the precautionary approach are also given for illustrative purposes. The 10th percentile is given for the F estimates since in a precautionary approach one would like to be relatively sure F was below the reference point. The 90th percentile was given for the B estimate since one would like to be relatively sure biomass was above the reference point. The actual percentile used will depend on the implementation of the precautionary approach. Note that F_{pa} should be lower and B_{pa} should be higher than the selected percentiles as they reflect the uncertainty in the BRPs only and not on the current estimates of F and B.

Table 2.2.1: Comparison of point estimates and bootstrap results for Fcrash, Fmsy, and Bmsy estimates for North Sea plaice when only the S-R data were resampled. Treatments included the source of S estimates, "WG" were values taken from the assessment working groups where a constant maturity ogive was used, "RV" values were estimated using annual maturity ogives, and resampling method, either resampling S-R pairs or resampling residuals from the original S-R fit. Bootstrap results include the mean, its coefficient of variation (CV), the median, and selected percentiles. For F estimates, the 10th percentile is given, while for B the 90th percentile is given.

			Bootstrap			
S-R Data	Resampling	Point Estimate	Mean	CV	Median	Percentile
F_{crash}						10%
RV	Pairs	1.03	1.08	17%	1.09	0.84
RV	Residuals		1.10	17%	1.06	0.88
WG	Pairs	2.39	3.49	75%	2.61	1.32
WG	Residuals		3.77	83%	2.70	1.34
F_{msy}						10%
RV	Pairs	0.55	0.57	17%	0.58	0.45
RV	Residuals		0.58	17%	0.56	0.47
WG	Pairs	0.55	0.62	32%	0.57	0.41
WG	Residuals		0.64	36%	0.58	0.42
B_{msy}						90%
RV	Pairs	157	157	22%	148	190
RV	Residuals		154	15%	151	187
WG	Pairs	261	262	23%	256	313
WG	Residuals		238	20%	234	310

The life history data (weight at age, F at age, and maturity at age) were also resampled to investigate the sensitivity of the BRP estimates to their variation. Annual vectors were chosen randomly from those available for the decade 1957-66. Trials were conducted with no variation in life history data, by bootstrapping one variable at a time, then including all three. The S - R data for the entire series were bootstrapped by selecting pairs at random with replacement in each trial. The revised (RV) S estimates were used and 100 trials were used for each test. The results indicated that there was little variation in BRP estimates due to variations in the life history data, at least over the time period of interest (Table 2.2.2). The CVs on the three BRPs were similar for the S - R variation only, weight at age, and maturity at age trials. They increased when variation on F at age was introduced, suggesting that this variable had the strongest effect.

Table 2.2.2: Comparison of CVs of bootstrap estimates of Fmsy, Fcrash, and Bmsy when life history data (maturity at age (Mat), weight at age (Wt) and F at age (F)) were resampled. The run "S/R" included variation only in the S -R data, and the run "All" included variation in S - R and all life history data. The greatest amount of additional variation was associated with the F at age data.

	CV of Estimate		
	Fmsy	Fcrash	Bmsy
S/R	20%	21%	20%
Mat	17%	18%	18%
Wt	18%	18%	19%
F	22%	26%	19%
All	21%	25%	23%

Bootstrapping was also used to estimate the variance of $F_{0.1}$ and F_{med} reference points. In this case the S - R pairs were resampled, the revised S series was used, variation in life history data was included, and 100 replicates were calculated. The estimated CVs on $F_{0.1}$, F_{med}, F_{msy}, and F_{crash} were 10%, 9%, 20 % and 25% respectively

2.2.2.2.4 Observations

It is always important to check if the bootstrapping procedure is doing what it is supposed to. A paired scatterplot of parameters and the replicate number from the individual runs is a useful diagnostic (Figure 2.2.5). The parameter estimates should be independent of the run number. In the case of a Ricker stock recruitment relationship and if only the S -R data are varied, then F_{crash} and F_{msy} should be mapped exactly on the a parameter. This isn't the case, however, if the life history data are varied. The mean bootstrap estimates should be close to the point estimates.

It is important to consider how random selections are made when comparing treatments. In the examples presented above, no attempt was made to control the sequence of random selection. It might have been useful to select the S - R pairs in the same manner when comparing the effects of variation in different life history variables on the estimation CV. This might not have been necessary in the case of testing the CV associated with the resampling method. This problem might be overcome by increasing sample size. Unfortunately time did not allow full examination of this issue and further work is warranted.

Bootstrapping provides a distribution of estimated BRPs which may be used in conjunction with the estimated variance of population estimates to define Fpa and Bpa. This may be an advantage over using a function such as $e^{-2\sigma}$ which assumes a specific distribution of the BRP.

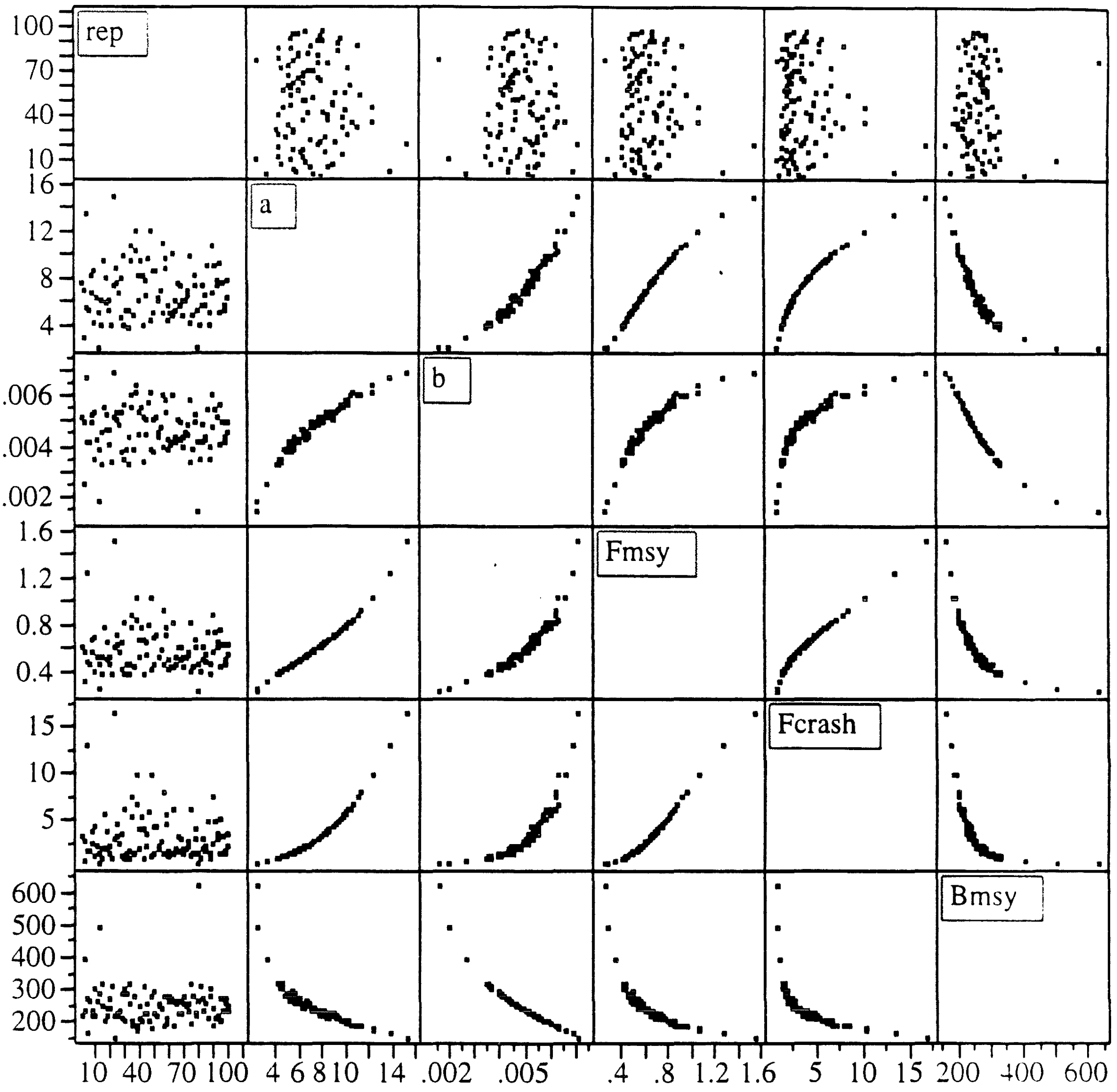


Figure 2.2.5: Multiple scatterplot of bootstrap replicate number, estimates of the Ricker S - R fits and estimates of biological reference points for North Sea plaice. This is a useful diagnostic plot. The replicate runs should be independent and this is confirmed by the scatter of points wrt the replicate number. It is expected that a is highly correlated with Fmsy and Fcrash, and this too is confirmed here. The plot also shows the high correlation of the Ricker curve parameter estimates (a and b).

2.2.2.3 Other methods

Ideally, reference points and their variance should be calculated in the context of a full assessment. Therefore, variance in estimation of reference points should acknowledge the full assessment uncertainty, for example, uncertainty in estimates of natural mortality, stock size, recruitment, maturity at age, and weight at age. In addition, the extra structural uncertainty in the stock recruitment relationship should be considered. These uncertainties can be very large. For example, the 95% joint confidence intervals for stock and recruitment illustrated by Richards et al. (1997, BO1) suggest that estimation error in stock and recruitment can mask any underlying stock recruitment relationship.

Patterson (WP1) provides an example of how a Bayesian approach can be used to address uncertainty in BRPs and the management advice associated with a harvest control law that uses the BRPs, directly in the stock assessment. The approach is particularly appealing because it integrates various sources of uncertainty in a single computational framework leading directly to the forecasts and TAC advice. Monte Carlo simulation has also been used in the past to estimate uncertainty in current stock status relative to BRPs (Anon. 1993 Report of the Methods WG, 1993).

An alternative approach that was not explored during this meeting would be to carry out a bootstrap of the assessment itself, e.g. by resampling the residuals of the indices of abundance. These would be used to construct pseudo-index data sets which would be tuned repeatedly, with replacement. Each bootstrap run would then lead to a new stock-recruitment observation set which would be used to calculate the parameters of the stock recruitment function. Simultaneously, each bootstrap run would provide new estimates of selectivity, which would be used to calculate the relevant BRPs. In this fashion, the correlations between the two sets of information, selectivity and S-R data, would be maintained.

Other forms of bootstrapping are possible. For example, if S and R are estimated with covariance, then pairs of points may be selected from joint distributions.

2.2.3 Special considerations

It should be made clear that all variance estimates are conditional on a number of assumptions that are made. In the age-structured examples above, the bootstrap approach made fewer assumptions than did the delta method approach. However, the variance estimates for F_{crash}, etc. from the bootstraps were still conditional on assuming a specific parametric stock recruitment relationship, a type of model uncertainty that was not addressed by the procedure. The impact of this assumption could be lessened perhaps, by assuming a 3-parameter functional form. But, still, the estimated variances would be conditional on that assumption. In light of the recent focus that variance estimates of BRPs are taking (e.g. in terms of the precautionary approach), it seems prudent to recommend that

- the various relevant sources of uncertainty be accommodated as realistically as possible, and
- the assumptions made (implicit or otherwise) be clearly stated.

BRPs, like most stock assessments, are typically carried out in a single-species framework. The group has not considered the advantages and disadvantages that would be associated with multispecies considerations. But multispecies BRPs will be required if multispecies management is attempted at some time in the future, and it would be interesting to begin to explore this possibility.

A more immediate point of interest is the role that density dependence may play on BRP estimation. As Patterson (WC2) showed, there is strong evidence of density dependent growth, maturation, and possibly natural mortality, in Norwegian spring-spawning herring. When density-dependence processes were modeled directly, the estimated stock dynamics were better able to explain the full range of historical fishery observations (WC2). Density dependence may take place in various populations and it is appropriate to attempt to model it directly. However, special efforts should be made to ensure that the dependence is real and not an artifact of size-selective fishing and sampling practices.

2.3 Available information on Biological Reference Points for ICES stocks

The Working Group received a review of data availability by stock from recent ICES stock assessment Working Group reports (Sparholt, WP3). The number of stocks for which each type of estimate has been calculated is summarised below:

Number of Stocks:		126
Stocks with Age-Structured Assessments		65
Estimates of F_{crash}	1	
Estimates of F_{msy}	1	
Estimates of F_{med}	55	
Estimates of F_{max}	57	
Estimates of F0.1		55
Estimates of F_{lim}		1
Estimates of F_{pa}		4
Definitions of MBAL		19

The small number of F_{pa} and F_{lim} values proposed arises because few assessment Working Groups had met since these measures had been proposed.

2.4 Conclusions

Work made by the Group allowed for the comparison of two simple methods to estimate uncertainty in BRPs. Figure 2.2.2.1 suggests that the delta method can provide a reasonable approximation to some equilibrium relationships, particularly in the region around the observed trajectory. The bootstrap seems to perform much better in conveying uncertainty in the region of high F values where no observations have been made and appears to be a preferable tool. In addition, bootstrapping can be used to approximate the variances of the various BRPs while, in this age-structured example, the delta method can only be used to approximate the variance of F_{crash}. However, the delta method can still provide useful information and is much easier and faster to implement, making it desirable as well.

Estimates of the reference points and their associated bootstrap-based CVs for North Sea plaice were highly dependent on the treatment of maturity ogives, and this dependence has not yet been explored fully. Until this aspect has been resolved, values presented here should not be taken as stock-specific estimates but as values presented to illustrate a methodological approach.

3 PRECAUTIONARY APPROACH

3.1 Conclusions from the 1996 working group report

In its 1996 report, COMFIE reviewed various international agreements relating to the precautionary approach for fisheries. These agreements restrict the range of acceptable harvest control laws and how these laws may be reflected in annual advice. Comfie interpreted these agreements to conclude that

- fishing should be limited to sustainable levels
- uncertainty should not be a reason to maintain high fishing mortality
- the stock biomass should be kept above B_{MSY}
- fishing mortality should be kept below F_{MSY}
- in the absence of other information, F_{MSY} may be taken as a limit reference point
- in the absence of other information, B_{MSY} may also be taken as a limit reference point
- there should be only low probability that limit reference points are exceeded

Sustainability implies that the probability of exceeding the fishing mortality at which the stock crashes (F_{crash}) should be very low. F_{med} is one of the few available estimates of a sustainable fishing mortality, intended to be lower than F_{crash}. Because F_{med} may be as high as F_{crash}, it must be taken as an upper bound on an acceptable fishing mortality unless better estimates are available. An estimate of F_{MSY}, on the other hand, is rarely available, and even when it is, it tends to be highly uncertain. Even in those cases where F_{MSY} exists, it cannot be taken as a target fishing mortality, since various agreements explicitly state that F_{MSY} is an upper bound (limit reference point) which should not be exceeded. In the absence of any stock and recruitment information, F_{max} is often used in place of F_{MSY}, but F_{MSY} is commonly less than F_{max} and hence F_{max} must also be considered an upper bound on a fishing mortality satisfying various international requirements. If F_{max} is ill-defined, then $F_{0.1}$ instead of F_{max} could be used in the decision process.

In 1996, COMFIE interpreted the international agreements as specifying B_{MSY} as a biomass limit reference point in the absence of other knowledge. However, subsequent review of the agreements revealed that no biomass reference point was specified. Instead, B_{MSY} was identified as a potential rebuilding target for overfished stocks.

The Working Group interpreted the concept of a biomass-rebuilding target as Pr ($B \geq$ rebuilding target) ≥ 0.5 and synonymous with B_{pa}. B_{MSY} can be used as B_{pa} and would be consistent with international agreements that F should be lower than F_{MSY}. This implies that F_{pa} must be less than F_{MSY} and the implied target biomass associated with F_{pa} will be greater than B_{MSY}.

3.2 Recent developments on the precautionary approach

ICES recently established a study group of ACFM to design a form of advice consistent with the precautionary approach. The study group on the precautionary approach to fisheries management met in February 1997 (BP6). The study group suggested that ICES should explicitly consider and incorporate uncertainty about the state of stocks in management scenarios. In particular, thresholds should be proposed which ensure that limit reference points are not exceeded. Both fishing mortality rate and biomass limit reference points are required.

For any given stock, the study group recommended that the probability of exceeding the limit fishing mortality rate reference point be no more than 5% for any given year. Therefore, ACFM needs to formulate harvest control laws such that this probability is satisfied. The study group defined this type of upper bound on fishing mortality as the precautionary fishing mortality F_{pa}. One suggested method for calculating F_{pa} is through the relationship

$$F_{pa} = F_{lim}e^{-2s}$$

where 2s is an approximate estimate of the uncertainty. The value of s should take account of different sources of variation and not just the uncertainty in the current assessment. If the fishery is managed to the maximum recommended fishing mortality, then F_{pa} becomes an implicit target.

Similar considerations apply to biomass limit reference points. The study group defined the precautionary biomass B_{pa} as a biomass level that can be used to avoid B_{lim} with high probability. For example, B_{pa} could be set at a level which reflects natural variations in recruitment. Alternatively, if B_{lim} is defined, then B_{pa} can be derived as a higher biomass which corresponds to the uncertainty in the annual biomass estimate.

The NAFO Scientific Council met in June 1997 to comment on application of the precautionary approach for NAFO stocks (BP7). NAFO reviewed the ICES study group report and other papers including Thompson and Mace (BP3). The framework proposed by NAFO differs somewhat from that proposed by ICES. Three biomass reference points (B_{lim}, B_{buf}, B_{tr}) and three fishing mortality reference points (F_{lim}, F_{buf}, F_{target}) were defined. Definitions of B_{lim} and F_{lim} are identical to ICES terminology, while B_{buf} and F_{buf} are comparable to B_{pa} and F_{pa}, respectively. For example, NAFO suggested the relationships

$$B_{buf} = B_{lim}e^{+2s}; \quad F_{buf} = F_{lim}e^{-2s}$$

for data-rich stocks, although no specific comments on the interpretation of s were provided. In addition, NAFO defined the target recovery level B_{tr}. For overfished stocks, this is the total biomass which would produce MSY. The target fishing mortality level F_{target} depends on management objectives, but must be set at a level below or equal to F_{buf}.

NAFO also proposed an action plan for implementation of the precautionary approach. This includes a review of the 1997 Comfie report, a workshop in the spring of 1998 to determine reference points for stocks within NAFO and to specify management control laws, and implementation of the precautionary approach in formulating advice for 1999.

3.3 Definitions of harvest control laws in relation to the precautionary approach

Various control laws could be developed in relation to the concepts of limit and target reference points. The set of harvest control laws suggested by ICES and NAFO are somewhat different. For example, the ICES definition of B_{pa} is equivalent to the NAFO definition of B_{buf}. However, NAFO suggests that the fishery close if current stock biomass is below B_{buf}, a more conservative action than implied by ICES. In addition, ICES does not define explicit targets. The NAFO concept of F_{target} allows for explicit fishing mortalities smaller than F_{buf} , but at the limit,

$$\max(F_{target}) = F_{buf} = F_{pa}$$

These concepts are illustrated in Figure 3.1. Note that the maximum fishing mortality rate decreases to 0 at B_{buf} for NAFO and B_{lim} for ICES. Equilibrium biomass corresponding to F_{pa} (ICES) gives an implied biomass target, while equilibrium biomass corresponding to F_{buf} and F_{target} (NAFO) give implied rebuilding targets and post-rebuilding targets, respectively.

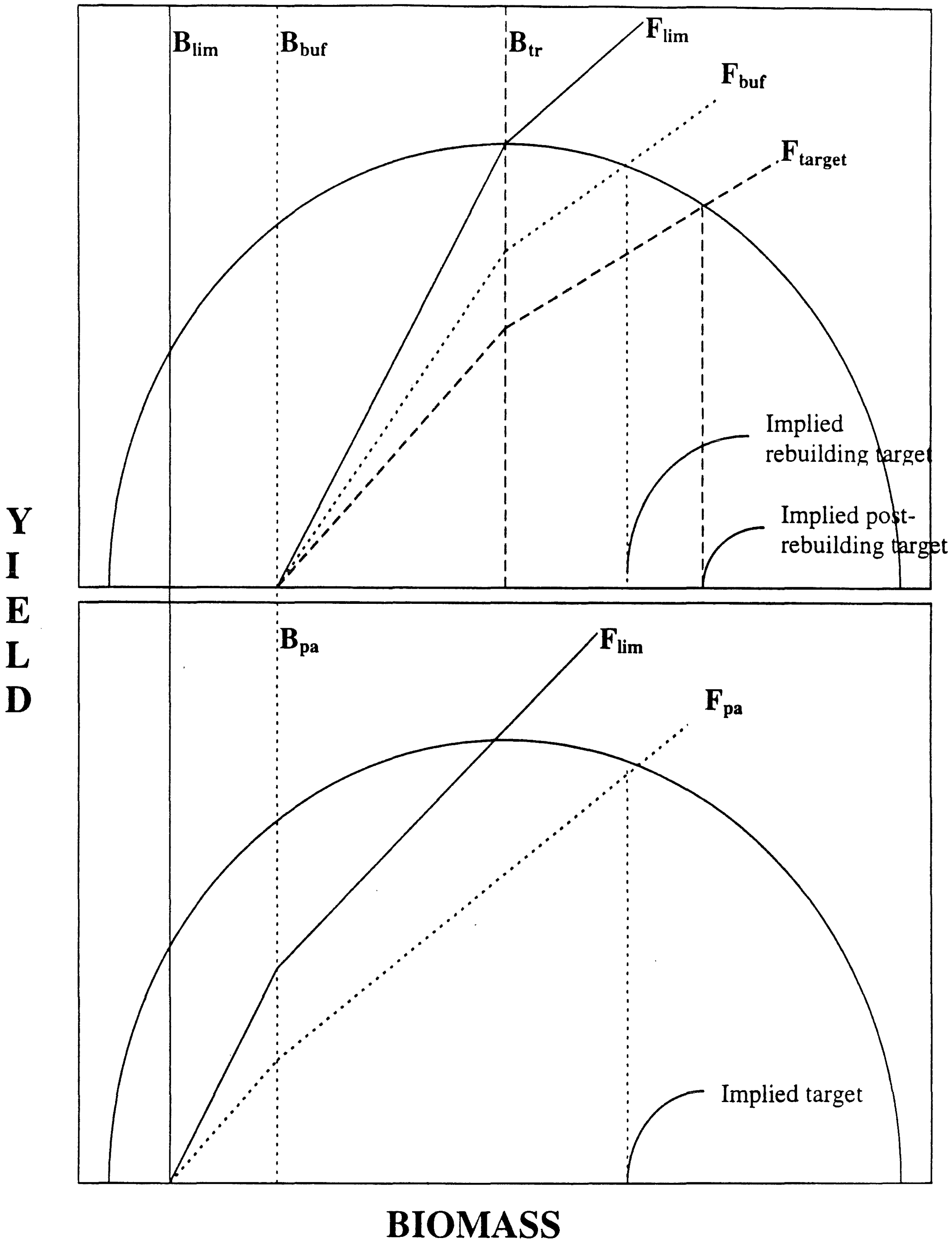


Figure 3.1: Equilibrium yield as a function of biomass with harvest control laws suggested by NAFO (top panel) and ICES (bottom panel).

4 EVALUATION OF HARVEST CONTROL LAWS BY SIMULATION

4.1 Simulation Experiments and Methods

The performance of harvest control laws may be evaluated using simulation studies. A wide variety of simulation experiments may be implemented and it is useful to classify them. The WG identified three classes of simulation experiments, simple Process (P) error, Process-Observation (PO) error and full Process-Observation-Model (POM) error (Figure 4.1.1) . All these models require definition of an underlying fishery system. The simple P experiments implement the harvest control laws based on the state of the population in the underlying fishery system, i.e. it assumes perfect knowledge of the system and perfect implementation of the control laws. The PO and POM experiments implement the harvest control laws based on the perceived state of the stock, i.e. perfect knowledge of the system is not available. The PO experiments approximate a perceived system by simply adding error to the population state variables, e.g. population abundance. The POM experiments more appropriately generate observed data with error and incorporate the stock assessment procedure to estimate the perceived state. It is important to note that only the POM experiments allow evaluation of harvest control laws when the models in the assessment procedure do not correspond exactly to the models generating the underlying fishery system. In full POM experiments, the performance of control laws depends on their interaction with the assessment methods used to infer stock status and the detailed make up of the underlying system which is to be managed. When possible, full POM experiments are advocated, but useful results may be obtained more readily with the simple P and the PO experiments. Specifically, a wide range of harvest control laws may be examined with the simpler experiments and those control laws which are not successful at achieving objectives may be discarded. It is unlikely that harvest control laws which perform poorly in those experiments could perform better when greater uncertainty in the perceived state of the system is introduced. The full POM experiments may then be used to explore more fully the more promising harvest control law options.

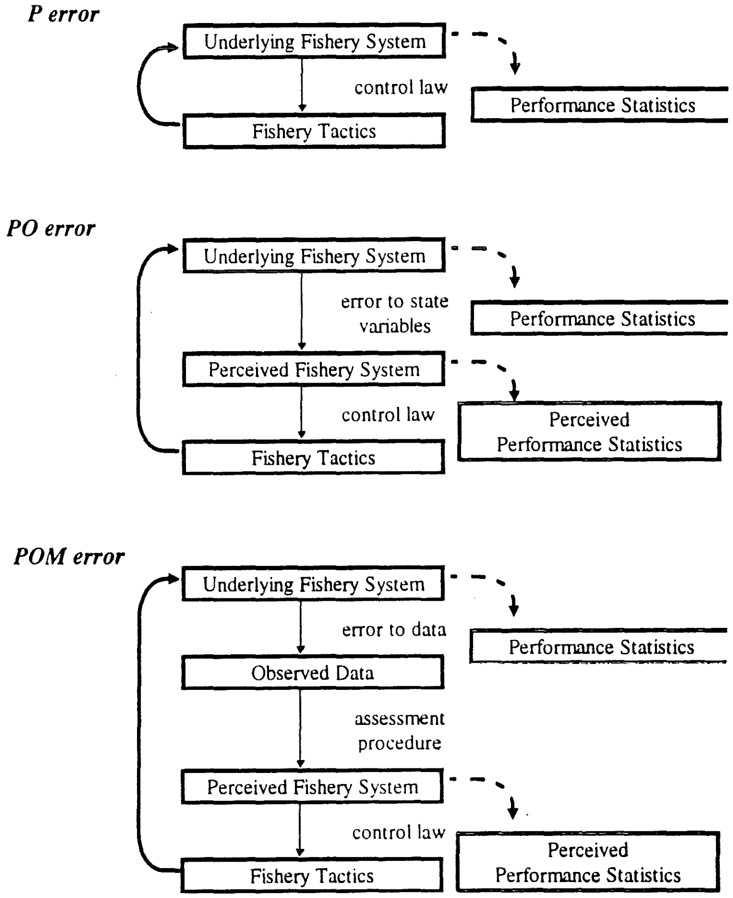


Figure 4.1.1 Classes of simulation models for evaluation of harvest control laws.

The WG also employed the following standard terms for these three classes of experiments to describe how the underlying fishery system was generated:

- Parametric: employs population dynamics relationships, e.g. Ricker stock/recruitment relationship and assumed error distributions
- Non-Parametric : resamples past observations of population state variables

So, for example, we may have a Non-Parametric P error experiment or a Parametric POM error experiment.

Useful insight can be gained by applying these methods and examining the results for both real case studies and experimentally generated populations. The real case studies reveal the complications which may arise in practice and the challenges of interpreting results and formulating advice. The experimentally generated data permits a controlled design which can span the range of life history characteristics and where the true population values are known. The WG applied the simulation methods to both real case studies and to an experimental design of generated populations.

4.2 Harvest Control Law Form

The form of the harvest control law considered was based on recent developments associated with the Precautionary Approach and is illustrated in Figure 4.2.1 . When the spawning stock biomass exceeded B_{pa} the fishing mortality rate was set to equal F_{pa} . In practice the fishing mortality rate would be permitted to be less than or equal to F_{pa} . When the spawning stock biomass was between B_{pa} and B_{lim} , the fishing mortality rate was set to decrease linearly in relation to the decrease in biomass. Below B_{lim} , the fishing mortality rate was set to zero or a very small value.

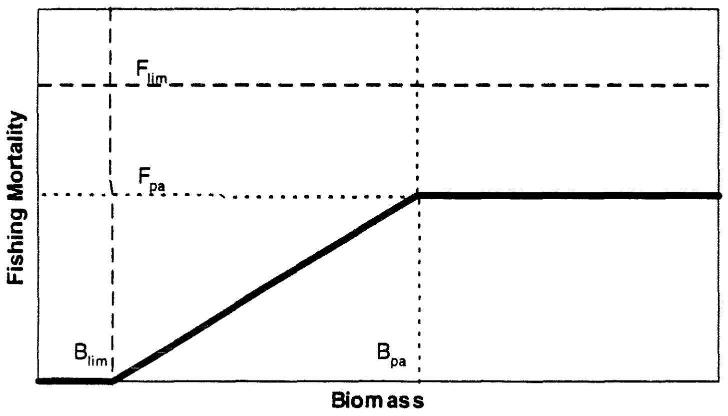


Figure 4.2.1 Generic form of a harvest control law.

Implementation of the harvest control laws to be consistent with the Precautionary Approach requires consideration of some further details which happen to be very important for their performance. Given limit and precautionary biomass levels of $^1/_2$ B_{MSY} and B_{MSY}, respectively, simulated estimates of these can be taken as input values to form a basis for the catch control laws. If staying away from a single fishing mortality limit reference point, F_{lim}, such as F_{crash} is taken as an important goal, then this may possibly be achieved by estimating F_{lim} and then defining F_{pa} by multiplying a point estimate by a constant which can be conveniently described by $e^{-2\kappa}$. Alternative versions of F_{pa} can be defined based on the general rule of identifying a limit fishing mortality (estimated limit reference point, e.g. F_{crash} or F_{MSY} or conservative proxy estimates, e.g. F_{med} or $F_{0.1}$) and reducing from that level by $e^{-2\kappa}$ where κ is a number which needs to be picked to satisfy criteria of compliance with the precautionary approach.

Therefore, some F_{pa} candidates appear through earlier considerations and candidates which appear in various international agreements discussed earlier in this report and other candidates appear through the interpretation of specific criteria mentioned in such agreements. We also consider the performance of variations of F_{crash}, F_{MSY} and two variations of F_{comfie} , $F_{comfie(1)} = \min(F_{MSY}, F_{med})$ and $F_{comfie(2)} = \min(F_{MSY}, F_{med}, F_{0.1})$.

The WG considered the following reference points for the examples:

- $B_{lim} = {}^1/_2\, B_{msy}$
- $B_{pa} = B_{msy}$

- $F_{lim} = F_{msy}$, F_{crash}
- $F_{pa} = F_{crash}\, e^{-2\kappa}$, $F_{0.1}$, $F_{comfie(1)}\, e^{-2\kappa}$, $F_{comfie(2)}$, $F_{MSY}\, e^{-2\kappa}$

Reference points could be dynamically generated within the simulation experiment based on the data. We refer to simulation evaluation models which do this as internal reference points (IRP), e.g. Parametric POM error : IRP. In some instances reference points are based on externally derived quantities such as a WG consensus on MBAL and are accepted as fixed values. We refer to simulation evaluation models which do this as external reference points (ERP), e.g. Non-Parametric PO error : ERP. For further discussion of estimation of reference points see Section 2.

	Process error	**Process & Observation error**	**Process, Observation & Model error**
Internal Reference Points	P : IRP	PO : IRP	POM : IRP
External Reference Points	P : ERP	PO : ERP	POM : ERP

4.3 Performance Evaluation

Performance evaluation of alternative harvest control laws was chosen to be consistent with interpretation of the Precautionary Approach. The WG reported the chances that biomass would decrease to below B_{lim} and the chances that the fishing mortality rate would exceed F_{lim} for each year over the time horizon for which the simulation was conducted. A simple summary table of the chances that the fishing mortality rate would exceed F_{lim} for all years, the chance of recovery in 5 years, 10 years and 20 years was used to identify time lines for further examination when there were too many to consider. The WG emphasizes that the results of simulation experiments should only be viewed as comparative. These results should not be taken as absolute estimates of forecasts. The experiments are designed to compare the performance of alternative harvest control laws.

4.4 Parametric process-observation (PO) error models

4.4.1 Construction of a Simulated data for testing harvest control laws

Given the large number of ICES stocks with widely different population dynamics, data availability and unknown error structures, it was considered appropriate to test proposed harvest control laws on simulated data sets. This has the advantage of allowing the evaluation of the success of the candidate control laws in relation to the known, deterministic properties of the simulated populations.

Given the large number of dimensions of population parameters in an age-structured population model, and the fact that only a reasonably small number can meaningfully be tested, only two levels (high and low) of a restricted number of population parameters could be included in the experimental design. The parameters in the design matrix were:

1. Growth: fast or slow
2. Shape of stock- recruitment relationship : flat with respect to SSB, or declining
3. Variability about stock recruitment relationship: high or low
4. Selection pattern : flat on all fish, or selection on mature fish only.

This leads to a 4x4 = 16 experimental design matrix. All other population parameters were either made dependent on some combination of the four in the experimental design, or else were eliminated by rescaling. Shapes of the growth and recruitment curves were chosen to represent high and low cases as typically observed in fisheries data sets, but no values were taken from any real fish stock. No attempt was made to extend the range to include stock with extreme population dynamics (e.g. anchovy or orange roughy), but rather to represent the typical range of stocks assessed by ICES.

Details of the construction of the pseudo-data sets follow:

Age range

All parameters are calculated for ages, a, 0 to 35.

Natural Mortality

M= 0.2 for all ages and years, except for 100% senescence on 1 January at age 36 (ie there is no plus-group in the calculation)

Growth

Growth in weight W at age a is modelled as:

$$W_a = 100(1 - e^{-K.a})^3$$

where K make take one of two values: K=1.5 for fast growing fish, or K=0.4 for slow-growing fish. Growth and mortality within years is not modelled, so that fish are assumed to spawn on 1 January and to have the same weight in the catch as in the stock. The two growth functions are plotted in Figure 4.4.1.

Maturity

It is assumed that fish spawn when they reach half maximum size. The proportion of fish of age a O that spawn is given by

$$\begin{gathered} \text{if}(W_a < 50)\text{then} \\ O_a = 0 \\ \text{otherwise} \\ O_a = 1 \end{gathered}$$

Recruitment

Recruitment is modelled as a stock-dependent process of Beverton-Holt form. Fish recruit on 1 January at age 0 when they have weight 0.

$$R_y = \frac{1000.SSB}{(B + SSB)}.\exp(\varepsilon_y)$$

In order to ensure comparability across different population models, the parameter B has been made conditional on the other model parameters as:

$$B = b.\ SSB_0$$

where SSB_0 is the stock size for F =0, and b may take the value 0.1 or 0.01. The form of the stock-recruit relationship for the two values of this parameters are given in Figure 4.4.1.

Variability in Recruitment

Variability of recruitment is modelled as a normal distribution of e, as N(0,s2), where

s2 = 0.4 or 1.5 to simulate low or high variability in recruitment.

Selection Pattern

Two selection patterns (S) as fishing mortality relative to a reference fishing mortality are defined:

(1 - 'Uniform') - S = 1 for all ages

(2 - 'Mature') - S = 1 for mature fish
S = 0 for immature fish

Reference fishing mortality

This is defined as the mean fully-recruited fishing mortality (ie mean F fora ges where S is not equal to zero).

Biological reference points

Table 4.4.1 shows estimates of some biological reference points calculated from the above parameters (K, b, s, choice of selection pattern) as defined above. They have been calculated by simple tabulation of yield against fishing mortality in intervals of F=0.01, hence their precision is no greater than that corresponding to an interval in F of 0.01.

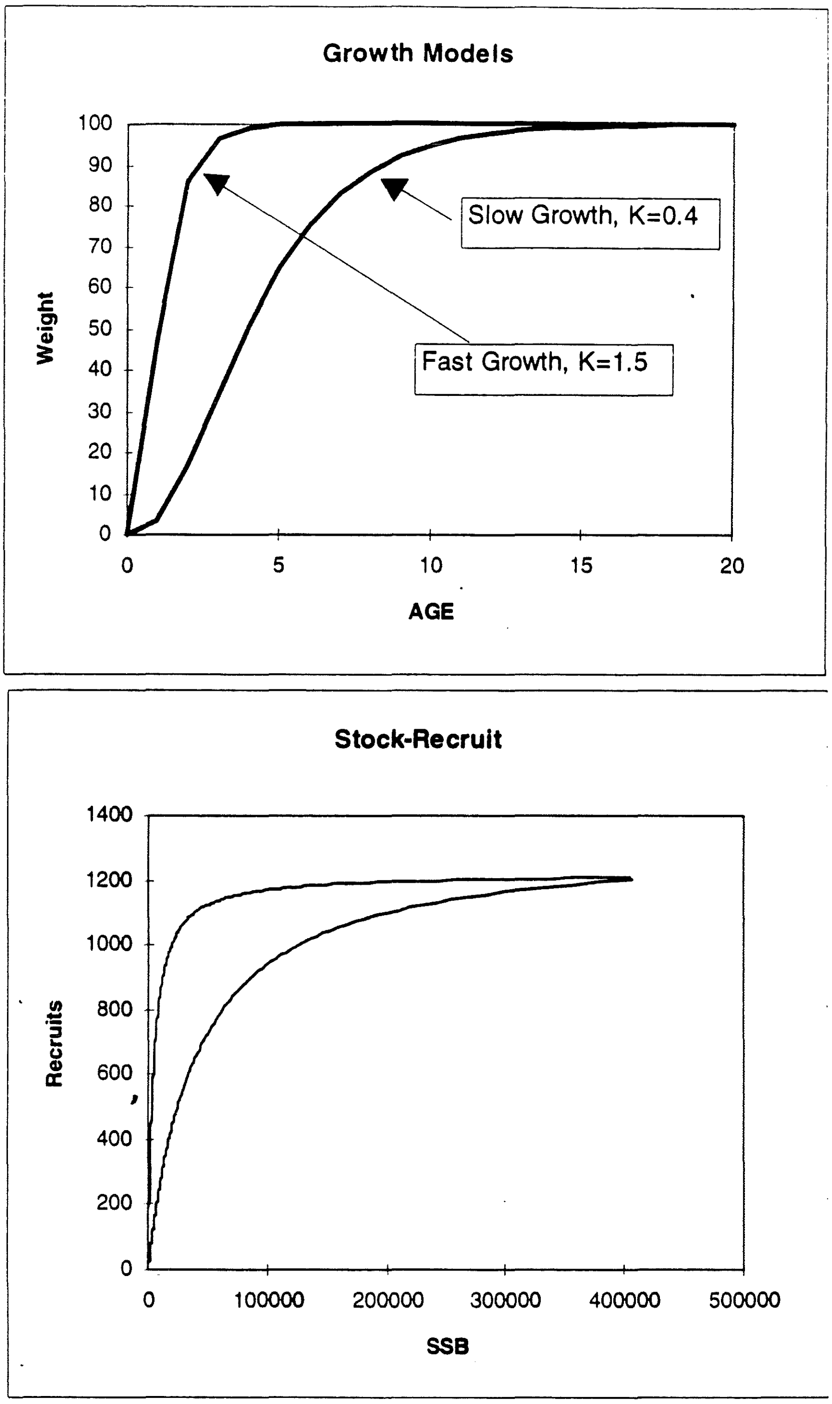


Figure 4.4.1. Growth models (upper panel) and recruitment models (lower panels) used for the simulations

4.4.2 Information available to management

Rather than implement an assessment model (POM), a simplified simulation method is used to obtain some basic results. Thus, measurement and assessment errors are simulated by assuming that estimates of reference points are done initially (while defining the harvest control law) and that these have a CV of 40% (i.e. standard error of 0.4 on log scale).

The growth and maturation parameters are assumed known and fixed equal to the true population values. Annual estimates of stock size are assumed to be unbiassed but to include a CV of 0.2. The same annual error multiplier is assumed for biomass and recruitment when F_{med} is estimated.

4.4.3 Examples of deterministic trajectories

Figures 4.4.2-4.4.4 give examples of harvest control laws along with projected trajectories of catch, SSB and fishing mortality using two different representations. Also given in each figure is the equilibrium curve.

The harvest control laws shown are obtained by using the confidence interval for the respective parameters, i.e. using the underlying (true) κ=0.4 as the known uncertainty in the estimates of F_{crash}, F_{MSY} and $F_{comfie(1)}$.

In the alternative approach, any reference point can be used as a basis in the harvest control law. The examples given here are based on $F_{crash}\ e^{-2\kappa}$,$F_{MSY}\ e^{-2\kappa}$, and of course variations on F_{comfie}. Two versions of the latter are considered, firstly $F_{comfie(1)}=\min(F_{MSY},F_{med},F_{0.1})$ and secondly $F_{comfie(2)}=\min(F_{MSY},F_{med})\ e^{-2\kappa}$. When using this alternative approach κ was chosen so as to satisfy the criterion that the probability of recovery of the stock above the MSY level was achieved with about 50% probability for all 16 simulated stocks after 10 years of applying the harvest control law.

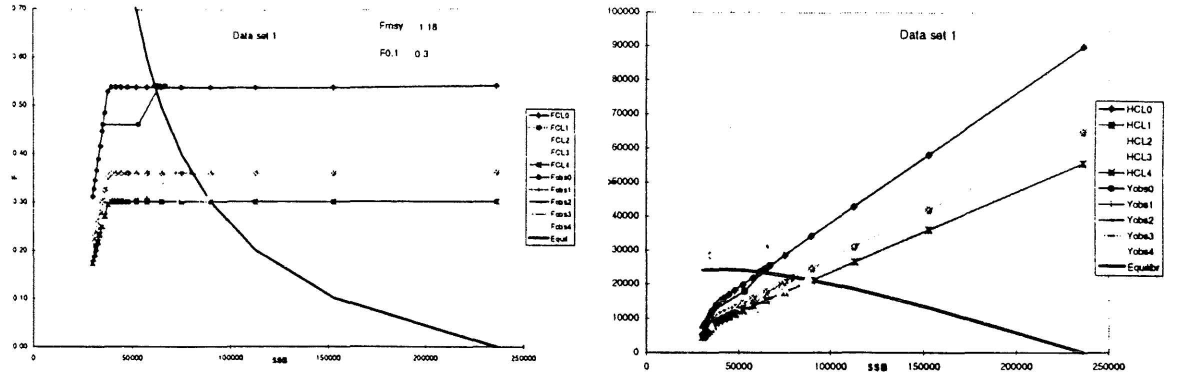


Figure 4.4.2. Deterministic simulations using generated data set 1. Harvest control laws based on (0) F_{crash} with κ=0.4, (1) F_{MSY} with κ =0.4, (2) $F_{0.1}$ with κ =0, (3) F_{comfie} without $F_{0.1}$ but with κ =0.4 and (4) F_{comfie} with $F_{0.1}$ and κ =0. (a) Results plotted in the S-F plane, where the fishing mortality in the harvest control laws is piecewise linear (b) Results plotted in the S-Y plane, where the equilibrium yield curve is in its most common form.

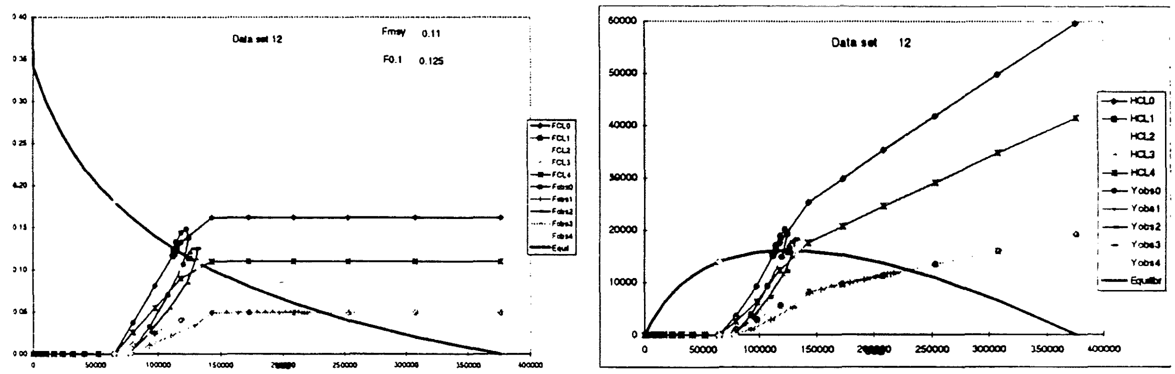


Figure 4.4.3. Deterministic simulations using generated data set 12. Harvest control laws based on (0) F_{crash} with s=0.4, (1) F_{MSY} with κ=0.4, (2) $F_{0.1}$ with κ =0, (3) F_{comfie} without $F_{0.1}$ but with κ =0.4 and (4) F_{comfie} with $F_{0.1}$ and κ =0. (a) Results plotted in the S-F plane, where the fishing mortality in the harvest control laws is piecewise linear (b) Results plotted in the S-Y plane, where the equilibrium yield curve is in its most common form.

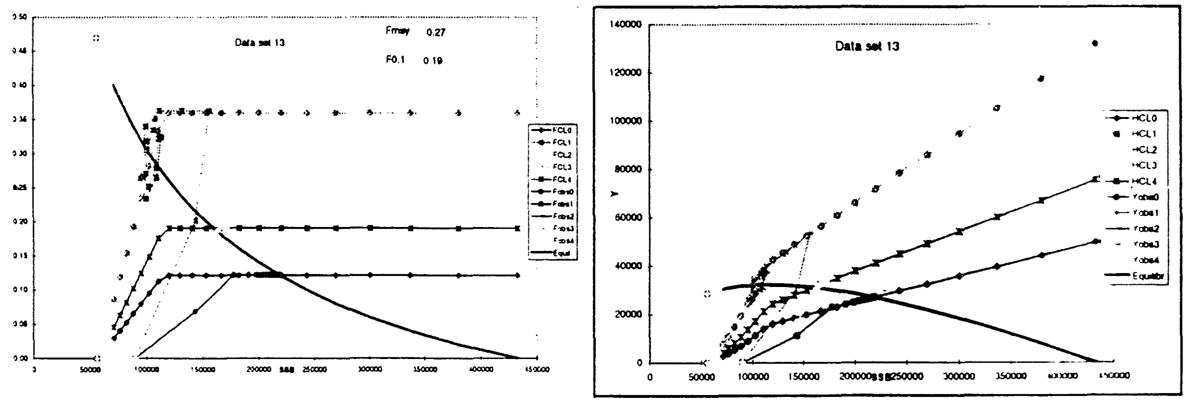


Figure 4.4.4. Deterministic simulations using generated data set 1. Harvest control laws based on (0) F_{crash} with κ=0.4, (1) F_{MSY} with κ =0.4, (2) $F_{0.1}$ with s=0, (3) F_{comfie} without $F_{0.1}$ but with κ =0.4 and (4) F_{comfie} with $F_{0.1}$ and κ =0. (a) Results plotted in the S-F plane, where the fishing mortality in the harvest control laws is piecewise linear (b) Results plotted in the S-Y plane, where the equilibrium yield curve is in its most common form.

4.4.4 Choices of scenarios

Figure 4.4.5 shows how the probability of recovery in 10 years increases as is increased in the F_{MSY}-based rule using data set 13. It is seen that simply using the correct standard error of 0.4 is nowhere near sufficient to allow for recovery with a high probability. If this formulation (i.e. $F_{pa}=F_{MSY}\, e^{-2\kappa}$ within the same HCL) is to be used, it is therefore clear that alternative values of κ need to be considered if recovery is an objective.

One approach to this is to select values of κ to fulfill a given probability of recovery (as described in Section 4.2). For example, it is possible to stipulate a minimal probability of 50% in achieving B_{MSY} in 10 years. It is seen in Figure 4.4.5 that if F_{MSY} is to be used as a basis for an F_{pa} then this will have to be reduced to a small fraction of the original value if the rebuilding target is to be met.

Initial population sizes were generated by assuming the population to start in equilibrium, i.e., with the equilibrium recruitment corresponding to a fishing mortality which gives a stock at ½ B_{MSY} . The stocks are thus assumed to start off in a depleted state and need to go through a rebuilding phase in order to meet the rebuilding target of B_{MSY}. In addition, initial stock size is generated by adding stochastic process error onto these stock sizes. These errors are taken as lognormal, with standard errors on a log-scale of 0.65, 0.50 and 0.45 on the youngest ages but 0.2 on the older.

