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The development of precautionary and biological limit reference points for the 3Ps cod stock

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Abstract

A number of reference points are suggested in the context of 3Ps cod. These are computed for the final SPA model accepted in the most recent assessment of this stock. F_{loss} and spawner biomass corresponding to 50% asymptotic recruitment are suggested as initial limit reference points. At current stock size there is a low risk of falling on the wrong side of these limit reference points in both short and medium term risk analyses for a status quo TAC of 30,000 t. However, there is a high risk of remaining below B_{msy} and a significant risk of exceeding F_{msy} for the status quo TAC in both short and medium term risk analyses.

Résumé

Des points de référence sont suggérés pour la morue de 3Ps. Ces points sont calculés pour le modèle final d'analyse séquentielle de population qui a été accepté pour la plus récente évaluation de ce stock. Il est suggéré d'utiliser F_{loss} et la biomasse des géniteurs correspondant à 50 % du recrutement asymptotique comme points de référence limites initiaux. Selon la taille actuelle du stock, et avec un TAC maintenu à 30 000 t, il y a un faible risque que les résultats des analyses du risque à court et à moyen terme si situent à l'extérieur de ces points de référence limites. Cependant, avec ce TAC maintenu, il y a un risque élevé de demeurer à un niveau inférieur à B_{msy} et un risque significatif d'obtenir un niveau supérieur à F_{msy} dans les analyses du risque à court et à moyen terme.

Introduction

In the February 1998 assessment of the 3Ps cod stock two precautionary reference points were considered for an SPA applied to the offshore component of the stock to evaluate TAC options for 1998 – the probability that the stock would not grow and the probability that fishing mortality would exceed $F_{0.1}$ (Stansbury et al. 1998). The offshore biomass was estimated to be about 100,000 t and the risk analysis indicated that for a 12,500 t offshore quota in 1998 the probability of fishing mortality exceeding $F_{0.1}$ was less than 10% and that with this quota there was a 50% probability that offshore spawner biomass would not grow. A “last resort” extrapolation for the inshore of an estimate from a tagging study in Placentia Bay to the whole inshore area using gillnet catch rate data gave an estimate of 115,000 t for the inshore. Based on a total biomass of 215,000 t, it was suggested that an $F_{0.1}$ TAC would be about 40,000 t and that, in the absence of a full risk analysis for inshore and offshore combined, a TAC not exceeding 50% of the $F_{0.1}$ level, i.e. 20,000 t, might be considered to be precautionary. It was noted that a TAC of 50% $F_{0.1}$ would correspond to <10% probability of exceeding $F_{0.1}$. The TAC was set at 20,000 t for 1998.

In the March 1999 assessment (Brattey et al. 1999) risks associated with TAC options for the 1999 fishery for the whole stock were evaluated relative to two precautionary reference points – risk of exceeding $F_{0.1}$ and the risk of the spawner biomass falling below an arbitrary level of 100,00 t. The results showed that the TAC resulting in a 10% probability of exceeding $F_{0.1}$ was 22,000 t. It was estimated that there was a 9% risk of the spawner biomass falling below 100,000 t with a catch of 20,000 t. Evaluating the probability of the stock not growing was not considered a priority at the time because spawner biomass was estimated to be at the highest level since 1959 at 145,000 t. The TAC was set at 30,000 t for 1999 corresponding to about a 25% risk of exceeding $F_{0.1}$.

In the October 1999 assessment of 3Ps cod in St John’s attention was given to the development of a number of reference points with particular emphasis on biological limit reference points, and this is discussed in more detail below. Before doing so, it may be valuable to briefly review the TAC’s implemented for 1999 on the 3 other cod stocks assessed in the March 1999 Zonal Assessment relative to the risk analyses that appeared in the respective Stock Status Reports (SSR’s) for these stocks.

For the 4RS3Pn cod stock the TAC was set at 7,500 t which would, according to the SSR allow "marginal growth" in population size and a large probability of decrease in abundance for a stock which was assessed to be at a low level. For the 4TVn cod stock the TAC was set at 6,000 t which would allow "no increase" and a large probability of decrease, again for a stock assessed to be at a low level. For the 2J3KL cod stock the TAC was set at 9,000 t with unquantifiable (but large) risk of something bad happening to the remnant of the stock concentrated in the inshore. Clearly the precautionary approach has had very limited penetration in the setting of TACs on cod stocks in Atlantic Canada in this early post-moratorium period. Canada was criticised in the September 1999 meeting of NAFO for not being precautionary with respect to 2J3KL cod. Clearly there is a need to progress in the development of an objective precautionary framework of Canadian stock assessments.