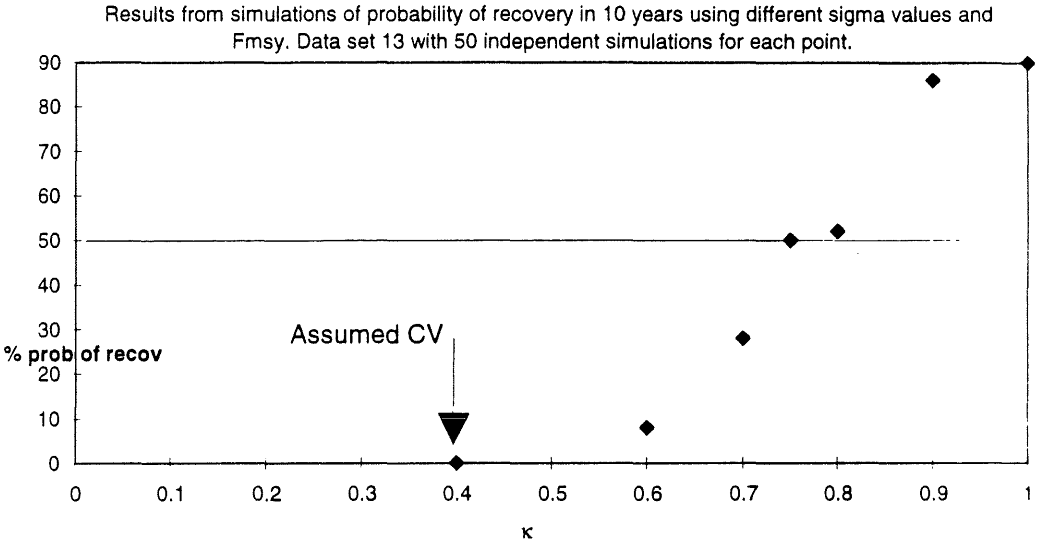


Figure 4.4.5 Recovery probabilities from simulations based on F_{msy} using increasing values of κ, starting with the true value, 0.4. Underlying population taken from simulated data set 8 (the worst case for F_{MSY} with this criterion). A 50% probability of recovery is only attained when κ is increased to about 0.75.

4.4.5 Results

Tables 4.4.2-7 give summaries of results from the simulations. It is seen that some of these simulated populations are quite difficult in terms of obtaining recovery. In particular it is seen that a strategy such as F_{MSY}, which gives decent catches (75% of MSY or more in Table 4.4.8) gives very poor performance in terms of rebuilding the stock (possibly as low as 0% in Table 4.4.5).

It is also seen that even using a strategy using $F_{0.1}$ can in some scenarios result in a lack of rebuilding of the stock (Table 4.4.5). In this particular case it is of some interest to consider the effect of reducing F to 0 at a higher biomass than F_{lim},, and this is also shown in Table 4.4.5. This is implemented through increasing the slope of the line from $F_{0.1}$ at B_{MSY} so that it reaches zero at a level, B_{buf}, higher than B_{lim},. In this example B_{buf} is taken as ¾ B_{MSY}. It should be noted that /// is so high that the resulting F_{pa} will in many cases be considerably less than $F_{0.1}$.

Finally, Figures 4.4.6-7 illustrate the tradeoffs involved in going from low yield-low risk to high yield-high risk harvest control laws. This is particularly clear in Figure 4.4.6, where the worst case (of 16) of probability of biomass falling below B_{lim} is plotted for each harvest control law against the worst case (of 16) of the expected average annual yield from that harvest control law. From Table 4.4.2-7 it is clear that data sets 4, 8, 12 and 16 are very difficult due to the recruitment dynamics. Figure 4.4.7, therefore, shows the results when using only the remaining 12 data sets.

Table 4.4.2 Expected number of years until recovery.

	CCL									
	Fcrash	Fmsy					F0.1	Fcomfie	Fcomfie w/F0.1	F0.1 w/Bbuf
	1.5	0	0.25	0.5	0.75	1	0	0.5	0	0
DATASET										
1	2	27	14	2	2	2	2	2	2	2
2	2	30	26	15	6	2	16	2	3	18
3	4	23	14	9	4	4	24	4	16	23
4	9	29	24	17	13	10	29	8	12	28
5	2	25	11	2	2	2	5	2	3	5
6	2	30	27	19	9	5	24	3	6	25
7	4	27	20	9	4	4	25	4	17	24
8	10	30	26	21	16	10	30	8	13	30
9	5	22	10	6	4	5	18	5	10	15
10	9	26	21	13	7	7	25	7	11	24
11	6	21	13	8	7	6	27	6	18	24
12	13	27	23	18	14	13	30	11	15	27
13	3	21	13	6	4	3	17	3	9	18
14	9	27	23	16	9	7	26	7	11	26
15	5	23	12	8	5	5	29	5	16	26
16	14	27	24	20	15	13	30	11	15	29

Table 4.4.3 Probability (%) of fishing at above Fmsy

	CCL									
	Fcrash	Fmsy					F0.1	Fcomfie	Fcomfie w/F0.1	F0.1 w/Bbuf
	1.5	0	0.25	0.5	0.75	1	0	0.5	0	0
DATASET										
1	0	7	0	0	0	0	0	0	0	0
2	0	6	0	0	0	0	0	0	0	0
3	0	24	5	1	0	0	10	0	5	11
4	0	20	3	0	0	0	9	0	1	10
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	24	4	0	0	0	5	0	2	5
8	0	18	3	0	0	0	3	0	0	4
9	0	25	5	0	0	0	9	0	4	9
10	0	20	5	0	0	0	7	0	1	7
11	0	22	4	0	0	0	39	0	13	40
12	0	20	5	0	0	0	35	0	3	35
13	0	23	7	0	0	0	4	0	2	5
14	0	19	7	0	0	0	3	0	1	3
15	0	28	5	1	0	0	35	0	9	35
16	0	17	5	1	0	0	30	0	2	29
All Max.	0	28	7	1	0	0	39	0	13	40

Table 4.4.4 Probability (%) of recovery (B>Bmsy permanently) in 5 years

	CCL									
	Fcrash	Fmsy					F0.1	Fcomfie	Fcomfie w/F0.1	F0.1 w/Bbuf
	1.5	0	0.25	0.5	0.75	1	0	0.5	0	0
DATASET										
1	100	4	37	98	100	100	98	100	100	96
2	100	0	4	35	78	98	31	98	91	24
3	93	16	34	62	86	88	10	79	23	8
4	48	0	5	23	41	53	1	60	24	1
5	100	4	51	100	100	100	79	100	93	82
6	99	0	3	17	63	83	3	90	64	4
7	86	4	21	55	79	84	4	84	24	5
8	40	1	4	15	26	43	2	50	24	0
9	86	19	59	76	88	89	27	80	52	37
10	57	4	14	35	59	58	4	55	33	10
11	43	12	19	27	37	45	1	35	15	9
12	20	2	6	6	19	21	0	22	11	4
13	97	26	51	86	95	95	33	98	59	24
14	51	4	12	30	53	67	4	58	42	6
15	63	15	40	52	67	67	3	76	34	7
16	25	5	4	18	28	26	0	34	17	0
All Min.	20	0	3	6	19	21	0	22	11	0

Table 4.4.5. Probability (%) of recovery (B>Bmsy permanently) in 10 years.

	CCL									
	Fcrash	Fmsy					F0.1	Fcomfie	Fcomfie w/F0.1	F0.1 w/Bbuf
	1.5	0	0.25	0.5	0.75	1	0	0.5	0	0
DATASET										
1	100	5	45	98	100	100	99	100	100	97
2	100	0	6	42	80	99	34	100	93	30
3	100	24	55	76	97	100	16	99	40	16
4	69	1	13	34	58	68	1	78	59	3
5	100	10	57	100	100	100	84	100	94	85
6	100	0	6	24	71	87	9	97	85	6
7	100	6	27	73	96	99	8	98	40	10
8	70	2	8	24	43	66	2	74	51	0
9	99	23	75	91	100	100	36	99	74	48
10	74	8	25	53	81	87	8	85	59	14
11	96	30	59	80	94	99	10	97	37	20
12	51	6	19	31	52	59	1	56	41	7
13	100	29	61	90	99	100	39	99	69	28
14	73	5	17	44	73	84	6	86	61	9
15	99	24	62	81	98	99	5	99	46	11
16	49	7	16	30	45	56	0	59	44	2
All Min.	49	0	6	24	43	56	0	56	37	0

Table 4.4.6 Probability (%) of recovery (B>Bmsy permanently) in 20 years.

	CCL									
	Fcrash	Fmsy					F0.1	Fcomfie	Fcomfie w/F0.1	F0.1 w/Bbuf
	1.5	0	0.25	0.5	0.75	1	0	0.5	0	0
DATASET										
1	100	9	66	100	100	100	99	100	100	98
2	100	2	21	61	88	100	57	100	97	52
3	100	36	68	82	100	100	27	100	59	31
4	88	9	27	57	73	84	10	95	82	10
5	100	22	76	100	100	100	90	100	98	89
6	100	1	8	45	82	93	26	100	95	22
7	100	14	42	87	100	100	25	100	56	28
8	84	3	17	40	58	84	5	93	78	1
9	100	36	79	94	100	100	52	100	88	65
10	88	22	41	71	96	98	19	98	85	25
11	100	44	76	95	100	100	20	100	55	28
12	80	14	36	57	76	77	3	87	73	15
13	100	38	65	93	99	100	54	99	83	50
14	82	12	29	62	85	92	15	95	84	14
15	100	30	75	91	100	100	9	100	64	20
16	71	13	29	43	69	78	1	84	72	5
All Min.	71	1	8	40	58	77	1	84	55	1

Table 4.4.7 Probability (%) of collapse (B<Blim in any year after the initial 5 years).

	CCL									
	Fcrash	Fmsy					F0.1	Fcomfie	Fcomfie w/F0.1	F0.1 w/Bbuf
	1.5	0	0.25	0.5	0.75	1	0	0.5	0	0
DATASET										
1	0	15	0	0	0	0	0	0	0	0
2	0	78	38	3	0	0	1	0	1	5
3	0	21	4	1	0	0	2	0	3	2
4	0	57	21	8	2	1	43	0	5	45
5	0	17	0	0	0	0	0	0	0	0
6	0	85	42	9	2	1	34	0	2	21
7	0	32	9	0	0	0	5	0	3	5
8	1	76	47	21	8	2	68	2	14	66
9	0	9	1	0	0	0	1	0	0	1
10	0	38	8	0	0	0	10	0	0	12
11	0	10	0	0	0	0	2	0	2	5
12	2	23	12	4	3	2	41	2	9	29
13	0	19	2	0	0	0	0	0	0	0
14	1	42	31	4	3	0	23	0	4	22
15	0	17	1	0	0	0	12	0	4	5
16	4	42	27	14	12	5	58	3	26	48
All Max.	4	85	47	21	12	5	68	3	26	66

Table 4.4.8 Expected average annual yield in % of MSY.

	CCL									
	Fcrash	Fmsy					F0.1	Fcomfie	Fcomfie w/F0.1	F0.1 w/Bbuf
	1.5	0	0.25	0.5	0.75	1	0	0.5	0	0
DATASET										
1	33	98	93	80	66	49	81	60	75	81
2	33	98	89	81	61	47	80	31	37	79
3	37	85	74	62	46	33	83	41	75	83
4	34	75	71	56	46	30	79	19	32	76
5	26	89	80	68	53	40	76	48	69	77
6	24	83	72	60	49	38	70	19	37	67
7	31	84	78	67	50	37	81	50	77	81
8	29	75	72	62	47	31	77	23	34	79
9	46	88	78	58	42	28	87	43	80	87
10	40	87	75	59	42	29	85	23	49	87
11	27	80	65	48	33	22	87	32	72	85
12	27	81	62	48	32	19	77	14	31	77
13	45	90	78	65	47	33	88	42	80	87
14	44	90	76	57	48	31	92	21	42	87
15	30	83	69	55	38	26	88	35	74	88
16	30	73	74	50	37	23	83	15	31	80

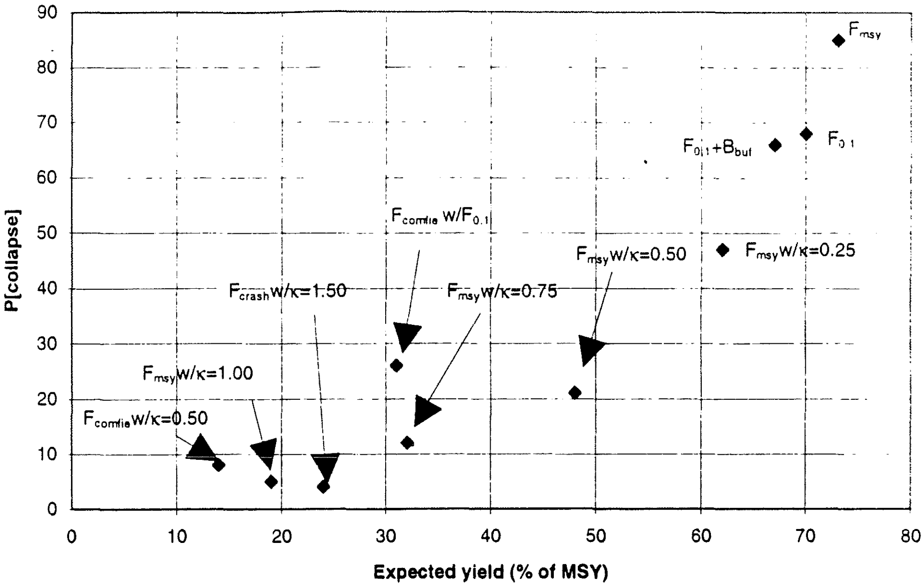


Figure 4.4.6. Worst case expected yield against worst case probability of collapse for each catch control law considered in section 4.4. Worst case is defined as the minimum yield and maximum probability, respectively. All 16 data sets included. The point labels indicate the underlying fishing mortality in the catch control law along with any additions such as the level of κ (e.g. F_{msy}w/κ=0.50 indicates using F_{msy} with κ =0.5).

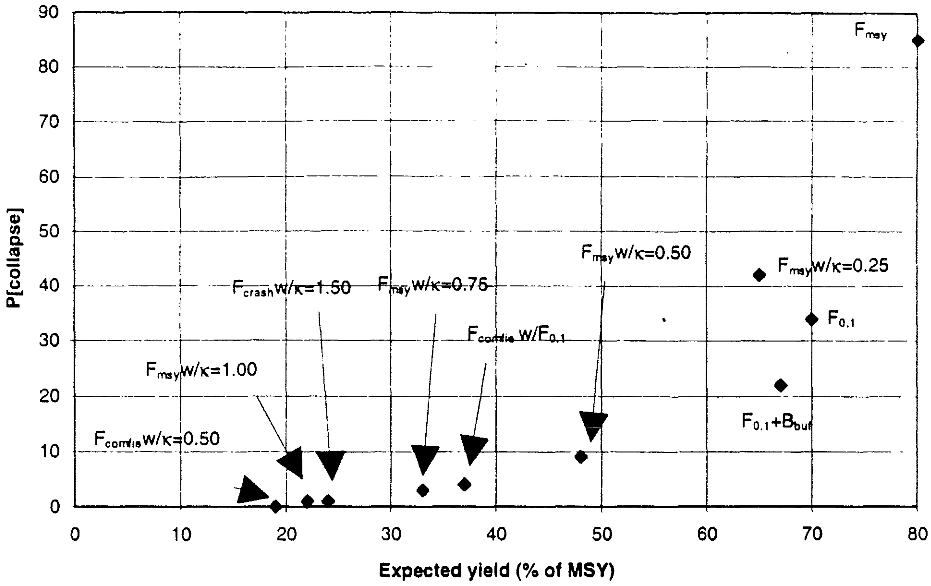


Figure 4.4.7. Worst case expected yield against worst case probability of collapse for each catch control law considered in section 4.4. Worst case is defined as the minimum yield and maximum probability, respectively. Data sets 4, 8, 12 and 16 omitted. The point labels indicate the underlying fishing mortality in the catch control law along with any additions such as the level of κ (e.g. F_{msy}w/κ=0.50 indicates using F_{msy} with κ =0.5).

4.5 Simulations based on North Sea Plaice-like stock

4.5.1 Introduction

This section primarily outlines results of control law evaluation for a North Sea plaice-like stock carried out using a POM error : IRP experiment described in Section 6; CFEWG, 1996 and Kell *et al* (WC8). That model comprises an underlying fisheries system in which catchabilities, maturities, growth and recruitment are all modelled using extensive data sets, as part of the comprehensive fishery evaluation for North Sea flatfish fishey. The underlying fishery system generates data with observation error and assessments are carried out which lead to the perceived fishery system, which is used as a basis for control of the underlying fishery system (see Sections 4.1 and 4.2) . The model has been run for a range of control law options and with recruitment, mis-reporting and effort control variations. Prior to interpreting the results of the POM error :IRP experiment, a PO error : IRP experiment was also run to compare the outputs with those obtained using full feedback control.

First, a POM error :IRP experiment was run deterministically and stochastically using simulated data set 13 (Section 4.4.1) . A PO error :IRP experiment was run using the same software for the POM error experiment. The results are described in Section 4.5.2 and compared with a PO error :ERP experiment described in section 4.4.2.

Second, a PO error : ERP experiment for North Sea plaice , using the spreadsheet described in Section 4.4, was run for some of the simpler options investigated using the POM error experiment. This was done to compare the effects not just of feedback but also of the underlying fisheries system model being different to the assessment. Results are presented and discussed in Section 4.5.3.

4.5.2 How do stochastic components and feedback effect our perception of control law effectiveness?

The point of using POM error experiments is that evaluations and comparisons can be made when account is taken of underlying fishery system mis-specifications (i.e. imperfect knowledge). In the comparisons made here, however, no mis-specification is included and noise is introduced only in recruitment and catch. The comparisons show, therefore, how feedback alone might affect this particular simulation. Any stochastic effects will be small in the simulation set up and the interaction of the noise specification with feedback, will be minimal. Reference to WC8, however, where extensive stochastic outputs are shown across a range of weak structural assumptions, reveals a potentially rich set of stochastic behaviours.

In Section 4.4.2., Tables 4.4.2-8 show the probabilities of recovery and collapse for 16 simulated stock data sets. The text table below shows the results obtained using the PO error :IRP and POM error :IRP experiments using the same Fishlab software, and the spreadsheet based PO error :ERP experiment, on simulated data set number 13 (Table 4.4.1) using $F_{pa} = F_{0.1}$, with $B_{lim} = 0.5\ B_{msy}$; $B_{buf} = 0.75\ B_{msy}$ and $B_{pa} = B_{msy}$. For the POM error experiment, the assessment used was XSA with exact catch at age data and one tuning fleet representing an unbiased survey.

	P(F > Fcras)	P(F> Fmsy)	P(B > Bmsy;5)	P(B > Bmsy;10)	P(B > Bmsy;20)	P(B < Blim)	E(Y %MSY)
PO :ERP	0.0	0.03	0.34	0.38	0.59	0.0	89
PO :IRP	0.0	0.03	0.46	0.58	0.74	0.0	74
POM :IRP	0.0	0.03	0.54	0.87	0.93	0.0	68

The PO error :IRP experiment results broadly agree with those calculated with PO error :ERP (spreadsheet) experiment reported in Section 4.4. Any differences in the two PO experiments could be due to a variety of minor simulation differences. These include a constraint of F = 0.1 in the PO error :IRP experiment, included to make comparisons with the POM error experiment; a slightly different initial population structure; use of different random number genrators; the internal generation of F_{pa}; the use of F_{max} as an estimator of F_{msy} and minor projection program differences, including the interpolation technique and the use of F_{max} as an estimator of F_{MSY}. For future comparisons, a standard population generator should be constructed.

In the PO error :ERP experiment runs, the fishery is closed, SSB recovers quickly and thereafter the fishery operates at the externally supplied reference point $F_{0.1}$ (= 0.19). The PO error :IRP experiment displays very similar behaviour with the IRPs being set close to the ERP values. The deterministic trajectories of F, or the stochastic medians, are completely flat (Figure 4.5.2). The medians of the stochastic runs lie on the deterministic trajectory because the only noise in the simulations is normally distributed about recruitment and catch. Note that the probabilities in the text table are conditional on the noise levels introduced in the simulations.

The POM error :IRP experiment results are different (Fig. 4.5.2). This is entirely due to the explicit addition of assessments and feedback to the underlying fishery system. The POM error :IRP experiment leads to slightly slower recovery than the PO error :IRP experiment but with F levels reduced less severely in the early simulation years and eventual higher levels of SSB. F is only slowly recovered towards 0.19, whilst in the PO error :IRP experiment runs, F is reduced immediately and eventually jumps to 0.19. Overall yield in the POM experiment is lower.

This difference occurs because the natural mortality is 0.2 and F_{pa} is 0.19 or less - at the beginning of the simulations, SSB is at 0.5 B_{msy} and the control law requires that F_{pa} be set to a small value. As the simulations start, therefore, the assessments converge poorly (Pope, 1972) and F is over estimated in this case. (Note that shrinkage across F was not used in the assessments and the assessment data were unbiased.) The results from the POM error :IRP experiment indicate slower recovery and a gain in yield, than the PO error :IRP experiment. The stochastic POM experiment results are only slightly different to the deterministic trends. It can be seen, however, that even the small introduction of noise into recruitment can lead to different stochastic results when feedback is included in the simulations. With fuller descriptions of errors in the simulations and interactions between structural components, the stochastic behaviour with feedback can be very different. This, of course, will have an effect on the probabilities set for judging performance. A POM error experiment, although more difficult to set up than a PO error experiment, is more able to correctly capture the statistical structure of the variances and co-variances in the assessment and control models.

Generally, the differences between PO and POM error experiment results depend on the detailed underlying fishery system model and the particular assessment and control laws employed. For other simulation runs, the discrepancy between PO, POM and stochastic runs could be quite different.

The most noticeable effect seen in Figure 4.5.2 is that the feedback in the POM experiment has a more marked effect than introducing stochastic effects.

4.5.3 A comparison of PO error :ERP and POM error :IRP experiments used to evaluate control laws for a North Sea plaice-like stock

The Parametric PO error : ERP experiment used in Section 4.4.2 was also parameterised for North Sea plaice, in as consistent a manner as possible with the POM error :IRP experiment's underlying fishery system. The model was run for four control laws with an underlying Ricker recruitment model, true catch reporting and catch control. The four control laws studies can be seen in the caption to Figure 4.5.3 and are described in the PA SG and Section 2.1 of this report. The particular SSB limit and pa levels were chosen for consistency with the F limit and pa levels, rather than using B_{msy} as a default. The use of B_{msy} would have simply closed the fishery.

The POM error :IRP experiment for North Sea plaice had previously been used to investigate the same control laws under the same assumptions in the underlying fishery system and with full XSA assessments and feedback. The parameterisation of the assessments was in accord with that used by the North Sea Demersal WG. Figures 4.5.3 a-d compare yield versus SSB results from the two experiments, run deterministically. These demonstrate the differences in general behaviour but cannot convey the very different stochastic behaviours that can result from the far more complex POM experiment, as shown in WC8 and indicated above.

In general, the PO error :ERP experiment results in far tighter trajectories of yield and SSB, and mostly keep SSB below the SSBpa levels. The POM error :IRP experiment, in contrast, always indicates longer recovery periods but to higher SSB levels. Detailed comments on the POM error experiment results are given below. The intention here is to highlight that even with relatively simple underlying fishery system model differences and no major structural mis-specifiactions, the assessment and feedback control loop of the POM error .IRP experiments lead to a different understanding of the control law behaviours which is not always intuitive. This is in line with the comparison made on simulation number 13, above, but the PO error :ERP and POM error IRP results are now far more discrepant.

4.5.4 Using the full Parametric POM error : IRP experiment for a North Sea plaice-lik stock

Extensive runs were reported in WC8. The four control laws were investigated, as well as replacement F as an alternative, not just as reported in the previous section but with all combinations of mis-reporting or not, Ricker recruitment or an autoregressive time-series recruitment model, and catch or effort control. The full range of outputs are too large to include here, but some examples for a particular control law and underlying fishery system specification are shown in Fig. 4.5.4.

The control law stops over-fishing by reducing fishing mortality and promoting a recovery in an over-fished stock by increasing spawning stock biomass. The *recovery contròl law* is intended to move the fishery (stock) into a sustainable region of the F versus SSB plane by triggering management at particular levels of F and SSB.

F_{Limit} and SSB_{Limit} (and hence F_{PA} and SSB_{PA}) can be derived from a range of biological reference points without altering the control law definition as given in Figure 4.5.1:

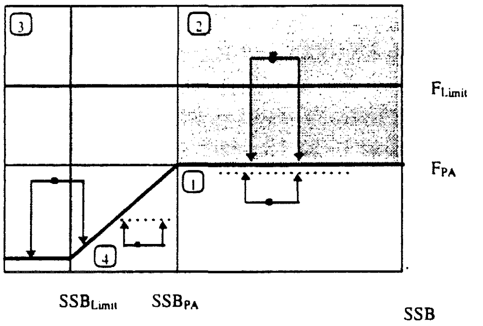


Figure 4.5.1 F_{Limit}, SSB_{Limit}, F_{PA} and SSB_{PA} define four regions of the F-SSB plane in which a particular control rule operates.

Region 1: This is the sustainable region and as long as SSB stays above SSB_{PA} F is set to be the average of the status quo F_{SQ} and F_{PA}.

Region 2: The stock is subject to over-fishing although SSB is above SSB_{PA} and hence the level at which the stock is said to be over-fished. The control rule reduces F by setting a new F which is F_{PA}.

Region 3: SSB has fallen below a level at which the probability of being currently over-fished is greater than 5% and F is above a safe level. The safe level of F is no longer defined simply by F_{Limit} or F_{PA} since the stock has a high probability of being over-fished and F must be reduced below the level thought safe for a stock which is not currently over-fished. The safe level (F_{Taper}) is defined as a line drawn between the points defined by ($F_{Closure}$, SSB_0), ($F_{Closure}$, SSB_{Limit}) and (F_{PA} and SSB_{PA}). $F_{Closure}$ is not the zero level of F but a small value to allow for by-catch and a research fishery to provide tuning data for assessments to monitor the state of the stock. Note that if F falls below M, the convergence of many tuned VPA methods is poor. The control rule reduces F by setting a new F which is F_{Taper}.

Region 4: The stock is at a low level but the current level of F is not over-fishing the stock since SSB and F are below SSB_{PA} and F_{Taper}, respectively. F is set to be the average of the status quo F_{SQ} and F_{Taper}. The ICES Study Group on the Precautionary Approach to Fisheries Management defined limits and thresholds (the PA levels) but not targets. In order to evaluate the performance of a HCL, a target is required. Implicitly, the PA level has been chosen as the target.

A number of important features of the North Sea flatfish fisheries, including size-dependent discarding and high-grading, are likely to have a major influence on control law performance and may need to be taken into account when making detailed comparisons of the performance of harvest control laws for a North Sea plaice-like stock. Accepting these shortcomings, the POM error :IRP experiments presented in WC8, probably represents the best potential basis for providing advice on North Sea plaice control laws, and may also be used for illustration of some general points. As currently implemented, the underlying fishery system consists of a fleets catchability model fitted to vessel trip data (CFEWG, 1996). This allows exploitation pattern to change in response to management as different fleet components are differentially affected. Basic biological parameters are also modeled on market sample and survey data, such that the maturity and weight-at-age in the underlying fishery system are different to those assumed in the assessments (CFEWG, 1996 and see Section 6.1). This can lead to considerable mis-perception of the true state of the underlying system, causing certain classes of control law to perform badly.

Although Fmed is appealing as an F_{pa}, it is clear from the simulations presented in WC8, that problems arise due to poor assessments at low F levels. Fmed is so low that the fishery is effectively closed and the data required for assessments become inadequate. Many BRPs such as $F_{0.1}$, F_{msy}, F_{max}, are similarly low, and their use would result in similar difficulties. Unless alternative assessment methods are to be used, it will not in practice be possible to utilise a control law parameterised using these BRPs. Alternative assessment procedures which are robust at low F levels therefore need to be investigated.

The stock and recruitment based BRPs (e.g. F_{Loss} and F_{crash}) are sensitive to mis-reporting and are also affected by inappropriate maturity or weight-at-age data. Given the levels of mis-reporting, discarding and high-grading which are known to exist in the North Sea flatfish fisheries, it would seem inadvisable to use these BRPs as part of a control law. Neither of these reference points results in SSB being recovered to the current MBAL, with greater than 95% probability, within even 20 years.

Results of runs with Flim set as $F_{CrashMedian}$; $F_{pa} = 0.91 * F_{lim}$; B_{lim} = 150,000t and B_{pa} = 300,000t are shown in Fig. 4.5.4. With no mis-reporting, F levels are reduced sufficiently low that the SSB returns to around 300,000t within 10 years in 95% of cases, under most test conditions. The simulations result in median SSB in the region of 400,000t and median F in the region of 0.25. This state is reached in 10 to 15 years and appears to be stable. With mis-reporting, however, F is maintained at lower levels for a longer period and median SSB overshoots to the region of 600,000t before median F rises and median SSB starts to decline. The stochastic results (Fig. 4.5.4.c) indicate the very wide spread of F and SSB levels that result from the noise, misperceptions and interactions of features such as mis-reporting. No attempt has been made here to interpret these for the purpose of management advice, although outputs relating to objectives could easily be derived (see e.g. CFEWG, 1996).

The control law parameterised with $F_{CrashMedian}$, associated with the particular B_{lim} and B_{pa}, would appear, therefore, to be a candidate for further exploration. It might, with further refinement and a detailed exploration of F_{pa}, SSB limit and pa levels, provide a basis for management of the North Sea plaice.

Note that F_{pa} calculated as $0.91 * F_{CrashMedian}$ was considerably higher than $F_{0.1}$ in the POM experiments (Fig. 4.5.4 a and b). Use of the control law, however, still led to SSB being recovered to high levels and yield being maintained. Case specific work of the kind reported here can lead to precautionary management without adopting over conservative reference points derived for general usage.

Last year at CEFWG, the plaice model utilised here was used to examine the implications of multi-annual strategies and a simple method of reducing F gradually to a target level (taking the average of F_{sq}, F_{med} and F_{mbal}). This year, WC8 reported the use of replacement F * 0.8 as a means of gradually reducing F towards a target level with a high probability of ensuring that SSB could only be increased in each year. The gradual reduction approaches have merit in that whilst they undoubtedly are less precautionary, they can recover stocks with less adverse effects on fisheries. Also, with catch control, severe reductions in F are likely to lead to mis-reporting. The scenarios with mis-reporting, examined in WC8, show that even a weak mis-reporting in response to F reduction, can cause severe difficulties in the application of control laws, due to biases in the assessments. The gradual reduction approaches, together with the multi-annual control law applications could also be further investigated for a range of control law formulations.

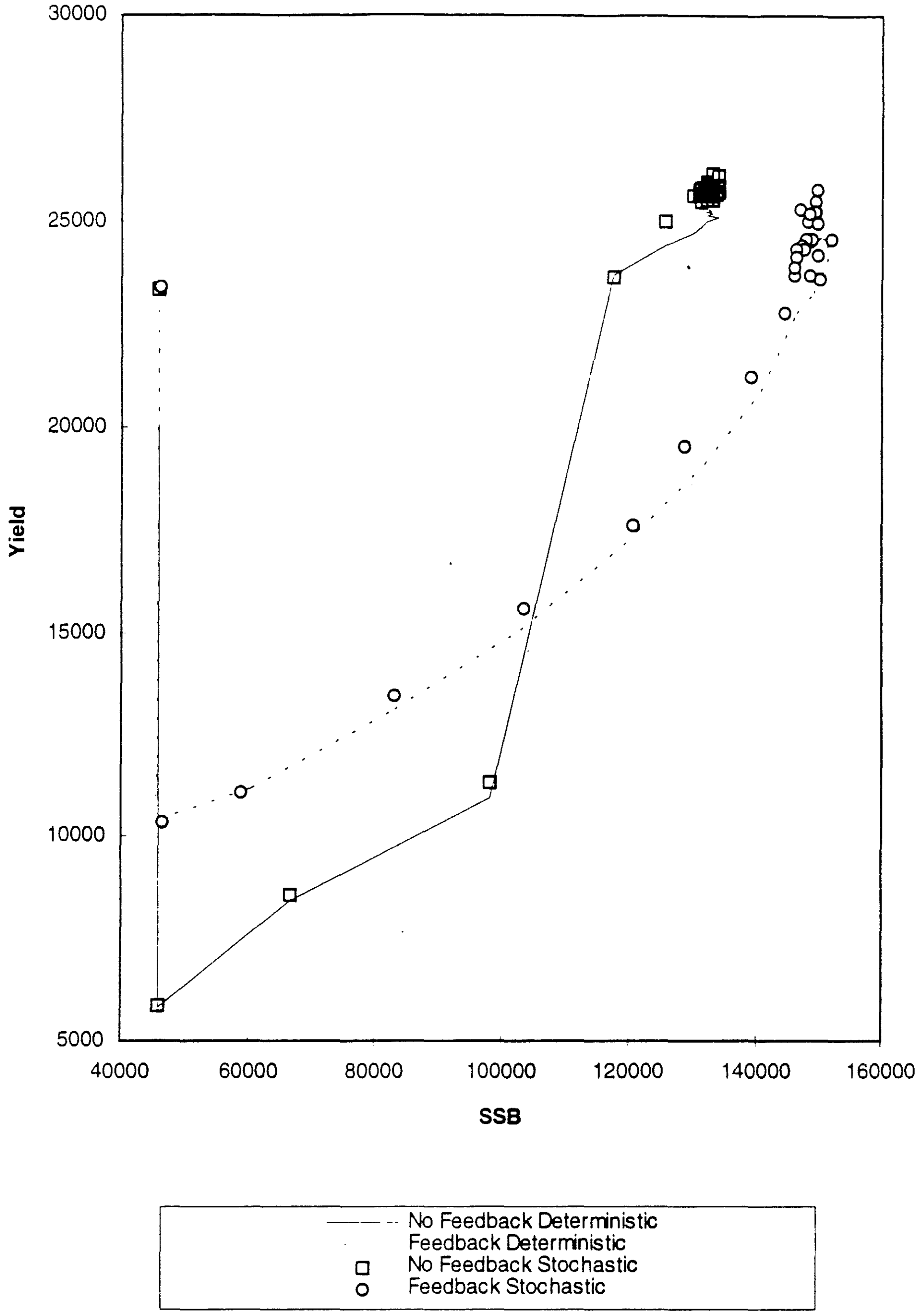


Figure 4.5.2 Yield versus SSB for PO error: IRP and POM error: IRP experiments run on simulated data set 13.

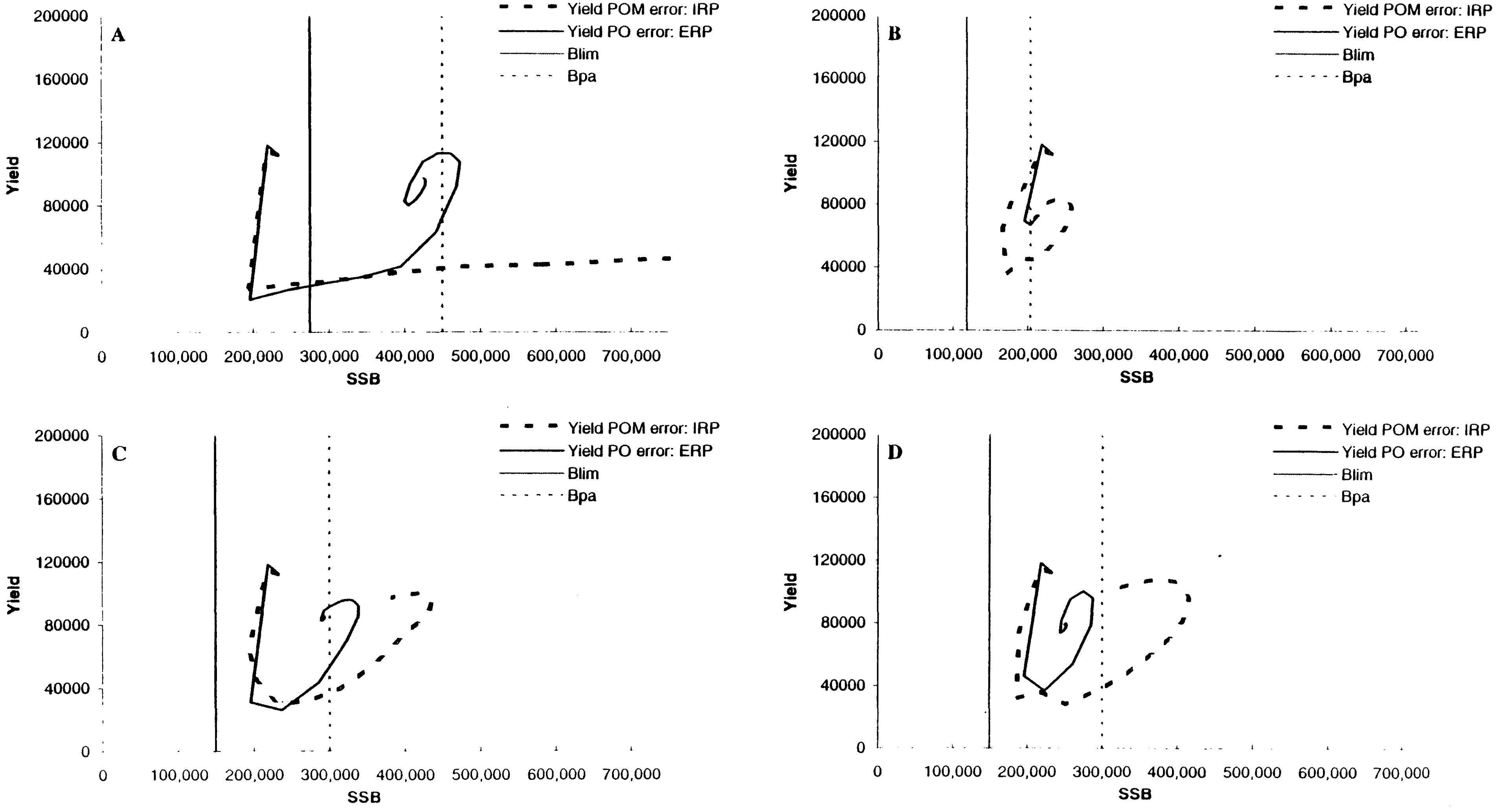


Figure 4.5.3 Yield vs SSB for PO error: ERP and POM error: IRP experiments. A) B_{LIM} = SSB90% R 90% Surv , B_{PA} = 164% B_{LIM}, F_{LIM} = F_{MED} , F_{PA} = 82% F_{MED}. B) B_{LIM} = SSB50% Ricker (B_{PA} = 171%), F_{LIM} = $F_{CRASH\ RICKER}$ (F_{PA} = 64%). C) B_{LIM} = SSB50% R Median (B_{PA} = 200%), F_{LIM} = $F_{CRASH\ MEDIAN}$ (F_{PA} = 89%). D) B_{LIM} = SSB50% R Median (B_{PA} = 200%), F_{LIM} = F_{LOSS} (F_{PA} = 91%)

Figures 4.5.4 a and b - Deterministic summary graphs

These plots summarise the deterministic behaviour (no stochastic or measurement error but including model mis-specification) of each experiment. They are primarily used as a check that the experiments are implemented correctly, but are also used for initial interpretation prior to stochastic runs.

Phase plots of F_{bar} against SSB and yield against SSB for both the operating model (i.e. the system) and the assessment (i.e. the perception) allow the behaviour of the control law under each experiment to be seen. The values of F_{Limit}, F_{PA}, SSB_{Limit} and SSB_{PA} from the system model are plotted for comparison. These are independent of the perceived status of the stock. The historical trajectory in the phase space is plotted for comparison, the perceived and true historical trajetories are the same. The replacement F and yield are also shown. If the system F and yield are above these values then SSB will decline. This allows the performance of the reference points to be assessed even though they are based on equilibrium assumptions.

The biases in the assessment for both F_{bar} and SSB and the level of mis-reporting are plotted against time. Such biases can cause the control law to under- or over-shoot the target.

The assessed F and SSB reference points and actual values of the limit and action reference points are plotted over time. This allows the bias and their stability over time, in the perceived values, to be seen.

Figure 4.5.4. c

Stochastic output of Fbar and SSB, and sample convex hulls at 5 and 15 years for FCrashMed scenarios with and without mis-reporting. Key: solid horizontal line: F_{limit}; dotted horizontal line: F_{PA}; solid vertical line: SSB_{Limit}; dotted vertical line: SSB_{PA}; unfilled triangle: mean generated under the system model; connected pluses: median (by year) generated under the system model; circle: identifies the particular year (namely, 5 and 15) from the assumed starting year of the experiment; unfilled triangle (inverted): median obtained under the perception of the system model for the particular year identified; inner polygon: convex hull corresponding to the 50th percentile region under the system model; outer polygon: convex hull corresponding to the 95th percentile region under the system model

Catch control, mis-reporting, Ricker stock recruit model, F Crash Median as F Limit and SSB 50% R Median as SSB Limit.

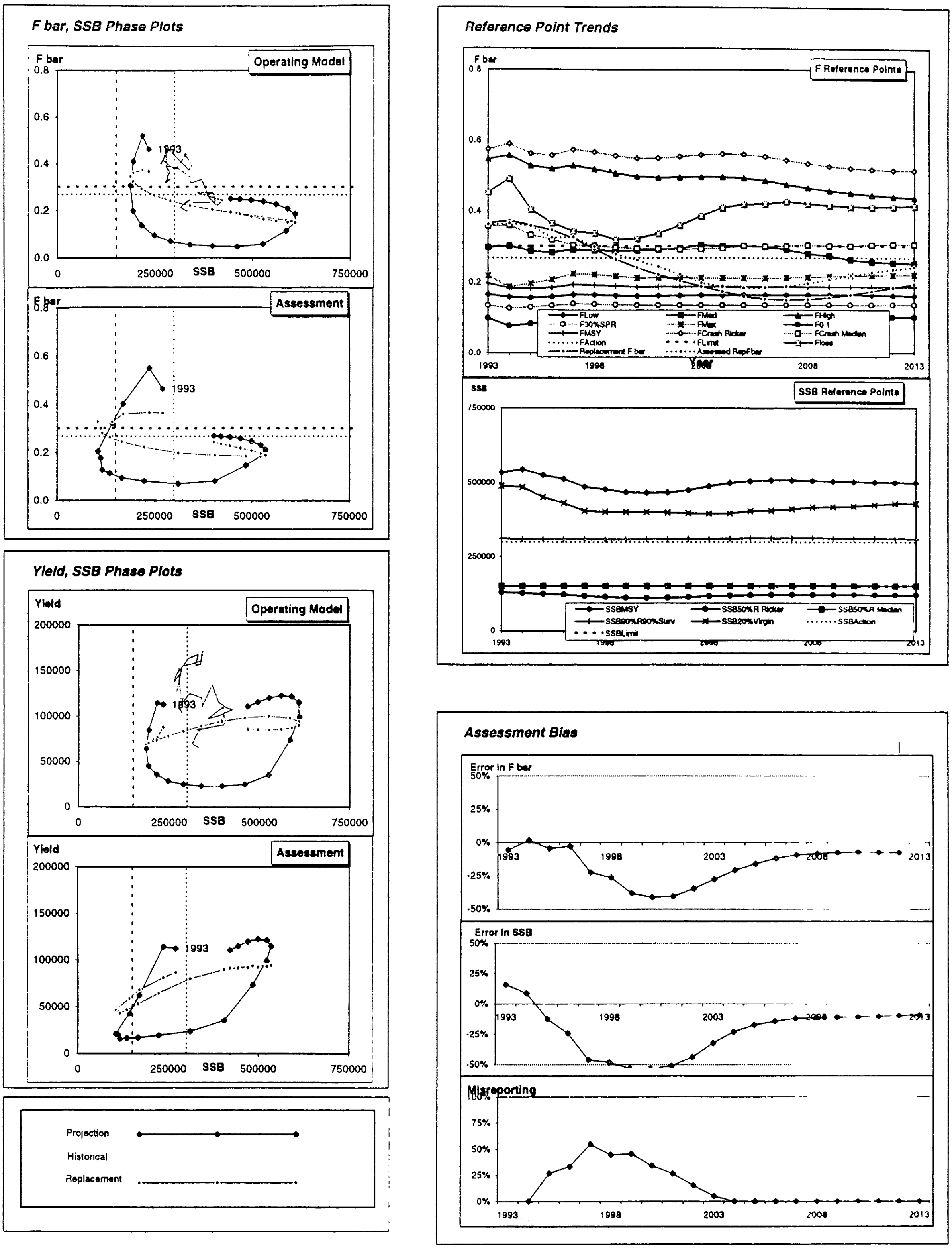
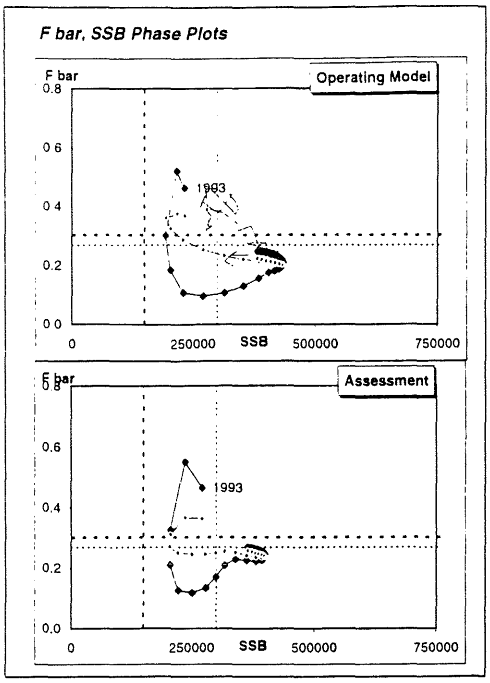
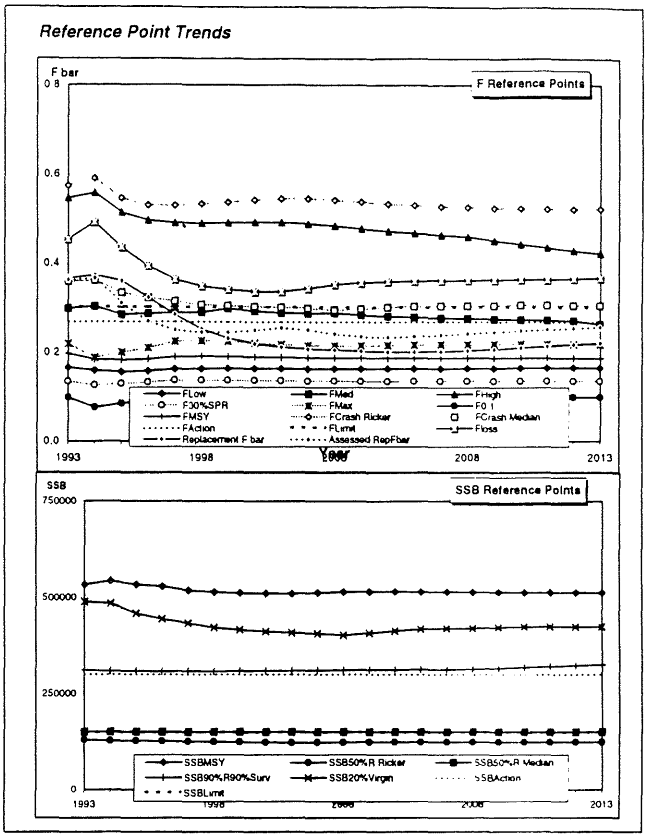


Figure 4.5.4a

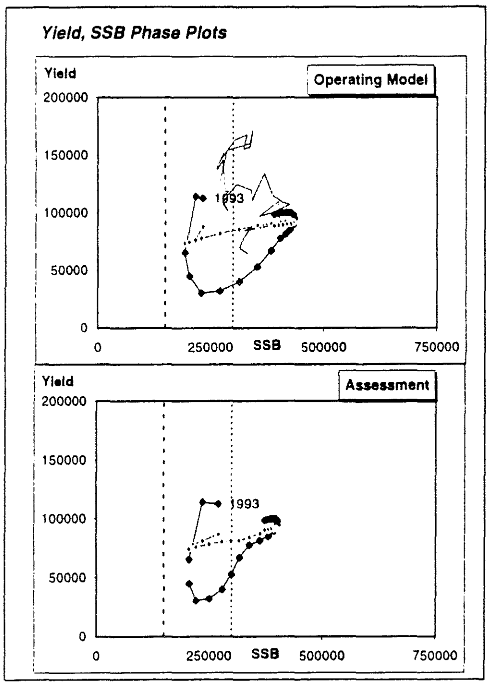
Catch control, no mis-reporting, Ricker stock recruit model, F Crash Median as F Limit and SSB 50% R Median as SSB Limit.



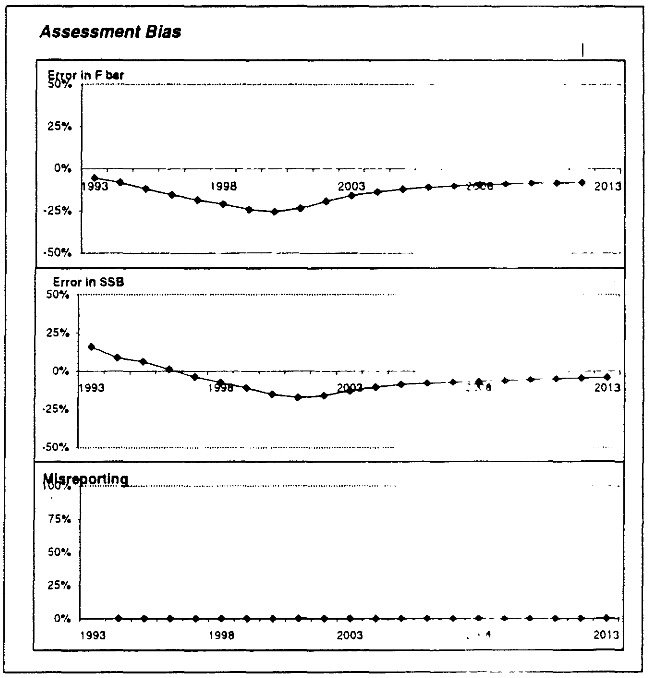
F bar, SSB Phase Plots



Reference Point Trends



Yield, SSB Phase Plots



Assessment Bias

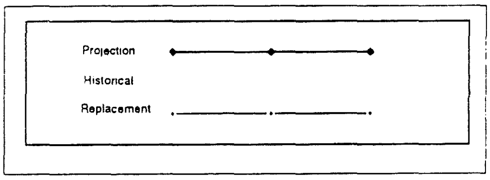
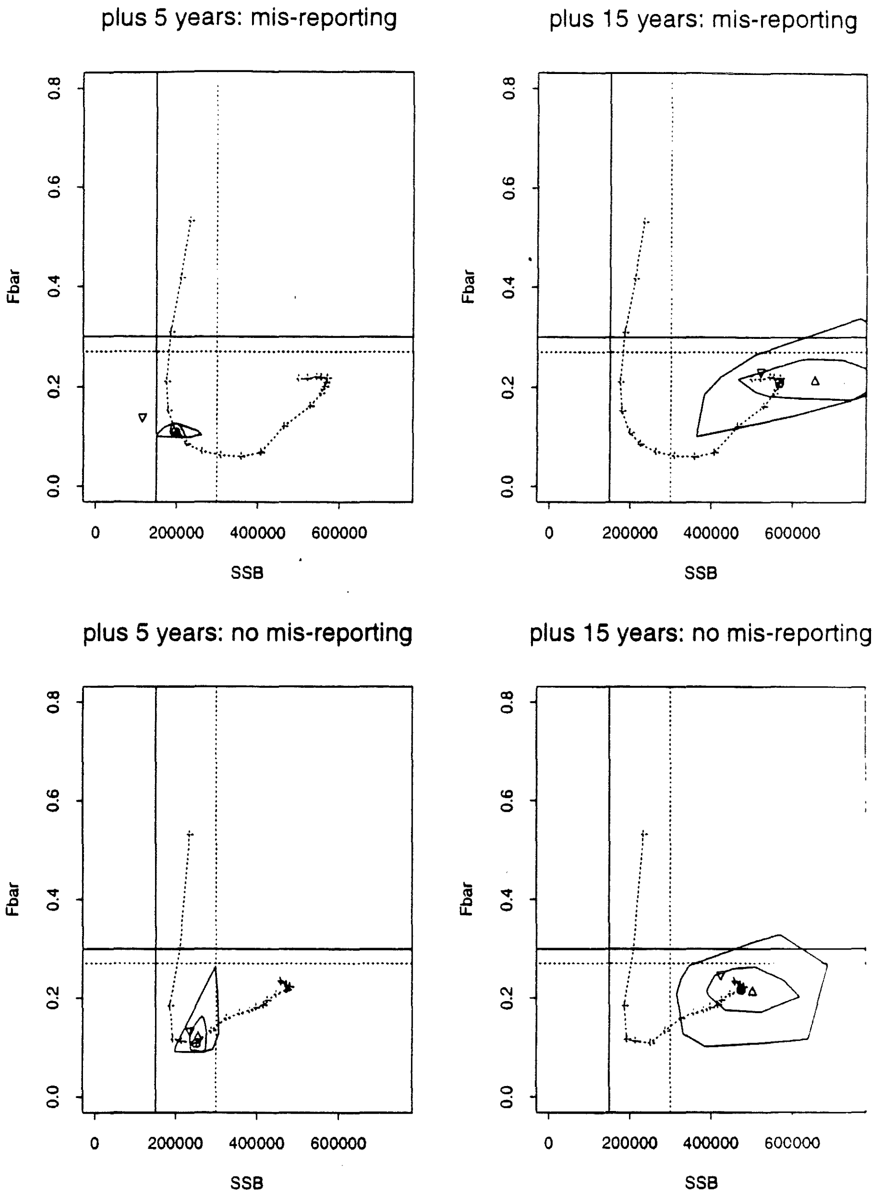


Figure 4.5.4b



plus 5 years: mis-reporting

plus 15 years: mis-reporting

plus 5 years: no mis-reporting

plus 15 years: no mis-reporting

Figure 4.5.4c

4.6 Norwegian spring spawning herring

The Norwegian spring spawning herring is described in Section 10 , where details concerning the biology and management are given. The herring had a stock collapse during the 1970s. During the collapse period the management goal was that the spawning stock should built up to above 2.5 million tonnes, which was the limit below which it was perceived that the recruitment would be dependent on the spawning stock. In this section a simulation experiment is conducted using a Process-Observation error model (PO, see Section 4.1).

Observation error

The Northern Pelagic and Blue Whiting WG considered various possible ways of tuning the VPA for Norwegian spring spawning herring (ICES 1997/Assess:14). Based on the range of plausible results one may set the observation error to 30%. Also, that WG made a Bayesian assessment, from which a survey error of 30% also may be deduced. This value was used in medium-term simulations, in which full correlation between ages 4 and older was assumed, which also is assumed in the present simulation runs. No covariance matrix for the final maximum likelihood estimate was provided. More details on the assessment procedure is given in section 10.

Supposing the perceived stock has a multiplicative error of E, the true F - F_{true} - may be calculated from:

$$N_{true} \times F_{true} \times (1 - \mathrm{Exp}(-F_{true} - M)) / (F_{true} + M) = N_{perceived} \times F_{perceived} \times (1 - \mathrm{Exp}(-F_{perceived} - M)) / (F_{perceived} + M)$$

where $N_{perceived} = E \times N_{true}$

which is implemented in the model by solving the above equation.

Harvesting control rule

The 2.5 million tonnes spawning biomass reference point that have been in effect in almost two decades - and that have worked well during the upbuilding phase of the stock - may be looked upon as an external reference point and will here be taken as a precautionary reference point below which the spawning stock should fall with low probability in the long run. What is at present not in place for the management of this stock is a definition of which precautionary action should be taken when the stock approaches this limit, which might happen during the first few years since there are no confirmed strong yearclasses after the 1992 year class. The following harvesting control law will be evaluated:

B_{pa} = 2.5 million tonnes
F_{pa} = 0.15, externally given
F_{lim} = Fpa $e^{2\kappa}$
Bl_{im} = 0.5 million tonnes

The F_{pa}-value is the F-value at which the stock is managed at present $\kappa = 0.3$ reflects the observation error.

The applied (perceived) F equals F_{pa} when the perceived spawning stock is above B_{pa}, and decreases linearly to zero at B_{lim} as a function of perceived spawning stock biomass when the spawning stock is below B_{pa}.

The effective precautionary point are the externally given B_{pa} and F_{pa}. Since there in this case is no assumed F-value from which one wants to stay away, the F_{lim} as defined above does not determine the harvest control in any way, and is used in the present simulations for diagnostic purposes only. However, it is useful to see how often it is exceeded, should one later want to use a harvesting control bounded by a precautionary F-value.

B_{lim} will also be taken as externally given. It would be important for implementation of reference points in practical management that they represent quantities that are meaningful to managers. B_{pa} should be taken as a limit point below which managers perceive a clear threat to future yield and B_{lim} should be taken as a limit point below which managers perceive a clear danger to the stock. Based on past history of the stock, the above values might be possible candidates.

The simulation model uses a Beverton-Holt recruitment model with logarithmic errors estimated from a VPA where the youngest age is zero years. Since the stock now is in a stage were it has recovered from a collapse and is regaining its previous migration pattern with feeding in the Norwegian Sea it is felt that life history variables from the pre-collapse period are appropriate and these were meaned for the years 1950-1970. The ecploitation pattern for 1996 was used. The natural mortality is 0.15 for ages 3 and older and 0.9 for ages 0-2, as decided by the Northern pelagic and Blue Whiting Fisheries Working Group (ICES 1997/Assess:14). The simulation period is 100 years and the number of simulation runs was 200.

Results

Figure 4.6.1 shows the first 15 spawning stock trajectories and figure 4.6.2 shows the first 15 F-value trajectories.

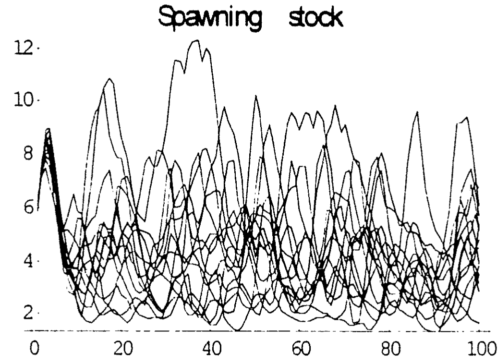


Figure 4.6.1. Spawning stock biomass trajectories for Norwegian spring spawning herring

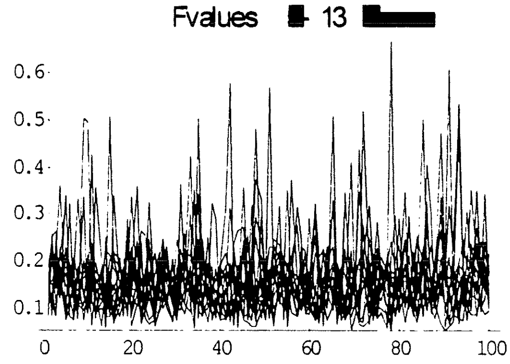


Figure 4.6.2. Trajectories of realised F-values for Norwegian spring spawning herring

Figure 4.6.3 shows the 10, 50 and 90% quantiles for the spawning stock. The spawning stock stabilises around 4.0.

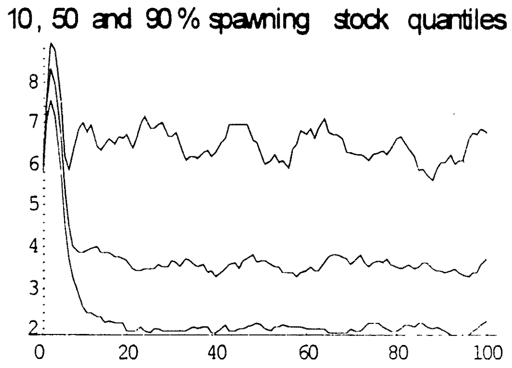


Figure 4.6.3. Time series quantiles for the spawning stock. Norwegian spring spawning herring

Figure 4.6.4 shows the 10, 50 and 90% quantiles for the realised F-value.

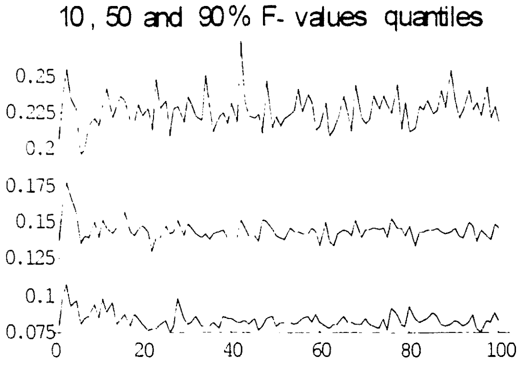


Figure 4.6.4. Time series quantiles for the realised F-value. Norwegian spring spawning herring.

Figure 4.6.5 shows the 10, 50 and 90% quantiles for the yield. The median yield seems to stabilise around 0.7 million tonnes, but with a significant probability of exceeding one million tonnes in periods.

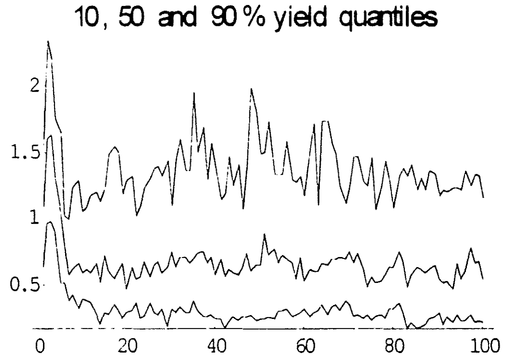


Figure 4.6.5. Time series quantiles for the yield. Norwegian spring spawning herring.

Figure 4.6.6 shows the relative number of times the spawning stock was below B_{pa} as a function of time. This starts to happen after the seventh simulation year because of the high present stock size and after 20 years stabilises around 25%. It is unclear whether the increasing fluctuation towards the end of the series is real or an artefact from using too few simulation runs. The probability of the spawning stock falling below B_{pa} may be viewed as being high in a precautionary context if one considers spawning stocks below B_{pa} as a danger zone for the stock, and a lowering of the F_{pa} might be considered should these results still hold true when the model is made more realistic in the recruitment and growth dynamics (see section 10).

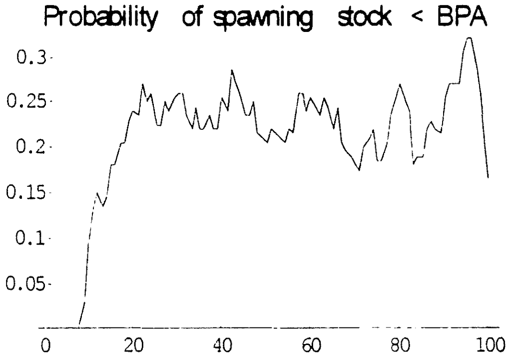


Figure 4.6.6. Relative number of spawning stock falling below 2.5 million tonnes in the simulation runs for Norwegian spring spawning herring.

Figure 4.6.7 shows the relative number of times the F-value exceeded F_{lim}. This happens in less than 10% of the runs in any year.

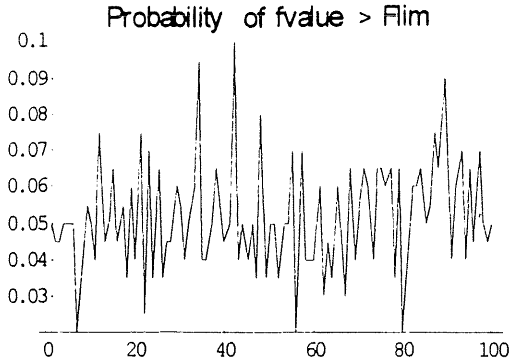


Figure 4.6.7. Probability of F exceeding F_{lim} for Norwegian spring spawning herring

The results obtained through the present simulations are dependent on how well the recruitment model realises the herring recruitment model dynamics with large but infrequent yearclasses. Also, the model used does not apply abundance-dependent growth which is potentially important for this stock. These features are discussed in some more detail in section 10.

4.7 Haddock on Eastern Georges Bank

The haddock on Georges Bank have supported a commercial fishery since the early 1920's. Since 1990 Canada has used eastern Georges Bank as the basis for a management unit. During the two decade period between the early 1930s and the early 1950s, catches from eastern Georges Bank were relatively stable, generally ranging between 20,000t and 40,000t . Record high landings were reported from eastern Georges Bank in the 1960s, reaching about 60,000t. Catches dropped rapidly to 2,600t by 1972 and subsequently increased to a high of 25,000t in 1980. Since then, catches have declined to a low of 2,100t in 1995 and increased to 3,700t in 1996. A calibrated VPA for 1969-96 was available. Only an approximate age composition of the catch from eastern Georges Bank for 1931-55 could be obtained but it was considered suitable for an illustrative VPA. The current total biomass remains at less than a third of the average sustained over those two early decades (Figure 4.7.1). Examination of the pattern of recruitment against mature biomass (approximated by biomass for ages 3-9) indicates that the chance of observing a strong year-class is significantly lower for biomass below about 40,000 t while the chance of observing a weak year-class is very high (Figure 4.7.2). Since 1969, only the 1975 and 1978 year-classes have been near the long term average abundance.

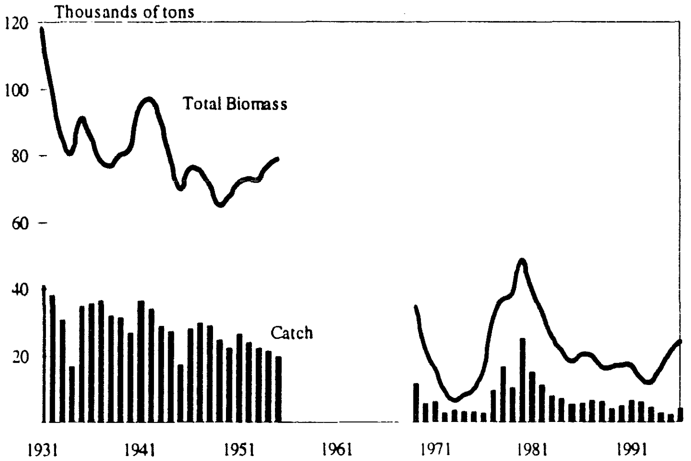


Figure 4.7.1 Catches and total biomass estimates for eastern Georges Bank haddock.

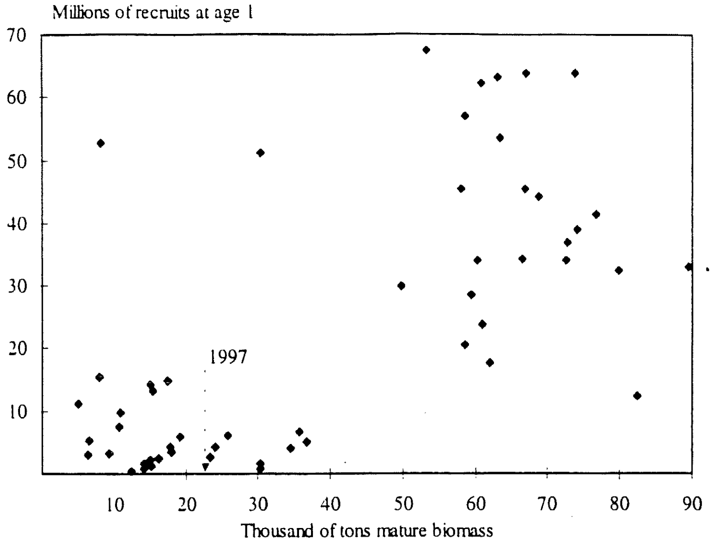


Figure 4.7.2 Stock and recruitment pattern for eastern Georges Bank haddock.

Although not rigidly adhered to, Canada continues to view $F_{0.1}$ as a practical target for a harvest strategy and assessment advice commonly includes results from forecasts using this strategy. Forecasts for eastern Georges Bank haddock at $F_{0.1} = 0.28$ in 1997 indicated that the biomass for ages 3 and older was projected to decrease slightly between 1997 and 1998. In view of the depleted state of the stock, the Canadian quota was set at a level consistent with a fishing mortality rate of roughly half $F_{0.1}$. Industry and managers considered it desireable to rebuild the mature biomass to over 40,000t and asked that alternative harvest strategies be investigated.

Four harvest control laws employing external reference points were considered for this simulation study

- HCL 1 : $B_{lim} = 0$; $B_{pa} = 40{,}000t$; $F_{pa} = 0.28$; F decreases proportionately for $B < B_{pa}$
- HCL 2 : $B_{lim} = 0$; $B_{pa} = 40{,}000t$; $F_{pa} = 0.28$; $F = 0.14$ for $B < B_{pa}$
- HCL 3 : $B_{lim} = B_{pa} = 40{,}000t$; $F_{pa} = 0.28$; $F = 0$ for $B < B_{lim}$
- HCL 4 : $B_{lim} = B_{pa} = 0t$; $F_{pa} = 0.28$
-

The performance of these alternative harvest control laws was evaluated by comparing the chances that the biomass would be above the 40,000t rebuilding level and by comparing the yield over a 30 year time horizon. An estimate of F_{msy} was not readily available, therefore the chance of exceeding a fishing mortality limit reference was not computed.

Non-Parametric P error : ERP

The starting population abundance for ages 1-9 in year 1997 were taken from results of a VPA calibrated with DFO spring, NMFS spring and NMFS fall surveys since 1986. The population was projected to the year 2027, a 30 year time horizon. The following processes were modeled as stochastic and values for them were generated by resampling past observed values

- exploitation pattern (partial recruitment to fishing) for the 30 year projection was obtained by resampling observed exploitation patterns : from 1992-96 for age specific values at ages 1-3, from 1969-96 for age 4 (excluding outlier values <0.5 and >1.5) and from 1969-96 pooled over ages for ages 5-8 (excluding outlier values <0.5 and >1.5)
- catch average weight at age for the 30 year projection was obtained by resampling observed fishery weight at age from 1969-96
- population begining of year weight at age for the 30 year projection was obtained by resampling observed DFO spring survey weight at age from 1986-97
- recruitment at age 1 was resampled from observed recruitment from 1931-97 (years 1956-68 missing) conditional on 3+ biomass being <40,000 or >40,000 t

Non-Parametric PO error : ERP

Using an identical structure to that described above, observation error was included by adding lognormal error to the population abundance values and then applying the harvest control law to the perceived population state. Coefficients of variation on population abundance at ages 1, 2 and 3-9 were taken as 70%, 45% and 35% respectively to correspond with recent assessment results.

Results

For both the P error and the PO error experiments, HCL 3 increased the chances of exceeding the 40,000t rebuilding threshold fastest and remained over 80% after year 12 (Figure 4.7.3). HCLs 1, 2 and 3 showed similar performance, reaching only about 40% by year 12 and taking over 20 years to achieve over 80%. In the PO error experiments, performance of HCL 3 was somewhat worse but only marginally worse for the others. Results for yield are displayed as "box and whisker" plots. Only HCL 3 implemented complete fishery closures and these occured fairly frequently (> 25% chance) in the first 10 years, but did not occur at all after about 15 years. Although there were frequent closures and the range of annual yield was more variable in the first 10 years for HCL 3, the cumulative yields in the first 10 years were similar for all HCLs and by the 15th year, HCL cumulative yields were higher.

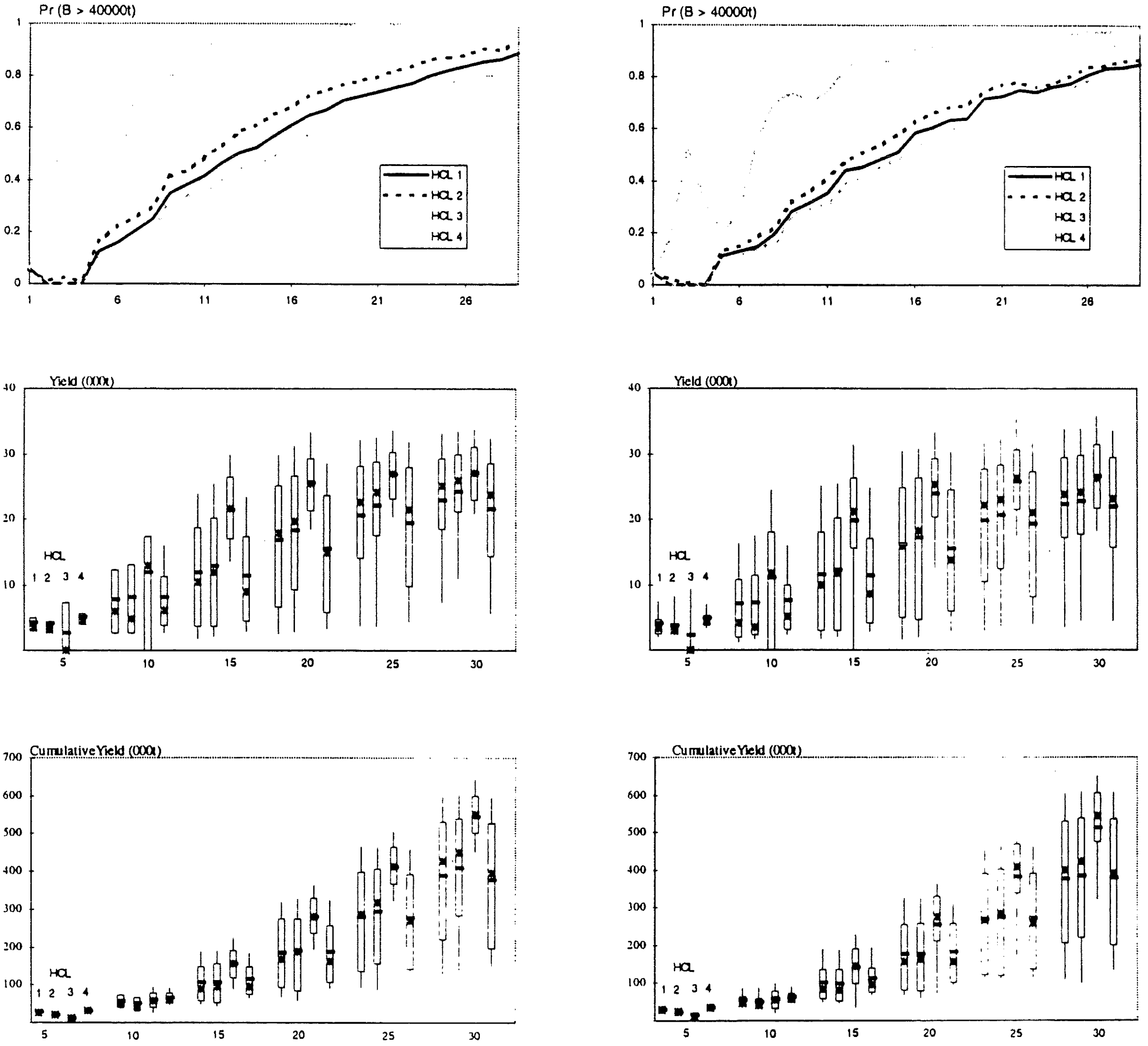


Figure 4.7.3 Performance of 4 alternative harvest control laws from non-parametric simulation experiments of eastern Georges Bank haddock.

Given the assumed underlying population dynamics, $F_{0.1}$ appears to be a practical F_{pa} and HCL 3 results in the most rapid rebuilding from the current depleted state. The abrupt shifts between closure and opening in the first 10 years are likely to be disruptive to the conduct of fisheries and result in the dismissal of this option for socio-economic reasons. It should be possible to find a compromise HCL which achieves most of the conservation benefits while avoiding wide inter-annual variation in advice. A possible generic form for such a control rule would show a rapid decrease in F when B dropped below B_{pa} with a less rapid decrease as B approached B_{lim} (Figure 4.7.4).

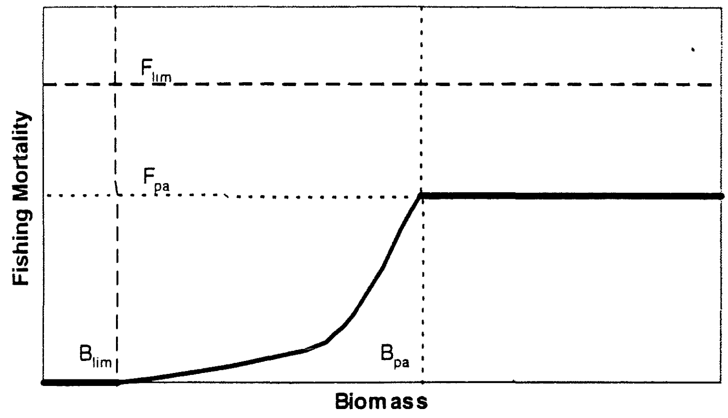


Figure 4.7.4 Alternative form of HCL to improve conservation benefits while avoiding frequent abrupt closures during a recovery period.

Further Considerations

The following additional simulations experiments merit further investigation and could provide additional insight.

There are two observations of average abundance recruitment for mature biomass below 40,000t and it appears that recovery may be dependent on experiencing a yearclass of this magnitude. These two observations were from the 1975 and 1978 yearclasses and we have not observed any yearclasses of that magnitude in about 20 years. It would be informative to explore the recovery behaviour of this system if the 1975 and 1978 yearclasses were removed from the observed stock-recruit pattern.

Prior to the early 1990s, the fishing mortality rate on age 2 and 3 averaged about 50% and 100% of that for ages 4 and older while in recent years those values have decreased to about 5% and 50% respectively. Evaluate the importance of the recent reduction in the exploitation pattern values for age 2 and 3 by conducting a simulation employing the historical pattern.

Extend the time horizon for promising harvest control laws to determine if similar asymptotic probabilities are achieved.

Investigate the impact of alternative stock and recruitment functions, e.g. three biomass sections instead of two with a less abrupt transition

Conduct comparative parametric simulation experiments.

Explore the impact on conclusions of the externally provided reference points by defining suitable rules to dynamically compute reference points internal to the simulations.

The observations should be investigated for additional structure or correlation in the processes which might be modeled, e.g. differences in weight at age by cohort.

Promising harvest control laws identified from the P and PO experiments should be evaluated with a full POM simulation experiment study.

These simulation studies should be viewed as a comparative tool and results should not be considered as absolute forecasts. It would be useful to develop comparative measures for performance evaluation to avoid the possibility that casual users interpret the results as absolute forecasts.

4.8 North Sea herring

The Working Group was asked to evaluate the use of medium term projections for North Sea herring in conjuction with harvest control laws (BC 4). An extensive treatment of this question was not possible within the time-frame set. However, the WG did discuss the components and relevance of the approach in general terms.

The model used by the Herring Assessment Working Group (HAWG) is described in the background document BC 3. It states the objective of keeping the risk of SSB going below a limiting biomass (MBAL = 800 000 tonnes) to be below 5%. A precautionary biomass level is chosen above the MBAL. Then three levels of fishing mortality are chosen, so that the chance of falling below MBAL stays around 5%. In the F-biomass space, this means a three step HCL as shown in Figure 4.8.1. The fishing mortality at the intermediate biomass level (between MBAL and B_{pa}) was set at half the F above the B_{pa}. Furthermore, a simple approach was presented to represent biases in the assessment procedure and due to misreporting.

The HCL's derived by the HAWG can be directly compared to the methods developed by the COMFIE WG. A major difference appears to be the control measures to be taken when the biomass is between the MBAL level and the B_{pa}. In the HAWG method the target F is simply halved, whereas in the COMFIE approach a (curvi-) linear relation is assumed between F_{pa} and F_{lim}. The underlying system in the HAWG model has not been considered in detail.

It was found that a number of input files were not in accordance with the HAWG assessment report (ICES, 1997). These files were corrected.

The WG recommends that a subgroup of the HAWG be installed where the results of simulations and a thorough description of the method be drafted in a working document to the ACFM. Furthermore the WG recommends to the HAWG to take notice of the methods for evaluating HCL's that were developed at the COMFIE WG and the general conclusions drawn from other simulation experiments.

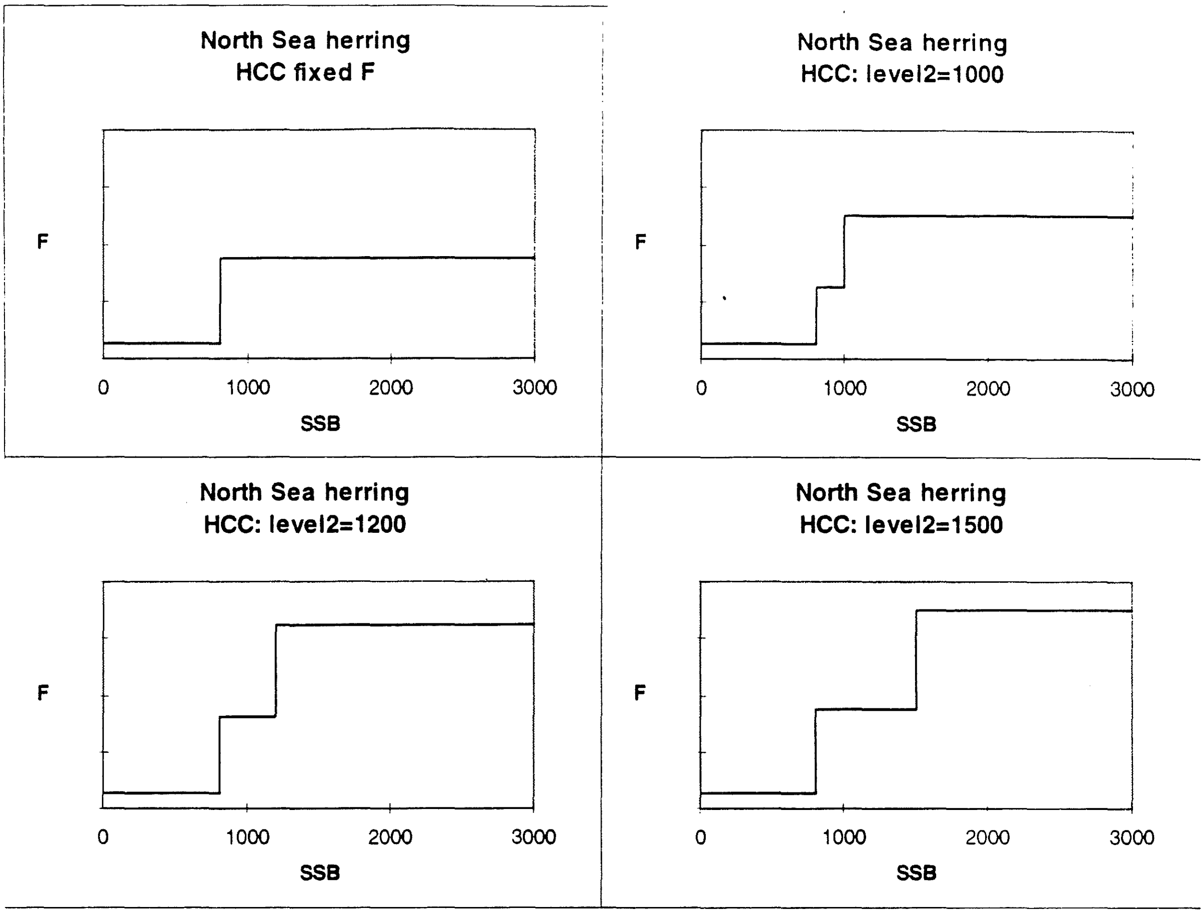


Figure 4.8.1 North Sea herring Harvest Control Laws considered

4.9 Implementation Considerations

Diffferent assessment techniques may need to be used by the assessment WGs if particular control laws are to be adopted. B_{lim} and B_{pa} levels used to parameterise control laws may be sufficiently high that resulting advice, if implemented, would lead to low Fs or even closed directed fisheries. Tuned VPA assessment methods may have poor convergence properties at low fishing mortality rates, relative to natural mortality (REFERENCES). The "standard" ICES WG assessment technique XSA, is a tuned VPA method and is used widely for a range of stocks. In the North Sea plaice simulations(Sec. 4.5), fishing mortality was often reduced to very low levels resulting in poor XSA performance for a wide range of the control laws across a variety of experimental treatments, and making interpretation of the results unsatisfactory. The implication is that a range of assessment methods is needed, some of which are less dependent on convergence than VPA. There will be a need to evaluate the performance of particular control laws, parameterised with specified BRPs, in combination with particular assessment methods (a combination of a particular assessment type and a particular control law being referred to as a *management procedure*; LTMM WG 1994). This can only be done within the POM simulation experiment described in Section 4.1.

Generally, model error such as unaccounted mis-reporting or wrongly assumed recruitment or growth/maturity dynamics, can lead to serious biases in the perception of the system. This can lead to very poor simulated management performance which might be undetectable in reality and cannot be evaluated in the P and PO simulation experiments. Even without model errors, POM simulation experiments may produce very different results to the simpler simulation experiments (see section 4.5). In the context of comprehensive fishery evaluations, it is recommended that P and PO simulation experiments be used to screen control laws, in order to reject options, prior to more detailed evaluation with POM simulation experiments.

Ultimately, the performance of a control law is case specific depending among other things on the type and quality of data, the assessment procedure and implementation of the management system. The success of implementation may be influenced by the nature of the control law. For example, a gradual rebuilding plan may be more effectively implemented than one which requires severe reductions in catch. A control law which calls for a moratorium may be impractical to implement at all. The control laws evaluated by the WG implemented $F = 0$ below B_{lim},. Considering the difficulty of implementing control laws where F is reduced to zero below B_{lim}, an alternative which merits further investigation is a control law which decreases non-linearly below B_{pa} (see Fig. 4.7.4). Further, the quality of data and the ability of the assessment method to effectively use that data to estimate population state will differ in these two cases (see Section 4.5.3). These types of considerations reinforce the desireability of conducting POM simulation experiments.

BRPs which are calculated from estimates of SSB and recruitment are likely to perform poorly when faced with mis-reporting, unreported discarding, high-grading, inappropriate biological parameterisations etc. In the simulations for the North Sea plaice-like stock which include mis-reporting, both the F_{loss} and $F_{CrashRicker}$ based control laws perform very poorly. This is because the assessments lead to a highly biased perception of the underlying fishery system and the implemented controls lead to undesirable effects. Performance is further degraded when wrong assumptions are made about the underlying recruitment process. The implication is that unless SSB and recruitment estimation is unbiased, BRPs based on these estimates should not be used to parameterise control laws. Therefore it is desireable to conduct tests of the robustness of SSB and R estimates to the various inputs and assumptions in the assessment.

It is desirable to employ a common simulation framework to conduct P, PO and POM error simulation experiments. Features could be turned on or off during the exploratory phase. When the analyses have progressed to evaluation of POM simulation experiments, a common practical approach has been to first investigate the implications of uncertainty when the underlying models and the perceived models correspond, then to investigate the robustness of the HCL when there is mis-specification in the perceived models and finally to investigate interactions between model mis-specifications.

Deterministic simulation work is a useful first step in model verification and for giving an overall impression of likely performance. It is necessary however to move to full stochastic simulations in order to explore model reaction to noise in parameters and uncertainty in structure.

The Working Group did not explore the fully probabilistic implementations of harvest control laws which utilize the uncertainty in both the limit reference points and in the estimate of current stock status (see for example Patterson WP1).

4.10 Advice on Harvest Control Laws

The Working Group addressed the problem of recommending an appropriate harvest control law for stocks for which no specific case studies have been performed. These comprise most ICES stocks at present. The Working Group's criteria were that such a harvest control law should meet the following requisites:

1. It should be consistent with the precautionary approach, in that it should lead to a low risk of depletion.
2. It should achieve as high a yield as possible, consistent with a low risk of depletion.
3. It should be robust to uncertainty in estimates of biological reference points, estimates of current population state, and to a wide range of plausible underlying stock dynamics.
4. It should in so far as possible be based on reference points for which estimates are presently available, or could readily be calculated.

The Working Group stresses that perceptions of appropriate harvest control laws will be stock-specific and will be subject to change, but desires to provide an appropriate proposal for immediate application in cases where knowledge is limited.

The Working Group's proposal for such a default harvest control law is:

$$F_{pa} = F_{0.1}$$
$$B_{lim} = 0.5\ B_{MSY}$$
$$B_{pa} = B_{MSY}$$

with the caveat that for stocks with strong underlying stock-recruit dependence and high recruitment variability(variance up to 1.5) a still more cautious approach may be needed to avoid stock collapse, possibly by defining a level above B_{lim} at which F is set to zero, named B_{buf} in NAFO terminology.

The reasons for this proposal are:

1. In the simulation experiment (Section 4.4.2), it was found that attempting to base harvest control laws on F_{crash}, F_{MSY}, and F_{comfie} reference points resulted in generally poor performance in terms of yield compared to the probability of stock collapse.
2. The performance of the harvest control law is not dependent on the precise estimation of B_{MSY}, hence the use of simple approximations are unlikely to degrade the performance of the harvest control law significantly. One might consider in a case specific fashion whether such approximations as (B_{MSY} = 0.5. Unexploited stock size) may be appropriate, or even whether MBAL is in practice a proxy for B_{lim} or $B_{pa.}$
3. A comparative study of harvest control laws for Georges Bank haddock concluded that a constant $F_{0.1}$ fishing rate was incautious *per se*, and needed to be supplemented with additional measures to reduce the fishing mortality at low levels of stocks size (Section 4.7) . This finding is in close agreement with the results of the simulation experiment.
4. The F_{crash}, F_{MSY}, and F_{comfie} reference points can only be estimated with low precision whereas $F_{0.1}$ can be estimated more reliably (Section 2.2.2.2).
5. The F_{crash}, and F_{MSY} reference points are not estimated for most stocks at present (Section 2.3.).

In consequence of the above, the Working Group recommends that Assessment Working Groups should attempt to obtain estimates of B_{MSY} such that they may calculate a catch in accordance with this harvest control law, for stocks where no case-specific studies have been completed.

In the absence of B_{MSY} estimates, the assessment Working Groups should consider whether currently defined MBALs might reasonably be used either as B_{lim} or B_{pa}.

Then the procedure would be:

- Estimate $F_{0.1}$ for a recent selection pattern
- If stock size is above B_{pa}, the catch forecast is the catch for F= $F_{0.1}$
- If stock is below B_{lim} the catch forecast would be set at a low level to represent unavoidable fishing mortality; strictly this would be set equal to zero.
- In the range of stock sizes between B_{lim} and B_{pa}, the catch forecast should be made according to F = $F_{0.1}$ * (Stock Size - B_{lim} /(B_{pa} - B_{lim}))

Such a calculation could be named a 'Default Precautionary Catch Forecast' and provided for management purposes along with the other usual options. Present studies suggest that management according to such a harvest control law should in most cases be consistent with obtaining reasonable yields for low levels of risk, and is consistent both with leading to the recovery of heavily-exploited stocks, and with the new exploitation of virgin stocks.

It should therefore form a useful basis for beginning the formulation of harvest control laws in a wide range of scenarios.

5 MISREPORTING

5.1 Overview

Conventional population models, and the catch forecasts which are based upon them, rely on the assumption that catches are reported without significant error. Under- or over- reporting of catches will cause bias in the population parameter estimates, including catch forecasts, that are calculated by such models. Quantification of such biases will normally be case-specific, and therefore will best be considered in the context of comprehensive assessments and case studies. For present purposes, a short review of recent approaches to age-structured stock assessment is presented, and conclusions drawn about the precision of some parameter estimates fom such modelling studies are summarised. Inferences from an analytic approach are also drawn.

Only the case of stocks measured with unbiased surveys, but from which misreported catches are taken is considered here.

Alternative models can be formulated which do not depend on catch information (Cook, 1995; Fryer et al, BD 1, Gavaris and van Eeckhaute, BD3; Patterson,BD2, BD4;), but observations from fishery systems are normally so variable that either such models return very imprecise parameter estimates, or else rather strong constraints must be imposed on the models, which clearly involves a risk of introducing biases.

In general terms, it is clear that the most important observations made from a fishery system are the catches, and in the absence of catch information estimates of population parameters tend to depend quite strongly on model assumptions.

The Working Group draws the following conclusions:

- When misreporting occurs, reasonably robust estimates of stock size can be calculated using appropriate models, but estimates of fishing mortality become highly uncertain.
- The precision of F-status quo forecast catches deteriorates rapidly under misreporting, but forecast catches for a target fishing mortality are more stable and have a lower mean squared error.
- When misreporting is suspected, stock assessment models that can explicitly model uncertainty in reported catches should be used in preference.
- Such models will usually require some constraint or smoothing of fishing mortality values.
- For a simple approximation, for stocks surveyed at the end of the fishing year, the F-status quo forecast catch is biased by the same amount as the recent misreporting and the forecast catch for a target fishing mortality is biased by the same amount as historic catches.
- For stocks surveyed at the start of the fishing year, the bias in the F-status-quo forecast catch becomes a quadratic function of the bias in the recent reported catch. Bias in the forecast catch for target fishing mortality becomes a linear decreasing function of bias in the recent reported catch. In both the foregoing cases the form of the functions are strongly dependent on levels of fishing mortality.

Arguments supporting these conclusions are developed further below in a short review of methods of assessing fish stocks when catches may be misreported.

5.2 Methods Based on VPA

5.2.1 Deviation from Conventional VPA

Given VPA estimates of stock size B_y in year y and a survey index of abundance U_y, the conventional assumption (ignoring age-structure) is that:

$$U_y = Q.B_y \exp(\varepsilon_y) \qquad (1)$$

Arguably, biases in catch reporting would be translated into biases in B_y, and two methods were proposed for detecting misreporting based on detecting a failure of the assumptions in this model. O'Brien (1997, WD1) proposed using a resistant regression method (Rousseeuw and Leroy, 1987) to detect such deviations. The method is summarised below:

Firstly, the model is rewritten with an extra parameter to investigate failure of the linearity assumption:

$$B_y = \alpha U_y{}^{\beta} \exp(\varepsilon_y) \qquad (2)$$

taking logarithms

$$\ln(B_y) = \ln(\alpha) + \beta \ln(U_y) + \varepsilon_y \qquad (3)$$

This model can be fitted using a least median of squares estimator as a suitable method for finding a starting point for rejecting outliers, using the estimator of parameters a and b as given by:

$$\min_{\alpha,\beta} \mathrm{median}_y |\ln(B_y) - \ln(\alpha) - \beta \ln(U_y)|^2 \tag{4}$$

On obtaining parameter estimates for a and b, one may test whether the estimate of b so obtained conforms to the model assumptions used in the VPA procedure (normally b=1). Based on the above, the probability of obtaining a VPA estimate B_y given available survey data can be computed from prediction formulae given in Anon. (1995). This forms a simple test of two of the the assumptions in (1) above, but is predicated on independence of B_y and U_y, which would normally not hold true as all appropriate survey information is usually included in assessment models which estimate stock size B_y.

5.2.2 A VPA without reported catches

A calculation analagous to a VPA can be made based on the proportions of fish at age in the sampled, reported catches (Gavaris and van Eeckhaute, 1996). In this calculation, only relative estimates of year-class strength can be made.

The method depends on replacing the conventional VPA equation with an analagous equation based on proportions $P_{a,y}$ of fish at age a in year y relative to proportions $P_{ref,y}$ at some reference age *ref*, and finding a numerical solution for $F_{a,y}$ (a ^{1} *ref*) in

$$\frac{P_{ref,y}(F_{ref,y} + M)}{P_{a,y}(F_{a,y} + M)} = \frac{N_{ref+1,y+1} F_{ref,y} (e^{F_{ref,y}+M} - 1)}{N_{a+1,y+1} F_{a,y} (e^{F_{a,y}+M} - 1)} \tag{5}$$

With this change, and imposing appropriate constraints on selection pattern in the fishery and selectivity in the survey gear, an ADAPT-type population model can be fitted with a conventional objective function.

This approach was used to calculate a historic time-series of relative stock size and fishing mortality for Georges Bank Haddock. The resulting stock trend and relative cohort abundance estimates were closely comparable to traditional VPA estimates, but fishing mortality estimates so calculated were found to be dominated by noise.

5.2.3 The influence of misreporting on XSA

Investigations reported in Sinclair *et. al.* (1990), Anon. (1991) and Anon. (1993) revealed retrospective patterns which indicate significant biases in the estimates of fishing mortality, population abundance and spawning stock biomass derived from a variety of stock assessment methodologies. In these analyses the most recent estimates from the assessment have been considered to be the "truth" and methodological elastoplasts, such as shrinkage, have subsequently been applied in an attempt to reduce the variation. Sinclair *et al.* (1990) concluded that the patterns could result from misreporting, a trend in tuning index catchability and/or model misspecification.

Simulations using a perceived stock derived from an operating model subjected to misreporting, were used to examine the bias induced in F, N, SSB and biological reference points derived from a VPA. The underlying structure of the operating model stock is based on the North Sea plaice data set described in section 6. Recruitment exhibits a decrease at higher SSB's but shows no evidence of a decline towards the origin, characteristic of many stocks within ICES. Mean F increased throughout in the first half of the time series but has remained relatively stable in the second. Anon. (1996) fitted a constrained Ricker spawning stock and recruitment curve to the data and this has been used to estimate the biological reference points. XSA with light shrinkage (C.V. 200%) was used for the assessment. In each run the misreporting was induced as a trend starting in 1985, all ages were misreported equally. Effort is not misreported.