Precautionary and limit reference points for 3Ps cod

In the October 1999 Groundfish Regional Assessment (RAP) in St John's there was considerable debate regarding the development of reference points for 3Ps cod. It was generally agreed that there was a need to once again communicate risk with respect to stock growth and the $F_{0.1}$ level. These were considered to be precautionary reference points – when there was a sufficiently high risk of falling on the wrong side there might be some precautionary reduction in TAC to prevent worse situations arising. In addition to precautionary reference points, it was decided that there was a need to evaluate candidate biological limit reference points.

It was concluded that determining biological reference points was the responsibility of biological scientists and no one else, and where suitable estimates of spawner stock and recruitment were available, there was no reason to delay in putting forward definitions of biological overfishing. Further, the Precautionary Approach dictates that there should be only a small probability of falling on the wrong side of limit reference points and it was suggested in the RAP that this would constitute no more than a 10% probability. The RAP benefited from the participation of 3 EU fisheries scientists who had extensive experience with biological reference points through participation in the ICES assessment working groups. In addition, the RAP gave consideration to the paper "In search of thresholds for recruitment overfishing" by Myers et al. (1994) in which 3 spawner biomass thresholds are defined which could be used to determine when recruitment overfishing was taking place.

Beverton-Holt and smoother fits to the stock-recruit data

Most of the reference points in use require estimates of spawner stock and recruitment and some require a model fit to these data. Two models were explored with respect to the final QLSPA run accepted at the October 1999 assessment of 3Ps cod (Brattey et al. 1999). The first model was a Beverton-Holt stock-recruit model fitted to the data using maximum-likelihood methods assuming lognormal errors (Fig. 1). The second model was a kernel smoother (Fig. 2) assuming a Cauchy probability density function with the shape parameter selected by minimising the cross-validation sums of squares, where the predicted value was the Cauchy weighted mean recruitment at each observed spawner stock size. Two versions were considered – one which included only the observed data and one which also included a data point at the origin. Subsequent analyses showed that one of the reference points (F_{loss}) was sensitive to the approach taken. In ICES assessment working groups the current practice is to fit a lowess smoother to the data with the span chosen by examining the Akaike Information criterion. ICES used to include an additional data point for the origin but is no longer doing so according to EU participants in the October RAP.

Estimated reference points

Several reference points were considered in the October 1999 RAP. Two additional reference points, suggested at the DFO Precautionary Approach Project Workshop, (Nanaimo, November 1999; Richards and Schnute 2000) are also considered – F_{msy} and B_{msy}. The estimated values of the reference points from the final run of the QLSPA used in the assessment of the stock is given in Table 1 conditional on the input vectors of weight, maturity and partial recruitment. The corresponding lines are shown relative to the stock recruit scatter and Beverton-Holt fit in Fig 3. Input vectors of weights, maturity and partial recruitment are also given in Table 1. These were derived from averaging the values for 1997 and 1998. The reference points are each briefly described below.

1. F_{med} – fishing mortality corresponding to the median survival line through the stock recruit scatter – precautionary
2. $F_{0.1}$ – fishing mortality corresponding the 10% of the slope through the origin in a yield per recruit model – precautionary
3. F_{loss} – highest level of fishing mortality that can, on average, be expected to be sustainable at the lowest observed spawner biomass level - limit.
4. $F_{35\%SPR}$ – fishing mortality corresponding to 35% of the spawner biomass per recruit relative to that obtained with no fishing - limit.
5. F_{high} – fishing mortality corresponding to a survival rate in which only 10% of the stock-recruit data points are above the replacement line - limit.
6. F_{msy} – fishing mortality corresponding to the equilibrium spawner biomass at maximum sustainable yield - precautionary.
7. Spawner biomass corresponding to 50% of asymptotic recruitment - limit.
8. Spawner biomass corresponding to the intersection of F_{high} replacement line and the 90^{th} percentile recruitment value (Serebryakov, 1991 and Shepherd, 1991) - limit.
9. Spawner biomass corresponding to 20% of the virgin spawner biomass (Beddington and Cooke, 1983) - limit.
10. B_{msy} – spawner biomass corresponding to maximum sustainable yield - precautionary.

After considerable discussion, the October 1999 3Ps cod RAP selected F_{loss} and spawner biomass corresponding to 50% of asymptotic recruitment for limit reference points for the 3Ps stock. F_{loss} was calculated using the Cauchy kernel smoother with an additional data point for the origin (Fig. 2). It was noted that F_{loss} was sensitive to the method for determining expected recruitment at the lowest observed spawner biomass. There was some concern in the RAP that F_{loss} was estimated to by higher than F_{high} – apparently an unusual situation with respect to ICES stocks.