A series of simulations are presented to illustrate the effects of various type of misreporting. Simulation 1 has misreporting of the catch at age data only (a 5% increase per annum), simulation 2 has misreporting of both the catch at age data and commercial fleet catch at the same rate with unbiased surveys. Simulation 3 is a run with catch at age data misreported at 5% and very naughty tuning fleets misreporting at 10% per annum. In each case the bold line indicates the operating model truth.

Figures 5.2.3.1, 5.2.3.2 and 5.2.3.3 present the retrospective results from the assessment, in each case the bold line indicates the operating model truth. In each case misreporting results in under estimation of SSB and over estimation of the historical F. However the magnitude of the bias and its pattern are characteristic of the type of misreporting. If the catch at age data alone is misreported, Figure 5.1, the SSB is consistently revised downwards by successive assessments. Historical F is over estimated but the terminal values are under estimated at younger ages and have only a small bias at the older ages. When both the tuning fleet catch and the catch at age data are misreported the magnitude of the bias in SSB and historical F are unaffected but the retrospective pattern is perceived to have improved (Figure 5.2.3.2). The terminal values are still consistent with the underlying truth at the youngest ages but over estimated at the older ages. In both simulation 1 and 2 the magnitude of the terminal F values estimated by the assessments are of the same order as the "truth". If the fleet data is misreported at a faster rate than the catch at age data (Figure 5.2.3.3) the retrospective patterns in SSB and F are inverted. SSB is revised upwards by each successive assessment. The bias increases considerably.

Figure 5.2.3.4 presents the residual plots for the simulation with equivalent misreporting of catch at age and fleet data. When fleet data is misreported in the same proportion as the catch at age data, the misreported fleet dominates the calibration of the VPA, inducing opposing trends in the residuals of the surveys. An important point to note from simulation 3 is that if a fleet is misreporting more than the overall catch at age data is misreported then the fleet CPUE will fall faster than the VPA estimated population abundance and this will appear in the diagnostics as a significant correlation between catchability and population size.

Misreporting underestimates population abundance (e.g. recruitment) and SSB, it results in points on the recruitment SSB plot which are therefore biased diagonally towards the origin (Figure 5.2.3.5). This results in underestimates of both spawning stock biomass and recruitment and a subsequent bias in the majority of the reference points derived from fitted relationships between them (Figure 5.2.3.6). As with the bias in the estimation of F, fishing mortality reference points may be over or under estimated conditional on the misreporting scenario and the structure of the spawning stock and recruitment data prior to misreporting. In general the SSB reference points for this stock are under estimated for this stock structure and are therefore conservative. Fishing mortality reference points are over estimated if the fleet catches are "true", under estimated if the fleet data is also misreported.

The influence of misreporting on the assessment results will be confounded with changes in other conditional assessment parameters e.g. natural mortality, catchability, but in general these will exacerbate the effects and their influence may be small relative to misreporting. The simulations examined here have confirmed the results of Sinclair *et al.* (1990) but have established that the retrospective patterns may have diagnostic value in the detection of misreporting.

Recent advice from ACFM has been for a reduction of tuning data sets used in the tuning of ICES assessments to the 10 most recent years. Whilst this removes historical noise from the assessment, it will reduce the length of the time series of residuals available for the detection of problems.

If misreporting is influencing an assessment the "truth" is more likely to be the first assessment in the series not the last.

Figure 5.2.3.1 **The retrospective bias introduced to a perceived stock assessment by the introduction of catch misreporting**

Fleets and surveys true, catch misreporting 5% increase per annum

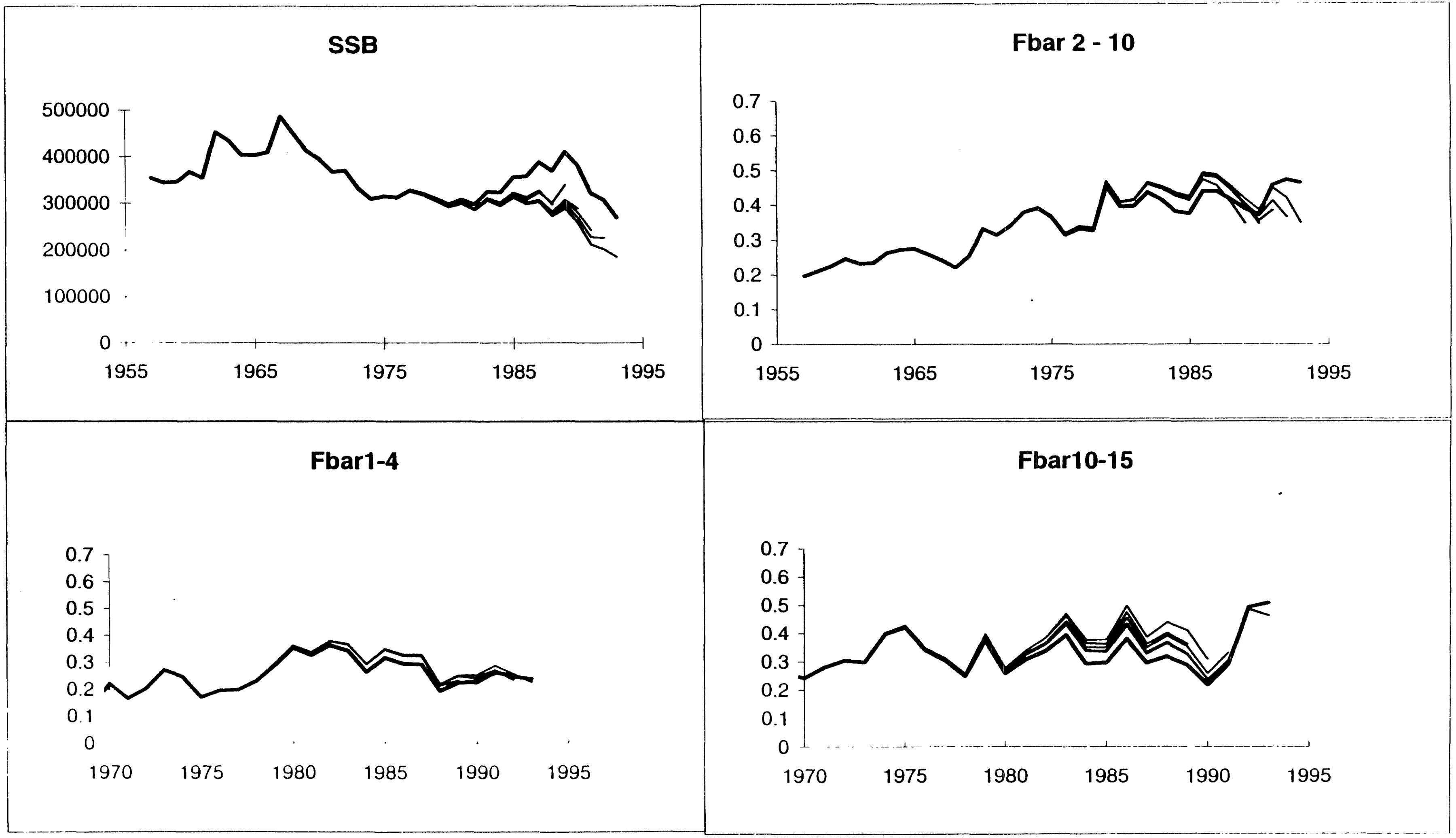


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Figure 5.2.3.2 **The retrospective bias introduced to a perceived stock assessment by the introduction of catch misreporting**

Surveys true, fleets misreporting 10% and catch 5% increase per annum

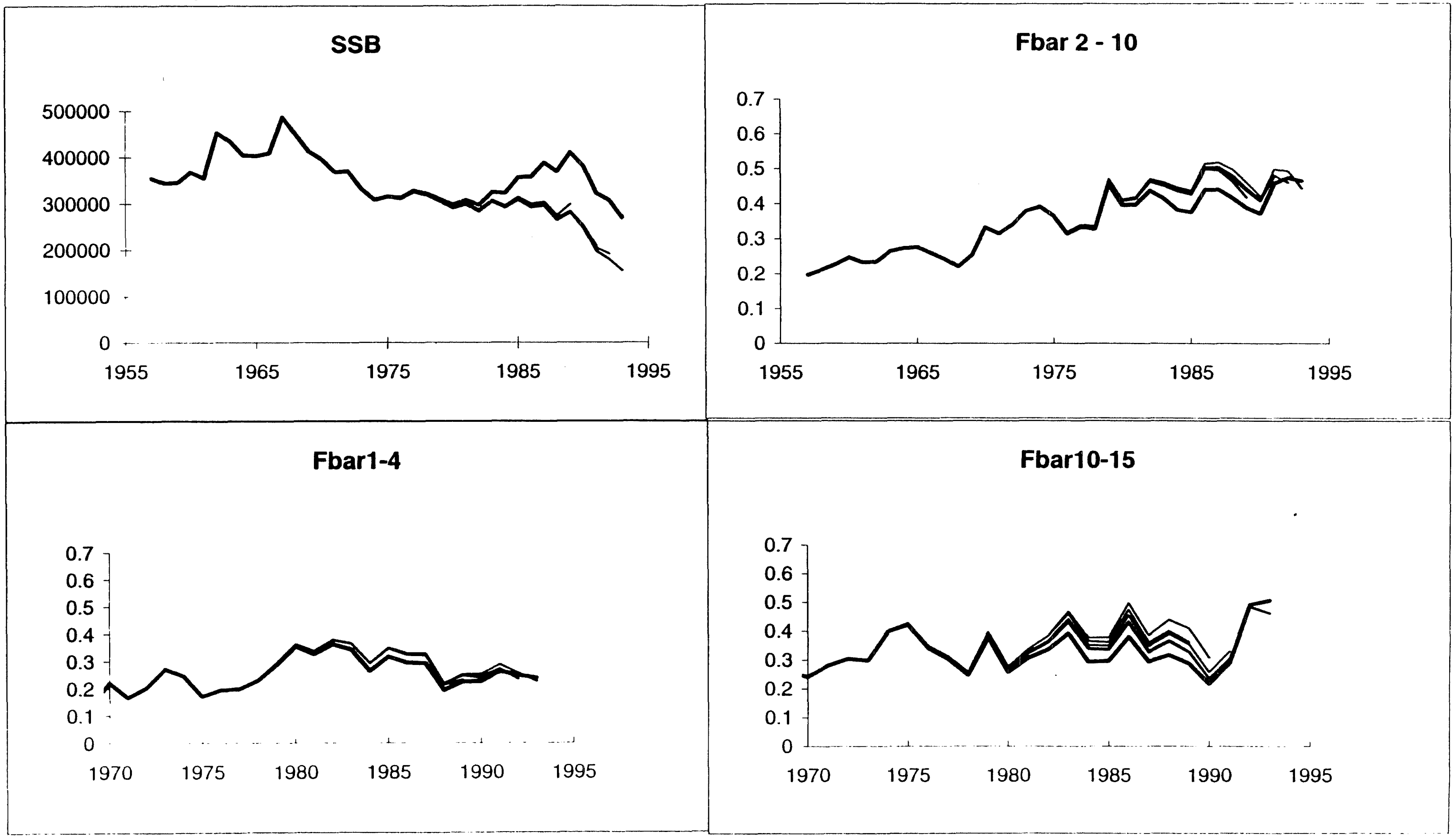

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Figure 5.2.3.3 The retrospective bias introduced to a perceived stock assessment by the introduction of catch misreporting

Surveys true, fleets misreporting 10% and catch 5% increase per annum

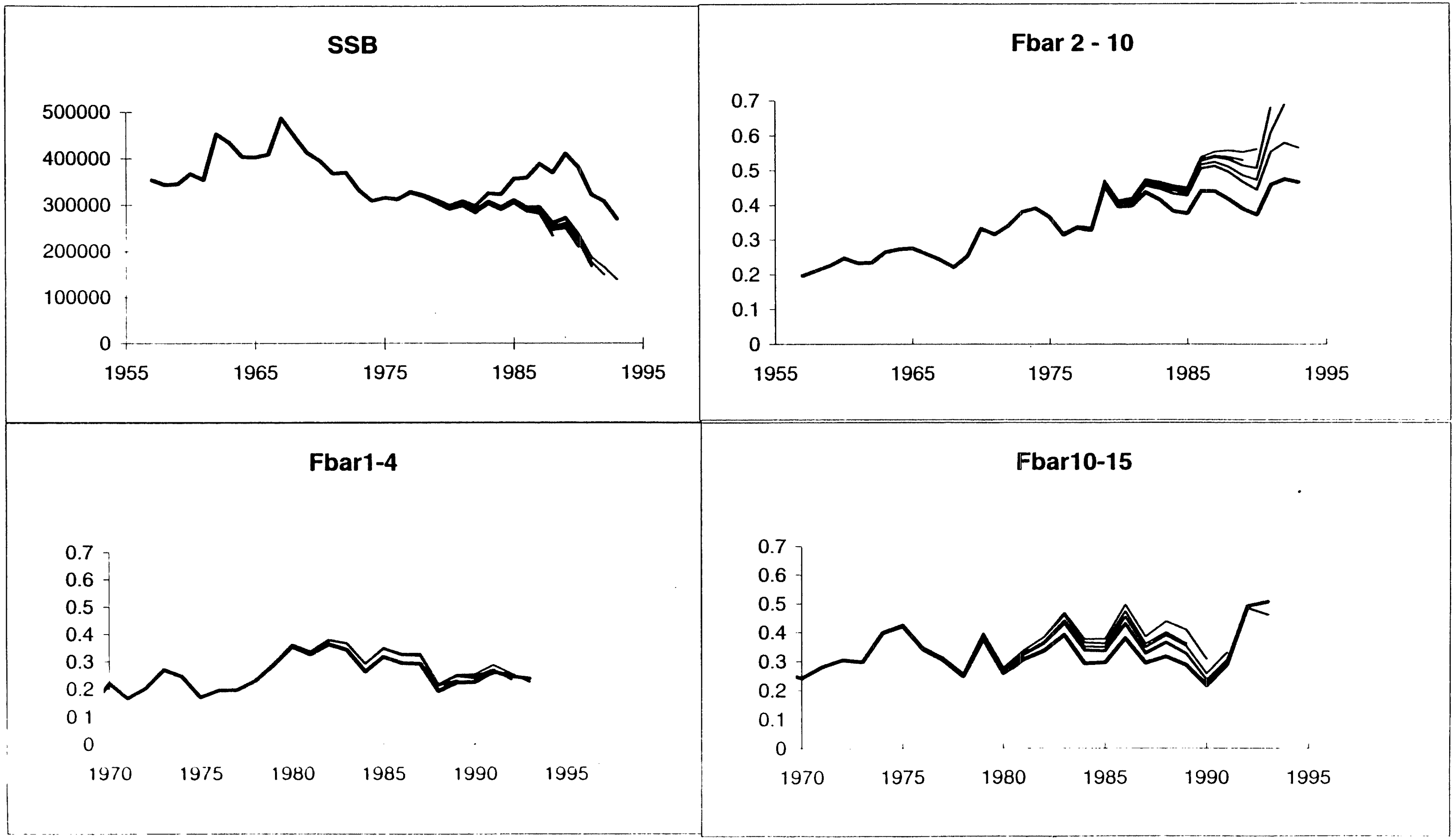

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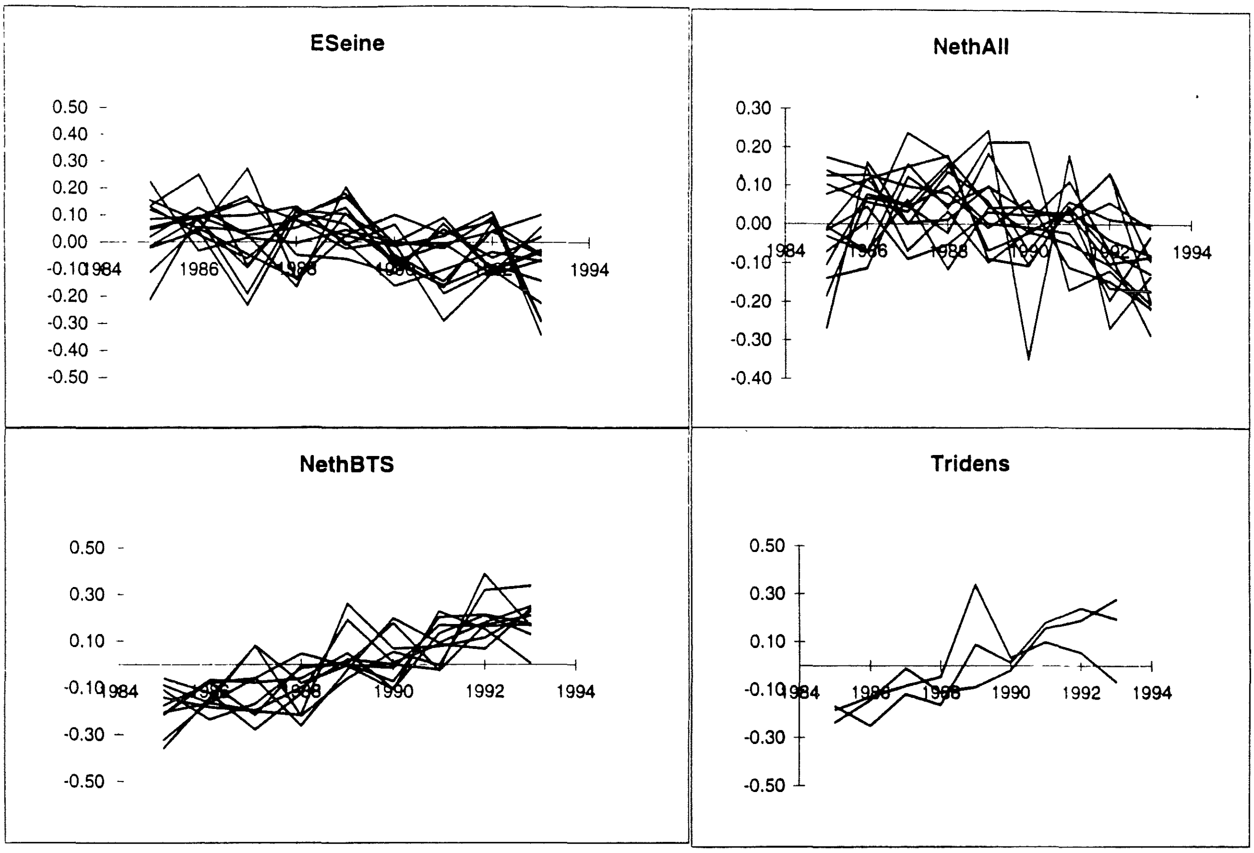
Figure 5.2.3.4 The log catchability residuals resulting from an assessment with equivalent misreporting of catch at age and fleet catch data.

Constant log catchability residuals



Proportional catchability residuals

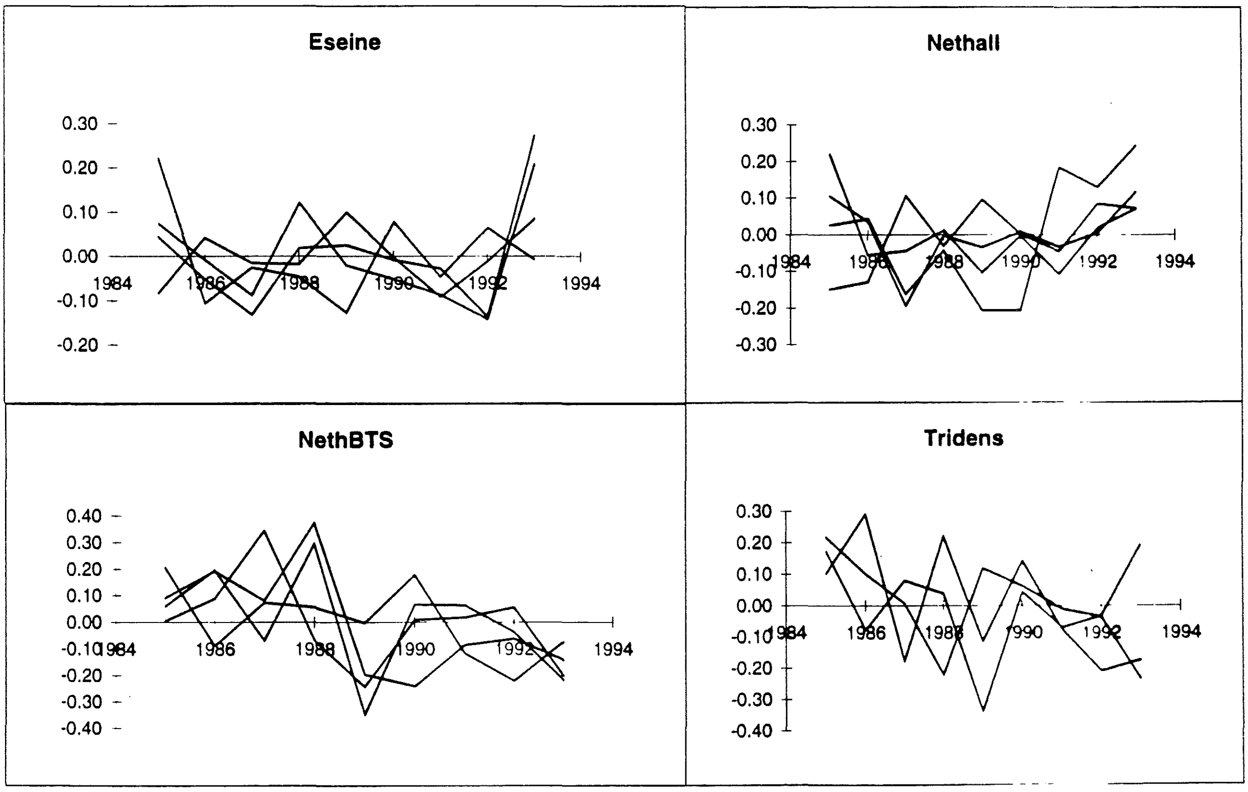


Figure 5.2.3.5 **The influence of misreporting on the perceived spawning stock and recruitment relationship**

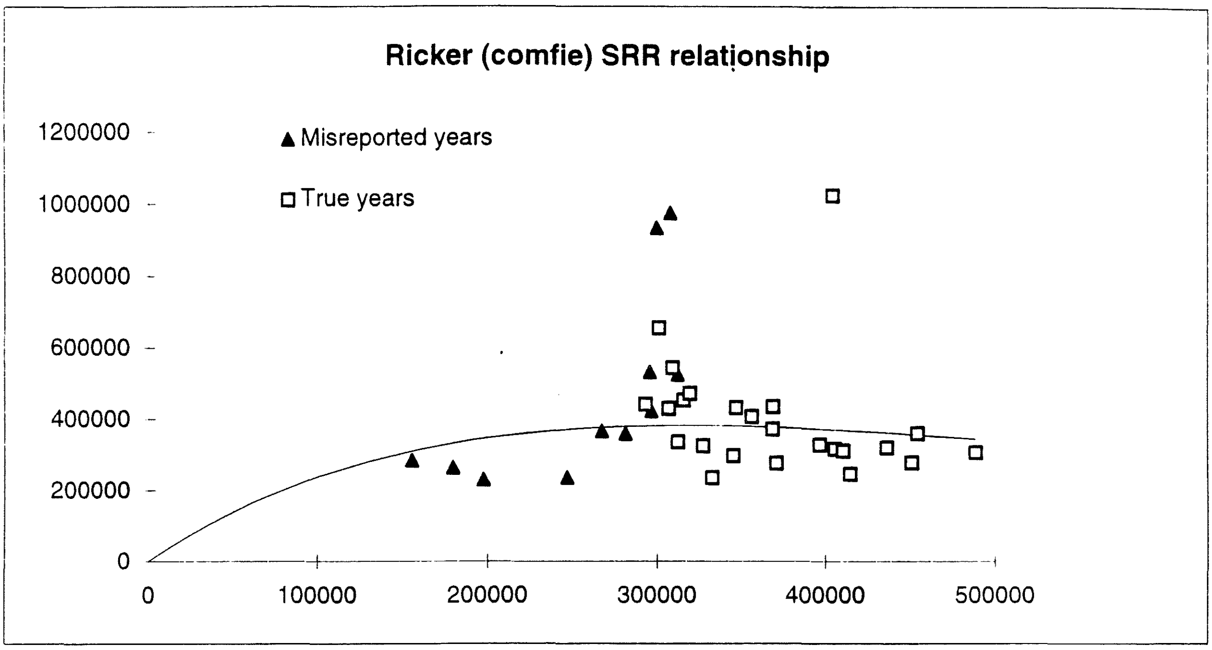
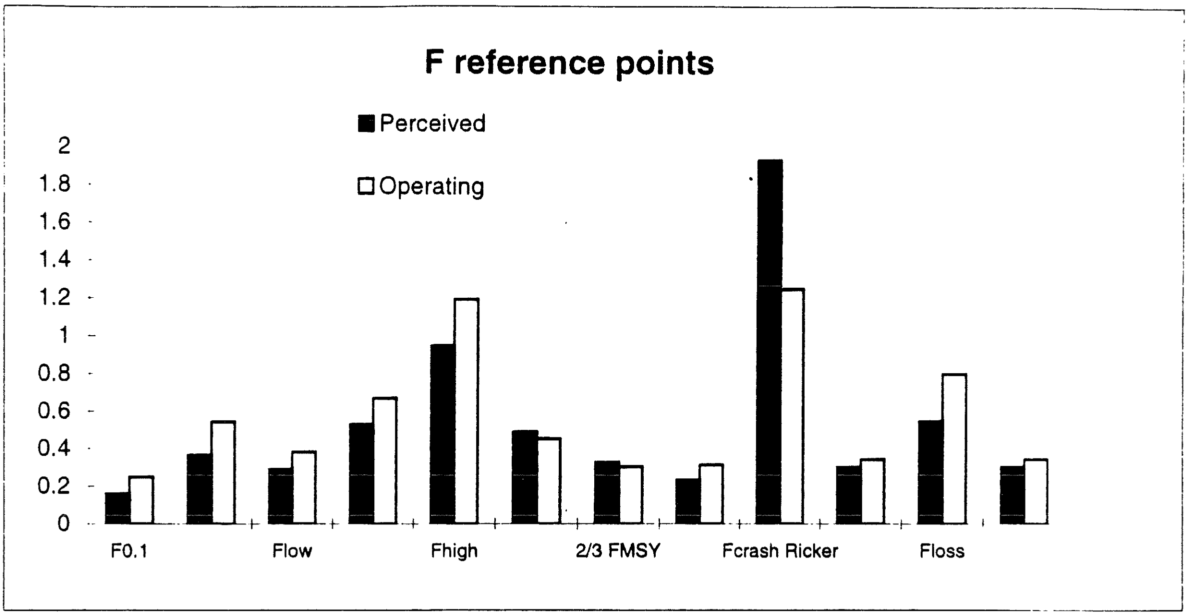
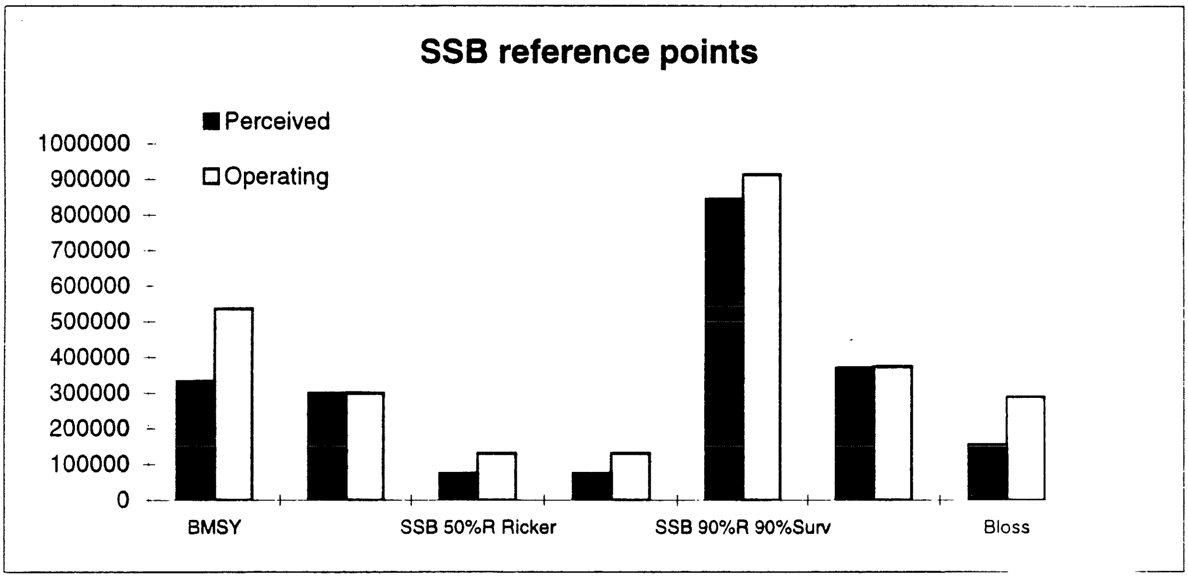


Figure 5.2.3.6 The influence of misreporting on the perceived spawning stock and fishing mortality reference points





5.3 Methods Based on Separable Models

5.3.1 Survey-Only Model

Estimating trends in stock size and fishing mortality from age-structured surveys requires the imposition of some structural constaints, as noted above. Cook (1995) imposed the following model structure on age-structured survey data alone in order to estimate stock trends:

a: Assumption of separability of fishing mortality F into a year effect f_y and an age-effect s_a

$$F_{a,y} = f_y s_a \tag{6}$$

b. Constraints on age-specific catchability Q =1 except for the youngest age, the value for which is chosen arbitrarily.

c. A penalty function dependent on an arbitrary weighting factor l is added to the objective function to reduce the sensitivity of estimates of f_y to noise in the data.

Fishing mortality year effects and relative recruitments $N_{0,y}$ are estimated by a nonlinear minimisation of:

$$\sum_{a,y}\left(\ln(U_{a,y} / Q_a N_{a,y}\right)^2 + \lambda \sum_y (f_y / f_{y-1})^2 \tag{7}$$

The method was applied to North Sea haddock in order to seek to detect misreporting effects on VPA stock size estimates. No such effects were detected. The method only estimates relative recruitments and fishing mortalitites, and depends on a regression method to scale to stock size estimates over a time period in which misreporting is believed to be unimportant. The precision of the catch forecasting method was not estimated.

5.3.2 Survey and Catch Sampling Model

The model described above was extended (Patterson, 1997; BD2) to include information on biological sampling of catches, on the assumption that when catches are misreported, the proportions at age in the catches as reported from sampling of reported landings still represents the age-structure of the total catch. Therefore the assumption is made that catches are not selectively misreported by size. No penalty function was included.

The model has separable underlying structure, and model parameters (fishing mortality and recruitment by year) estimated by maximising a likelihood function with three components containing information on annual catch in weight L_y , proportions in the catches at age P_y, and survey information $U_{a,y}$. Nuisance parameters are catchabilities Q_a, survey variances s^2_i, variances of catches s^2_c and effective sample size t^2. An approximation of a multinomial distribution is made by defining the variance $\tau^2\xi$ of a proportion P as

$$\tau^2 \xi = \hat{p}_{a,y}(1 - \hat{p}_{a,y}) + 0.01 \tag{8}$$

where the predicted proportions in the catches at age are notionally

$$\hat{p}_{a,y} = \frac{f_y s_a \overline{N}_{a,y}}{\sum_a f_y s_a \overline{N}_{a,y}} \tag{9}$$

where N bar represents the mean population number in the year, = N.(1-exp(-Z))/Z.

The log-likelihood component for proportions in the catches is:

$$-\frac{1}{2}\Sigma_{a,y}\left(\ln(2\pi\,\xi_{a,y})+\ln(\tau^2)+\frac{(P_{a,y}-\hat{P}_{a,y})^2}{\tau^2\,\xi_{a,y}}\right) \tag{10}$$

and the component for the total catch in weight is

$$-\frac{1}{2}\Sigma_{y}\left(\ln(2\pi)+\ln(\sigma_c^2)+\frac{(\ln(\Sigma_a\,\hat{C}_{a,y}\,W_{a,y}-\ln(L_y))^2}{\sigma_c^2}\right) \tag{11}$$

The component for surveys of the stock is conventionally:

$$-\frac{1}{2}\Sigma_{a,y}\left(\ln(2\pi)+\ln(\sigma_i^2)+\frac{(\ln(Q_{i,a}\,N_{a,y})-\ln(U_{i,a}))^2}{\sigma_c^2}\right) \tag{12}$$

Variances of the model components are then calculated iteratively and conditionally.

Models of this type have been used to address misreporting problems in North Sea Cod, North Sea Haddock, West Scotland Cod, West Scotland Whiting and West Scotland Haddock. A simpler version, with a linear constraint on f with respect to time, has been used to assess misreporting problems in herring (Anon, 1997 (ICES ASSESS/8), Patterson, 1997 [BD4]) .

5.3.3 Time-Series Model

A Working Document was presented which outlined the application of Gudmundsson's (1994) time-series approach to stock assessment for assessing stock trends in West Scotland cod in a fashion that was robust to misreporting. The approach is conceptually similar to the approach in 5.3.2, but has the additional advantages that it is simple to obtain rough standard errors for estimated numbers and fishing mortalities at age, and catchability can be made time-dependent. However, it has the disadvantages of a need to use inear approximations of the catch equations, a reliance on normal distributions, and a certain arbitrariness in the specification of variance matrices. There is also a certain arbitrariness in the initial estimates of the prediction variance and in the starting values.

As for the other methods, it was found necssary to impose some smoothing of fishing mortalities in order to obtain stable estimates.

5.4 Assessment Error Under Catch Misreporting

5.4.1 Simulation Approach

Precision of catch forecasting under conditions of misreporting has been addressed by simulation by Patterson (1996, BD2). Conclusions from that document are that under conditions of substantial misreporting (< 50 % of catches reported) and typical survey precisions (Survey CV 10 to 90%):

Using conventional VPA:

- Misreporting weakly biases stock size estimates, e.g. a 40% catch reporting results in approximately 10% bias in stock size.
- Misreporting greatly biases estimates of F, e.g. a 40% misreporting leads to a 60% bias in F.
- Misreporting affects status quo F forecasts in a similar way to the bias in F for obvious reasons, e.g. a 40% catch reporting leads to approximately 50% bias in status quo forecast catch.
- Forecasts of catch for a given target F are more robust to misreporting, and such forecasts are only biased by some 30% for 40% catch reporting (and precise survey information)

Using a separable model (equations 9-11 above) but excluding the catch reporting term resulted in estimates with low bias but overwhelmed by variability. Best results were obtained in the simulations by using an iterative re-estimation of the s_c^2 term, which resulted in status-quo catch forecasts with a mean squared error of around 50% and a mean squared error around 20% for catch forecasts for a given target fishing mortality.

Specific recommendations based on this study are that under conditions of misreporting in recent catches the procedure which leads to forecasts with lowest mean squared error is :

1. Only base forecasts on a known target fishing mortality, and not on a recent estiamted.
2. Use a model of form of equations 7 to 9 above, including the iterative estimation of s^2 . Under the conditions simulated (survey CV 10 to 90% and catch reporting 100% to 40%) this procedure resulted in catch forecasts with less than 40% CV.

5.5 Misreporting via Biomass-dynamic models

Beginning with a biomass dynamics model of form

$$\begin{aligned} B_{y+1} &= B_y + G(B_y) - C; \\ U_y &= Q.B_y \end{aligned} \qquad (13)$$

where B_y represents biomass in year y, C reported catch in year y and G(B) a stock production function, then approximating fishing mortality as a yield biomass ratio

$$F_y = C_y Q_y / U_y \qquad (14)$$

5.5.1 Forecast Catch for F *status quo*

Based on the above, a forecast catch for *status quo* fishing mortality (Fsq catch) is:

$$C_{y+1} = \frac{C_y Q}{U_y}\left(\frac{U_y}{Q} + G\left(\frac{U_y}{Q}\right) - C_y\right) \qquad (15)$$

If misreporting occurs in year y and the reported catch Cy is different from the true catch Xy then the true Fsq catch is

$$X_{y+1} = \frac{X_y Q}{U_y}\left(\frac{U_y}{Q} + G\left(\frac{U_y}{Q}\right) - X_y\right) \qquad (16)$$

and the ratio between the Fsq catch calculated from reported catches to the true Fsq catch is

$$\frac{C_{y+1}}{X_{y+1}} = \frac{C_y(U_y/Q+G(U/Q))-C_y^2}{X_y(U_y/Q+G(U/Q))-X_y^2} \tag{17}$$

For convenience, this function is plotted in terms of C_{y+1}/X_{y+1}, C_y/X_y in Figure 5.5.1 for different levels of yield/biomass ratios. This shows that:

- for low levels of fishing mortality, bias in the forecast catch is approximately equal to the bias in the recent catch.
- at increasing levels of fishing mortality, over-reporting of catches leads to lower catch forecasts than one would expect if bias were constant, and under-reporting of catches leads to a higher catch forecast than one would expect if bias were constant.

Now for the case where historical misreporting has occurred prior to year y. This introduces a bias in Q through whatever stock assessment procedure is used, due to misreported historical catches. Ignoring time-series effects, a simple approximation to bias so introduced can be calculated. Allow that a biassed estimated of catchability due to misreporting, q, is calculated.

Since generally stock assessment models estimate catchability by some such procedure as:

$$q = \frac{\Sigma_y U_y}{\Sigma_y S_y} \quad ; \quad Q = \frac{\Sigma_y U_y}{\Sigma_y B_y} \tag{18}$$

where S represents an erroneous perception of stock size derived from misreported catches C. Generally stock assessments will have the property that

$$\frac{S_y}{B_y} = \frac{\Sigma_y C_y}{\Sigma_y X_y} \tag{19}$$

Then

$$q = Q\frac{\Sigma_y X_i}{\Sigma_y C_i} \tag{20}$$

and for shorthand denote a historical misreporting coefficient:

$$\alpha = \frac{\Sigma_y X_y}{\Sigma_y C_y} \tag{21}$$

The production function G(B) will also be biased by misreporting; denote by g(B) the estimate of the production function derived from misreported catches.

then

$$\frac{C_{y+1}}{X_{y+1}} = \frac{C_y q((U_y / q) + g(U_y / q) - C_y)}{X_y Q((U_y / Q) + G(U_y / Q) - C_y)} \qquad (22)$$

substitute q= aQ,

$$\frac{C_{y+1}}{X_{y+1}} = \frac{C_y \alpha \left[\left(\frac{U_y}{Q.\alpha} \right) + g\left(\frac{U_y}{Q.\alpha} \right) - C_y \right]}{X_y \left[\left(\frac{U_y}{Q} \right) + G\left(\frac{U_y}{Q} \right) - X_y \right]} \qquad (23)$$

If one ignores time-series effects that may bias the estimates, the production function g may be expected simply to scale according to a, so the following approximation can be made:

$$\alpha g\left(\frac{U_y}{Q\alpha} \right) \approx G\left(\frac{U_y}{Q} \right) \qquad (24)$$

which allows simplification to

$$\frac{C_{y+1}}{X_{y+1}} = \frac{C_y (B_{y+1} + X_y - \alpha C_y)}{X_y B_{y+1}} \qquad (25)$$

Some example plots of (12) for plausible values of a and C_y/X_y are given in Figure 5.5.1.

5.5.2 Forecast Catch for Known Target Fishing Mortality

By a similar argument, bias in such forecasts are given by:

$$\frac{C_{y+1}}{X_y + 1} = \frac{F_{target}\left(\frac{U_y}{q} + g\left(\frac{U_y}{q} \right) - C_y \right)}{F_{target}\left(\frac{U_y}{Q} + G\left(\frac{U_y}{Q} \right) - X_y \right)} \qquad (26)$$

which leads to

$$\frac{C_{y+1}}{X_{y+1}} = \frac{\frac{1}{\alpha}(B_{y+1} + X_y - \alpha C_y)}{B_{y+1}} \tag{27}$$

Some plots of the dependence of C_{y+1}/X_{y+1} on C_y/X_y for different levels of a and X_y/B_y are given in Figure 5.5.2. Negative slopes arise because underestimates in catches in one year lead to overestimates in stock size and in the catch forecast for the following year.

5.5.3 Dependence on Survey Timing

The foregoing is based on the assumption that survey measurement of stock size U_y are made at the start of year y. An alternative could be that survey measurements are made at the end of year y and return a measurement of B_{y+1}. In this case, bias in F-*status quo* catch is simply given by:

Note that as recent misreporting tends to historical misreporting, the ratio tends to 1.

$$\frac{C_{y+1}}{X_{y+1}} = \frac{C_y}{X_y} \quad (28$$

For the target-F case the bias in catch forecast is simply:

$$\frac{1}{\alpha} \tag{29}$$

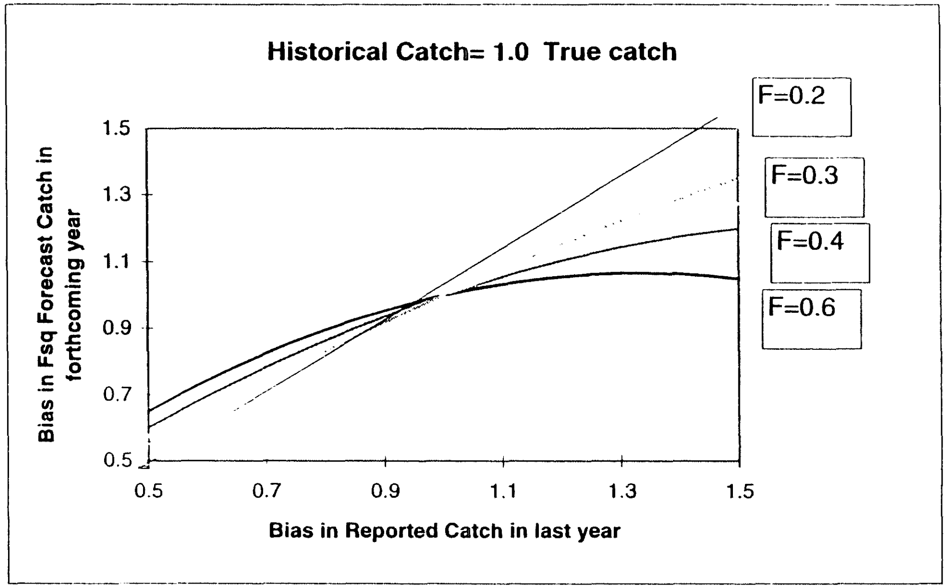
so the forecast is biased directly by historical misreporting.

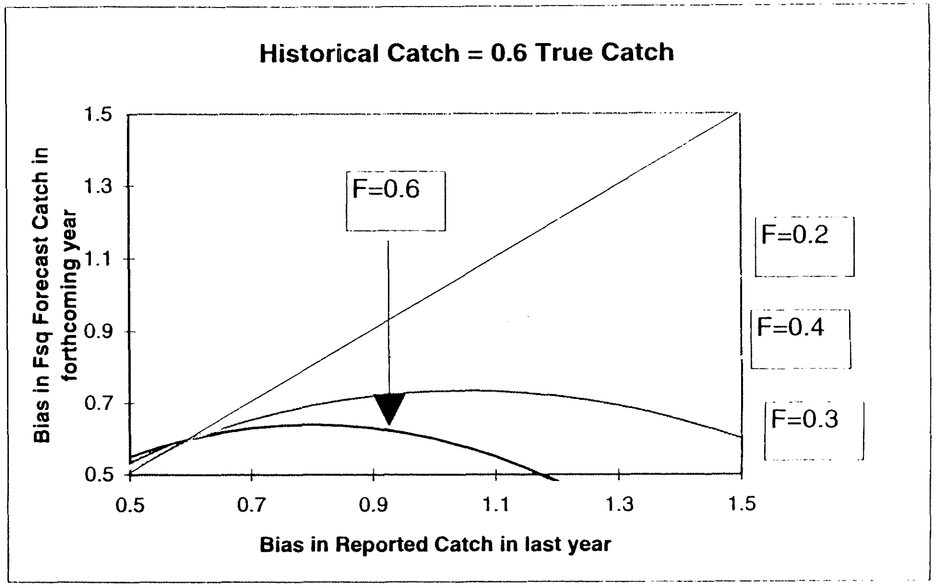
Conclusions:

1. The effect of misreporting on catch forecasts depends on the timing of surveys within the fishing year.
2. For stocks surveyed at the end of the fishing year, a target-F catch forecast is simply biased by historical misreporting (and will therefore be more robust to changes in reporting practices).
3. For stocks surveyed at the end of the fishing year, a status-quo F catch forecast is biased by recent misreporting divided by historic misreporting.
4. For stocks surveyed at the start of the fishing year, more complex relationships hold which are dependent on fishing mortality. In general:

- For F-*status quo* forecasts, (29) will be approximately correct only for low fishing mortalities. At higher fishing mortalities, under-reporting of catches in the most recent year will result in overestimation (relative to (29)) of forecast catches. Over-reporting of catches will result in underestimation (relative to (29) of forecast catches).

- Target - F forecasts, at low levels of fishing mortality (less than about 0.5) will be less biased than recent reported catches, but the direction of the bias is reversed. At high levels of fishing mortality the forecast will be more biased than recent catches.





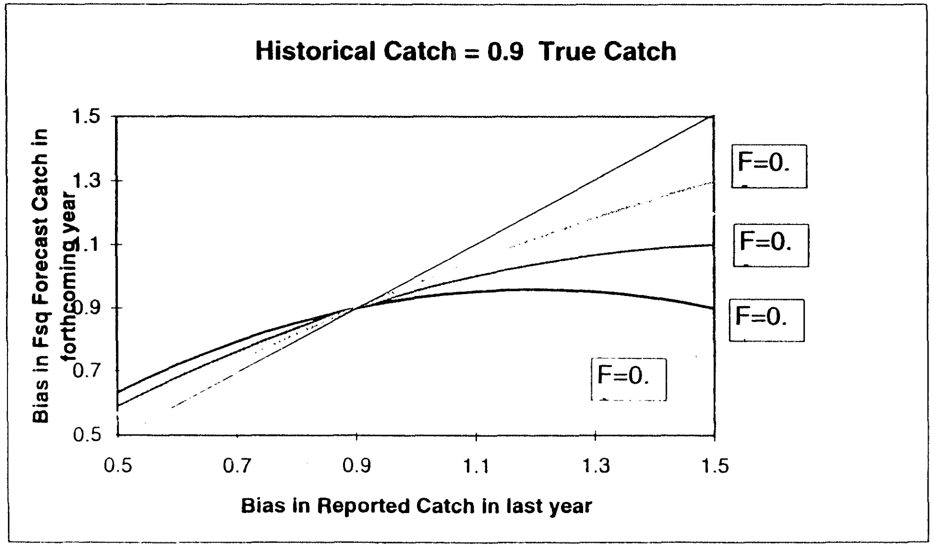


Figure 5.5.1. Effect of misreporting in the most recent year on F-status quo forecast catch, for different levels of historical misreporting. Stock assumed measured by surveys at the start of the year.

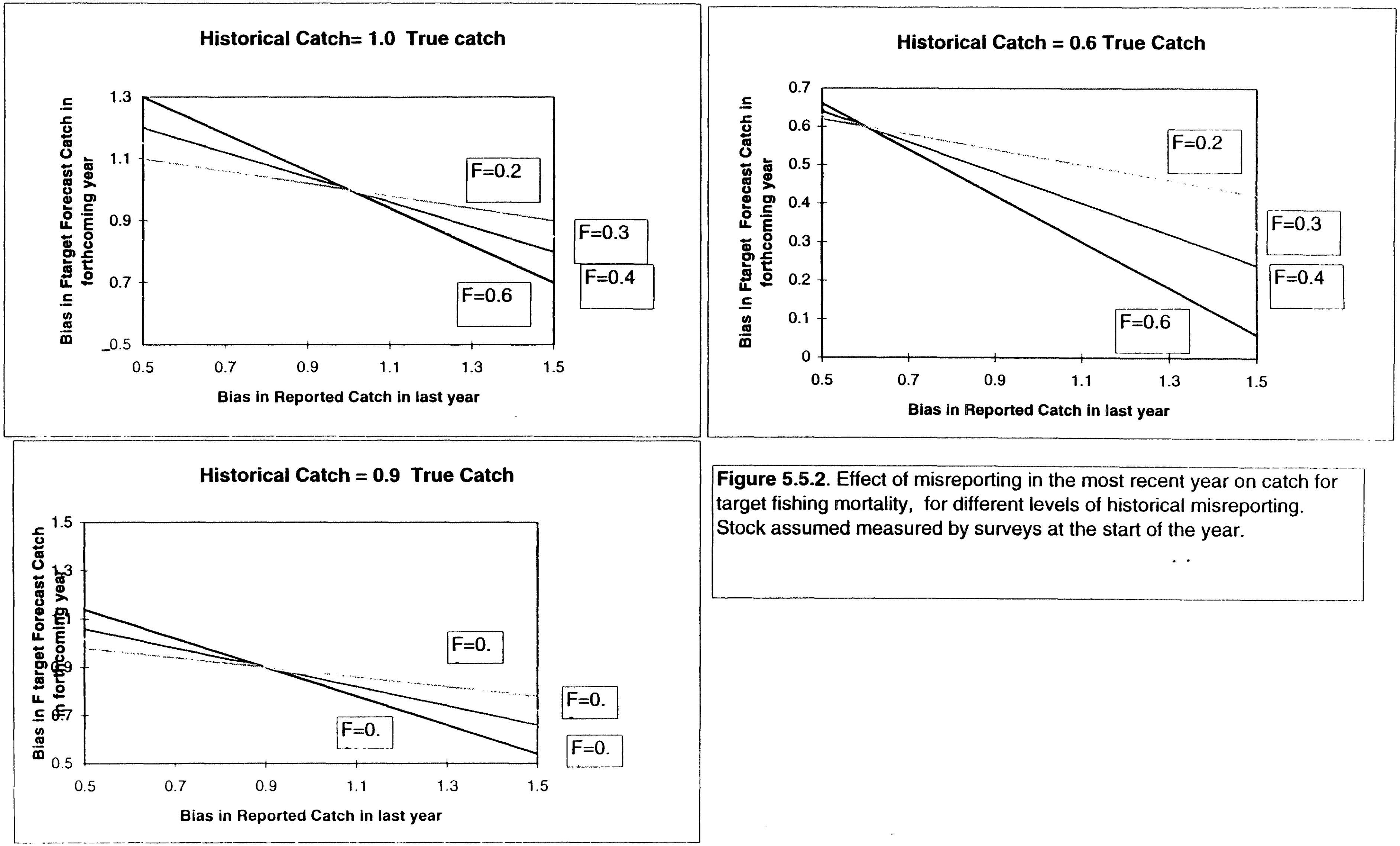


Figure 5.5.2. Effect of misreporting in the most recent year on catch for target fishing mortality, for different levels of historical misreporting. Stock assumed measured by surveys at the start of the year.

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6 COMPREHENSIVE FISHERY EVALUATION OF NORTH SEA FLATFISH

6.1 Introduction

In this section components of the plaice and sole fisheries, the ecology and the economics required to conduct a comprehensive fishery evaluation (CFE) for the North Sea flatfish fishery are discussed. North Sea flatfish is a suitable choice for starting a CFE because it forms a relatively well-understood fishery system with two main target species (sole and plaice) and one dominating fleet (beam trawl) for which a wealth of information is available. Whilst the system is relatively simple, it comprises sufficient complexities to make it a model for pursuing this new approach to fisheries evaluation, and seeking results which can be applied in fisheries management. In the following Sections, appropriate components of the CFEs are identified and described briefly, data sources are identified and priority areas for further study are mentioned.

6.2 Historical perspective

In the North Sea, flatfish have been exploited for more than 100 years. The earliest data go back to the turn of the century when extensive studies were started focussing on the basic ecology (distribution, abundance, growth, maturation, fecundity, feeding, migration). Since then, various studies on the ecology and population dynamics of plaice and sole have been conducted. In the 1950s a regular market sampling programme was set up to estimate the size-composition and age-composition of the commercial landings which form the basis of the stock assessments carried out annually by ICES. Around 1970, research vessel surveys were started to study the variability and distribution of recruitment, and to study the trends in abundance and distribution of the exploited stock. In addition, specific research projects were carried out to enhance our understanding of certain aspects of the ecology of the species (early life history, migration, growth, fecundity, feeding). Economic data on prices, costs, earnings, fuel consumption and investments have been collected in the Netherlands since the 1950s.

The studies have shown that the level of exploitation on plaice has varied considerably through time, but has been at a relatively high level since the turn of the century (Bannister, 1978; Rijnsdorp & Millner, 1996). The level of fishing mortality on sole started to increase only after the (re-)introduction of the beam trawl fleet in the early 1960s (de Veen, 1978; Millner and Whiting, 1996).

6.3 Fisheries

6.3.1 Fleet composition (gear) and target species

The North Sea flatfish fishery is mainly directed at plaice (*Pleuronectes platessa*) and sole (*Solea solea*) using a variety of fishing methods. Other species taken include the flatfish turbot, brill, dab, lemon sole and flounder; together with roundfish species such as cod, haddock and whiting. Plaice is mainly caught in a mixed beam trawl fishery that contributes to more than two-thirds of the international landings and uses a small mesh size of 80mm. Part of the beam trawl fishery is directed at plaice, employs large meshed nets (120mm), and is carried out in the central North Sea. One third of the international landings is caught collectively by otter trawl, Danish seine and gill nets. Beam trawl fisheries are mainly carried out by the Netherlands, Belgium and the UK and to a lesser extent in recent years by Germany. Seine and gill nets are used in Denmark and the UK. In 1989 the EU installed a closed area in the south-eastern North Sea to protect undersized plaice. In this so-called 'plaice box' fishing with vessels greater than 300 HP working with towed gear (beam and otter trawl) was not permitted in the 2nd and 3rd quarter of the year. In 1994 the 'plaice box' was extended to the 4th quarter and since 1995 has been closed during the whole year. The fleet of Euro cutters with engines less than 300 HP, which could fish exclusively within the 12 mile zone and the plaice box, expanded following the installation of the 'plaice box' (ICES, 1994).

6.3.2 Fleet dynamics: effort (re-)allocation, interference, catchability and technical interactions

A major component in the appraisal of the impacts of a fishery on a resource such as a fished stock is effort allocation. Effort allocation is expected to respond to changes in the availability of target species, their relative contribution to the total catch, prices and costs, and the management regime. No studies that have attempted to tackle the problem of effort allocation in the North Sea flatfish are known to members of this Working Group. One possible approach, which has been applied in several cases (see, for instance, Gillis *et al.*, 1993) would be to apply appropriate concepts such as the ideal free distribution from behavioural ecology. Preliminary work started at RIVO-DLO focuses on the analysis of the dynamics of effort allocation in relation to the distribution of the fisheries resources and the interaction between fishing vessels exploiting the same local patch of the fishery.

An additional point of interest is the by-catch of non-target quota species like cod and whiting. Since the North Sea flatfish fishery is a mixed fishery, by-catch of non-target species is difficult to avoid using the current fishing gear. A stringent regulation on one of the non-target species could dramatically affect the fishing patterns at sea and may, for example, lead to high rates of discarding.

6.3.3 High grading, discarding and unreported landings

Stringent quota regulation may lead to high-grading by fishermen selectively discarding low-priced size classes. For plaice this may occur during the spawning period when large spent fish are discarded because of their low price. Alternatively, high grading may occur in autumn when a strong year-class recruits to the fishery. High grading will cause a substantial bias in the perceived state of the stock due to error in the estimated catches; as well as biasing knowledge about their age structure. This problem requires further study and may become important in the future if restrictive TAC's are implemented (Gillis *et al.* 1995a,b).

Discarding of undersized fish is a serious problem in the flatfish fisheries due to the relatively small meshed gear used. The problem mainly affects plaice (ICES, 1987). Discarding was estimated to be about 50% in numbers in the 1980s (van Beek, 1990). It is likely, however, that the level of discarding has changed over time due to changes in market conditions, growth rate and effort distribution (technical measures such as the 12 mile zone and the 'plaice box'). Therefore, there is an urgent need to reconstruct the historical discarding pattern in order to adjust the time-series of VPA recruitment estimates. Such an exercise is feasible using the available data on the growth rate by cohort, the selection ogives estimated during discard trips made on-board of commercial vessels at different historic periods, length composition of the landings, and data on the distribution of fishing effort. The interpretation can be enhanced if information could be made available on the market condition of fish landed (prices by market category of plaice, sole and other by-catch species).

In the late 1970s and 1980s, the estimated total landings are uncertain due to unreported landings. In 1990 this situation has improved due to a stricter enforcement of the legislation, but a critical re-appraisal of the estimates of unreported landings and their age-composition is still required.

Data available: Size distributions in the landing (CEFAS, RIVO-DLO); selection ogives from discard trips around 1970, 1980 and 1990 (de Veen & Rodenburg, 1971; de Veen et al., 1975; van Beek, 1990); growth data from surveys (various sources) and otolith studies (RIVO); effort distribution (CEFAS, RIVO, others);

6.3.4 Economics

6.3.4.1 Prices

Prices are determined by demand factors as well as supply factors. When looking at the demand factors it is important to distinguish between the fresh market (restaurants, fish shops) and the filleting industry. The fresh market is always in need of large sized plaice and sole and hence, prepared to pay a higher price as compared to the filleting industry. The filleting industry is targeting on the processing of white fish and looks for substitution of other fish species when prices of plaice and sole are too high. It is a global market and not merely an EU market. On the supply side the landings have a highly seasonal pattern which will determine the price to some extent and higher landings will generally result in lower prices. Also there is a quality aspect in the price of plaice since during the spawning season the quality of large plaice is poor and hence, the prices are lower.

For a CFE it is important to model the prices adequately since these will modify the behavior of fishermen through high-grading and mis-reporting (Section 6.3.3). To be able to calculate management options, it is important to be able to understand and predict the development of the markets:

- Are there new markets opening for plaice and sole such as in China?
- Are there new markets for other species such as dab that could be caught by beam trawlers?

A thorough understanding of the markets and their development is necessary to obtain an understanding of the linkage between prices and effort and hence, to better understand the development of fish stocks and the effectiveness of their management.

6.3.4.2 Costs and earnings, profits, net result, employment and investments

To be able to see the economic performance of the fleet and to be able to understand the individual behavior of fishermen, not only are prices important but also the costs and earnings of fishing. Earnings are determined by prices and the amount of landings (target species as well as by-catch species). There are also other types of earnings such as the selling of quota to third parties and tourism. For costs, it is important to distinguish between

- costs depending on effort (fuel costs, fishing gear, maintenance);
- costs depending on landings (crew share, auction costs); and
- depreciation and interest costs (for hull and engine).

These costs will determine and possibly explain the short and long term behavior of fishermen. For instance, a fisherman may fish for a few years with a low degree of maintenance of his vessel and compensate his low earnings due to low catches. Although it is not economically sound to keep on fishing, this fishermen may be postponing maintenance in the hope that a strong year-class will enter the fishery in the future and he will then earn the money necessary for the maintenance and up-keep of his vessel.

Profits are the difference between costs and earnings and will often result in investments in newer and more efficient vessels. This could lead to more pressure on management and a higher probability of undesirable side effects. There is a socio-economic aspect to the fishery which involves the local fishing communities and the inheritance of culture. This often means that there is a strong pressure to assure both present and future employment in the fishery.

6.3.5 Environmental impact

North Sea flatfish are mainly exploited by beam trawl gear and concern has been raised that this gear, like other heavy trawls, may have a detrimental effect on the ecosystem, in particular on the benthos (ICES, 1988). The impact of (beam-) trawling has been studied extensively in the recent years (de Groot and Lindeboom, 1994) and is still the subject of ongoing research. The focus of the research is on experimental studies of the direct impact on the sea-bed in trawled and untrawled areas, the study of the micro-distribution of the fishery and its relationship with benthos and sea bed characteristics (Rijnsdorp *et al.*, 1997). The topic is on the agenda of the ICES Working Group on Ecosystem Effects of Fishing and results will be reported to this group. Beam-trawling is a highly energy-intensive fishery and this aspect could be included in an assessment of the environmental impact of (beam-) trawling.

6.4 Biological system

6.4.1 Stock structure, spawning and nursery areas, and migration

The location and importance of the spawning areas has been established by the extensive ichthyoplankton surveys (Harding *et al.*, 1978; ICES, 1986, 1991), whereas the location and relative importance of the nursery grounds is known from the ICES coordinated pre-recruit surveys (ICES, 1984; van Beek *et al.*, 1990). Tagging experiments with adult fish tagged during spawning time showed that adults return to the spawning ground. Tagging experiments with juvenile fish showed that specific nursery areas can be linked to spawning areas (ICES, 1989; 1992). This led to the conclusion that within the North Sea, different (sub-) stock components can be distinguished. Although each component has a specific spawning area and nursery area, mixing occurs during the feeding period (de Veen, 1978). It is uncertain, however, to what extend exchange of individuals occurs between the sub-components.

A critical evaluation of the stock structure, the exchange between management units and the migration behaviour of plaice and sole is currently being conducted in an EU-project by the Fisheries Laboratories of Belgium, Denmark, England and the Netherlands. In this project, all the available conventional tagging data on plaice and sole will be collated and (re-)analysed; together with the data on the distribution of juveniles and adult fish. The results will be compared with data on North Sea plaice from recent experiments using data storage tags (DST) that make possible a reconstruction of the ground tracks of plaice [Arnold and Metcalfe, 1997]. The results will be used to develop an improved simulation model of the spatial dynamics of plaice.

6.4.2 Growth

Growth has been studied extensively. One important source of information is the market sampling programmes and trawl surveys carried out in several countries. Otoliths are used for age determination and a CFE should include a check of the consistency of ageing across countries and across time.

Growth rate differs between the sexes after sexual maturation. Substantial changes have been documented in the mean size at age, the length increment estimated by back-calculation of otoliths and in the condition factors (Millner and Whiting, 1996; Rijnsdorp and van Leeuwen, 1996). Changes occurred in both pre-recruit, as well as recruited size classes. The current view is that the changes in growth have a multiple cause. Statistical analysis of the back-calculation data has shown that the variance in growth can be explained by density-dependent effects in both the juvenile and the adult phase, effects of increased levels of nutrients in the coastal waters and the effects of the increase in beam trawling.

Pre-recruits are distributed in shallow coastal waters and migrate to deeper offshore waters as they grow. Therefore, it is likely that the offshore movement, and hence the recruitment to the fishery, will be affected by the growth rate of the juveniles. This aspect is typical for flatfish and has important implications for the effect of the growth rate on the level of discarding.

Fisheries in general will selectively remove the fastest growing fish from a cohort which complicates the analysis of the changes in growth rate. However, the data from conventional tagging studies on North Sea plaice and sole (Section 6.4.1) can be used to determine growth rates through time and possibly, space.

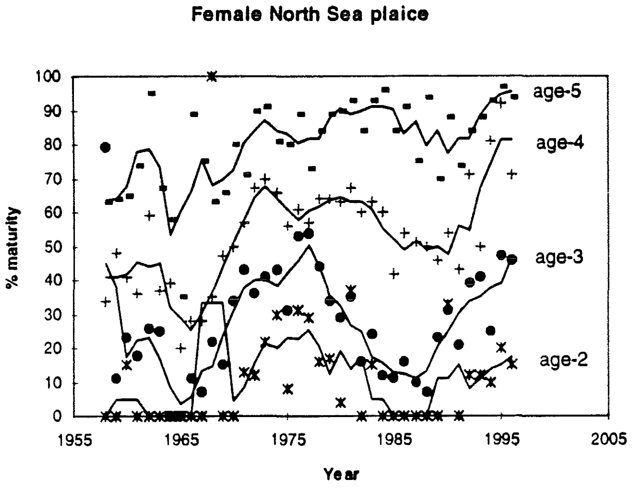


Figure 1. Plaice: percentage of mature females of age 2 to 5 as observed in the Dutch market sampling programme.

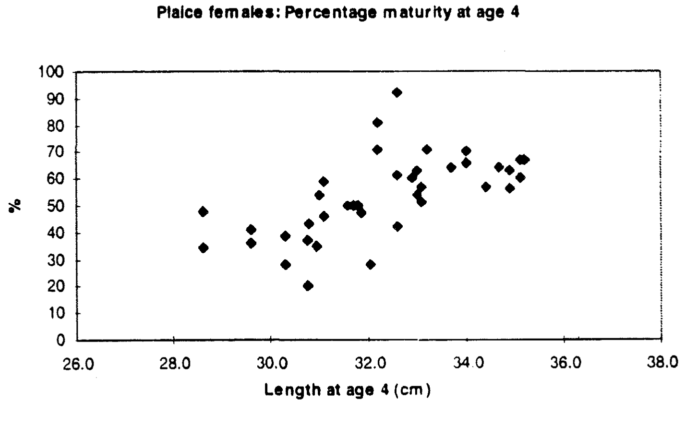


Figure 2 Plaice: Scatter plot of the percentage maturity at age 4 against the length at age 4.

6.4.3 Maturation

Maturation data are routinely collected during market sampling programmes, or have been studied in particular case studies (de Veen, 1976; Rijnsdorp, 1989; Ramsey, 1993; Witthames & Greer Walker, 1995).

The process of sexual maturation is linked to the growth of the fish. Males mature at a smaller size and a younger age than females. There are indications that differences in growth rate in the juvenile phase of plaice affect the process of maturation 2-3 years later (Rijnsdorp 1993b). In both plaice and sole the proportion of mature fish at age increases with the increase in growth rate. The proportion maturity at age appears to be more variable than the length at first maturation. The onset of sexual maturity appears to be slightly different among the sub-components within the North Sea and adjacent waters.

Figure 1 shows how the proportions of mature females at age varied between the years 1958-95. The data were estimated from the market samples taken in the Netherlands during the spawning season (1st quarter of the year). In the 1970s the proportion of mature females increased considerably from about 30-40% at age 4 in the early 1960s to 60% in the mid 1970s. After a slight reduction in the 1980s, the proportion mature appeared to increase to about 80% in the mid 1990s.

The results shown in Figure 1 will be biased for the youngest age groups (age group 2 and 3) which are not yet fully recruited to the fishery. Further work is needed to derive unbiased estimates of the proportions of mature females at age. A potential approach might be to employ the apparent relationship between the maturation and growth (Figure 2).

The possibility of density-dependent effects on maturation has not been studied in detail. An indirect effect can be expected through density-dependent effects on growth.

In plaice, the size at first maturation and the age at first maturation decreased between the turn of the century and the present time period. These changes could be due to the selection of late maturing genotypes. Although the observed changes were in line with the theoretical expectations and could not be fully explained by a phenotypic plasticity but the data do not provide a formal proof of genetic selection (Rijnsdorp, 1993a).

6.4.4 Fecundity and egg quality

Sole fecundity shows a geographical pattern with size-specific fecundities decreasing from high values in the eastern North Sea to lower values in more southern areas (Witthames *et al.*, 1995). This pattern coincides with an increase in mean egg sizes from north to south (Rijnsdorp & Vingerhoed, 1994).

Analysis of the fecundity data of plaice collected in three periods during this century (1900s, late 1940s and 1980s) revealed substantial differences. Fecundity of the smaller size classes appeared to have increased between the late 1940s and the 1980s. Fecundity of the larger size classes, however, did not differ substantially between the 1900s and the 1980s, but was substantially lower in the late 1940s (Horwood *et al.*, 1989; Rijnsdorp, 1991). Because no difference in ovary weights were observed, this could indicate a change in egg size and hence, egg quality.

An analysis of the size-specific fecundity in conjuction with the back-calculated growth of individual females did not reveal an effect of growth rate on fecundity (Rijnsdorp, 1989; Millner *et al.*, 1991), in contrast to experimental results of Horwood *et al.* (1989). This may suggest that density-dependent effects on the size-specific fecundity are unlikely. However, density-dependent growth may result in females lagging behind in body size which will have a negative effect on absolute fecundity.

6.4.5 Sex ratio

In flatfish the percentage females in the population generally increases with age, indicating a difference in mortality rate. In plaice, part of the difference in mortality rate is due to the higher catchability of males during the spawning season. This implies that the sex ratio at age will change in response to a change in the level of fishing mortality. These relationships should be carefully examined in both species of North Sea flatfish (plaice and sole).

6.4.6 Recruitment

Plaice and sole spawn numerous pelagic eggs which suffer high rates of mortality. Egg mortality appears to be a function of ambient water temperature and egg size. Generally, egg mortality rates decrease at lower water temperatures. Also the cumulative egg mortality of plaice is lower at low water temperatures despite the longer incubation period. It is not known which agents cause egg mortality, although it is generally held that predation may be the main cause (Bailey and Houde, 1989; Leggett and DeBlois, 1994).

Few data on the mortality rate of demersal juvenile sole are available. For plaice, extensive work has been carried out in the Wadden Sea indicating density-dependent mortality during a short phase just after settlement (van der Veer, 1986; Beverton and Iles, 1991). Indirect evidence seems to support the importance of density-dependent processes during the early demersal life history phase, but this needs careful analysis of the available data. In sole, however, there is clear evidence that demersal stages may suffer from additional mortality during cold winters (Rijnsdorp *et al.*, 1992). This applies to juveniles as well as adult fish. No quantitative estimates of the relationship between mortality and temperature is available, although additional mortality seems to occur when the water temperature falls below 3 degrees Celcius (Woodhead, 1964a, 1964b).

Estimates of M of the adult plaice are based on the decline in CPUE of year classes that were represented in the catches just prior to and after World War II.. M was estimated to be 0.14 for males and 0.08 for females (Beverton, 1964). However, the age determination was based on reading whole otoliths. Recent re-analysis of a sample of post-war otoliths could not reproduce the original age reading. Using the sliced and burned otoliths, a substantial underestimation of the age was suggested. A carefull check of the potential impact on the estimate of M in plaice is needed.

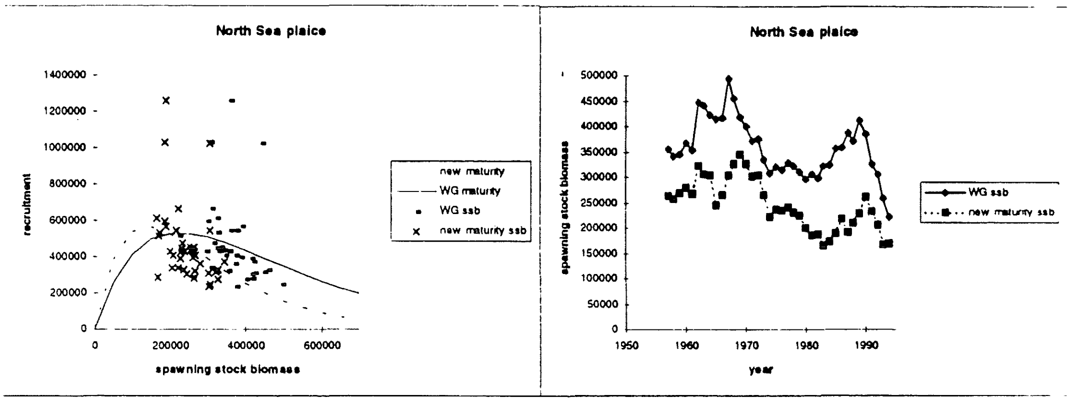


Figure 3. Stock recruitment relationship of North Sea plaice as estimated by the Working Group in 1996 (full line) and the relationship after correcting the SSB for the observed variations in maturation (broken line; left hand panel) and the time trends in SSB (right hand panel).

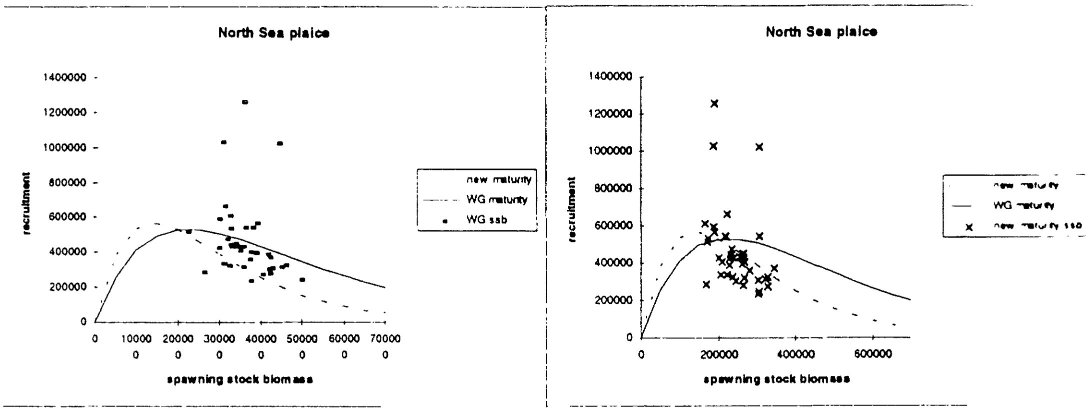


Figure 4. Scatter plots of VPA estimates of Recruitment and SSB assuming a fixed maturity ogive as done in the Stock Assessment Working Group (left hand panel) and that after taking account of the variability in the percentages mature females at age (right hand panel). Fitted relationships shown in both panels. Full line relationship assuming fixed maturation; broken line: variable maturity.

6.4.6.1 Stock and recruitment

The stock-recruitment relationship is generally analysed from the information obtained from VPA calculations. The VPA estimates of recruitment and SSB, however, may be substantially biased due to variations in discarding, maturation, sex ratio's and fecundity. Also, variations in the proportion of recruit spawners should be considered because these could produce less viable eggs. It is urgently needed to utilise all available data on these aspects to improve the estimate of the spawning potential (spawning stock biomass, SSB). As an illustration of the possible effects, stock-recruitment relationships were compared during the Working Group using the uncorrected SSB obtained from the most recent stock assessment of North Sea plaice.(ICES, 1997) and a series of SSB corrected for the observed changes in the female proportions mature at age (Figures 3 and 4). Implications of this in terms of the effect on biological reference points is explored in section 4.

6.4.6.1.1 Correcting VPA recruitment for discarding

It is well-known that discarding is an important problem in the North Sea flatfish fishery. The problem affects mainly plaice which has a much lower selection factor (2.2) than sole (3.3). Discard rates on individual vessel trips vary considerably in relation with the location and time of the year. The average discard rate of plaice is estimated at 50% in numbers (van Beek, 1990). Survival of discards is low (van Beek *et al.*, 1990) and the mortality generated by discarding is affected by the mesh size, the minimum landing size and the selection ogive.

6.5 Assessment

6.5.1 Data problems

There are several problems concerning the assessment of flatfish stocks. First, there is uncertainty in the total international landings due to the occurrence of unreported landings, in particular in the mid 1980s. Second, no estimates of discarding are available. Third, male and female flatfish differ considerably in certain characteristics (growth, maturation, natural mortality, catchability) that may have an impact on stock assessments. Fourth, catchability may differ among seasons due to differences in behaviour as shown for example in North Sea plaice (Beverton, 1964).

6.5.2 Current procedures

Extended Survivors Analysis is used for the assessment of both North Sea plaice and sole (ICES 1997). Data are assembled by country, as far as possible separated by sex. Market samples are taken at Dutch, English, Belgian, Danish and Scottish auctions to generate fleet specific age-length keys, weights at age in the catches and weights at age in the stock. Total official landings by country are split up in catch in numbers using age-length keys by fleet.

In the most recent assessment (ICES 1997) the following tuning indices were used:

> *North Sea Plaice*: Netherlands CPUE, Netherlands Bottom Trawl Survey (BTS), Netherlands Sole Net Survey (SNS), English Seine CPUE.
> *North Sea Sole*: Netherlands CPUE, Netherlands Bottom Trawl Survey (BTS), Netherlands Sole Net Survey (SNS), German Solea Survey

The same effort index is used to calculate the catch per unit effort (CPUE) for plaice and sole of the Dutch beam trawl fleet. This assumes a completely mixed fishery. If fishing patterns would indicate that a directed fishery has developed towards a specific target species, the combined effort index would no longer provide an adequate estimate of the fishing effort on North Sea flatfish. This may need further investigation.

6.5.3 Alternative procedures

The currently used age-based analysis is only one of the possible assessment techniques. Alternative procedures include other age-based methods, length-based assessments and the use of stock production models. In evaluating the performance of a number of alternative techniques it would be possible to consider the cost effectiveness of each in turn.

The effect of the problems summarised in Section 6.5.1 on the perception of the state of the stock, and the biological reference points, should be investigated in detail. The results of a separate sex quarterly disaggregated VPA, and corresponding biological reference points, can be compared with those obtained from a traditional combined sexes annual VPA. The performance of alternative assessment methods may be evaluated against this background.

6.6 Management

6.6.1 Input

The current management is based on annual single species TAC's accompanied by technical measures with regard to mesh size, minimum landing size and closed areas. At the national level, different measures may apply with regard to quota (ITQs, monthly/weekly quota) and effort regulation (maximum HP, maximum number of fishing days). An overview of the management of North Sea plaice and sole is given by Daan (1997), who presents the dilemma's and interactions between management advice, regulation and political conflicts.

A major problem with the TAC management of North Sea flatfish is that it controls the landings but not the catches. A reduction in TAC may result in an increase in discarding, high grading or misreporting, but not to the intended decrease in fishing mortality. In addition, TAC management may affect the distribution of the fisheries and hence affect the stock assessment (i.e. the perception of the fishery) by violating the constant catchability assumption (see section 6.9, recommendation 1.4). Also, the management of flatfish may be influenced by the management of North Sea roundfish such as cod which are taken in substantial amounts as a by-catch in the beam trawl fishery.

It is relevant to consider alternative management regimes and explore their performance in the North Sea flatfish fishery context, especially within a system of effort regulation which either directly limits effort or raises taxes on effort-related costs.

6.6.2 Output

Results of different management regimes have to be compared in order to assess both the effectiveness and the cost efficiency of the measures.

From the explorations using the Lowestoft POM model (Section 4.2.2), it can be concluded that precautionary management will result in a substantial reduction in fishing mortality compared to the current levels. This leads to an increase in the uncertainty of the perception of the fishery if traditional assessment methods are being used. This suggests that priority should be given to the exploration of the performance of other assessment methods (see also section 4.5 for a more extended discussion).

6.7 Comprehensive fishery modelling

Two approaches to comprehensive fishery modelling have been presented at the Working Group. A general outline of these approaches and some results follow. The first approach was developped to explore the biological and economic effects of management regulations with a spatial dimension such as the plaice box. The second appraoch focussed on the evaluation of harvest control laws and management strategies.

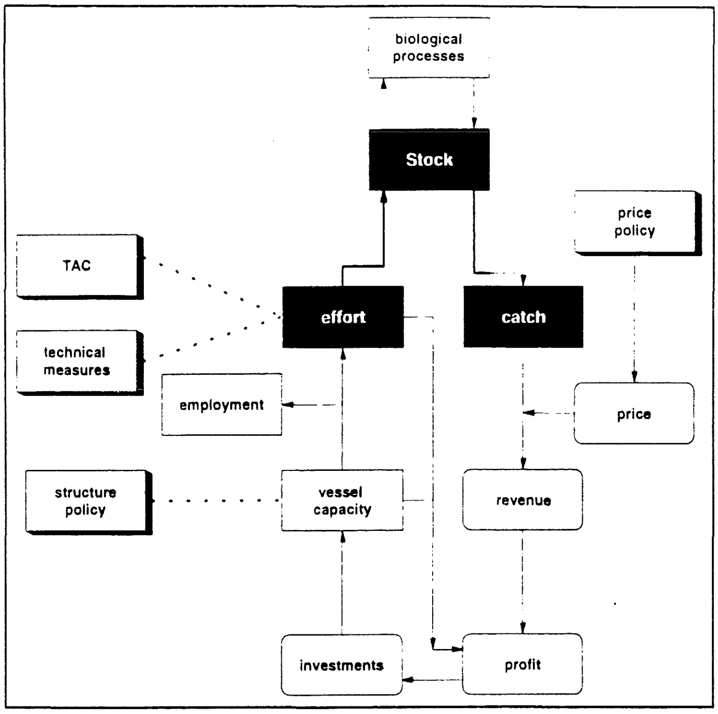


Figure 5 FLATFISH 2.0 flowdiagram

Figure 6 FLATFISH 2.0 spatial grid

6.7.1 A spatial bio-economic simulation model of North Sea flatfish (FLATFISH 2.0)

6.7.1.1 General description

A spatial bio-economic simulation model for the North Sea flatfish fisheries (FLATFISH 2.0) was presented with a main focus on the Dutch situation (Figure 5, Pastoors *et al*, 1997a, 1997b; Dol, 1996; Rijnsdorp & Pastoors, 1995). The model uses 110 ICES rectangles of 30x30 miles as a spatial grid (Figure 6). Two species are incorporated: plaice (*Pleuronectes platessa*) and sole (*Solea solea*). Both species are separated in several size-classes corresponding to Dutch market categories, discards and pre-recruits. Biological processes incorporated are: growth, natural mortality, fishing mortality, recruitment and migration. Options are available to incorporate density dependent growth and changes in growth rate due to environmental factors. Economical processes are: price estimation, costs and earnings calculations and effort allocation.

Scenario analysis: an example:

The simulation model FLATFISH 2.0 was used to do a scenario-analysis of the effect of different plaice-box options. Two options were contrasted:

1. In the first option the closure of the plaice box in the second and third quarter only and for vessels larger than 300 HP (the 1989 situation) was assumed to be continued there after. This can be viewed as a status-quo scenario.
2. In the second option the plaice box was closed in the second and third quarter for the years 1991 to 1994. From 1995 onwards it was assumed to be closed for all quarters (as was the policy since 1995) but it was also assumed that it was closed for all vessels (including the vessels smaller than 300 HP).

Recruitment was estimated as a random selection from the log-normal distribution of historical recruitments. Stochasticity was implemented by using a series of runs with different random seeds. For each scenario 100 runs were made.

6.7.1.2 Results

Figure 7 shows the median and the 5th and 95th percentiles for the spawning stock biomasses of North Sea plaice and sole. The first scenario shows a substantially higher level of discarding than the second scenario due to the generation of fishing mortality in the plaice box in the first and fourth quarter of the year. The net results of the fishery show very positive effects of the all year closure as well (Figure 8). Closure of the fisheries in nursery areas can thus have positive effects for both the stock (less discard mortality) and the catches (catching the fish when they are bigger). The absolute levels of SSB and Yield generated by the model depends heavily on the assumption about the bias in the recruitment time series due to discarding. In the above simulations it was assumed that VPA recruitment amounts to 50% of the 'true' recruiment.

The model has also been used to explore the interaction of growth and migration on discarding. It was shown that the observed decrease in growth rate in the late 1980s can well explain the decrease in the plaice stock due to an increase in the cumulative effect of discarding in spite of the establishment of the plaice box (Rijnsdorp & van Beek, 1996).

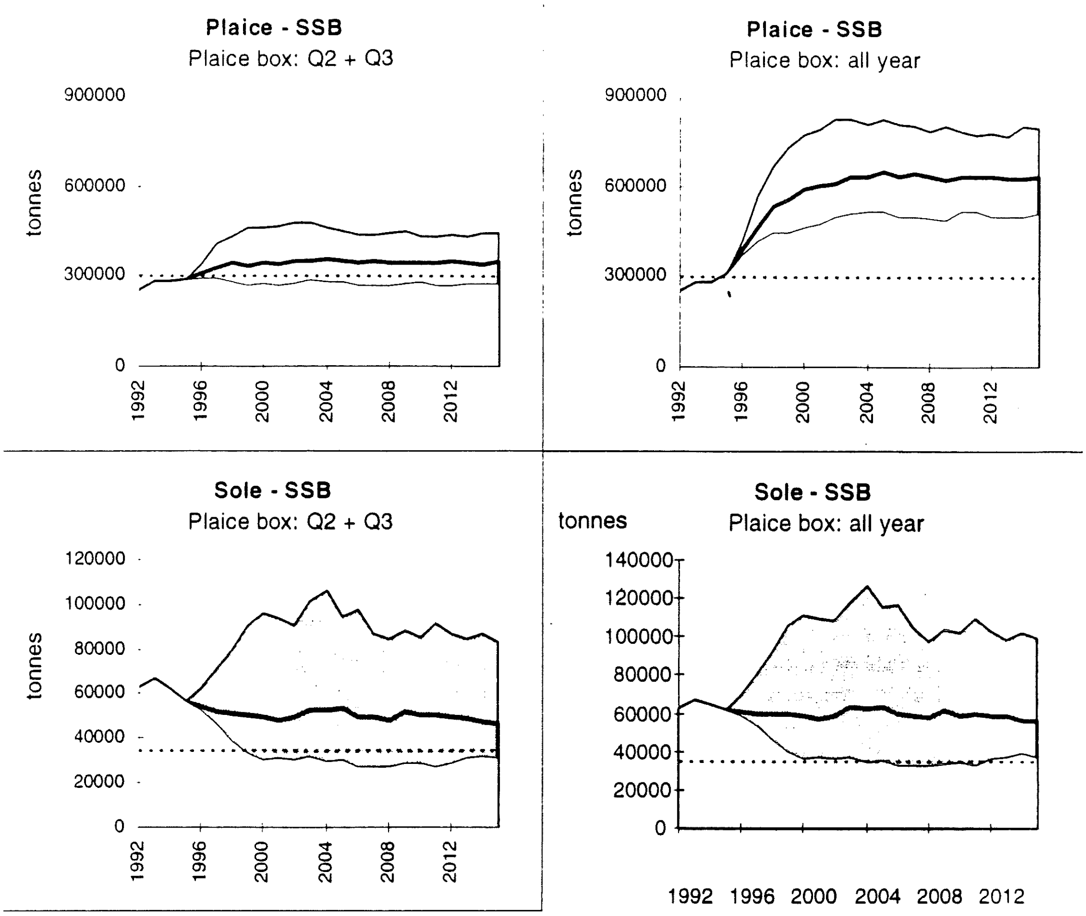


Figure 7 FLATFISH 2.0 scenario analysis. Plaice and sole SSB.

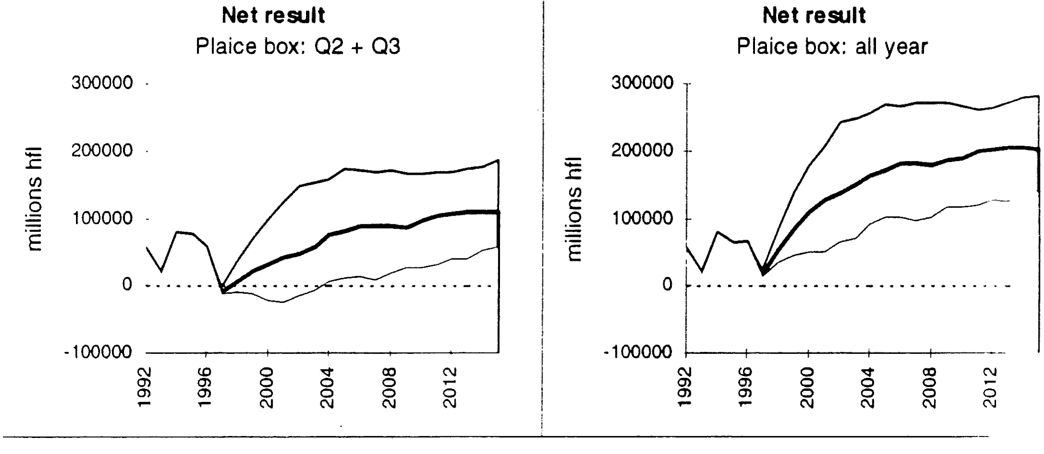


Figure 8. FLATFISH 2.0 scenario analysis: net results of the (Dutch) fisheries.

6.7.2 Comprehensive Fishery Evaluation of North Sea plaice (FISHLAB)

6.7.2.1 Model description

The basic structure of the CFE simulation model consists of an underlying fishery sytem about which inferences are to be made by simulation. Observations are simulated with known error and then used to estimate the status of a perceived system.

The operating model is essentially the same as documented in [ICES(1996a)] but with two different stock-recruitment relationships: a constrained autocorrelated Ricker model [ICES(1996a)] and an autoregressive time series recruitment model [O'Brien 1997, WC7]. Length-at-age has been derived through local non-parametric regressions rather than through a parametric growth model, as previously reported in the Working Documents that were presented at the 1996 meeting of the Comprehensive Fishery Evaluation Working Group. Trends were not modelled in any of growth, maturity and fleet selection. However, the selection pattern for total F was allowed to change because the share of catch-by-fleet was set at the level in the year 1993.

Few data regarding discarding are available but the means of smoothed quarterly percentages of plaice discards in Dutch commercial beam trawlers [ICES(1987)] were used to provide annual proportions discarded by age. Hence, multipliers were applied to selectivity-at-age and the same multipliers were then used for all fleets in the operating model. Discard selectivity-by-fleet and selectivity-by-age was calculated as the product of this multiplier and fleet selectivity-at-age. Discard mortality was calculated as the product of selectivity-at-age and effort for each fleet. All calculations were based on the observed time-series of VPA recruitment which is biassed due to discarding, and the results, therefore, are heavily dependent on the assumption of the level of discarding.

The assessment/control model is based on a tuned VPA, Extended Survivors Analysis [XSA, Darby and Flatman(1994)] with a catch projection to estimate catch quotas. The input Ns for the projection are obtained by projecting forward the Ns from the last data year to the end of the *current year* for which total effort or catch data are available but for which catch-at-age data are not. This is essentially the procedure adopted by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak [ICES(1996a, b)].

6.7.2.2 Scenario analyses

Using the North Sea plaice simulation model outlined in the previous Section 6.7.2.1 as an experimental tool, an investigation of the performance of a range of biological reference points (BRPs) embedded within a general harvest control law (HCL) was undertaken and the results presented in WC8. The simulated North Sea plaice stock was initially in a depleted state due to over-fishing and the intention of management was to increase spawning stock biomass and reduce fishing mortality to sustainable levels. The control law under such a regime was thus a *recovery control law*. However, once the stock had recovered it might be more appropriate to adopt another control law that *optimises* some property of the stock or the fishery. The intention was to be able to investigate the behaviour of a control law with a variety of reference points. The F_{Limit}s were defined by F_{crash} (based upon two different stock-recruitment relationships), F_{loss} and F_{med} (as these are the ones recommended by ACFM). The SSB_{Limit}s were then set using appropriate reference points and the following pairs were used to set the limits and actions in the experiments:

$F_{crash\ Ricker}$ and $SSB_{50\%\ R\ Ricker}$
$F_{crash\ median}$ and $SSB_{50\%\ R\ median}$
F_{loss} and $SSB_{50\%\ R\ median}$
F_{med} and $SSB_{90\%\ R\ 90\%\ survivors}$

The control law stopped over-fishing by reducing fishing mortality and promoted a recovery in an over-fished stock by increasing spawning stock biomass. The *recovery control law* was intended to move the fishery (stock) into a sustainable region of the F versus SSB phase space by triggering management at particular levels of F and SSB.

- One further control law based on replacement F was tested. In this, the management F was set each year to be the replacement F times a constant multiplier to enable the stock to be re-built. Note that by replacement F, we do not refer to F_{rep} which is calculated using average parameter values.

- Both catch and effort controls were investigated. Catches for each level of F were set using a simple short-term projection based on the estimates of stock size and F from the assessment. These catches were then taken from the fishery. Since the operating model is separate from the assessment, the actual F in the operating model could be very different from that in the assessment, reflecting uncertainty in both the models and their parameters. Alternatively, management could be based on effort where rather than estimating the appropriate catch level, F was assumed to be directly proportional to effort, allowing an effort multiplier to be set in the operating model.

A simple mis-reporting law was implemented for both catch and effort. For catch control, if the quota was less than last year's catch then the actual catch was the average of last year's catch and the quota, but the reported catches were the same as the quota; effort was not mis-reported. The result was that the catch-at-age data and commercial tuning indices were biased in years where catches were reduced. In the case of effort misreporting, occurring when effort was reduced in any year, catches were reported accurately and the true effort was taken as the average of the regulation effort and last years effort.

6.8 Conclusions

FLATFISH 2.0

It was concluded that although the analysis can only be presented as exploratory, it is important to be able to estimate the spatial-temporal patterns in the fishery. Changing fishing patterns due to changes of regulations or changes in the distributions of fish can have a high impact on the fishing mortality generated by the fishery. In addition, it provides a powerfull tool to explore the interactions of growth rate, migration and fisheries on the level of discarding which are of paramount importance in a CFE of the North Sea flatfish fisheries.

FISHLAB

While it was concluded that the modelling, analyses and simulations can also only be presented as exploratory, certain points are worth emphasising in relation to evaluating control laws and reference points. Evaluation is best performed on a case by case basis, taking due account of uncertainties and details. The robustness of management to uncertain structures is at least as important as including error estimates in assessments. Taking explicit account of the interaction between assessment, control based on asessments and the feedback to underlying system structure (i.e. the operating model), is the only way to assess the efficacy of management procedures. This is because performance needs to be evaluated for a *true* system being managed through imperfect perception. This is most obvious in extreme cases such as the mis-reporting scenarios investigated in WC8 and would undoubtedly be evident if, for example, multi-species interactions were explicitly modelled for the underlying system. For a more extended conlusion see Section 4.5.

General

The CFE simulation model implemented within FISHLAB has been developed following statistical analyses of the available fishery data at CEFAS, Lowestoft for North Sea plaice but further refinements to the CFE model may be necessary once Dutch data has been fully investigated. Obviously, similar analyses will be needed for North Sea sole so that the specification of a CFE simulation model can be implemented within FISHLAB for sole. Refinement of the plaice and sole models will need to explicitly include density dependent feed-back mechanisms operating in the demersal life history stages (density-dependent maturation, d-d fecundity, d-d growth).

6.9 Future work

The above considerations lead to the following proposed workplan.

1. The biological basis of the North Sea flatfish fishery needs improvement so that more refined models can be built. Specifically, the Working Group identified the need to:
    1.1. construct a time series of SSB estimates in which the observed variations in growth, maturity, sex ratio, fecundity and egg quality are taken into account;

  1.2. construct a time series of discard numbers at age to improve the VPA estimates of recruitment by taking account of the changes in discarding due to observed changes in growth, effort distribution and selection ogives;
  1.3. carry out a quarterly VPA separately on male and females to study the effects on the perceived state of the stock and the various biological reference points;
  1.4. analyse the fleet catch to take into consideration spatial patterns in catchability.

2. Alternative assessment methods, or modifications of existing methods, should be explored that are particularly suitable for stocks exploited at relatively low levels of fishing mortality.

3. The dynamics of effort allocation need to be studied in response to the dynamics in the distribution of fisheries resources and management regulation. This could form the basis to evaluate the effects of various management control laws on the responses of the fishery.

4. Insight in economic markets and their developments is needed to evaluate the socio-economic impact of fisheries management, in particular in relation to the precautionary approach.

It should be remembered, however, that not all of the potential refinements in modelling which might result from improvements in the understanding of flatfish stocks and the biology of the North Sea flatfish fishery will necessarily have an effect on the performance of the CFE simulation model. Simplification of spatial models might be investigated within the FLATFISH 2.0 simulation program prior to their incorporation into FISHLAB. The CFE simulation model implemented within FISHLAB will need substantial modification to incorporate management around the 'plaice box'.

7 COMPREHENSIVE ASSESSMENT OF NORTH SEA HERRING

7.1 Introduction

No attempt at a comprehensive assessment of North Sea Herring has yet been made, and therefore the Working Group proposes a work plan for such an evaluation to be made.

This work plan defines measures deemed necessary by the Working Group in order to complete a comprehensive assessment of North Sea herring. The Working Group suggests that this task be undertaken in two years, with most work being completed intersessionally. Work in the first year should be directed at reviewing basic knowledge about the stock, the data and analytic methods, and reviewing management objectives for the stock given present knowledge about the fishery.

Information so collated should be assessed by the Working Group at its next session, and an appropriate intersessional work plan for addressing the perceived problem areas will be proposed. This work plan for the second phase should define a set of tasks to resolve specific percieved problems in the current procedures of gathering data and assessing the state of the stock, to evaluate harvest control laws, and to provide information perceived as necessary in support of decision making.

The comprehensive assessment should preferably be finalised at the 1999 meeting of the Working Group, but at present it is unclear which ICES institutes can provide the necessary additional research effort to complete these tasks. Therefore the Working Group defines tasks perceived as necessary.

The first intersessional tasks are defined with the purpose of

(i) Determining the best available perception of herring stock biology
(ii) Determining methodological problems and concerns
(iii) Determining data problems
(iv) Determining catching sector characteristics
(v) Determining current management perceptions on the social, economic and biological objectives to be pursued.

7.2 Background

The North Sea herring stock was heavily fished in the late 1960s and early 1970s which, combined with a series of low recruitments, led to a stock collapse to a low level in the 1970s. A fishery closure was imposed, after which the stock recovered due to a series of strong recruitments. On subsequent re-opening, the stock and the fishery rebuilt progressively throughout the 1980s, but by the early 1990s fishing mortality had reached high levels. In 1996 a new estimate of the herring stock was made and found to be considerably below the MBAL. In consequence of the known decline in recruitment at low stock sizes, emergency measures were introduced to reduce fishing mortality by halving quotas within the year.

A significant part of North Sea herring catches are taken as juvenile fish in Division IIIa in a fishery that also catches sprat, IIIa/Western Baltic spring-spawning herring and also sandeel. A review of the stock for management purposes should also encompass the management of herring catches in this area.