Risk Analysis

Evaluation of Short term risk

Short-term risk, i.e. the risk associated with alternative TAC options for the year 2000 only, were evaluated by Noel Cadigan (DFO St John's) using the QLSPA - profile likelihood approach (Cadigan 1998, Brattey, et al. 1999). The associated risks of falling on the wrong side of the 6 fishing mortality reference points are illustrated in Fig. 4 and on the wrong side of the 4 spawner biomass reference points in Fig. 5. It is evident that, for current estimates of spawner stock size, there is a relatively low risk of falling on the wrong side of the reference points for most TAC options. With respect to spawner biomass reference points, for a 30,000 t TAC there is an appreciable risk of falling below B_{msy} and 20% virgin biomass. The only fishing mortality reference points for which there is an appreciable risk of falling above at a TAC of 30,000 t are $F_{0.1}$ and F_{msy}.

Medium term risk

While there was low risk of falling on the wrong side of most of the reference points in short-term risk projections, it was considered worth looking at medium term risk (see for example Rivard et al. 1999). Although spawner biomass for 3Ps cod is estimated to be at a high level, recruiting year classes are estimated to be small, albeit with considerable uncertainty. Future recruitment (year classes not estimated in the current SPA) are likely to be poorly predicted based on the scatter around any stock-recruit relationship. For this reason it was decided to limit the medium-term projection to 3 years (January 2002) by which time the youngest yearclass for which there was an estimate (1997, estimated from only one survey) would be 5 years old and more than 60% of the individuals would be mature. Deterministic runs were carried out with fixed weights maturities and partial recruitments (same values as Table 1) for TAC's equivalent to $F_{0.1}$ (Jean-Claude Mahe, IFREMER – RAP working paper). The results indicated a slowly declining spawner biomass. Projections with a PR skewed to younger ages corresponding to a proposed decrease in mesh size for gillnets resulted in a slightly more steeply declining spawner biomass.

Subsequent to the October RAP, the variance-covariance matrix of QLSPA estimates for survivors was used in a Monte Carlo simulation to examine the distribution of possible spawner biomass estimates to Janaury 1 2002 and of fishing mortality in 2000 and 2001. These projections assumed that the TAC of 30,000 t in 1999 would be taken and that a TAC of 30,000 t would also apply in 2000 and 2001. A sample of 100 realizations of the spawner biomass and of the fishing mortality are illustrated in Figs. 6 and 7. The associated frequency distribution and cumulative distribution for spawning biomass on January 1, 2002 are shown in Figs. 8 and 9 and for fishing mortality in 2001 in Figs. 10 and 11. Year classes younger than the 1997 year class do not have a large impact on this projection and were drawn randomly from past yearclasses with a weighting factor determined by the fitted Cauchy kernel described above. There is an increased risk of falling below spawner biomass reference points in the medium term projection. For example, the risk of falling below B_{msy} increases from 0.89 in the short term projection to 0.95 in the medium term projection. For 20% virgin spawner biomass the risk increased from 0.46 to 0.53. There was little change in the risk with respect to 50% asymptotic recruitment from 0.02 to 0.03. The risk associated with falling above fishing mortality reference points increased quite substantially in the medium term projection for a 30,000 t TAC. For $F_{0.1}$ the increase was from 0.22 to 0.97 and for F_{msy} the increase was from 0.28 to 0.97.

Non-stationarity and depensation

The stock-recruit data for 3Ps cod, typical of that observed for many other stocks, shows evidence of a non-stationary relationship (some factor other than spawner biomass changing systematically over time). Non-stationarity can make the fixing of spawner biomass reference points problematic because the system may never evolve back into its previous state. However, to assume, based on limited data, that a resource will not recover, and can therefore be continued to be fished at some lower “sustainable” level cannot be considered prudent.

Stocks that have not shown evidence of recovery even after a prolonged period of little or no fishing may be exhibiting depensatory behaviour (see Shelton and Healey 1999). In a stock that has not already undergone a sever decline, an argument can be made for setting the spawner biomass limit higher than might otherwise be the case if the possibility of depensation exists, in order to avoid the depensatory part of the relationship.