At present, the European Union and Norway are in consultations to define a harvest control law for future management of this stock.

It is proposed to organise future work as a number of research reports that can be written independently and collated at a later meeting. The tasks involved and the contents of these reports are described below.

7.3 Review of stock structure

The North Sea herring management unit (Herring in ICES Divisions IV and VIId) is comprised of a number of different herring sub-populations (Banks, Downs, Buchan) which have been believed to have quite distinct population dynamics. Furthermore, there is considerable mixing with herring in adjacent areas (Division IIIa and Division VIa(N)). The current spatial and population structure of herring in the management unit is not known at present, although both survey design and some aspects of management advice depend strongly on assumptions about stock structure. The Working Group proposes, therefore, to

- Undertake a review of current and historic information on migration and stock structure of herring in Divisions IV and VIIId, including also herring in IIIa, and where necessary a review of the dynamics of stocks in adjacent areas where North Sea herring are caught.

7.4 Review of Management Policy for North Sea Herring

Management policy for North Sea herring is presently a topic for active discussion. The Working group recommends:

- A review of historic management action, its effects and perceived advantages and disadvantages.

- A review of current perceptions of social, economic and biological objectives to be pursued by the interested parties

7.5 Review of the Observation Data Set

The working group requires a critical review of the available biological information, and a compilation of corresponding economic information, from surveys, commercial catches, and economic information.

- Review information on trawl surveys, larval surveys and acoustic surveys for North Sea herring, with particular emphasis on consistency of methods, survey variance, possible bias, divergence or conflicting trends among surveys, and coincidence of the survey area with stock location.

- Review information on commercial catches and sampling, with particular emphasis on possible misreporting by area.

- Collate information on prices of herring and, where possible, information on costs of fishing.

7.6 Review of Assessment Methods and Models

The assessment methods used should be documented in detail and examined for conflict between model assumptions and known features of the data. Some problems that have been identified by the Herring Assessment Working Group are a divergence between information from different surveys, time-trends in residuals, and suspected misreporting of catches. In previous years the Assessment Working Group repeatedly over-estimated stock size. Although the methodology used in the assessment is now different, it would be helpful to document why the over-estimation occurred. Furthermore, studies on stock-recruitment relationships remain inconclusive, although a workshop is planned to address this topic. The Working Group recommends:

- A review of current and historical assessment methods used for modelling North Sea Hering dynamics, including stock assessment, stock-recruit modelling and simulation modelling of harvest control laws.

7.7 Review of the Catching Sector

North Sea herring are caught in single-species human consumption fisheries and in mixed-species industrial fisheries by several nations. Each of the fleets has alternative catching opportunities (sandeel, other herring stocks, mackerel etc.) which may have strong effects on fleet dynamics. In order to begin exploring characteristics of fleet dynamics that may be relevant for management purposes, the Working Group requires:

- A review of the development and current state of the catching sector, especially in terms of

- Current levels of investment, alternative catching opportunities, markets, trends in fleet structure and gear, discarding and by-catches

7.8 Task Allocation

The tasks defined above are tasks perceived as necessary for the completion of a comprehensive assessment of the North Sea Herring, in the sense described at the previous COMFIE meeting. However completion of these tasks in one year appear to exceed the work capacity of COMFIE members with an interest in herring, and it is not clear where additional manpower to complete these tasks can be found within the ICES framework. The Working Group stresses that it is in general highly undesirable to allocate review tasks to workers closely involved in the same stock, as this is unlikely to provide new insights.

8 COMPREHENSIVE ASSESSMENT FOR NORTHEAST ARCTIC COD - STEP 1

8.1 Introduction

The Northeast Arctic cod is the largest cod stock in the North Atlantic and has for centuries been the basis for important fisheries. The stock has been the focus of numerous research projects and since the 1980's there has also been a large survey effort to monitor the stock. The data are extensive and provide a good basis for a comprehensive assessment, but the stock is strongly influenced by environmental and ecological conditions and this complicates the modelling.

Management in the most recent years has had the advantage of an increasing stock, but may be facing problems. Firstly, there has been a severe reduction in the area covered by the two main surveys during the last year which will make the assessment more uncertain. Secondly, there are strong indications that the stock was overestimated in the last assessment, but the reasons for this are not clear. The Working Group briefly reviewed some aspects of the stock assessment and catch forecasting procedure currently used to give management advice for this stock. A full review of methodology and available data could not be completed in the time of the meeting, and is therefore deferred to intersessional work in the context of a comprehensive assessment.

8.2 The Fishery

The cod fishery in the Barents Sea region was traditionally a Norwegian coastal fishery based mainly on the spawning concentrations in Lofoten (skrei fishery) and on younger cod following the capelin to the coast of Finnmark (spring or capelin cod fishery). An international trawl fishery in the Barents Sea expanded in the 1930's, but fishing mortality before the war probably did not exceed 0.4. After the war fishing mortality increased steadily and reached 1.0 in 1987, even if attempts had been made to manage the stock by TACs since 1975. From 1946 to 1977 the landings averaged 800,000 t, but the stock was declining and after 1977 the increase in fishing mortality could not prevent a drop in the catch level. In 1989 and 1990 strong management measures were agreed upon and the fishing mortality was reduced to less than 0.3 in 1990. As a result of the reduced fishing mortality and improved growth and recruitment, the stock rapidly increased and the TAC reached 700,000 t in 1994-1996 and was increased further to 850,000 t in 1997.

The cod fishery is currently dominated by the coastal states Norway (coastal fisheries and trawl) and Russia (mainly trawl), accounting for more than 80% of the landings. Other countries also use trawl and the Norwegian coastal fisheries (gillnet, longline, handline, Danish Seine) represent approximately 30% of the total landings.

Nearly all of the cod fishery is directed, but there are usually bycatches (haddock, saithe, redfish, Greenland halibut) and cod may also be taken as bycatch in fisheries with other target species. Mixed fisheries with no particular target species hardly exist in the Barents Sea region, although a vessel may change target species during a trip.

8.3 Stock and Biology

Northeast Arctic cod is characterised by variations in recruitment and growth which to a large extent are linked to environmental factors. The influx of warm Atlantic water into the Barents Sea varies periodically and when the influx is large the sea temperature increases and the nursery area expands. The stock is adapted to this situation and good recruitment only occurs in years with relatively high temperatures when the nursery area is large. Because of the periodical character of the influx, good year classes tend to come in groups of two or more and is normally followed by a period of poor year classes. This causes the stock to fluctuate strongly. The growth is extremely variable. It is affected by the temperature, but more by the availability of suitable prey, especially capelin. The capelin stock has collapsed at least twice and is currently at a low level but showing signs of increase. During these collapses the growth of the cod has been dramatically reduced. The cod currently is maturing when it is around 7 years old, but the age at maturity has been 2-3 years higher in earlier periods.

8.4 Research

The desire to understand the dynamics of this large resource has attracted scientists throughout this century and there has been much research on the stock, both on the biology and for management purposes. Biological research on this stock comprises many aspects, but has been much concentrated on the spawning and recruitment processes. Presently, research on the maternal effects in the spawning process is showing interesting results which could be important for management in the future.

The need for monitoring the stock has triggered a large survey activity, especially after 1980. The surveys are described in more detail in Sections 8.9 - 8.12. The data collected during these surveys are also used to investigate multispecies interactions and environmental (temperature) effects. Furthermore, the experience from the surveys has been the basis for studies of sampling trawl efficiency and fish behaviour. Norwegian and Russian surveys now provide most of the data used in the VPA tuning, but on the older age groups, Norwegian and Russian data on CPUE are also used.

The stock monitoring also requires biological sampling of cod from commercial landings. In Norway the sampling is complicated because of the large number of landing sites (approximately 400) and the complexity of the fishery with several gears and seasonal and regional differences in size composition. However, the coverage of the coastal fishery has been considered satisfactory, whereas sampling from trawlers should be improved. The Russian fishery is dominated by trawl and the sampling programme is extensive. Sampling is also carried out by some of the other countries. There are some age reading problems and Norway and Russia have annual meetings of experts to discuss them.

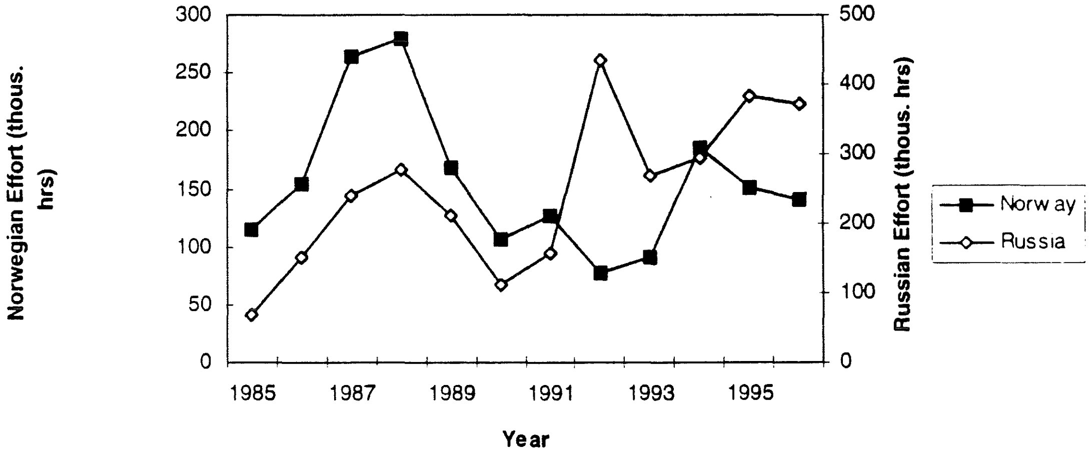
The quality of the commercial sampling is difficult to evaluate because the exploitation pattern may vary as the dominant age groups change with the year class abundance and the availability is affected by changes in temperature and prey stocks. However, the year class strength is usually clearly reflected in the catch-at-age data through most of the life history. The time series of catch-at-age data at ICES goes back to 1946 and can be extended backwards, at least to 1932. However, data on weight at age and maturity at age prior to 1982 are only fixed values which clearly deviate from the actual levels in some of the earliest years. Work on updating this time series is in progress.

8.5 Catch Statistics

Both Norway and Russia have well established systems for recording of the landings. Some misreporting or non-reporting may have occurred, but before the large cut in TAC in 1990, this was not considered a serious problem. In 1992 the Norwegian Coast Guard reported that there was reason to suspect overfishing of the quotas in some of the trawl fisheries. This was based on combining logbook inspections with observations of the vessels operating in the area. The Arctic Fisheries Working Group in 1993 reviewed the available evidence and agreed on an estimate of 130,000 t of unreported landings in 1992. The Working Group concluded that it was likely, based on anecdotal information, that some level of overfishing also occurred in 1990 and 1991 and decided that estimates of 25,000 t and 50,000 t, respectively, would be appropriate. The Working Group has later decided to set unreported landings in 1993 and 1994 to 50,000 t and 25,000 t, respectively, assuming that the increase in TAC had reduced the problem. In recent years observations from the Coast Guard have not indicated unreported landings.

The management measures introduced in 1989-1990 were severe and in view of the unreported landings the reliability of the catch data during this period has been questioned. However, both Norwegian and Russian data show a substantial drop in trawl effort from 1988 to 1990 (Figure 8.5.1), which indicates that the reduction in TAC had a marked effect on the fisheries.

Figure 8.5.1. Trawl Effort - Barents Sea



8.6 Discards and bycatches

Discarding of cod was common prior to 1990 and comprised both undersized and bigger fish, the latter mainly if the fish was going to be salted. The exception were the vessels from the Soviet-Union where no discarding took place. In 1990, the Norwegian authorities introduced a ban on discarding. This was combined with a programme for monitoring the catch compositions and a mandate to close areas where the proportion of undersized fish in the catches exceeds the legal limit. There are claims that discards of legal-sized fish have been high in some Norwegian fleets the last couple of years, but there are no data to support it.

8.7 Management

The stock is shared between Norway and Russia and the TAC is set by The Joint Russian-Norwegian Fishery Commission. The ACFM advice has been the basis for the TAC and in the 1990's the Commission has been careful not to go outside the options ACFM provides. It seems to be generally accepted that F_{med} = 0.46 (arithmetic mean, age groups 5-10) should not be exceeded and that the spawning stock should be kept above 500,000 t (MBAL). However, apart from maintaining the catches and the stock at a sustainable level, there is no stated long-term strategy in the management.

One particular management problem concerns a relatively small area of international water in the middle of the Barents Sea. Although most of this area is characterised by cold water, in some years it is possible to have a good cod fishery there and annual landings from the area have in recent years approached 50,000 t. So far there has not been any agreement on management in this part of the Barents Sea and the Russian-Norwegian Commission will probably continue to set the TAC without taking the additional catches into account.

In spite of the attempts to keep fishing mortality at or below F_{med}, this was not achieved in the years 1993-1995, partly because of unreported landings and the fishery in the international zone, and partly because the stock had been overestimated. The latter is in contrast to 1990-1992 when the stock was underestimated. The text table below shows TAC, catch and corresponding fishing mortalities in the most recent period.

Year	TAC	Pred. F	Catch	F (Ass. 1996)
1989	300	0.53	332	0.70
1990	160	0.32*	212	0.28
1991	215	0.32*	319	0.33
1992	356	0.42	513	0.42
1993	500	0.42	582	0.51
1994	700	0.46	771	0.67
1995	700	0.45	740	0.58
1996	700	0.46	750	0.41
1997	850	0.38		

*F_{low}

8.8 Current problems

Up to the winter of 1996 it was believed that the development of the stock was reasonably well controlled. The surveys then, however, indicated that the mortality was higher than expected and especially the spawning stock appeared to be overestimated. However, revision of the estimates of cannibalism led to improved medium-term prospects for the stock and the warning signals from the surveys were not taken as seriously as they probably should have been. There was nevertheless consensus among the Norwegian scientists that the assessment in 1996 overestimated the stock, but it was not clear why and by how much.

In the winter of 1997 Norwegian research vessels were denied access to the Russian economic zone and the survey therefore covered only about half the normal area. The Russian survey in the autumn of 1996 also had a much poorer area coverage than normal. This means that for the next assessment, data from the main surveys used in the tuning will be severely reduced in quality. The Norwegian winter survey and the Lofoten survey on the spawning stock in late March, however, provided enough information to confirm that there is a discrepancy between the predicted stock size and what was observed. In Section 8.14 possible reasons for the discrepancy are discussed. The survey indices for the Norwegian bottom trawl and acoustic survey for 1997 used in Section 8.14-8.15 are based on an adjustment of the observed indices assuming that the proportion of each year class in the survey area was the same in 1997 as in 1996.

8.9 Russian Surveys

An annual trawl survey for abundance estimation of young fish has been carried out since 1946. In the 1970's both the acoustic technique and underwater observations to assess bottom fish stocks were introduced. In 1982 a multispecies trawl survey was introduced in the Barents Sea, during which both the young fish and the adult fish were simultaneously assessed for the first time. In 1986 it became a multispecies trawl-acoustic survey. To estimate the abundance of fish distributed in the 8-meter bottom layer, sampling trawl efficiency coefficients (differentiated by species and length groups) were used. In this case the density of fish in the pelagial (above 8 m from the bottom) was determined by the acoustic method. However, due to insufficient reliability of the differentiated coefficients for sampling trawl efficiency, these have not been used since 1988. The abundance of fish in the zone fished by a bottom trawl was determined using a trawl or acoustic method, depending on the vertical pattern of fish distribution near the bottom, adjusting the values according to the regression relationship between catches and mean value of echo-intensity in the bottom channel of the integrator along the area swept. The survey before 1982 was conducted in autumn-winter. From 1982 the survey has been conducted in October-December. Investigations in 1987-1989 confirmed that this was an optimum period for abundance estimation of young and adult fish. Since 1995 separation of echo intensities by species (cod, haddock, redfish) is done, dividing the each species into three length groups, i.e. small, medium and large. Besides those mentioned, other aspects of the multispecies trawl-acoustic survey have not been significantly changed since 1982. The gear used in this survey is not very efficient in catching younger fish and it is planned to change it in the 1997 survey. This will, however, create problems with the time series.

Since 1985 the survey has also been used to estimate acoustic abundance indices. The two sets of indices (trawl-acoustic and acoustic) are used as separate fleets in the VPA tuning.

8.10 The Norwegian combined acoustic and bottom trawl survey

8.10.1 The Time Series

Current objectives

The main objectives are:
- to obtain indices of abundance for different length and age groups of the target species cod, haddock, golden redfish, deep-sea redfish and Greenland halibut
- to estimate mean length and weight at age for cod and haddock
- to collect stomach samples of cod for studies of cod growth and predation on important prey species, itself included (cannibalism)

History

The first attempts to survey young cod and haddock in the Barents Sea by means of acoustics was started in 1970. From 1976 the acoustic survey has followed a well-defined schedule and working plan. In 1980 there was a malfunction of the acoustic system. From 1981 the activity included a stratified random bottom trawl survey and in the beginning it was only meant to be a supplement to the acoustic survey. Due to relatively high temperatures and changes in the distribution of young cod the survey area was extended in 1993.

Table 8.10.1 Time period, area covered, number and type of vessels, vessel days, person days at sea, number and type of trawl stations in the Norwegian demersal fish survey in the Barents Sea winter 1981-1997.

Year	Period	Area (nm^2)	Vessels Res/Com	Vessel days	Person days	Trawl st. bottom/pel	swept area
1981	20.1-27.2	88835	1R/2C	114	456	?	273
1982	26.1-5.3	88835	1R/2C	111	432	324/0	262
1983	26.1-5.3	88835	1R/2C	100	428	350/7	279
1984	28.1-9.3	88835	1R/2C	113	472	340/12	271
1985	25.1-8.3	88835	1R/2C	102	456	364/25	300
1986	23.1-3.3	88835	2R/1C	112	666	280/76	193
1987	26.1-3.2	88835	2R/1C	94	554	263/21	209
1988	10.1-8.3	88835	2R/1C	112	732	299/27	192
1989	27.1-26.2	88835	2R/1C	85	475	291/33	203
1990	29.1-3.3	88835	2R/1C	74	414	283/8	231
1991	30.1-6.3	88835	2R/1C	77	488	320/23	302
1992	28.1-7.3	88835	2R/1C	78	450	298/38	218
1993	10.1-25.2	137642	2R/1C	107	789	321/114	243
1994	21.1-10.3	143840	2R/1C	103	652	359/69	289
1995	27.1-2.3	186554	3R	85	610	399/36	300
1996	5.2-5.3	165281	3R	79	636	362/31	329
1997[1]	3.2-3.3	87549	3R	62	510	286/13	178

Changes to the acoustic survey and to the bottom trawl survey

Table 8.10.2 Changes in survey design, methods, gear etc. in the Norwegian demersal fish survey in the Barents Sea winter 1981-1997.

Year	Change from	To
1984	Representative age sampling, 100 per station	Stratified age sample, 5 per 5-cm length group per station
1986	1 research vessel, 2 commercial trawlers	2 research vessels, 1 commercial trawler
1987	60 min. tow duration	30 min. tow duration
1989	Bobbins gear	Rock-hopper gear (time series corrected)
1990	Random stratified bottom trawl stations	Regular station grid, 20 n.m. distance
1993	TS = 21.8 log L - 74.9 for cod and haddock Fixed survey area (A,B,C,D), 1 strata system, 35 strata Regular station grid, 20 n.m. distance No constrain technique on bottom trawl doors 5 age samples per 5-cm group, 2 per stratum Weighting of age samples by total catch (ALK) in numbers	TS = 20 log L - 68 for all demersal species (time series corrected) Extended, variable survey area (A,B,C,D,D',E,S) 2 strata systems, 53 + 10 strata Regular station grid, 3 densities Constrain technique on bottom trawl doors 2 age samples per 5-cm group, 4 per stratum (cod and haddock) Weighting of age samples by swept area estimate
1994	35-40 mm mesh size in codend	22 mm mesh size in codend
1995	Constant effective fishing width of the trawl 2 research vessels, 1 commercial trawler	Fish size dependent effective fishing width (time series corrected, not a change to the survey) 3 research vessels
1996	2 strata systems and 63 strata 2 age samples per 5-cm group, 4 per stratum	1 strata system and 23 strata 1 age sample per 5-cm group, all stations with > 10 specimens (cod and haddock)

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[1] Norwegian zone only

Comments to Table 8.10.2

- For the acoustic time series it should be noted that when the estimated target strength for cod was changed in 1993 and the time series corrected, there was no correction due to changing to the new echosounder EK500 in 1990-1991. The older equipment had a lower performance and "detected" less fish than the new equipment. This means that the acoustic indices from before 1990 are relatively lower than the current indices.
- The size of the survey area has not been constant. The original strata system was extended in 1993 and in 1996 the strata system was changed to fewer and larger strata. The original strata system was based on observed distributions of cod in 1978-1980. At higher temperatures in the Barents Sea the distribution area increases. The regular station grid in 1990-1992 was extended beyond the original strata system but there are signs that the survey did not cover the whole distribution. This lack of coverage should mainly have effect on abundance indices of 1 and 2 year olds (see also the point on reduction in mesh size).
- In the years 1994-1996 the restraining rope technique for controlling the door spread was applied to 50 percent of the trawl stations. There was no overall significant effect on catch rates by size class. The effect could be masked by other sources of variability including diurnal variation.
- In 1994 there was a reduction in the mesh size in the codend of the sampling trawl. The bottom trawl survey data indicate that this increased the catch rates of 1 year olds drastically. There has been no attempt to correct for this change and care should be taken when interpreting results for 1 (and even 2) year olds.
- A size dependent effective fishing width of the trawl was introduced in 1995. The time series was corrected by revising the software and recalculated back to 1989. The abundance indices previous to 1989 was corrected based on the mean length at age. NOTE: The time series previous to 1989 includes 2 corrections (both multipliers).
-

In addition to these changes the instrumentation measuring the performance of the trawl has been improved through the time series. Stations where the performance of the trawl are poor are not used in the estimation (poor performance = problems with the door spread, bottom contact of the gear etc.) The ability to detect such problems has been improved and there is reason to believe that this has led to relatively higher catch rates.

8.10.2 Estimation of abundance

The bottom trawl survey

The abundance indices from 1989 to present have been estimated as described in the following. For each trawl station and length a point observation of fish density is calculated:

$$\rho_{s,i} = \frac{f_{s,i}}{a_{s,i}} \qquad \text{(1st)}$$

$\rho_{s,i}$ numbers of fish/nm^2 observed at station s (length i)

$f_{s,i}$ raised length frequency

$a_{s,i}$ swept area:

$$a_{s,i} = \frac{d_s \cdot EW_i}{1852} \qquad \text{(2nd)}$$

d_s towed distance (nm)

EW_i length dependent effective fishing width:

$$EW_i = 5.91 \cdot i^{0.43} \qquad \text{(3rd)}$$

$$EW_i = EW_{15} \text{ for } i \le 15 \text{ cm}$$

$$EW_i = EW_{62} \text{ for } i \ge 62 \text{ cm}$$

Point observations of density at length are summed up to 5 cm length groups $\rho_{s,l}$ where l denotes length group. Stratified indices of abundance by length groups and strata:

$$L_{p,l} = \frac{A_p}{S_p} \cdot \sum_{s \text{ in stratum } p} \rho_{s,l} \qquad \text{(4th)}$$

$L_{p,l}$ abundance index, stratum p, length group l

A_p area (in nm^2) of stratum p

S_p number of stations in stratum p

These indices are estimated for each of the strata within the main areas A, B, C, D, D', E and S, shown in 8th. Indices are also summed up by the main areas.

The traditional estimation of age-length keys has been changed to estimate keys that for each 5 cm length group give weighted proportions of the observed age groups. Such keys are estimated for each of the main areas. Each age sample from the same stratum and length group is given the same weight:

$$w_{p,l} = \frac{L_{p,l}}{n_{p,l}} \qquad \text{(5th)}$$

$n_{p,l}$ number of age samples in stratum p and length group l

Proportions are estimated as:

$$P_a^{(l)} = \frac{\sum_p n_{p,a,l} \cdot w_{p,l}}{\sum_p n_{p,l} \cdot w_{p,l}} \qquad \text{(6th)}$$

$p_a^{(l)}$ weighted proportion of age a in length group l and stratum p

$n_{p,a,l}$ number of age samples age a in length group l and stratum p

Note that the weighting factors can be summed up to total swept area estimates. The weighting factors describe each age sample's "share" of the total swept area estimate. A small bias is introduced because age samples from the same 5 cm length group are given equal weight even if we have assumed a length dependent catching efficiency. Numbers at age are calculated as:

$$N_a = \sum_p \sum_l L_{p,l} \cdot P_a^{(l)} \qquad \text{(7th)}$$

Mean length and weight is calculated (only weight is shown):

$$W_a = \frac{\sum_p \sum_l \sum_j W_{a,p,l,j} \cdot w_{p,l}}{\sum_p \sum_l \sum_j w_{p,l}} \qquad \text{(8th)}$$

$W_{a,p,l,j}$ being the weight of sample j in length group l, stratum p and age a

The acoustic survey

The survey area is divided into rectangles of half a degree (30 nm) in the north-south direction and one degree in the east-west direction. For each species (or species group, e.g. redfish) and rectangle the arithmetic mean of echo density (s_A) is calculated for the layer from the surface and down to 10 m above the bottom (pelagic echo density) and for the 10 m layer nearest the bottom (bottom echo density). Until 1992 the entire water column was treated as one layer in this procedure and also cod and haddock were taken as one species group. Echo densities are converted into fish density by:

$$\bar{\rho}_A = \frac{\bar{s}_A}{\bar{\sigma}_A} \qquad \text{(9th)}$$

$\overline{\rho}_A$ mean fish density (number / nm^2) in rectangle

$\overline{s}_A$ mean echo density (m^2 pr. nm^2) in rectangle

$\overline{\sigma}_A$ mean backscattering cross section for single fish (m^2) in rectangles

For cod, haddock and redfish the backscattering cross section (σ), target strength (TS) and fish length (L in cm) are related as (Foote 1987):

$$\mathrm{TS} = 10 \cdot \log\left(\frac{\sigma}{4\pi}\right) = 20 \cdot \log(L) - 68 \qquad \text{(10th)}$$

Until 1992 a target strength formula $\mathrm{TS} = 21.8 \cdot \log(L) - 74.9$ was applied for cod and haddock. The 1981-1992 part of the time series has later been corrected using the new target strength/length relationship (Aglen and Nakken 1994).

The backscattering cross section - length relationship allow the equation above to be written on a more appropriate form for practical use:

$$\overline{\sigma}_A = 5.021 \cdot 10^5 \cdot \overline{s}_A \,/\, \overline{L^2} \qquad \text{(11th)}$$

$\overline{L^2}$ being the mean of "squared lengths" (bottom and pelagic by rectangle).

Mean square fish lengths, $\overline{L^2}$, are estimated in the following way:

For each rectangle two sets of trawl catches are selected, one representing pelagic echo density and one representing bottom echo density. This is a subjective process and also trawl catches outside the rectangle are used. Only bottom trawl catches are applied for the bottom layer, while both pelagic and bottom trawl catches are used for the pelagic layer. Length distribution for each species, sub-area and layer is found by calculating the number in each 5 cm length group per towed distance for each station's catch, corrected for size dependent catching efficiency in the bottom trawl (Aglen and Nakken op. cit., see below). Let f_i denote the sum of catches per nm in length group i and let L_i be the length in cm in the centre of length group i .

$$\overline{L^2} = \frac{\sum_{i=i_{\min}}^{i_{\max}} f_i \cdot L_i^2}{\sum_{i=i_{\min}}^{i_{\max}} f_i} \qquad \text{(12th)}$$

After the mean density of a species ($\overline{\rho}_A$) in a rectangle and layer is calculated , this density is split into 5 cm length groups according to the length distribution in the rectangle, and the number of fish in each 5 cm length group is found by multiplying by the area in nm^2. Numbers in rectangles are summed up to each of the areas A, B, C, D, D', E and S. For cod and haddock the number of fish in each age group in each sub-area is found by applying the same age-length keys as estimated in the bottom trawl survey (see separate description)

Variance estimation

Only estimation of variance for the abundance indices by length groups in the bottom trawl survey is applied as a routine. Presented as CV's these show a CV level between 10 and 20 % for most length groups. There seem to consistently be a peak in the CV between 25 and 40 cm varying some between years. This "peak" seems to be related to diurnal changes in catch rates, and the largest difference between night and day catch rates is found for these length groups.

8.10.3 Sources of bias

Echo abundance

4 sources of bias in the estimation of abundance using acoustics are listed below:

- Detection problems close to the bottom: The echosounder can not separate fish echo close to the bottom from the bottom echo. The proportion of fish in this "dead zone" varies with a range of factors including time of day, fish density and feeding strategy. One can also expect some year to year variation of this proportion.
- Allocating of echo to different species: The postprocessing system (BEI) introduces a subjective element in the allocation of echo values to the different species. The use of predicted acoustic values from trawl catches are used to reduce the possibility of such subjectivity induced bias.
- Errors in the length distribution used to convert echo to numbers: The length distributions are estimated from trawl catches and there is no exact knowledge on the effective fishing height of the trawl. Some analysis indicates that large fish up to 50 meters above the bottom are caught in the bottom trawl. Bias towards lower length will increase the numbers estimated but reduce the biomass. See also the point under biological sampling on size dependent catching efficiency.
- Year to year variation in single fish mean echo strength: Single fish echo is depending on the size and shape of the swimbladder and the tilt angle. The size of the swimbladder is depending on fish size but the shape may differ due to changes in stomach content, liver condition and size of the gonads. It has been shown that a full stomach tends to "flatten" the swimbladder thus increasing the area backscattering surface. Year to year changes in feeding conditions could then introduce bias.

Biological sampling (trawl stations)

Bias in the swept area estimates are related to changes in the catching efficiency of the sampling trawl.

- The sampling trawl is not sampling different sizes with the same efficiency. This introduces a bias and varying growth makes this bias varying between years. This size dependent catching efficiency is also changing with temperature, time of day and possibly also depth.
- There are also signs that fish are caught easier at higher densities compared to being caught as single fish not affected by other fish in the vicinity. A higher catching efficiency at higher densities will introduce an overestimate for abundant year classes while poorer year classes are underestimated.

8.10.4 The Strata system

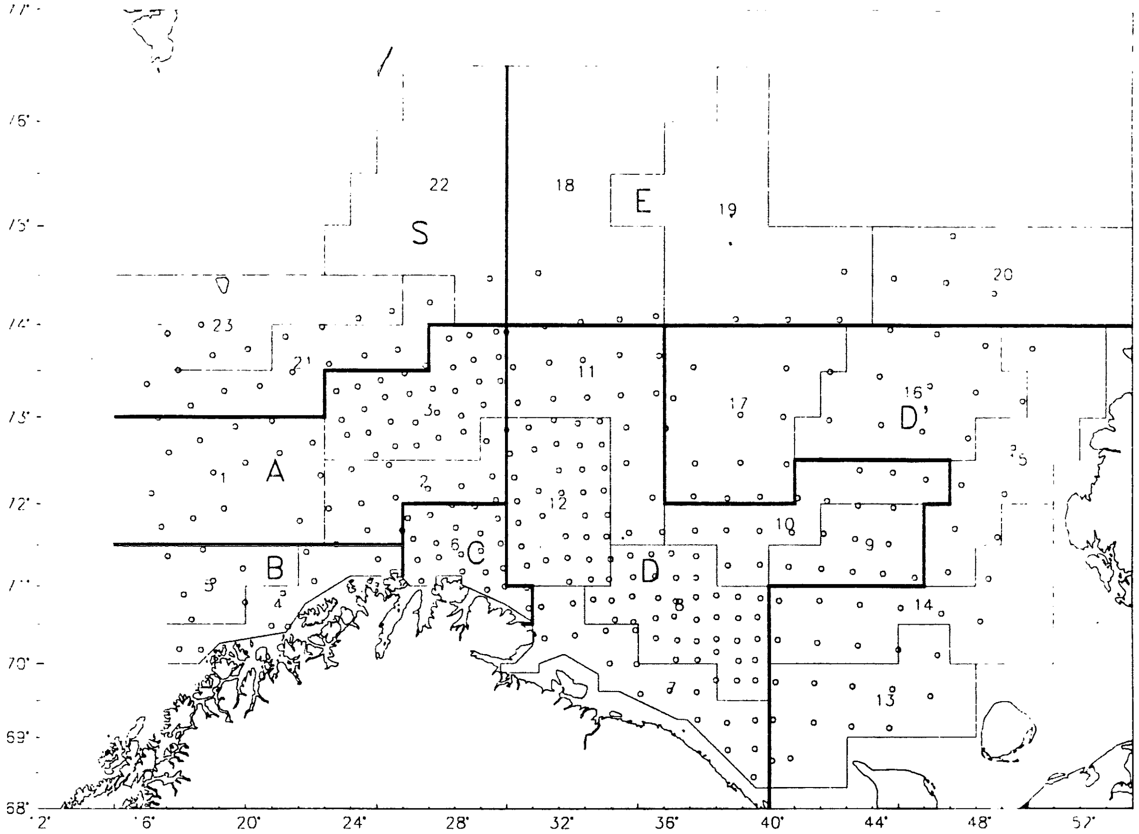


Figure 8.10.1 The survey area with main areas (A,B,C,D,D;E,S) and strata used in the bottom trawl survey since 1996. Stations taken winter 1996 are also shown, fixed positions, distance = 16/24/32 nautical miles.

8.11 The acoustic survey in Lofoten

8.11.1 The Time Series

The echosounder equipment in use since 1990 has been the Simrad EK500 with postprocessing and database storage using BEI (Bergen Echo Integrator). Earlier echosounders had a lower performance and the results are not directly comparable with later results. The introduction of BEI and the use of high resolution colour prints (echograms) may also have led to changes. Future comparisons with the converged part of a VPA analysis could possibly be used to find an overall correction factor (multiplier) for extending the time series backwards in time. The proportions at age together with mean length and weight at age are not affected by the change in echosounder equipment.

8.11.2 Estimation of abundance

The survey is designed as equidistant parallel transects covering 3 strata (North, South and Vestfjorden). For each stratum the total echo abundance is calculated as the weighted sum of echo abundance along each transect where the weights correspond to the distance (in nm) between transects. Using a weighted length distribution the numbers at each length are calculated. The courselines in Vestfjorden 1997 are shown in Figure 8.11.1.

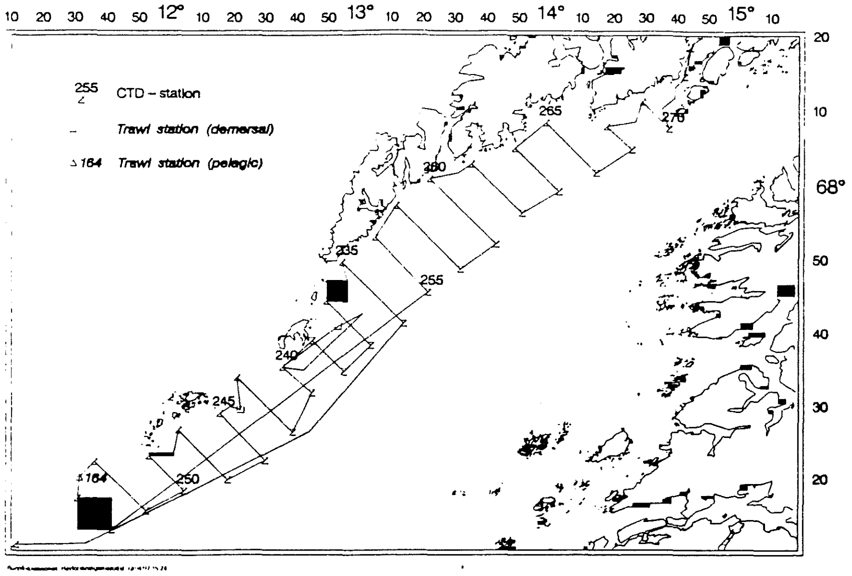


Figure 8.11.1 R/V Johan Hjort courselines in Vestfjorden 26.-29. March 1997.

8.11.3 Age-length keys

Age is determined using 5 cm stratified length intervals. The traditional estimation of age-length keys has been changed to produce "keys" that for each 5 cm length group and strata contains estimates of proportions:

$$p_{s,a,m,k}^{(l)} = \frac{\sum_{i}\left(n_{i,s,a,m,k}^{(l)} \cdot f_{i,l}\right)}{\sum_{i}\sum_{s}\sum_{a}\sum_{m}\sum_{k}\left(n_{i,s,a,m,k}^{(l)} \cdot f_{i,l}\right)} \qquad (13th)$$

where:

$p_{s,a,m,k}^{(l)}$ is the weighted proportion of stock s, age a, maturity m and sex k in length group l

$n_{i,s,a,m,k}^{(l)}$ is the number of samples at station i of stock s, age a, maturity m and sex k in length group l

$f_{i,l}$ is the density estimate at station i of length group l

Proportions are used together with the abundance estimates:

$$N_{s,a,m,k}^{(l)} = N_l \cdot p_{s,a,m,k}^{(l)} \qquad (14th)$$

Total estimates by summation:

$$N_{s,a,m,k} = \sum_{l} N_{s,a,m,k}^{(l)} \qquad (15th)$$

or:

$$N_{s,a} = \sum_{l}\sum_{m}\sum_{k} N_{s,a,m,k}^{(l)} \qquad (16th)$$

s	Stock: Coastal cod or NEA cod identified from otolith readings
a	Age: 5 to 12+
m	Maturity (spawning history): Immature, recruit spawners or repeat spawners
k	Sex: Female or male

8.11.4 Variance estimation

Variance estimates should involve all 3 levels of sampling.

- Variance in the echo abundance estimates. Each transect could be treated as a point observation assuming no or negligible error within the transect.
- Variance in trawl sampling for length distributions.
- Variance in age samples including the classification of otoliths into coastal cod or NEA cod.

There has been no attempts to estimate variances except for the echo abundance.

8.11.5 Sources of bias

Echo abundance

Measured total echo abundance along transects should be regarded as quite precise estimates of the total echo abundance from about 50 cm above the bottom to the surface. Fish concentrations closer to the bottom than this are not recorded and this "loss" constitutes an obvious source of bias. By comparing estimated echo abundance from trawl catches with observed echo abundance (station by station) it has been found that such "loss" is a large source of bias for haddock. Such loss is negligible for cod and saithe.

Another source of bias is the subjective process of allocating echo values between the different species. The allocation is partly based on the size and species compositions from the trawl catches, but relies also quite heavily on visual inspection of echograms. In the highest densities of cod (spawning) the proportions of other species in the catches are very low, typically less than 1 percent of the total estimated echo abundance.

A third source of bias is the possible changes in the acoustic performance of the swimbladder due to changes in liver condition, size of the gonads and stomach content.

Biological sampling (trawl stations)

The trawl stations taken during this survey are due to practical reasons not from a proper design. The fishermen in Lofoten have a high fishing effort during the time of the survey and large areas are blocked from the use of sampling trawl due to the high numbers of fixed gears (gillnets and longlines). This has been a common problem for most years except in 1992, 1993 and 1994 when most fishermen had caught their quota before the survey started, so for most years there have been few samples from the largest concentrations of cod.

The proportion of coastal cod is largest in low density areas and lowest in high density areas. This is clearly a source of bias, but the estimated proportion of coastal cod is typically less than 10 percent and the bias to the estimate of NEA cod will be quite small, although the bias in the estimate for coastal cod could be quite large.

Bias could also be introduced if the largest fish in one year class or if the oldest fish tended to be more abundant in the high density areas. An analysis of the trawl catches from the surveys in 1992, 1993 and 1994 showed a slight correlation between mean length at age and catch rates at each station, but not more than could be explained from changes between the 3 strata. An analysis of mean age in catches compared with catch rates showed a positive correlation in the data from the 1993 survey. This seems to somehow be related to the distribution of the very large 1983 year class that in this year was quite dominant in the spawning stock.

8.12 Other Surveys

In addition to the surveys described in Sections 8.9-8.11, there are three other surveys which are relevant for the assessment.

An international (presently Norwegian-Russian) 0-group survey has been carried out in August-September since 1965. This survey is aimed primarily at cod. However, the abundance index now has a limited value for predicting recruitment to the fishery because there will be more recent indices available from other surveys.

The Norwegian Barents Sea in winter do not cover the Svalbard area because of the ice. A bottom trawl survey has therefore been conducted in the Svalbard area in autumn to cover this component of the stock and the results have been used in the VPA tuning.

Because of the partial stock coverage of the Norwegian surveys, a new survey in July-August was started in 1995. At this time of the year nearly all of the stock can be covered and the aim is to make this the main survey for the assessment.

8.13 Retrospective analyses

A retrospective analyses were run based on last year's assessment procedure, but excluding the Lofoten survey (too short time series for a retrospective analysis), and excluding cannibalism. The retrospective values of reference F (5-10) indicate problems with the method especially in 1991-92, but this is mainly due to problems with catch and tuning data for the older ages, as the values of F_{5-8} seemed rather consistent retrospectively (Fig. 8.13). The change in survey design in this period as described in Section 8.10-8.11. The fishing mortality for the individual year classes has both been over- and under- estimated, however, in some cases rather considerably. The error in the predicted F for the year after the assessment, for which the quota advice is given, was larger (discrepancies of the same size as those shown in the text table in Section 8.7).

F_{5-10} is a useful reference F in historical analyses, however, F_{5-8} should also be presented by the Arctic Fisheries Working Group for easing analyses of current trends in fishing mortalities.

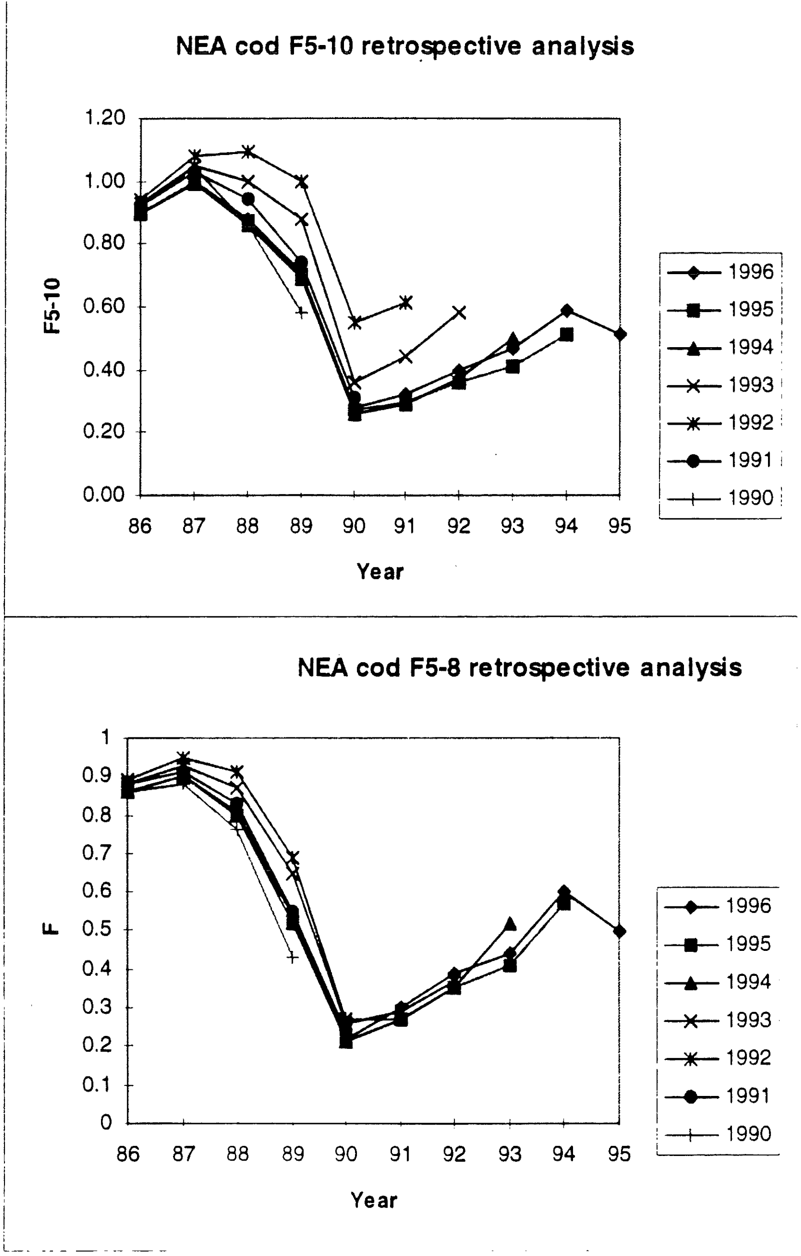


Figure 8.13

8.14 Comparison of trends in mortality in the VPA and in the survey data.

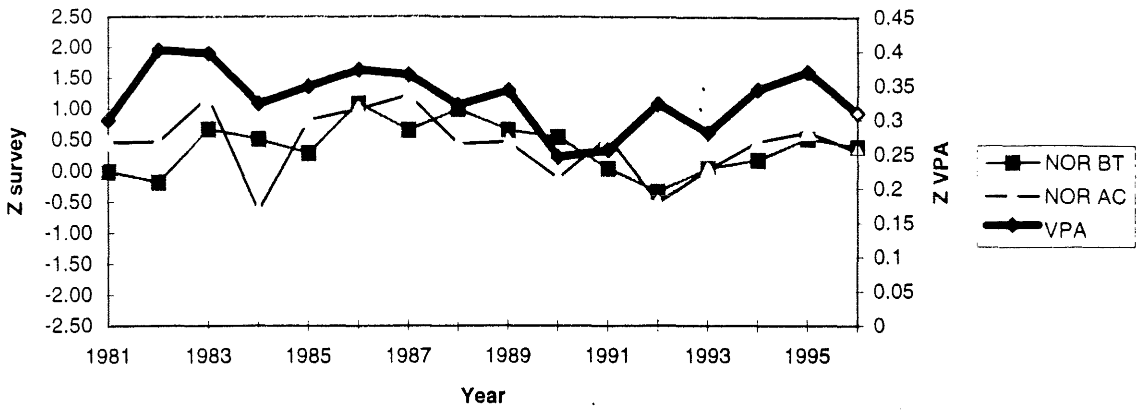
Figure 8.14.1 shows the mortality calculated directly from the Norwegian Barents Sea acoustic survey , the Norwegian Barents Sea trawl survey and the Lofoten survey, compared to the total mortality estimated in last year's assessment, for ages 4-8 in 1981-1996. These surveys were chosen because they show the best fit to the VPA. The mortality in year y for age a is given by $Z_{y,a}=-\ln(U_{y+1,a+1}/U_{y,a})$, where $U_{y,a}$ is the survey index. Figure 8.14.2 shows the same mortalities for the 1983-1991 cohorts.

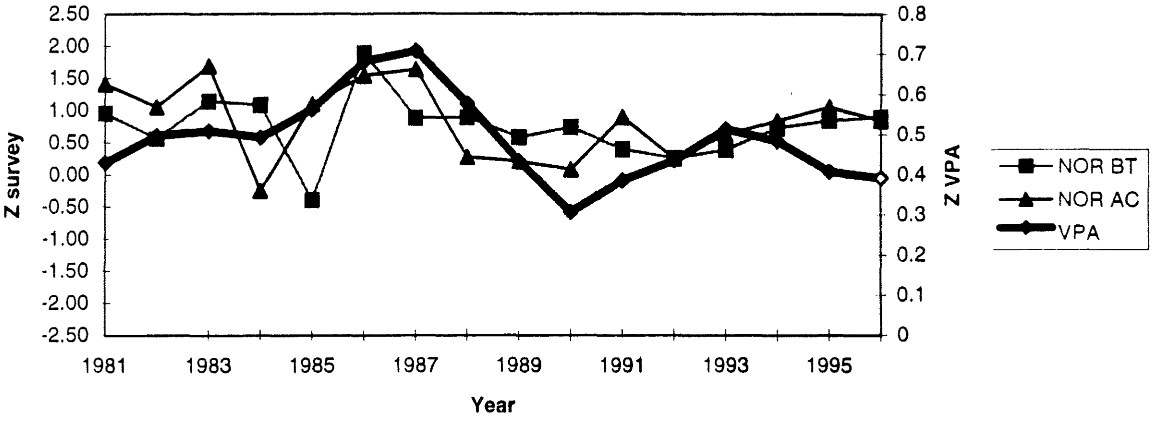
The mortalities derived from the surveys are more consistent in the later years of the period, which can be explained by the developments in survey design (Section 8.10 and.8.11). For age groups 5-8 (and cohorts 1989 and younger), the increasing mortalities in the surveys in the last three years is not reflected in the VPA, causing some concern whether the XSA detects the trends shown in the surveys. It should be kept in mind, however, that the survey indices giving the mortalities in 1996 were not included in the assessment made by the Arctic Fisheries Working Group in 1996, and that the VPA-derived mortalities for 1996 are calculated from the short-term prediction, assuming the catch in 1996 to be known and using an average fishing pattern for 1993-1995 (indicated by open instead of filled symbols).