Conclusion

A number of reference points are suggested in the context of 3Ps cod. Limit reference points are the responsibility of biological scientists and can be estimated from reliable spawner stock and recruitment information. In the case of the 3Ps cod stock, F_{loss} and spawner biomass corresponding to 50% asymptotic recruitment are suggested as initial limit reference points. There is a low risk of falling on the wrong side of these limit reference points in both short and medium term risk analyses for a status quo TAC of 30,000 t. However, there is a high risk of remaining below B_{msy} and a significant risk of exceeding F_{msy} for the status quo TAC in short term risk analyses. The risk of exceeding these reference points increases in the medium term projections at a 30,000 t status quo TAC. These reference points represent possible precautionary reference point for further consideration.

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Table 1. Input vectors of weight, maturity and partial recruitment and estimates of a range of fishing mortality and spawner biomass reference points based on the final QLSPA model.

Input vectors of weight, maturity and partial recruitment

Age	Jan1Wt	Mats	PR	Ave Wt
2	0	0.001	0	0
3	0.485	0.015	0.011	0.62
4	0.785	0.137	0.092	0.96
5	1.16	0.615	0.287	1.435
6	1.655	0.94	0.568	1.96
7	2.2	0.994	1	2.465
8	2.825	0.999	0.49	3.17
9	3.41	1	0.405	3.755
10	3.58	1	0.37	3.825
11	4.165	1	0.221	4.605
12	5.215	1	0.205	5.79
13	6.36	1	0.163	7.485
14	8.975	1	0.023	10.21

Fishing mortality reference points

	Floss	Fmed	F0.1	F35% SPR	Fhigh	Fmsy
Fully recruited F	1.964	0.892	0.586	0.882	1.652	0.56
Age						
7	1.964	0.892	0.586	0.882	1.652	0.56
8	0.962	0.437	0.287	0.432	0.809	0.274
9	0.795	0.361	0.237	0.357	0.668	0.227
10	0.727	0.33	0.217	0.326	0.612	0.207
Average F	1.112	0.505	0.332	0.499	0.935	0.317

Spawner Biomass reference points

Spawner biomass at 50% asymptotic recruitment	70635
Serebryakov-Shepherd Spawner biomass reference	72488
Spawner biomass corresponding to 20% of virign	132242
Spawner biomass at MSY	198551

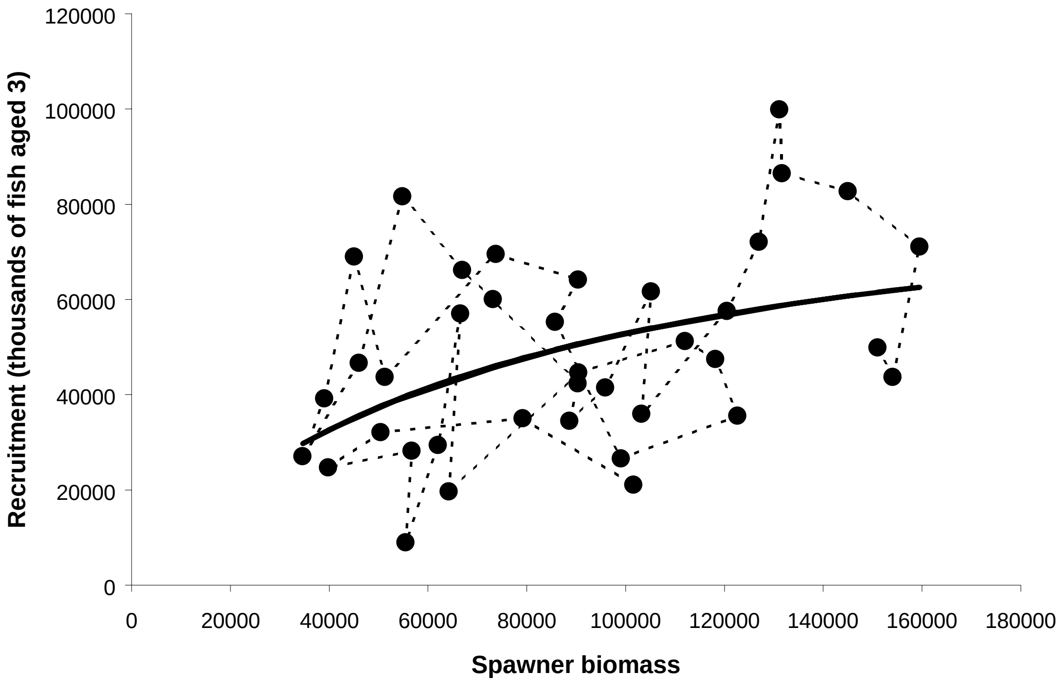

Fig. 1. Beverton-Holt model maximum likelihood fit to the estimates of spawner biomass and recruitment for the final QLSPA model from the October 1999 assessment.