The discrepancy in the last years is further illustrated by Figure 8.14.3, comparing the spawning stock biomass estimated and predicted in last year's assessment to the biomass estimate from the Lofoten survey for the years 1990-1997. The ratio between the Lofoten biomass estimate and the spawning stock estimate from the assessment is much higher in 1992-1993 than in the later years.

The abundance at the beginning of 1997 predicted from last year's assessment was compared to the abundance calculated from the 1997 survey indices from the three surveys mentioned above, adjusted by the catchabilities estimated in last year's assessment. Only in 1 of 17 cases was the abundance calculated from the surveys higher than the abundance calculated from last year's assessment. The discrepancy for the 1990 year class is big, and this year class will be the one contributing most to the catches in 1997, giving reasons for concern.

Figure 8.14.1 Mortalities calculated directly from surveys compared to mortalities estimated and predicted in last year's assessment


Mortality age 4 Northeast Arctic cod


Mortality age 5 Northeast Arctic cod

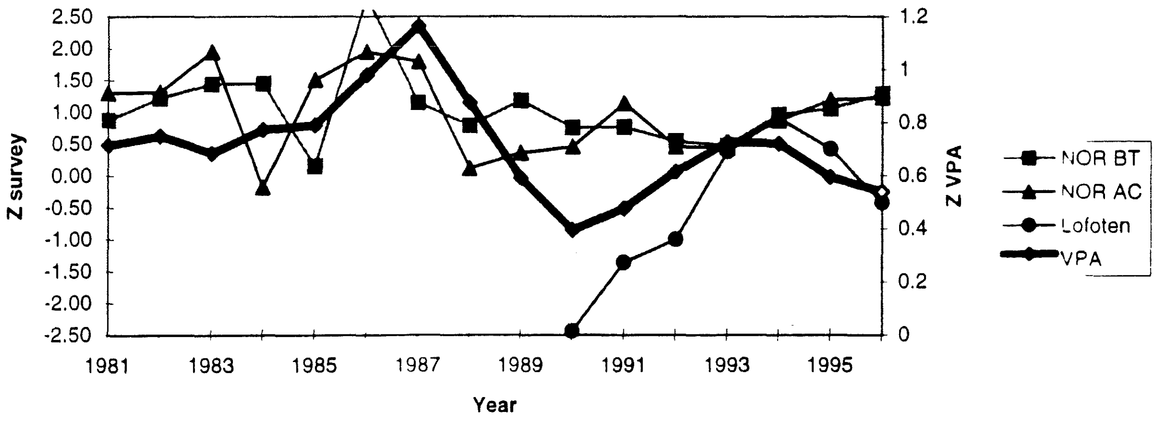
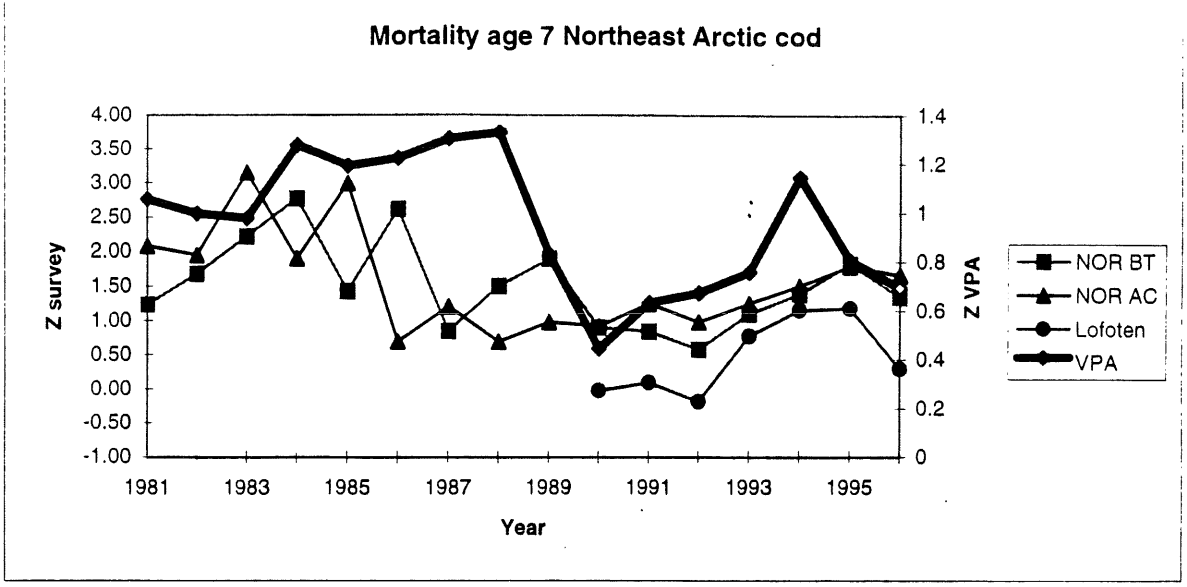

Mortality age 6 Northeast Arctic cod

Figure 8.14.1 (Cont'd) Mortalities calculated directly from surveys compared to mortalities estimated and predicted in last year's assessment



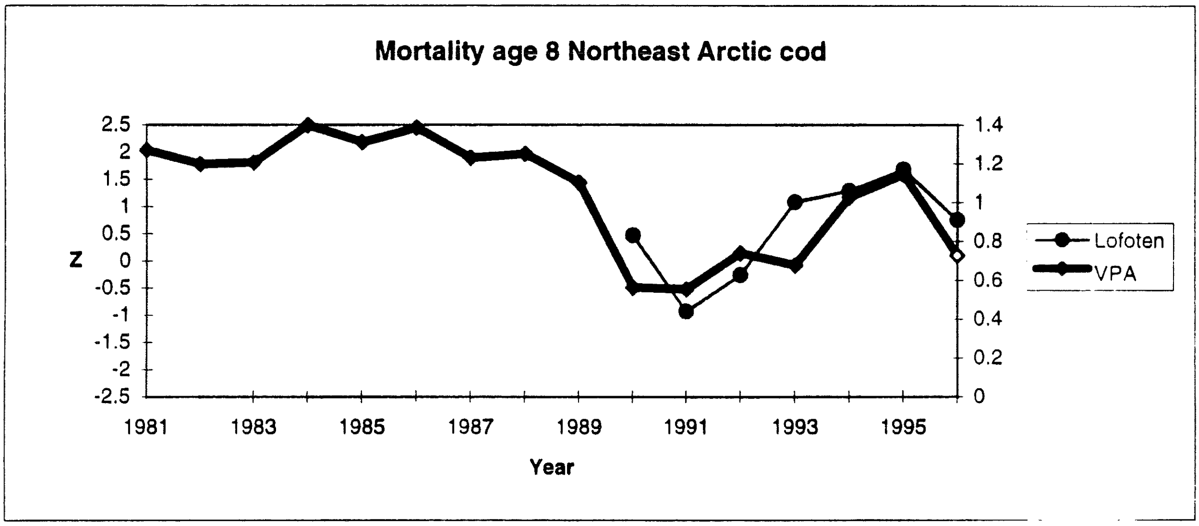


Fig 8.14.2 Mortalities calculated directly from surveys compared to mortalities estimated and predicted in last year's assessment

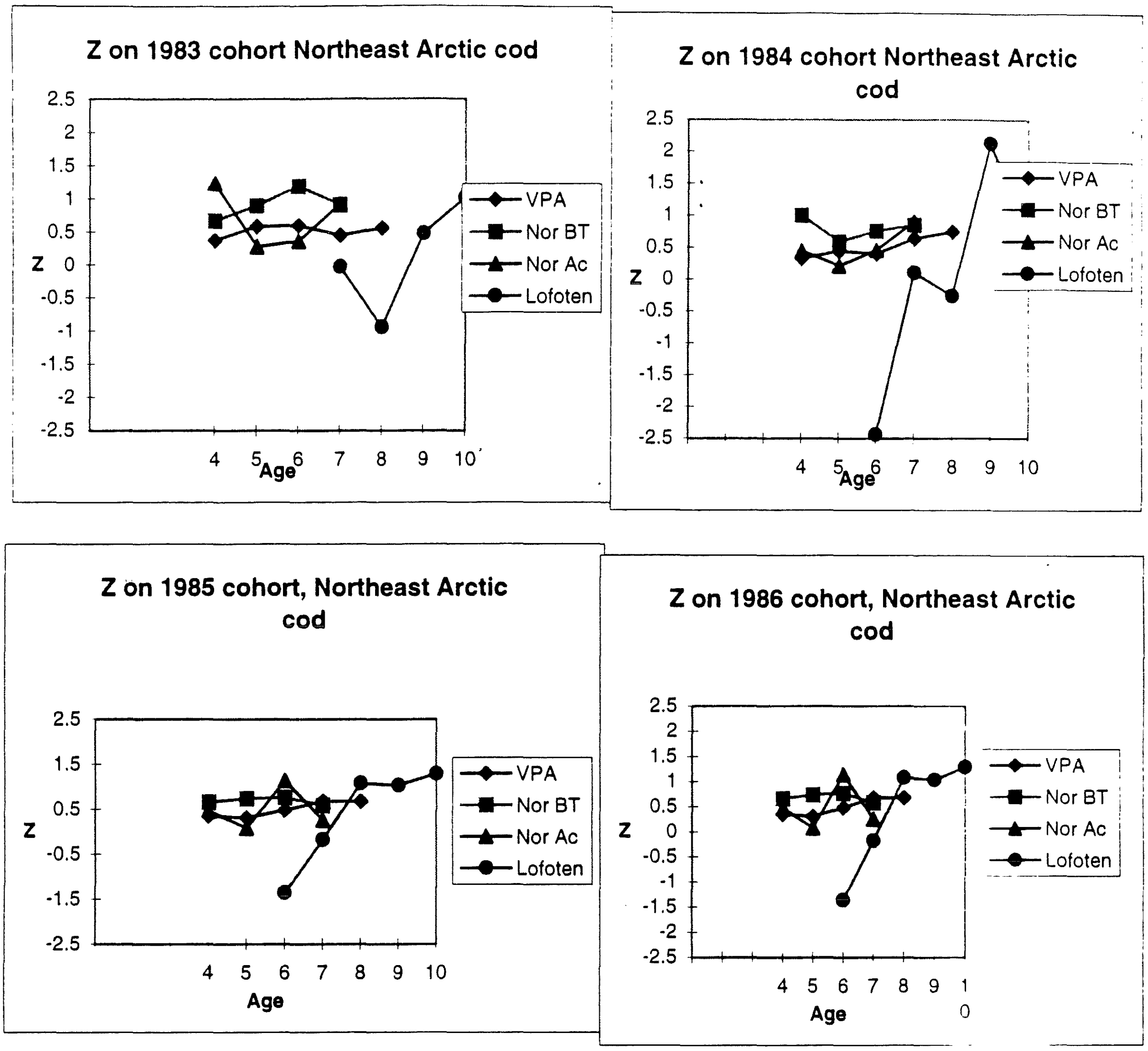
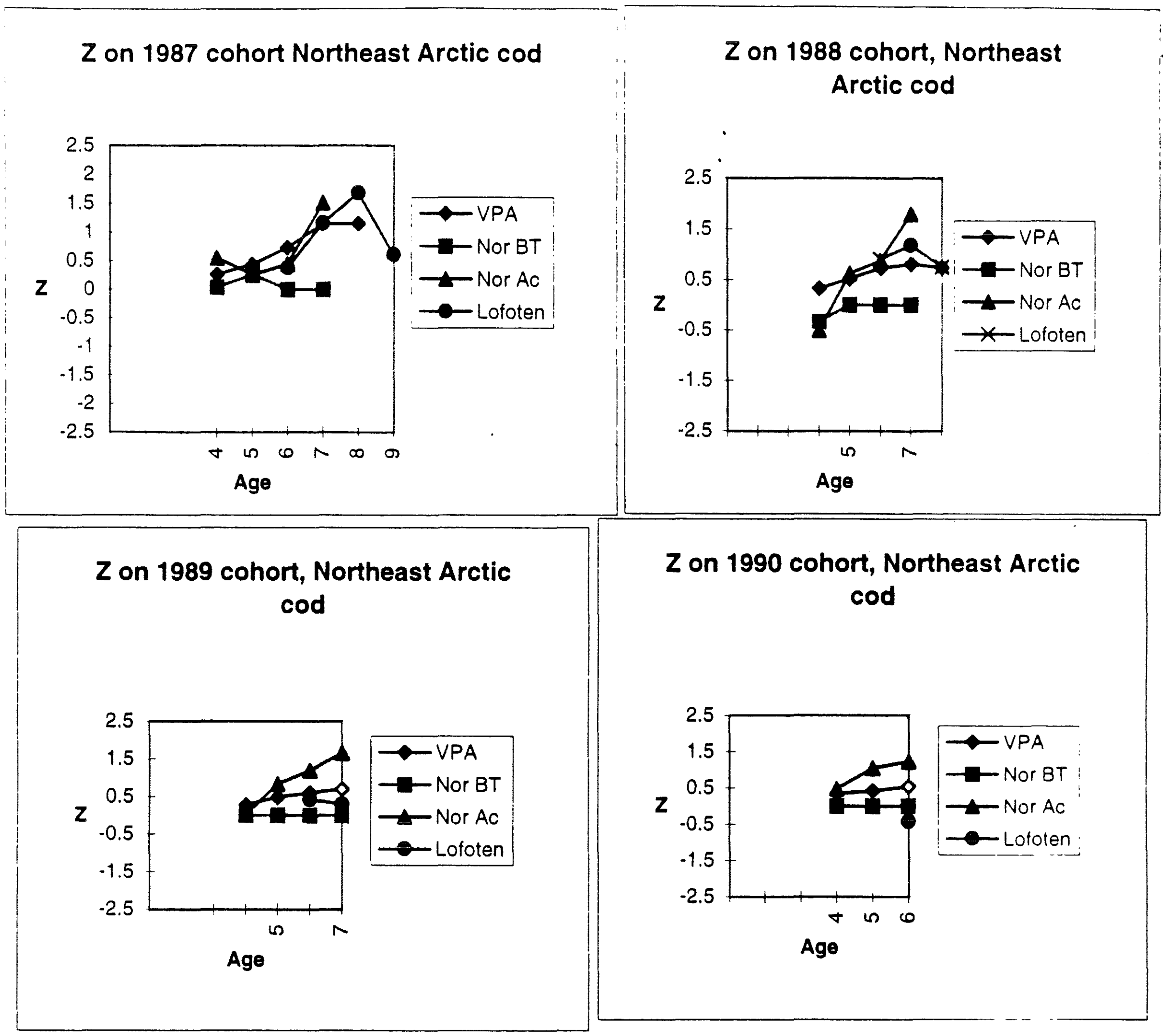


Fig 8.14.2 (Cont'd) Mortalities calculated directly from surveys compared to mortalities estimated and predicted in last year's assessment

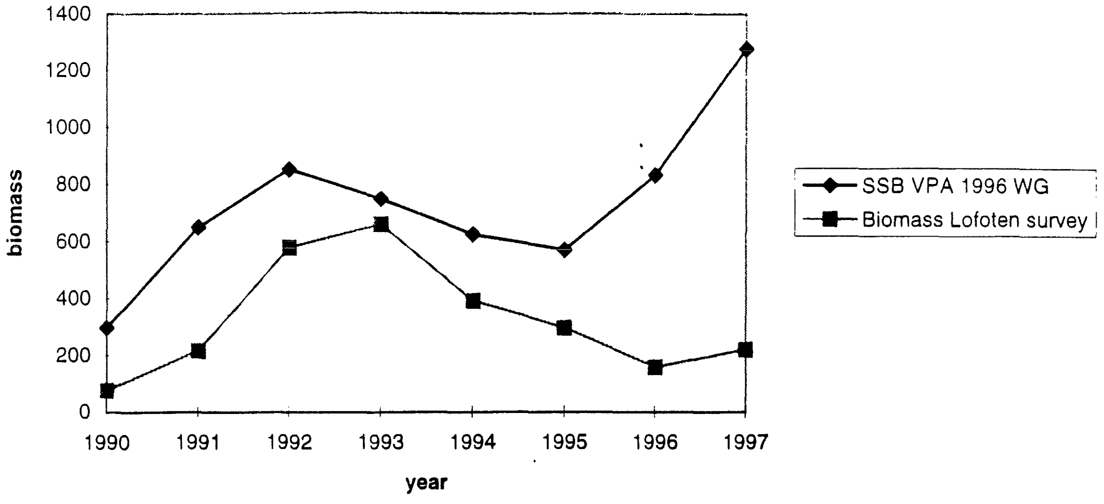

Z on 1987 cohort Northeast Arctic cod

Z on 1988 cohort, Northeast Arctic cod

Z on 1989 cohort, Northeast Arctic cod

Z on 1990 cohort, Northeast Arctic cod

Fig. 8.14.3 VPA SSB and Lofoten biomass



8.15 Including cannibalism in the assessment

Cod cannibalism has been included in the assessment of Northeast Arctic cod since 1995. This has been done by calculating the consumption in numbers by age from data on stomach content, predator abundance and temperature, for 3 areas and 2 half-years separately. For more details, see ICES C.M. 1997/Assess:4 and Bogstad and Mehl (1997). The cod consumed by cod was treated as an additional catch in the VPA, and the XSA was run until convergence. At the current meeting, this procedure was implemented in a spreadsheet version of XSA, making it easy to run. The cannibalism estimates obtained in last year's assessment were confirmed by the spreadsheet version of XSA with cannibalism. Observations made during the iterative fitting of the combined XSA and cannibalism model revealed that the estimated numbers of cod removed by cannibalism converged after 5 iterations. Fig. 8.15.1 shows the ratio of the population size at ages 1-3 estimated with and without cannibalism included in the XSA. Fig 8.15.2-8.15.6 shows the residuals for the various surveys for ages 1-4. There does not seem to be any overall improvement in the residuals when including cannibalism (dotted line) compared to when cannibalism is excluded.

Figure 8.15.7 shows the development in the mortality from age 1 to age 2, as calculated from the Norwegian Barents Sea bottom trawl and acoustic surveys, together with the mortality calculated from the XSA with cannibalism. The increase in the mortalities calculated from the surveys in the last years correspond well to the increased mortality indicated by the XSA with cannibalism. The survey data at age 1 (in February) are not included in the XSA tuning (what is presented as age 1 indices in the tuning data for these fleets are actually survey indices at age 2 shifted to the end of the previous year). This gives some promise for the inclusion of cannibalism to help predicting recruitment.

The present procedure for predicting the stock size with and without cannibalism included is given below:

1. Run XSA with or without cannibalism, down to age 1.
2. Obtain stock estimates at age 2-15 in the year after the last VPA year.
3. Obtain estimate of abundance at age 1 in the year after the last VPA year, using RCT3. RCT3 estimates will be different with and without cannibalism, a problem with including cannibalism is that the time series only go back to 1984, what to do with earlier years? Use age 3 or age 1 as VPA numbers in RCT3?
4. Prediction without cannibalism based on M=0.2 at all ages. Prediction with cannibalism based on assumption about M on younger ages (model taking into account abundance of cod (predator and prey), capelin and possibly also other prey species should be developed). In 1996 assessment: Last 3 years (1993-1995) average of cannibalism-induced M values used in the prediction (correspond to period with low capelin stock, low capelin stock also assumed in 1996).

Figure 8.15.1 The proportional increase in the estimates of Barents Sea cod population abundance at ages 1-3 resulting from the introduction of cannibalism

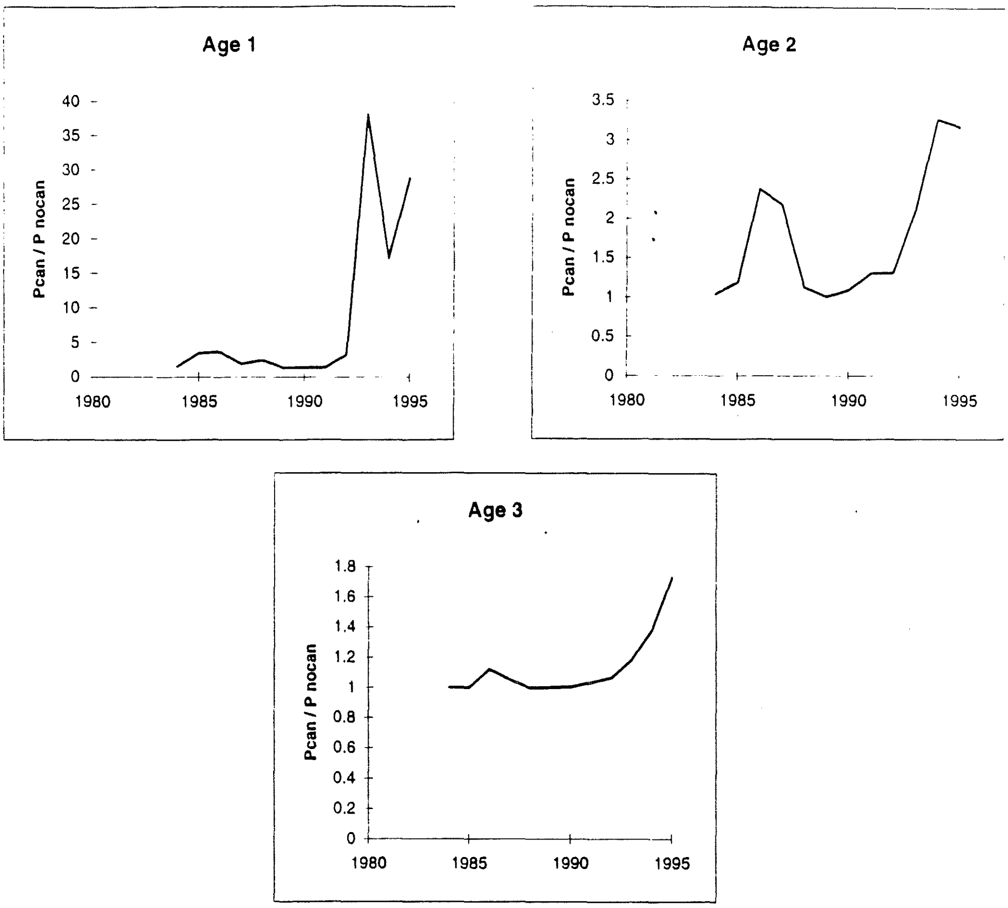


Figure 8.15.2 The changes in the time series of residuals resulting from the XSA fit to the Russian trawl survey (Flt43) before (solid line) and after (dashed) the introduction of cannibalism

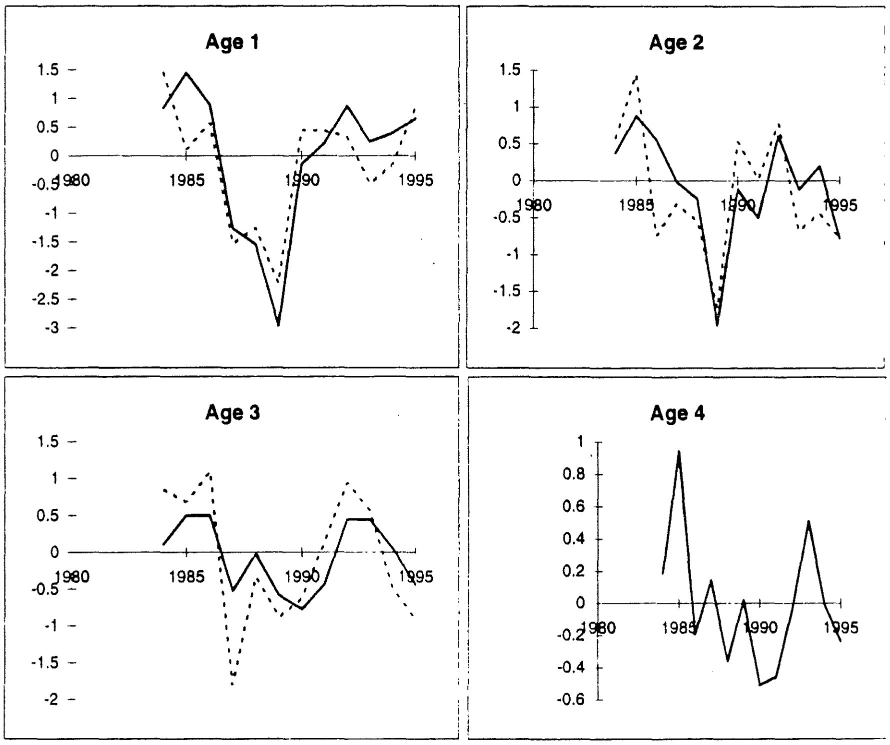


Figure 8.15.3 The changes in the time series of residuals resulting from the XSA fit to the Russian acoustic survey (Flt44) before (solid line) and after (dashed) the introduction of cannibalism

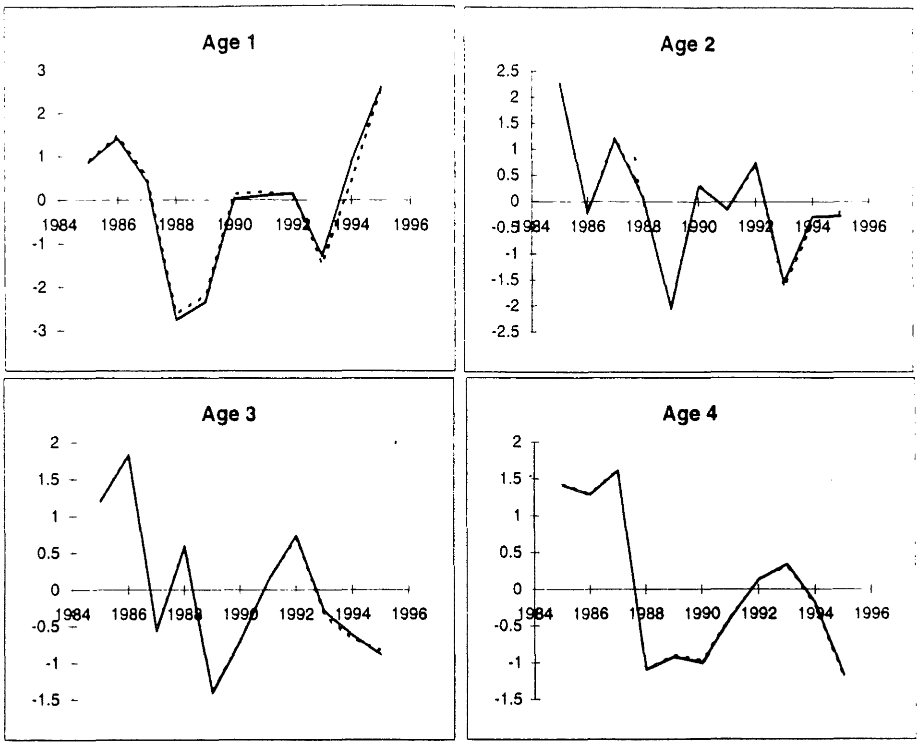


Figure 8.15.4 The changes in the time series of residuals resulting from the XSA fit to the Norwegian Svalbad survey before (solid line) and after (dashed) the introduction of cannibalism

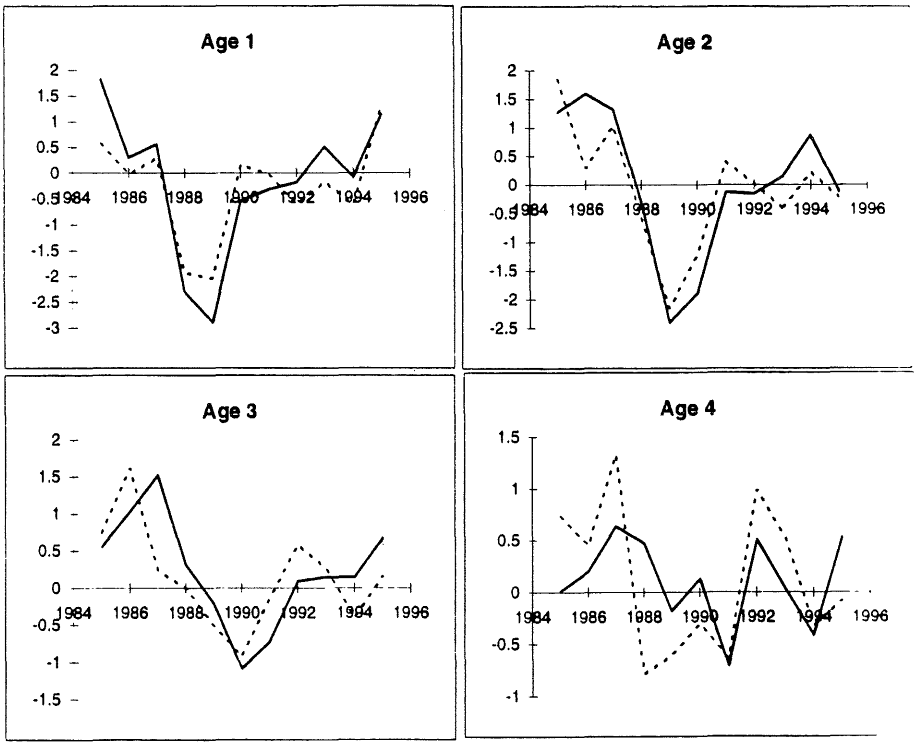


Figure 8.15.5 The changes in the time series of residuals resulting from the XSA fit to the Norwegian trawl survey (Flt54) before (solid line) and after (dashed) the introduction of cannibalism

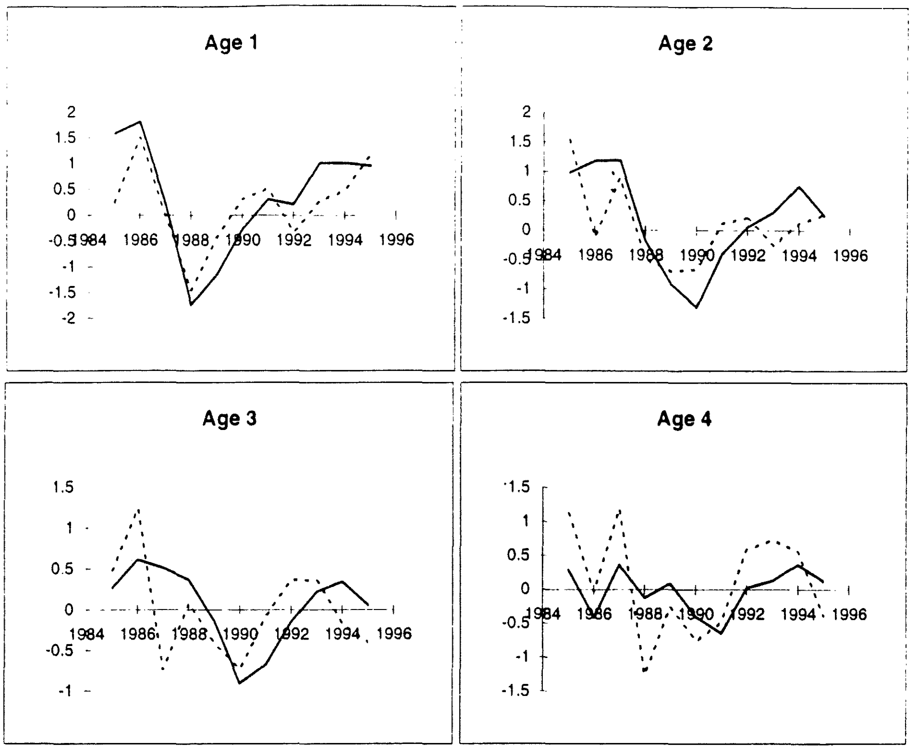


Figure 8.15.6 The changes in the time series of residuals resulting from the XSA fit to the Norwegian acoustic survey (Flt55) before (solid line) and after (dashed) the introduction of cannibalism

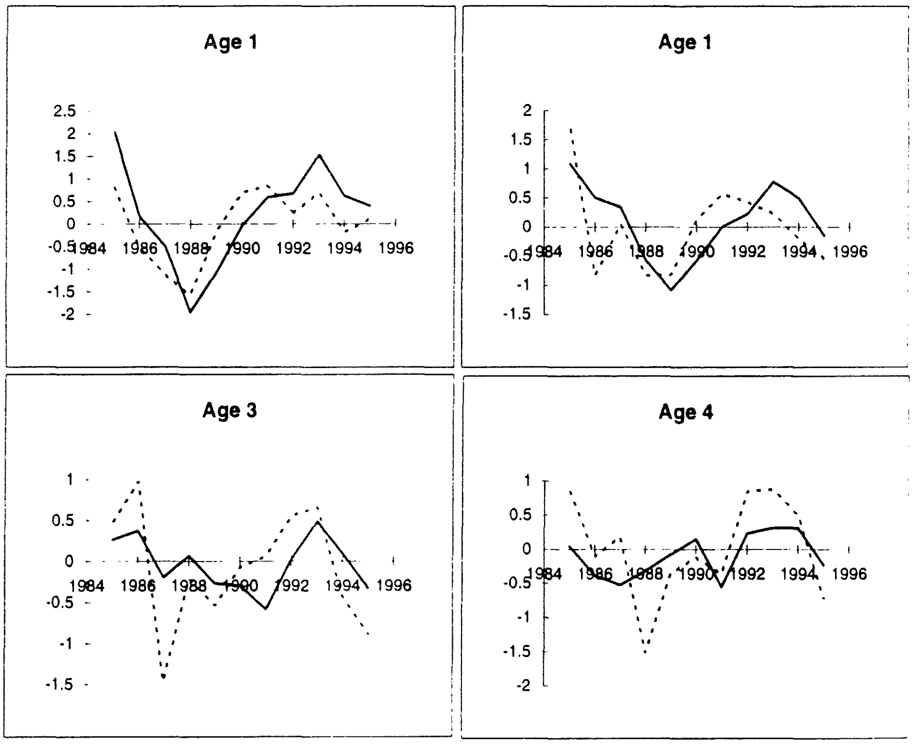
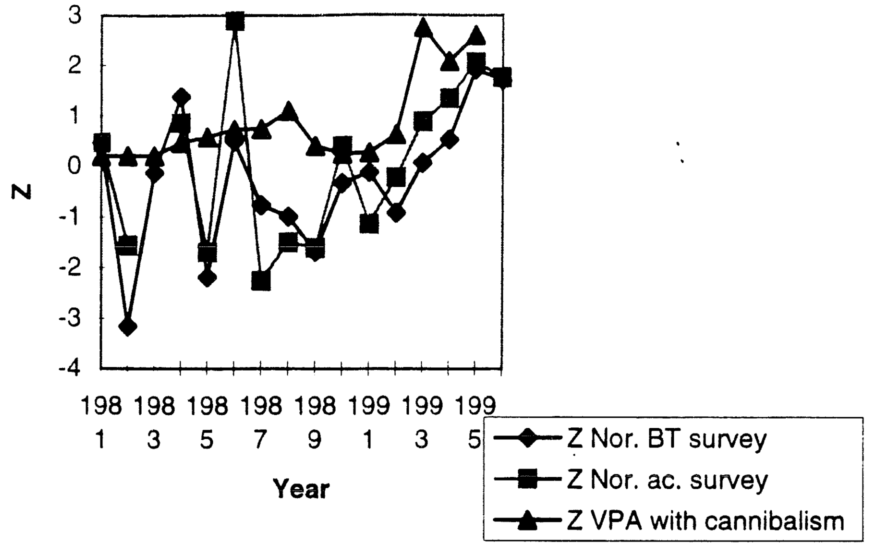


Figure 8.15.7 Mortality on Northeast Arctic cod - age 1



8.16 Conclusions

The Working Group makes the following recommendations for future work at the Arctic Fisheries Working Group:

1. Possible inconsistencies in survey data should be evaluated by calculating separate stock assessments using catch at age data and each of the surveys time series in turn.
2. Alternative assessments methods (e.g. ICA, ADAPT) should be used for comparative purposes. Some exploratory model fits with ICA gave considerably different results.
3. There are strong time trends in acoustic survey residuals, with positive residuals before 1990 and negative residuals in later years. This may be associated with the adoption of the more efficient EK 500 echosounder in 1990, whilst acoustic survey indices back to 1981 are included in the assessment. Consideration should be given to only using time series of measurements that were made with the same equipment, unless a calibration coefficient can be estimated.
4. The Working Group stresses that some recent survey observations for the older ages show lower levels than would be expected from the assessment. It seems likely that the level of exploitation is not sustainable, and perceptions of stock abundance may have to be revised downwards significantly if perceptions of survey reliability are altered.
5. Possible prediction problems associated with predicting the catches in the year when the assessment is carried out, should be identified.
6. Although the stock assessment calculations do not appear to be very sensitive to assumptions made about cannibalism, but it appears likely that stock forecasts based on the assessment will be very sensitive to such assumptions. It should be a priority of the Arctic Fisheries Working Group to test the sensitivity of stock forecasts to assumptions about cannibalism.

8.17 Further work towards a comprehensive assessment

A risk analysis will be carried out by the AFWG in this year's meeting. The main uncertainties in the prognosis for this stock is related to the initial stock size, individual growth and recruitment predictions. Both growth and recruitment are strongly dependent on multispecies interactions, and hence both short-term risk analyses and studies of management strategies will involve modelling of multispecies interactions. There are several modelling tools available for studying species interactions (in particular cod-capelin-herring interactions) in the Barents Sea. The most detailed model is MULTSPEC (Bogstad et al. 1997), which can be used as the underlying fishery system in a POM model (see Section 4). The MSVPA method has also been applied to the Barents Sea (Tretyak et al. 1997), this model at present comprises the species cod, capelin and herring , haddock, shrimp and polar cod. Simpler possibilities are models that are not area-structured: AGGMULT (Tjelmeland and Eide, 1997) and the Scenario Barents Sea model (Schweder *et al.* 1997) which is a full POM model. Both these models include bioeconomy. In Norway, national work on including bioeconomic considerations in the annual advice on TAC for NEA cod and NSS herring has been initiated, as described by Sandberg *et al.* (1997).

A comprehensive assessment of the cod, capelin and herring stocks in the Barents Sea could be a possible case study at the next COMFIE meeting.

9 COMPREHENSIVE ASSESSMENT OF SOUTHERN GULF OF ST. LAWRENCE GROUNDFISH AND HERRING FISHERIES

There is a growing need to evaluate not only single fish stocks but also the fishery systems in which they live and are exploited. Complex species interactions are likely to affect stock production. Fishing fleets compete for multi-species catches. Management regulations interact and often contradict each other. New techniques are required to define multi-species fishery systems on spatial and temporal scales appropriate for management and to evaluate the effectiveness of fisheries management measures at that level.

Hydrographic conditions, species composition, and fishery composition suggest the southern Gulf of St. Lawrence may be a suitable geographic region for a comprehensive fishery evaluation. The southern Gulf of St. Lawrence (southwest of the Laurentian Channel) is comprised of shallow waters (less than 100m) with relatively fresh surface waters influenced by runoff mainly from the St. Lawrence River drainage. Surface waters warm to over 15°C in summer and influence bottom temperatures to depths of 40 m, which includes about 30% of the seafloor in the area. Surface waters cool rapidly in winter and the area becomes ice covered. Water temperatures at imtermediate depths (30 - 75 m) remain cold (0°C or less) throughout the year. A considerable portion of the seafloor is covered by this cold layer. Despite these cold temperatures, fish species reflect more southerly areas in contrast to the northern Gulf where the fish community has a more northerly influence. Several commercially important fish and herring stocks are defined in the southern Gulf including cod, herring, American plaice, white hake, winter flounder, and yellowtail flounder. Witch flounder and redfish fisheries are also conducted in the southern Gulf, but these stocks span both the northern and southern parts of the Gulf of St. Lawrence. Fisheries in the Gulf of St. Lawrence are prosecuted mainly by vessels less than 65' in length. Tradition and vessel size has tended to result in these boats fishing close to home ports. There is little exchange of vessels between the southern and northern Gulf of St. Lawrence. Exceptions include offshore vessels (> 100') and vessels with home ports close to the Laurentian Channel.

The cod fishery produced the majority of groundfish landings over the past several decades. However, the cod fishery was closed in 1993 due to low stock abundance. The white hake fishery was also closed in 1995.

A comprehensive evaluation of the fishery system could include the following elements.

9.1 Single Species Assessments

Annual single species assessments describe trends in population abundance, biomass, and fishing mortality of cod, plaice, herring, white hake, winter flounder, witch.

9.2 Factors Influencing Cod Growth

Weights at age of cod have declined in the last 20 years from historical (since 1950) high values in the late 1970s to the lowest values observed in the mid-1980s. This change has had a considerable effect on stock production but the causes have not been well described. An analysis of alternative hypothesis is planned, including investigation of density dependent, environmental (temperature), and size selective mortality factors. Datasets include periodic cod stomach analysis, otolith backcalculations, stock size estimates, ambient temperatures, and occupied temperatures in the growing season.

9.3 Factors Influencing Cod Recruitment

Recruitment to the southern Gulf of St. Lawrence cod stock, and juvenile survival (R/S) have been well below average during the late 1980s and early 1990s. There has been no sign of improvement since the fishery was closed in 1993. Additional study is required to determine if this is due to increased mortality in the juvenile stage, due possibly to adverse environmental conditions, increased predation, or discarding. Alternatively, has this resulted from reduced fecundity or elimination of spawning components? While not all of these questions are tractable with current data (fecundity, predation), some work is possible on questions of environmental effects and spawning stock structure.

9.4 Natural Mortality of Cod

Previous estimates of M for this stock indicated values of 0.2 or less (Dickie 1963, Beverton 1965, Myers and Doyle 1983). All were based on data collected before 1980 and used either tagging data or considerations of life history characteristics. M has been assumed to be 0.2 for stock assessment purposes. Closure of the cod fishery and the existence of a relatively precise groundfish survey presents a unique opportunity to estimate natural mortality of this stock. Four groundfish surveys have been conducted since the cod fishery was closed in 1993. Cod catches have been restricted to by-catch in other fisheries and the available data indicate fishing mortality has been very low. A modified catch curve analysis in which variation in year-class strength was accounted for, was used to estimate natural mortality since the fishery closure (WC6). The results indicate that M in the last 4 years may be close of 0.4. While such a high M seems unlikely for a long lived species such as cod, it was not inconsistent with the observed commercial catches for ages 7 - 15 since 1950. The change in growth of cod described above suggest that cod may be reaching their maximum size faster in more recent years, and this may indicate M may have increased. Introducing an increase in M on the recent year-classes helps explain a pattern in residuals in SPA calibration. Additional research is warranted to determine if M is indeed this high, and to investigate the implications on assessments and management advice of a change in M.

9.5 Stock Identification

There is considerable uncertainty about the stock structure and appropriate management unit definition for white hake, witch flounder, and winter flounder. Morphometric and meristic data indicate at least 2 stocks of hake in the area, and that both may migrate out of the current management unit (NAFO Division 4T) in winter. Winter flounder are distributed in inshore waters and overwinter in estuaries. There may be limited exchange between areas such as Chaleur Bay, the Northumberland Strait, and the Magdellan Islands. Similarly, witch flounder is managed as one stock in the entire Gulf of St. Lawrence (NAFO Division 4RST). It is possible that separate northern and southern components exist. Research is currently underway on white hake stock structure.

9.6 Fishery Interactions

Technical interactions among these species vary seasonally and geographically. Under the current moratoria there is no directed fishing for cod and white hake, but these species are still taken as by-catch in other fisheries. Analysis of the commercial logbook data from the past 10 years would be useful for examining the predictability of fishery distribution and catch composition. Seasonal and spatial variations in catch compositions by different fishing fleets during the period 1986 - 92 revealed relatively stable patterns. Additional analysis is required to determine changes in fishing patterns since the closure of the cod and hake fisheries. Density dependent effects on distribution could also be investigated. This would be useful for examining the feasibility of single species quotas when one or more species are threatened. Furthermore, the aggregate fishing effort in the area was well above sustainable levels and substantial reductions are needed. What is the appropriate aggregate total fishing effort?

9.7 Biological Interactions

Periodic collections have been made to study feeding habits of cod, plaice, and white hake. Estimates of fish predation by cod have been produced. A recent study has addressed competition between cod and plaice. Seal stomach collections have been very sparse, however additional collections are planned for 1997.

9.8 Management

Management of southern Gulf groundfish fisheries is based on a constant fishing mortality strategy at $F_{0.1}$ implemented with limited entry regulations and TACs. The fishing fleets are broadly categorized into fixed gear (longline, gillnet, and handline) and mobile gear (otter trawl and seine) groups. The mobile gear fleets are further divided into two groups, one operates under individual quotas with a limited amount to transferability (temporary transfers for a single year are permitted) and the other operates under competitive quotas. The fixed gear component operates entirely under competitive quotas.

Additional regulations are used to control the size of fish captured (mesh and hook size), to improve catch data by prohibiting discarding, to limit by-catches of species currently under moratoria, and control the timing of fisheries either to avoid catching spawning fish or to spread catches throughout the year. Landings are monitored at dockside and vessels are required to hail catch estimates to monitors on a daily basis. At-sea data on catch composition, fishing strategies, and fish size are collected by fisheries observers who also report on compliance to regulations. Techniques are being developed to monitor the effectiveness of these various management measures in achieving management objectives.

10 COMPREHENSIVE ASSESSMENT OF NORWEGIAN SPRING SPAWNING HERRING

10.1 Introduction

The Norwegian spring spawning herring stock has the potential of giving a very high and sustainable - although strongly fluctuating - yield because it feeds in large areas in the Norwegian Sea. Once the largest pelagic stock in the North Atlantic it collapsed towards the end of the 1960s. Thereafter it was strictly managed and the stock increased slowly until a rich yearclass emerged in 1983 leading to a rapid increase in stock size in subsequent years. During the collapse period the stock was confined to Norwegian waters, but does now seem to regain its previous migration patter with feeding in the Norwegian Sea.

Since the stock is accessible outside the EEZ of any nation international agreements are necessary for conducting a proper management. The situation today is somewhat unsettled, which makes it important to have a comprehensive assessment of the stock as a foundation during the process of settling on an internationally agreed management of the stock.

A comprehensive analysis will involve a rather large number of people from different laboratories. Here it is only possible to point to problem areas and hint to possible solutions.

It should be noted that Russian researchers, based on data from an extensive drift net fishery, have provided a rich literature on geographical distribution of herring in relation to environmental conditions during the 1950s and 1960s, only a small part of which being available in the English language. This literature should be made available in connection with work on stock-environment relations during the comprehensive analysis of the stock.

For tables of stock variables used at present by ICES it is referred to the latest meeting report of the Northern Pelagic and Blue Whiting Fisheries Working Group (WG) (ICES 1997/Assess:14).

The background material in this section is taken from the report "Biological Modelling of Norwegian Spring-Spawning Herring Stock" in the ongoing EU project "Management of High Sea Fisheries" (Patterson 1997).

10.2 Historical perspective

There should exist a very long time series of information for this stock, but not all the historical data are readily accessible. Historical reports of catches of herring in the area have been considered back to 859 by Ljungman (1879), cited by Höglund (1976) in relation to a possible alternation between the Bohuslän and western Norway fishing areas. Perhaps the first formal recorded attempt at collating the available information was made by Boeck (1871), but this report is not generally available either. However, its contents have been extensively discussed by Devold (1963) who also reproduces a time-series of landings information beginning in 1810.

Sampling for length and age was introduced in Norway in 1907 (Hjort, 1914). Hjort reports age-compositions for the fishery (as % by number) from 1907 until 1913. Østvedt (1963) reports age-compositions from 1947 onwards. Marty and Fedorov (1963) use an early sequential population analysis method due to Derzhavin (1922) to reconstruct a time series of recruitment and stock size from 1905 to 1953, but the data used and the calculating method are not reproduced in detail. The age-structure of catches by Soviet gill-netters between 1950 and 1958 is given in Marty and Fedorov (1959) and Marty (1959). The source of the age-structure information used by Marty and Fedorov (1959) for the period between 1913 and 1950 could not be deduced from the published record, but such information would be extremely useful to extend the time-series of information for this stock.

Recovery of the age-structure information back to 1936 from Norwegian historic material is now under way (Røttingen, pers. comm.) but could not be used at present. The matter is made somewhat more complex by the need to separate catches of Norwegian and Icelandic spring-spawners made in the North Icelandic herring fishery (Jakobsson *et al.* 1996)

SOP discrepancies in earlier years are due to the inclusion of catches of juvenile fish in coastal area (less than 3 w. rings) in the landings data, whilst they are excluded from the age-structured data set (ages 3 and older) (Røttingen, pers, comm.).

10.3 Biological system

10.3.1 Stock structure, spawning and nursery areas, migration

The migrations of Norwegian spring spawning herring have been the subject of considerable interest, debate and controversy since before the start of this century. One long-term problem is whether the Norwegian Spring-Spawning herring may alter its migrations periodically to enter the Skagerrak and Kattegat in the winter, or whether the periods of abundance of herring in that area are due to strong year-classes of North Sea autumn spawning herring. As the last such period of abundant herring in the Skagerrak and Kattegat began in 1867 and ended in 1922, the factual basis for such debates depend on historical anecdote and excavation of herring remains.

The problem is well documented by Höglund (1976), who reviews briefly the 'Great Herring Alternation' between

G.O. Sars and A. Boeck in 1872. Höglund reports that many Norwegian fishermen and herring scientists believed that when the West Norwegian herring fishery failed it was because the herring had stopped visiting the West Norway spawning grounds and instead moved to the Kattegat and Skagerrak. This was also the view taken by Devold (1963). Records of catches in the two areas do appear to alternate over the last 150 years.

There are known to have existed periods of abundance of herring on the eastern shores of the Kattegat (the Bohuslän province of Sweden) each lasting for twenty to sixty years, and interspersed with long periods of herring scarcity. Ljungman (1879) claimed to be able to trace the history of such periods back to 859, and to have determined a periodicity coincident with solar activity cycles. The periodicity theory was taken further by Kolesnikov (1977, 1985).

Devold (1963, 1964) argued that the Bohuslän herrings were demonstrably Norwegian-spring spawning fish, on account of their large size as reported by fishery inspectors in historic documentation. In strong opposition to that view, Höglund (1976) found from excavations of herring vertebrae in discard pits on the Swedish shore that the sizes of herring being expolited corresponded more nearly to the sizes of modern North Sea autumn-spawning fish.

Annual migration patterns

The annual migration pattern of the Norwegian spring-spawning herring is, in general terms, now quite well established according to the schema presented by Dragesund *et al.* (1980), based in part on tagging experiments by Friðriksson and Aasen (1950). Adult herring spawn in February and March along the Western coast of Norway in the region of Møre. They then spread out in a feeding migration over large areas of the central Norwegian Sea, but the extent of this feeding migration has been very variable between years. After the summer feeding period, the fish usually gather to hibernate in a compact overwintering area. The location of this is also variable; in the period 1950-1968 this was located 50-100 miles east of Iceland, except for the winters of 1962-1965 when the fish overwintered much further north, between Bear Island and the coast of Norway. During the collapsed phase of the fishery from the 1970s onwards, the fish remained close to the Norwegian coastal waters. When the stock had recovered it resumed its feeding dispersal in the Norwegian Sea but overwintered in extremely compact shoals in deep fjords in Northern Norway.

Changes in spawning areas

Changes in the spawning area of the stock have been documented by Bergstad *et al.* (1991) and Johannessen *et al.* (1995). The spawning areas are located along the Norwegian coast between about 59°N and 67°N. Between 1900 and 1930 most of the landings during the spawning fishery came from the southernmost spawning grounds south of Bergen, but the fish abandoned these southernmost grounds after 1959 and two distinct spawning components could be distinguished until the recruitment of the large 1983 year-class to the spawning stock: One component spawned at Møre and overwintered in fjords somewhat north of the spawning area and another component spawned further north and overwintered in fjords in the Lofoten area (Hamre 1990). When the stock recovered, the spawning area expanded again and began to reoccupy the southernmost spawning areas. Another historic change in spawning area from a southerly to a northerly distribution has been documented to have occurred around 1870, and also preceded a decline in catches.

For present purposes, changes in the spawning area are probably unimportant as the area remains wholly within the Norwegian EEZ.

Changes in feeding areas

After spawning, the fish seek to feed. According to Toresen (1988) conditions in Norwegian coastal waters are warmer, and have a higher zooplankton abundance; herring growth in the coastal areas is faster than in the open ocean. Possibly for this reason, in the period when herring stock abundance was very low (1972-mid 1980s), the stock remained distributed close to the Norwegian coast. When stock abundance has been high (eg after the recruitment of the 1983 year class, and before the collapse of the stock in the late 1960s) the fish spread out after spawning to feed in the Norwegian Sea (Devold, 1963; Røttingen, 1987; 1986). This is the sort of density-dependent migration pattern extensively discussed by McCall (1990) and well described for Californian anchovy.

The location and extent of the feeding migration appears to be strongly dependent on climatic factors. Jakobsson and Østvedt (1996) explain the differences in the feeding migration observed between the periods 1950 to 1964 and 1965-1969 as due to changes in the strength of the East Icelandic current. This current forms a tongue of cold water protruding southwards from the area between Jan Mayen Island and the North Coast of Iceland, extending southwards along the east coast of Iceland. This intrusion of cold water was very extensive in the years 1965 to 1969, and in those years it appears that the eastwards herring feeding migration after spawning was limited by this cold water mass.

Three types of feeding migration have been proposed:

1. At low stock sizes (less than ca. 500 000 t), the fish stay close to the Norwegian coast.
2. At high stock sizes the fish spread out over the Norwegian Sea in late spring and early summer. The extent of the migration may depend on stock size, but:

    2.1 In 'warm' years, their migration crosses the East Icelandic Current and extends to the feeding grounds in North Iceland.
    2.2 In 'cold' years, they do not do so and their migration is restricted to the central and northern areas of the Norwegian Sea (e.g. 1965-1969, probably also 1996) .

However, in order to establish these relations for more quantitative use in the context of a comprehensive evaluation, further research would be needed.

A 'transition' distribution intermidiate between 2.1 and 2.2 above appears to have occurred in the years 1963-1966.

Although McCall's (1990) conceptual model of abundance-dependent migration is inherently appealing, it seems somewhat intractable to apply in this case. Firstly, there is little information that allows a description of the transition between the oceanic and the coastal types of distribution. The stock collapsed very quickly from 1.1 million tonnes in 1967 to 75 000 tonnes in 1969, and documentation of the change in distribution is not available. Similary, the stock recovery and return to the oceanic distribution occurred as a discrete event with the recruitment of the 1983 year-class, which was over 100 times more abundant than any preceding year-class since 1979. There is therefore virtually no information about the level or the fashion in which the transition between the oceanic and coastal types of distribution occur, save that the transition appears to have occurred between stock sizes of approximately 2.6 million tonnes and 75 000 tonnes in the declining phase, and between 360 000 tonnes and 2.2 million tonnes in the recovery phase.

Changes in overwintering area

For much of the known history of this stock before the collapse, it over-wintered in an area to the east of Iceland except for the years 1962-1965, when overwintering off Northern Norway occurred. Unusually, since its recovery due to the 1983 year-class, overwintering occurs in some of three north Norwegian coastal fjords (Ofotfjorden, Vestfjorden and Tysfjorden), different fjords being occupied in different years (Røttingen, 1992; 1988). The reasons for such changes in overwintering area are not understood and appear wholly intractable to modelling.

Future work

The broad features of feeding migration and selection of overwintering area and how these are related to environmental conditions should be established. However, substantial progress cannot be expected soon. Close contact should be held with national programmes in this field and results from these should be reviewed during the comprehensive evaluation.

10.3.2 Natural mortality

Before 1997 the ICES Working Group assumptions about natural (non-fishing) mortality of adult fish are M = 0.13 for age 3 to 14 from 1971 onwards, except for M =0.23 from 1991 until 1994 for the year-classes 1977 until 1987. This additional mortality was assumed to be imposed by an outbreak of the disease *Ichthyophonus hoferi* in the stock (ICES 1996/Assess:14). For the years 1950 until 1970 a value of M=0.16 was estimated by Anon. (1970). At the 1997 meeting of the Northern Pelagic and Blue Whiting Fisheries WG (ICES 1997/Assess:14) an M of 0.15 was adopted for ages 3 and older and an M of 0.9 for ages 0-2.

In the next section (10.3.3) it is shown that there is strong evidence of density-dependence in both maturation and growth. Hence, it would be reasonable to suppose that natural mortality may be strongly density-dependent also, as has been shown in some other herring stocks (Haist *et al.* 1993). In such a case, ignoring density-dependence in natural mortality will probably result in an overestimation of the appropriate exploitation rate for maximum sustainable catch and underestimation of the corresponding optimum stock size.

10.3.3 Growth

10.3.3.1 Weight at age in the stock

These weight at age in the stock used by ICES are obtained from measurements made in August Norwegian surveys in the Norwegian Sea. The weights at age appear to show a strong density-dependence. For example, when the stock was abundant at the start of the time period, fish of ages 10 to 13 were measured as weighing around 0.35 kg. In contrast, during the period of low stock abundance from the 1970s until the 1990s fish of the same age were estimated as weighing up to 0.5 kg.

During earlier history the sampling of weight data for the stock was probably not representative, to a large extent driven by the fishery. Except for Russian drift net samples there was little sampling in the open ocean. The herring was sampled as it approached the coast for spawning. A comprehensive assessment of Norwegian spring spawning herring should contain a revision of the weight at age in the stock in past years.

An alternative to using the WG weight at age for the stock is using the backcalculated length and calculating the weight from the condition factor of the 1983 yearclass (Holst 1996). This would possibly remove sampling biass, but would also make growth in weight dependent on growth in length. Yearly deviations from such a relationship might be important.

Figure 10.1 shows the weight at age in the stock used by the WG together with the spawning stock biomass on relative scale. Apart from a strange pattern around 1970 there seems to be an inverse relation between abundance and weight at age in the stock.

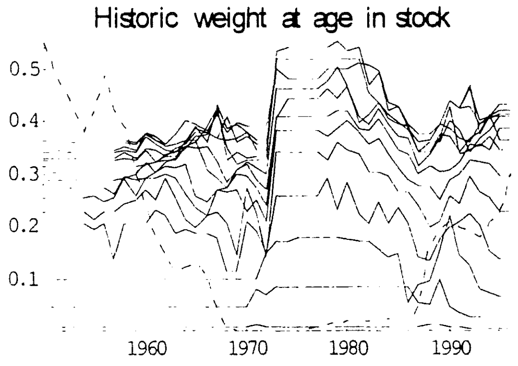


Figure 10.1 Historic weight in stock of Norwegian spring spawning herring for different ages (solid lines) and spawning stock (dashed line) as function of time.

Changes in herring growth have been described by Toresen (1988) and concomitant maturity changes by Toresen (1986) who noted strong differences in growth by weight and by length during periods of high (1950-1960) and low (1973-1983) periods. As he notes, the growth difference is not necessarily density-dependent, as the stock adopted a different distribution pattern during the periods of depleted abundance. However, it appears likely that an indirect mechanism occurs whereby more abundant year-classes spread out and extend into areas of less suitable habitat (Toresen, 1988).

Future work

The earlier obtained weight at age in the stock should be scrutinised, if possible. It should be explored whether basing weight at age in the stock on backcalculated lengths and using weight at age for the 1983 yearclass is a feasible approach.

10.3.3.2 Weight at age in catch

The weight at age in the catch are annual mean values for the Norwegian, Russian and Icelandic fisheries in most years. For the Norwegian fishery, a mean value of the prespawning winter fishery and the postspawning summer fishery is taken. These show, as one would expect, a similar pattern of density-dependence to that in the weights at age in the stock. Arguably, the two sources of information should be used in a single growth model which explicitly accounts for growth between the time at which the weight at age in the stock is measured, and the time of year when most catches are taken in the fishery. It would be desirable to develop such a model, but details of the measurement process for the two sources of information about growth are not currently available.

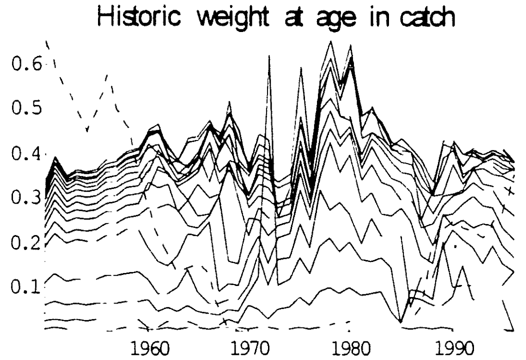


Figure 10.2 Historic weight in catch for Norwegian spring spawning herring for different ages (solid lines) and spawning stock (dashed line) as function of time.

Future work

Develop a growth model for assessment purposes where weight at age is dependent on stock size.
Compile Russian data from the Norwegian Sea and compare to the present ICES data file.

10.3.4 Maturation

The information on maturation is obtained from August surveys in the Norwegian Sea and the Norwegian coastal areas. Maturity appears to have been quite variable between years, as during the period of low stock size from 1973 to 1978 nearly all fish (>90%) were spawning at age 4, whereas in the period of high stock abundance (1950-1960) only between 60 and 85% of fish were spawing at age 6. This suggests some density-dependent process may be ocurring.

Future work

Develop a model for maturity at age that is dependent on stock size.
Compile Russian maturation data from the Norwegian Sea and compare to the present ICES data file

10.3.5 Recruitment

A number of complicating factors have been noted in the development of stock-recruit models for this stock. Recruitment is thought to be highly variable, subject to cod predation (Mehl, 1987, de Barros, 1995), cannibalism, environmentally-dependent, and also to have an approximately decadal cycle in the appearance of very abundant cohorts. Some of these features are discussed further below.

The Norwegian spring spawning herring stock is unusual in having an extremely variable year class strength, a feature which was recognised very early in the studies of this stock (Hjort, 1914). The VPA estimates show an enormous range of abundance at age 0, varying from the enormously abundant 1950 year-class ([illegible]50 billion fish) to the virtually failed 1971 year class (0.2 billion fish).

Mention of the decadal cycle hypothesis is made in Anon. (1996) where it is stated that 'the time series shows that there has always been a period of up to 10 years between years of good recruitment'. This feature is apparent from visual inspection of the long-time series of recruitment estimates given by Marty and Fedorov (1963). As a simple test of the possible importance of this feature of stock dynamics, a series of lagged correlations of year-class abundance estimates were calculated by Patterson (1997), using either recruitment estimates, or using a time-series extended back to the 1904 year class by including a Marty and Fedorov's estimates (rescaled by the 1950 year-class). This analysis shows only a rather weak suggestion of decadal-scale recruitment flctuations. These do not appear to dominate the recruitment dynamics. In contrast, short-term correlations (lagged by 1 to 4 years) do appear to be rather important.

Possible longer cycles in the dynamics of spring-spawning herring have been suggested (Boeck, 1871; Devold, 1963; among others). According to Hjort (1903, cited in Hamre, 1988) the fishery had been at a very low level from the period from about 1870 until the 1904 cohort brought the stock out of its depleted state. Thus, the period of high abundance of the stock that is recorded in the ICES assessment between 1950 and the mid 1960s is not necessarily a stable state of affairs. Indeed, Kolesnikov (1985) argued strongly that the stock dynamics were principally driven by long-term solar cycles in abundance over the period since 1755, as did Penin (1972). The mechanistic principle behind this cyclic dependence is, it is argued, that at minima of solar activity cold waters of the east Greenland current become widely spread from the western regions of the North Atlantic over its central, eastern and north-eastern regions causing cooling of the ocean (Katz, 1973). This coincides with the views of Sætersdal and Loeng (1984) and of Hamre (1988) that recruitment is lower when sea temperatures are lower. Although Kolesnikov's approach is presently rather unfashionable, it allowed him to make the remarkably accurate prediction in 1977 (Kolesnikov, 1977) that the next strong year-class would appear around 1982-1985. The 1983 year-class was one of the highest in the time series despite the adult spawning stock being at a low level.

However, the view of stock dynamics presented by Devold (1963) and elaborated on by Penin (1972) and Kolesnikov (1977, 1985) has been strongly opposed by Höglund (1976). His objections are mostly on the basis that the alternation of the nordic herring fisheries between the Bohuslän and western Norway areas could not be due to a change in migration pattern of a single stock. His objections do not necessarily invalidate the view of the Norwegian spring-spawning herring as a stock which has a very strong environmentally-driven component in its dynamics which has a time scale of many decades. Such dynamics are of course reasonably typical of small pelagic stocks worldwide (Lluch-Belda *et al.* 1985).

Dependence of 'the small herring fishery' on water temperature was noted by Hjort (1909), who showed that 'a definite amount of coast water in May outside the Sogn Fjord corresponds with the catch .... of small herring the following year (especially in northern Norway)'. Hjort continues:

'These striking points of agreement lead us to hope that it will be possible by means of hydrographical researches to foretell important occurrences both on land and in connection with the fisheries'.

Nearly 90 years later, this goal still eludes us.

From the foregoing it is concluded that there is no obviously overwhelming need to incorporate a cycle of around 10-years duration. Such a cyclic component may well exist, but it does not seem to be a dominant component in the dynamics of recruitment. As for the longer-term regime problem, that cannot be addressed appropriately as such a regime would have a period of around 80-100 years' duration, while the available observation set is only reliable for the most recent 45 years. The role of environmental variability in determining recruitment and consequent forecasting remains unresolved. Progress in modelling the part of recruitment variability that is dependent on adult spawning stock may be tractable, however, if such modelling is predicated on the assumption that parameters are estimated, and predictions made, within a single environmentally-stable régime, and short-term envoironmental fluctuations are treated as short-term uncertainty affecting an underlying deterministic process.

The dependence of recruitment on the adult stock may also include cannibalism, since the larvae during their northwards drift usually encounter the part of the adult population that did not take part in the spawning. Cannibalism has in this situation been demonstrated and the effect could potentially be important.

Thus for present purposes attempts to model recruitment will be predicated upon the assumption that recruitment is either independent of environmental change, or else that sufficient realism can be incorporated by modelling environmental change as a short term, time-related deviation about a long-term process.

Both time-series bias and bias due to stock size measurement error are recognised problems in fitting such relationships (Hilborn and Walters, 1992). However in the present case such problems are expected to be small as there is an unusually wide contrast in stock size.

Five different recruitment models for this stock were considered and used by ICES (ICES 1996/Assess:14). These included the traditional Beverton-Holt and Ricker models, used either with all available observations, or else excluding the very strong year-classes (1950, 1959 and 1983). The reason for excluding these year-classes from the model fits was that the parameter estimates were to be used for forecasting forthcoming recruitments which were believed from acoustic surveys on juveniles to be low. That treatment is not believed appropriate for the present usage, where it is not a requirement to make such constraining assumptions. Lastly, a bootstrapping approach based on a Beverton-Holt model with maximum recruitment constrained to 1.5 times the maximum observed recruitment was also proposed.

The 1997 meeting of the Northern Pelagic and Blue Whiting WG (ICES 1997/Assess:14), based on intersessional work, recommended that for present a Beverton-Holt model with logarithmic errors should be used in assessment. That working group also extended the VPA down to 0 years, as opposed to 3 years previously. The rationale for this extension was that in the pre-collapse period rather large catches were taken on juveniles, and including these into the VPA might improve the picture of the recruitment.

Figure 10.3 shows the present recruitment points and the fitted model.

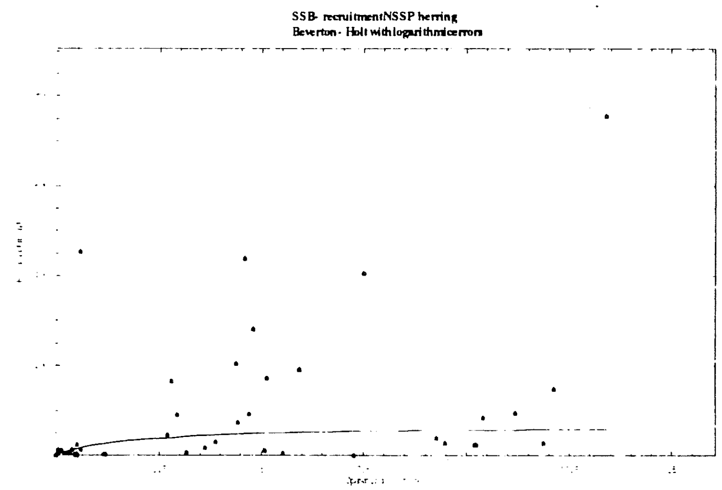


Figure 10.3. Spawning stock recruitment points and fitted Beverton-Holt function ($R = \frac{a \times S}{b + S}$) for Norwegian spring spawning herring.

The obtained parameters were a = 66.96, b = 1.83 and the residual standard deviation was 1.54 on logerithmic sclae.

Future work

Continue intersessional work on exploring recruitment models. Explore the possibility of including cannibalism and environmental factors.

10.3.6 Multispecies effects

While in the Barents Sea the herring may have a profound influence on the Barents Sea ecosystem. The most important mechanism seems to be that the herring may lead to drastic reductions in the capelin stock thereby causing decreasing growth of the cod stock, since the capelin is the main food item for the cod. In a Precautionary Approach context it seems that the underlying reasoning is that the bigger, the better. This is not disputed here, but negative side effects should not go unnoticed.

Future work

Establish the part of natural mortality on large yearclasses in the Barents Sea that stems from predation by cod in a quantitative way that is usable for assessment purposes. This relies on the assessment splitting the juvenile herring into a Barents Sea and a fjord component (see Section 10.3.7).

10.3.7 Two juvenile components

Large herring yearclasses drift into the Barents Sea, while small yearclasses are confined to Norwegian fjords. Thus, there is different growth and presumably different natural mortality. Part of the natural mortality in the Barents Sea may be assessed using cod stomach content, which is regularly sampled on cruises in the Barents Sea. Thus, the question arises whether we would do a better assessment if the analytical tools distinguished between herring the are reared in the Barents Sea and herring that are reared in the Norwegian fjords.

There is a yearly trawl-acoustic cruise in the Barents Sea in June that targets herring. It was tried during this years meeting of the Northern Pelagic and Blue Whiting Fisheries WG to use this cruise in the tuning, with no great success. Part of the reason for this might be that the crusie does not capture the whole yearclass. There is also a yearly trawl-acoustic cruise in December targeting herring in the fjords that might help split each yearclass into a Barents Sea component and a fjord component. Finally, the otoliths are different for the two components, which further would help splitting the two components from each other in retrospect.

Future work

Explore whether providing for two juvenile components in the assessment tools will improve the assessment or whether it will be of importance in a precautionary approach.

10.4 Assessment

10.4.1 Data problems

10.4.1.1 Bias in acoustic surveys

Environmental conditions that may lead to yearly bias in the survey index might be temperature influencing the depth at which the herring is found, since it has been demonstrated that the target strength value depends on depth because of swimming behaviour connected to buoyancy conditions (Huse and Ona 1996).This effect has not been accounted for in the survey indices. Also, different growth conditions in different years may lead to different size of the swimming bladder because of difference in specific weight of fat and muscle tissue, thereby affecting the target strength of the fish.

These sources of bias in the survey indices are under current investigation, and will probably be accounted for in the future. However, many past surveys may be difficult to recalculate. Therefor, tuning methods that may relax the assumptions of a catchability that is constant across year should be found.

Future work

Explore whether the assumption of a constant catchability can be lifted by formulating a likelihood for the tuning that takes into account the biological sampling in each individual survey.

10.4.1.2 Stock identification problems

Apart from the above mentioned problem with the trawl-acoustic surveys, there is an additional problem in the Barents Sea, where there are two different stocks of herring: Norwegian spring spawners which are spawned along the Norwegian coast, drift into the Barents Sea and migrates out for never to return, and the Arctic herring, which spawn in the southeastern part of the Barents Sea and remain in the eastern parts of the Barents Sea throughout their life. There might on occasions be difficult to distinguish herring from these two stocks from each other, often they are found together. There is at present ongoing activity to develop methods based on genetics. This might be another reason why the Barents Sea cruise was problematic to use in the tuning.

The Barents Sea survey, even if it is not at present part of the tuning of the Norwegian spring spawning herring stock, is very important in that it gives a first measurement of a strong yearclass, apart from the 0-group survey in August-September. Therefore, the problems associated with implementing this cruise into the assessment should be carefully studied, whether they be mixing, the analytical tools not being constructed for a split into a Barents Sea and a fjord component, or other.

In recent years there has been an international cooperation on surveyeing the herring in the Norwegian Sea. This survey may become a valuable tuning index.

Future work

The development of field methods for splitting the stocks based on genetics is going on. The quality of the survey would to some extent be dependent on the frequency of sampling in the overlap area. Try to establish a yearly uncertainty in the survey due to mixing and incorporate this uncertainty into the assessment.

Incorporate the survey in the Norwegian Sea into the assessment.

10.4.2 Current procedures

Prior to the 1997 meeting of the WG the assessment was done by tuning the VPA to 3 different acoustic survey series: a survey on the overwintering stock in December, a survey on the overwintering stock in January and a survey on the spawning stock. In addition, data from a tagging were included into the tuning. The tuning was performed in the traditional way of minimising sum of squares on a logarithmic scale. The catchability for each survey index was assumed constant across years and ages.

At the 1997 meeting this method was modified by introducing a gamma distribution for the surveys. The WG also systematically varied the underlying assumptions, showing rather large changes of the size of the perceived stock for a range of plausible assumptions.

Also, at the 1997 meeting of the WG the Bayesian approach was used for the assessment and the resulting distribution of parameters were used in medium-term projections of the stock. The probability distribution of survey indices was included in the estimation, allowing a choice between the normal, lognormal and gamma distributions.

The medium-term projections were also conducted using a simple spreadsheet model, which is a versatile tool, and needed in addition to the Bayesian approach.

The spreadsheet model that previously was used for the tuning was not applied at the 1997 meeting. However, a simple exploratory tool is needed in addition to the Bayesian software, which is computer costly and not universally accessible.

Future work

Exploring further details of the Bayesian estimation, why is the normal distribution selected over the lognormal and gamma distributions, what are the consequences of the maximum of juvenile natural mortality relative to adult natural mortality not being inside the allowed parameter range.

Implementing the Bayesian software at other laboratories and on more powerful computers (i.e. Bergen).

Re-establish the tuning spreadsheet with a gamma distribution of survey indices

Exploratory analyses have shown strong dependence of the stock size estimates on structural assumptions in the assessment model. Currently there is insufficient information to make objective choices amongst such structures. Future work should therefore focus on the provision of improved information, particularly experimental observations on acoustic survey catchability (see Section 17.2).

10.4.3 Biological reference points

It is customary to refer to the reference points F_{med}, F_{crash}, F_{msy} and $F_{0.1}$ in connection with the precautionary approach to management for many fish stocks and the possible applicability of these reference points for Norwegian spring spawning herring should be reviewed in a comprehensive management context

Spawning stock per recruit

Several of the most used biological reference points depend on the spawning stock that will be generated by recruits during their lifetime, which is dependent on the assumptions made on weight at age in the stock, maturity at age, natural mortality at age. Yield-based reference points also make use of assumptions on weight at age in the catch and exploitation pattern. In using reference points with management there will be uncertainty as to which values of these variables are most appropriate for the coming yearclasses. Here, these life history variables are taken from the successive cohorts from 1950 and shown as time series.

For F_{crash} and F_{msy}, which are dependent on assumptions made for the recruitment, a Beverton-Holt function with logarithmic errors has been used (Figure 10.3). For these reference points it will be the expectation value of the recruitment that matters, so the stock recruitment function has been multiplied with $\text{Exp}(0.5\ s^2)$ where s is the standard deviation of 1.54. However, for the exploitation pattern the 1996 values have been used, since there is no reason to believe that past exploitation patterns will be repeated. For the calculation of F_{crash} the recruits are assumed to be linearly dependent on the spawning stock and using the sum of expectation values of the recruitment makes sense in the calculations. For F_{msy} this is not so obvious and the results should be checked by simulation.

Figure 10.4 shows the time series of the reference points.

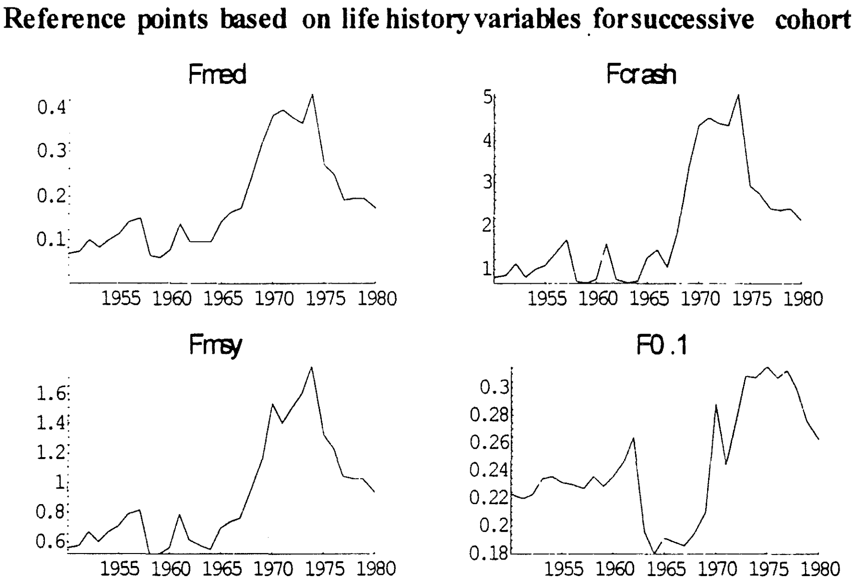


Figure 10.4. Times series of F_{med}, F_{crash}, F_{msy} and $F_{0.1}$ for Norwegian spring spawning herring, where life history variables have been taken from successive cohorts.

The effect from a change in stock variables during the collapse period when the herring stayed in the Norwegian fjords is evident. The data above contain only cohorts that have passed through the Vpa and the reference points based on stock variables form the 1983 yearclass is not included. There is an abrupt increase in reference points at the collapse of the herring, and the values seem to decrease as the stock is slowly recovering but still confined to the Norwegian fjords.

The herring is now gradually resuming its previous migration pattern with feeding in the Norwegian Sea and the situation for the stock might be expected to start resembling that of the pre-collapse period. Thus it seems reasonable to take F_{med} to about 0.1, F_{crash} to about 1.0, F_{msy} to about 0.6 and $F_{0.1}$ to about 0.2 as representative values for the pre-collapse period.

The F_{med} value seems surprisingly low and close to the F-value at which the stock is harvested at present. However, it may be disputed whether F_{med} is a rational reference point for this stock since it is the large but infrequent yearclasses that dominate the stock dynamics.

In section 2 the reference points were estimated using bootstrapping of life history variables and recruitment relations, which should be done also for these herring reference points. But prior to that assumptions on which historic period is considered be most representative for the (say) nearest decade must be discussed in the Northern Pelagic and Blue Whiting WG.

Estimation of F_{max} by simulation

The assessment model was run repeatedly for 100 years using different values of fishing mortality and with no observation error and the catch was sampled after 30 years to avoid initial transients. The life history parameters used were meaned values for the period 1950-1970. The F-value was varied between 0.05 and 0.4 and a total of 30 replicates were made. The result is shown in figure 10.5.

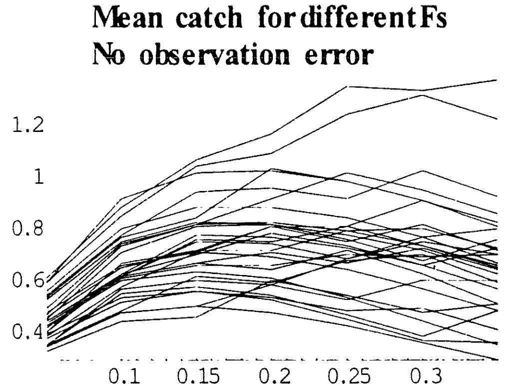


Figure 10.5. Mean simulated catch for different values of F. Norwegian spring spawning herring.

In some of these runs there is no maximum within the applied F-range. The general impression is that the maximum occurs for higher F-values for the simulations in which there were better recruitment, which would indicate that a harvesting strategy with decreasing F with decreasing stock would be rational not only from a conservation point of view, but also from an economic point of view.

In a precautionary context one wants to apply F-values that are below F_{msy}. From the above figure it seems that a lower bound on Fmsy might be about 0.15.

These simulations are intended as an exploratory analysis before a more formal method is adopted in the Northern Pelagic and Blue Whiting WG or recommended from the Comprehensive Fisheries Evaluation WG . A stock-dependent weight at age and, possibly, maturity at age, should be used in later analysis' of this kind, since the results are highly dependent on assumptions concerning these parameters. A model for dependence of life history variables on stock abundance should emerge during intersessional work in the two relevant Working Groups (Comprehensive and Northern Pelagic).

Future work

Recalculate reference points with associated uncertainty with the bootstrap method (section 2) using observed life history variables from different historic periods.

10.5 Management

During the upbuilding phase of the stock 2.5 million tonnes was used as a target spawning stock, based on the spawning stock-recruitment relationship at that time showing only low recruitments for spawning stocks below this value. Even if this value in this way is rather poorly defined this target was adopted and the management may be considered rather successful using this upbuilding target.

This reference point has been used also in recent years, but in connection with medium-term projections giving probabilities for the spawning stock to fall below 2.5 million tonnes in the course of 10 years for different F-values. The rationale has been that during 10 years the probability of good recruitment once should be relatively high, and a reasonably high spawning stock should be ensured during this time span This strategy has been complemented with a catch ceiling. ACFM recommends an F-value of 0.15 and a catch ceiling of 1.5 million tonnes. However, this lacks foundation in proper simulation studies and should be further explored

The present lack of international agreement on quota allocation between countries is a problem for a proper management of the stock. The quota allocation problem was in 1996 "solved" by countries unilaterally allocating quotas to themselves. This process is likely to drive the total quota to undesirably high levels.

Future work

Continue experimenting with harvesting control rules.

11 COMPREHENSIVE ASSESSMENT OF THE ICELAND HADDOCK FISHERY

11.1 Introduction

A comprehensive assessment of haddock in Icelandic waters has been underway for some time. Two working documents to the meeting presented a short summary of the current state of this evaluation. It is clear that a number of issues need to be resolved in order to complete a comprehensive assessment of the stock and fishery.

It is envisaged that the present project will result in a fairly extensive assessment of the biology of haddock in Icelandic waters along with an assessment of the effect of fishing and the yield potential of the stock. This does not include biological or technical interactions, however. Although these are clearly important, they will be undertaken as a distinct future project.

11.2 Routine assessments

Analytical assessments are conducted on an annual basis by the Marine Research Institute. These use XSA with whatever assumptions seem adequate from diagnostic outputs. The data sets used in the assessments include catches in numbers at age and survey abundance indices at age. Although quality control is undertaken with regard to retrospective patterns and other diagnostics, a full evaluation of the annual assessment method needs to be undertaken in the light of results from a comprehensive assessment of the stock.

No medium-term predictions are currently undertaken.

11.3 Data sources

In the first stage, the comprehensive evaluation is intended to evaluate all the usual data sources: Landings, commercial CPUE and effort, biological samples, survey abundance, stomach samples, mark-recapture and finally environmental data.

11.3.1 Growth and maturity

Local growth

There appear to be small areas where haddock grow much less than in other areas. This is seen both from the main groundfish survey, where there are highly significant variations in length at age at different stations and also from other, more local, surveys.

Maturation

Maturity at age has changed considerably in recent years. It is not known what causes these changes, but they may be linked to year-class strength, growth, fishing effort or all of these factors.

A part of the problem is that males mature earlier and this needs to be accounted for in assessments which are currently done for both sexes combined.

The growth-maturation process

Given the changes in maturation and local variation in growth, there appears to be a strong case for studying the whole process which links growth and maturation.

A pilot study involved looking at growth zones in available otoliths in an attempt to illucidate the relationship between growth and maturation. There seem to be some indications that mature female haddock are larger than the immature ones. However, this is not nearly as clear when more extensive samples are considered. The real question is, however, what the real reason is for the decision to mature and whether maturation delays or stunts subsequent growth.

The preliminary results presented to the meeting are inconclusive. One major conclusion from this pilot study is therefore that a fairly large number of otoliths needs to be examined in order to quantify these relationships.

As a part of the analysis it needs to be clarified whether otolith radii really reflect body growth. Preliminary investigations indicate that this relationship varies according to age, making the conversion from otolith radii to body length difficult.

A second study is underway with a larger sample size and more detailed analysis on each otolith. This second study includes a similar analysis to be undertaken on scales of the same fish.

11.3.2 Mortality

Natural mortality has traditionally been assumed to be 0.2 for this stock. Fishing mortality has been estimated using XSA. Other techniques such as the use of tagging data have not been tested but need to be, particularly since earlier predictions based on initial yearclass estimates resulted in predictions of increasing catches, which did not materialize.

11.4 Present and future harvesting regimes

At present the harvesting is at rather high F levels, although there are at present no clear danger signals. There is no formal harvesting strategy for the stock, but management advice has been to reduce fishing mortality. TACs are allocated by the Icelandic Ministry of Fisheries and an enforcement system is in place. An request has been made for the evaluation and recommendation of a formal harvesting strategy for this stock.

11.5 Immediate bottlenecks

The comprehensive evaluation can be separated into immediate work and part which can be delayed somewhat since they depend on the immediate issues.

11.5.1 The growth-maturation process

The single most diffuse issue at the moment is the interrelationship between growth and maturation. There is a need to improve understand this area and this is the focus of work at present.

11.5.2 Technical interactions

Haddock are to some extent caught in a joint fishery with cod and cod is harvested according to a formal harvesting strategy. There are at times conflicts which arise since the quota for haddock may be out of sync with the quota for cod.

Technical interactions are not a part of the present evaluation of this stock. This will be the primary research issue for this stock, after the current growth-maturation issue has been cleared up somewhat.

11.5.3 Tagging data

Earlier tagging investigations have indicated that haddock in Icelandic waters is a single stock with considerable spawning migrations. The fact that there appears to be strong variation in growth is somewhat contradictory to these earlier results. It is clear, therefore, that there is a strong case for investigating the tagging data further in order to obtain at least a firm qualitative picture of the migrations.

Similarly the tagging data should be used to verify mortality estimates.

11.5.4 Food availability

Apparently, food availability may be a limiting factor to growth. This needs to be evaluated in detail, with the aim of distinguishing between local low-density food supply, local density dependence in growth due to local predator abundance and other factors, as the implications for management differ.

11.6 Further plans

11.6.1 Models of biological and technical interactions

No studies are available on the importance of biological interactions to this stock. It might be a useful future exercise to include this stock in Bormicon, a spatially disaggragated multispecies model (Palsson and Stefánsson, 1995) in order to account for spatial differences in growth as well as multispecies and technical interactions.

11.6.2 Simulations of harvest control laws

Ultimately, some medium-term simulations will have to be undertaken to investigate the effects of using different harvest control laws. These simulations will have to be designed based on the outcomes of the research currently underway.

12 OTHER BUSINESS

12.1 ITQS

COMFIE considered the draft report of the Study Group on the Management Performance if ITQ (Individual Transferable Quota) systems. COMFIE agrees with the Study Group on the lack of standardised mechanisms for gathering and analysing socioeconomic data. If the Study Group could recommend standarised mechanisms, this work could assist COMFIE in evaluating alternative harvest scenarios. COMFIE also recommends that the Study Group consider the ITQ fishery for flatfish in the Netherlands as another case study. Such a case study could be a component of the comprehensive assessment of North Sea flatfish.

12.2 Information on catchability

The Working Group considered a proposal to evaluate further the use of experimentally-derived catchability estimates in stock assessments (Walsh, BQ 1). For most usual stock assessment procedures, the absolute value of catchability is unimportant so long as it is consistent between years. Stock assessments and management advice are highly sensitive to year effects in catchability, and experimental information that provide insights into such changes would substantially improve the quality of management advice. This is particularly the case where catchability can be modelled as a function of some easily observed parameter, such as temperature for example.

In some other cases, stock assessments can rely quite strongly on assumed values of catchability, as for example when acoustic surveys are used in some stock assessments. In such cases it would be particularly helpful to provide estimates of uncertainty in catchability.

A related problem is that many stock assessment procedures necessarily make arbitrary assumptions (based on historical calculations) about the selectivity of commercial fishing gear for the most recent years in the analysis. If estimates of commercial gear selectivity could be provided to assessment Working Groups, this could allow improved estimates of selection pattern and may allow a better insight into discarding practices.

However, such problems will usually be case-specific. Some recent interesting examples relating to catchability changes occurred in the North Sea herring acoustic surveys and in surveys for juvenile mackerel When such problems are perceived to occur in assessment Working Groups, there is often insufficient detailed knowledge of the surveying procedures to formulate plausible models explaining catchability changes.

As such catchability changes are usually first observed by, and cause most difficulties for the assessment working groups, the following procedure is proposed on a trial basis:

- Assessment Working groups should be invited to detail catchability-related assessment problems in data sets that are used for assessment purposes, where these problems cannot satisfactorily be dealt with at the Assessment Working Group level. The importance of such perceived problems for management purposes should be explained.

- A Study Group on catchability issues for management should be established and will choose a number of case studies to address in detail, on the basis of apparent tractability and importance for management purposes. The Study Group should ideally be comprised of members with particular expertise in:

- The stocks used for the case studies
- The methods being used for the surveys
- Spatial and statistical modelling
- Parameterisation of survey performance from experimental information
- The stock assessment procedures

and would have the following term of reference:

- The Study Group will seek to improve the precision and accuracy of catch forecasts made for the stocks of (.. as appropriate) by including additional information on environmental variables, survey gear performance data (or other information as deemed appropriate) in the estimation of catchability coefficients in stock assessment models.

12.3 Response to request from GLOBEC

Environmental effects on the fish stocks are important for many stocks and it has always been a problem to separate environmental effects from the effects of fishing. The problem has usually been restricted to investigating the effect of temperature on recruitment and growth. In fish stock assessment and management advice such relationships may be used in several different contexts.

1. Historical stock development. Explain (part of the) historical variation in recruitment and growth.

2. Short-term predictions (TAC advice). Use predictions of environmental parameters as basis for short-term predictions of recruitment and growth.

3. Medium and long-term projections of catch and biomass. Simulate changes in environmental parameters in models to generate variation in growth and recruitment.

COMFIE is mainly concerned with comprehensive fishery evaluation. In order to include environmental parameters in simulations, the nature of the relationship with recruitment or growth has to be numerically defined, including the error structure. So far there are few cases where this has been properly attempted.

COMFIE nevertheless feels that understanding the environmental impact on fish stocks is of great importance and encourages GLOBEC to continue this line of work. In particular, COMFIE would consider it useful for GLOBEC to:

1. Find numerical relationships between temperature and growth/recruitment, including the error structure, for as many stocks as possible and in particular those which are included in COMFIE's terms of reference.

2. Ensure that all potentially useful time series of temperature are readily available, also for scientists working with stock assessment models.

3. Improve the precision of predictions of environmental parameters.

4. Develop models for long-term variations in environmental parameters in relevant areas.

5. Investigate if the current programmes for collecting environmental data are optimal for evaluating environmental effects on fish stocks.

Another area where environmental effects may impact evaluation of stock status is interaction of environmental variables with catchability. Attempts to quantify relationships between these which could then be used to tighten relationships between abundance indices and population estimates would be welcome.

13 RECOMMENDATIONS

1. The Working group recommends that bootstrapping be used to estimate variance for biological reference points (Section 2.2).
2. The Working Group recommends that Assesssment Working Groups should attempt to obtain estimates of B_{msy}.
3. It is recommended that Working Groups be requested to calculate precautionary catch forcasts based on the precautionary harvest control law discussed in Section 4.10 where feasible.
4. When misreporting is suspected, stock assessment models that can explicitly model uncertainty in reported catches should be used. (Section 5)
5. A Study Group on catchability-related assessment problems should be established (Section 12.2)
6. The Working Group recommends that the next meeting of COMFIE be held at the NFMS Laboratory in Miami in January 1999.

14 BACKGROUND MATERIAL AND WORKING DOCUMENTS PRESENTED TO THE WORKING GROUP

14.1 Working Papers and Documents (W)

Precautionary approach and the stock-recruitment relationship (P)

WP1: Patterson, K.R. A possibly consistent approach to fisheries stock assessment, forecasting, estimation of biological reference points and provision of advice when a harvest control law is defined.

WP2: Lewy, P. and Lassen, H . From chaos to stability. The influence of stock-recruitment dynamics.

WP3: Sparholt, H., 1997. Table of reference points

Discard and misreporting (D)

WD1: O'Brien, C.M. Further investigation of an empirical method for the detection of unreported catches.

Case Studies (C)

WC1: Gavaris, S. Evaluation of Rebuilding Harvest Strategies for Eastern Georges Bank Haddock.

WC2: Patterson, K.R. Biological Modelling of the Norwegian Spring-Spawning Herring Stock

WC3: Stefánsson, G. Iceland haddock. Comprehensive stock assessment.

WC4: Jónsson, E. Local variation in growth of Icelandic haddock and its causes.

WC5: Tretyak, V.L. About single species optimization of Arctic Cod Fishery.

WC6: Sinclair, A. Natural Mortality of Cod in the Southern Gulf of St. Lawrence.

WC7: O'Brien, C.M. Time series modelling and simulation of North Sea plaice recruitment.

WC8: Kell, L.T., O'Brien, C.M., Stokes, T.K., Smith, M.T., Rackham, B.B. and Darby, C.D. Stochastic scenario experiments to investigate the utility of various biological reference points within harvest control laws.

WC9: Pastoors, M., Dol, W. and Rijnsdorp, A. Flatfish 2.0. A bio-economic model of North Sea flatfish fisheries.

WC10: Jakobsen, T. Northeast Arctic Cod. A Brief review of fishery, management, research and current problems.

WC11: Bogstad, B., Jakobsen, T. and Nakken, O. Problems in the assessment of Northeast Arctic cod.

WC12: Tjelmeland, S. Bits and pieces of the Norwegian spring spawning herring.

WC13: Sinclair, A. Comprehensive Assessment of Southern Gulf of St. Lawrence Groundfish and Herring Fisheries.

14.2 Background material (B)

Precautionary approach and the stock-recruitment relationship (P)

BP1: Garcia, S.M. Stock-recruitment relationships and the Precautionary Approach to Management of Tropical Shrimp Fisheries.

BP2: Mace, P., Botsford, L., Collie, J., Gabriel, W., Goodyear, P., Powers, J., Restrepo, V., Rosenberg, A., Sissenwine, M., Thompson, G. and Witzig, J. Scientific Review of Definitions of Overfishing in U.S. Fishery Management Plans.

BP3: Thompson, G.G. and Mace, P.M. The Evolution of Precautionary Approaches to Fisheries management, with Focus on the United States.

BP4: Powers, J.E. Benchmark Requirements for Recovering Fish Stocks.

BP5: Schnute, J.T. and Richards, L.J. Analytical models for fishery reference points.

BP6: Report of the Study Group on the Precautionary Approach to Fisheries Management.

BP7: Serchuk, F., Rivard, D., Casey, J. and Mayo, R. Report of the AD Hoc Working Group of the NAFO Scientific Council on the Precautionary Approach.

Catchability (Q)

BQ1: Walsh, S.J. Request from Working Group on Fishing Technology and Fish Behaviour (Fish Capture Committee)

BQ2: Thórarinsson, K. and Johannesson, G. Correcting for variation in catchability: maturity-related catchability variation in Icelandic cod.

Discards and misreporting (D)

BD1: Fryer, R., Reeves, S. and Cook, R. Stock trends in VIa cod: an assessment omitting catch data sullied by misreporting.

BD2: Patterson, K.R. Assessing fish stocks when catches are misreported: Model, Simulation Tests and Application to Cod, Haddock and Whiting in the ICES area.

BD3: Gavaris, S. and Van Eeckhaute, L. Assessment of Haddock on Eastern Georges Bank.

Case studies (C)

BC1: Vaage, R. Problems with the assessment of the North-East Arctic Cod in 1997.

BC2: Skagen, D.W. Medium term simulation of management regimes for North Sea herring.

BC3: Skagen, D.W. Long term equilibria for North Sea herring.

BC4: Cavaco, A. Request for advice on North Sea Herring.

BC5: ACFM Extract - North Sea Herring and North Sea Plaice.
BC6: ACFM Extract - Stocks in the Skagerrak and Kattegat; Herring Stocks South of 62°N; Sprat Stocks.

BC7 Report of the Herring Assessment Working Group for the area south of 62°N - March 1997.

BC8: Comfie, 27 June 1997. Selected pages from the 1996 Arctic Fisheries Working Group Report, intended to inform on the assessment problems for North-east Arctic Cod. (The quality Control diagram will be copied later).

BC9: Nakken, O. Past, Present and Future Exploitation and Management of Marine Resources in the Barents Sea and adjacent areas.

Related topics (O)

BO1: Richards, L.J., Schnute, J.T. and Olsen, N. Visualizing catch-age analysis: A case study.

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Anon. 1996c. Report of the comprehensive fishery evaluation working group. ICES CM 1996/Assess:20: 68 p.

Anon.1997. Report of the Herring Assessment Working Group for the area South of 62 degrees North. ICES CM 1997/Assess:8

Anon.1997. Report of the Northern Pelagic and Blue Whiting Fisheries Working Group. ICES C.M. 1007/Assess:14.

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