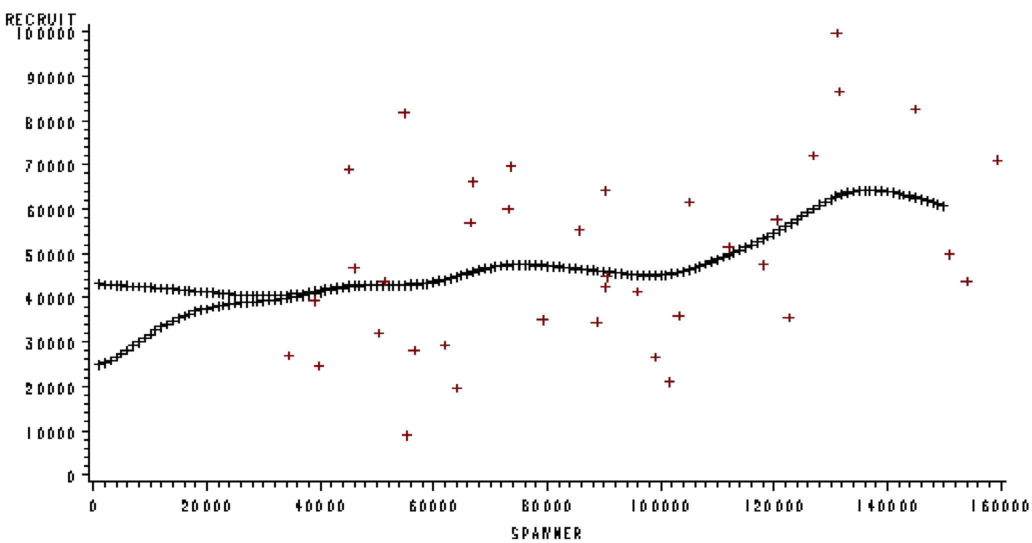

Fig. 2. Cauchy kernel smoother fitted to the spawner-recruit data from the final QLSPA model from the October 1999 assessment using cross-validation to estimate the shape parameter. Two smoothers are shown – one using the data and one using the data as well as a data point for the origin. The latter curve is the lower one at low spawner biomass.

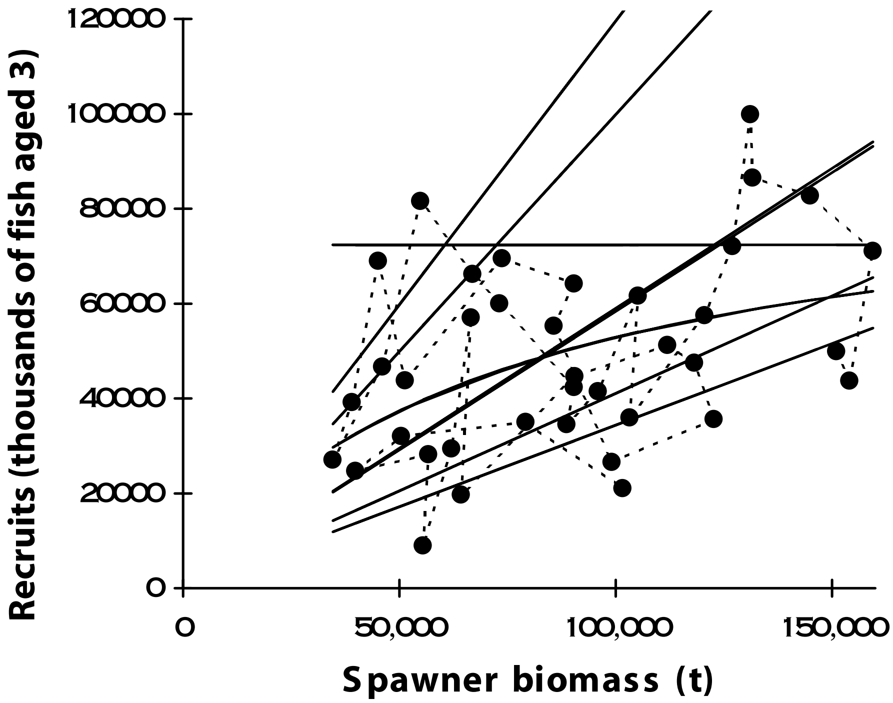

Fig. 3. Potential fishing mortality reference points for 3PS cod illustrated in stock-recruit space. The radiating lines are in clockwise order from 12 o'clock: F_{loss}, F_{high}, F_{med}, F35%SPR (these two lines are close together), $F_{0.1}$ and F_{msy}. The horizontal line is the 90th percentile recruitment and the curved line is the Beverton and Holt stock-recruit model fit to the data.

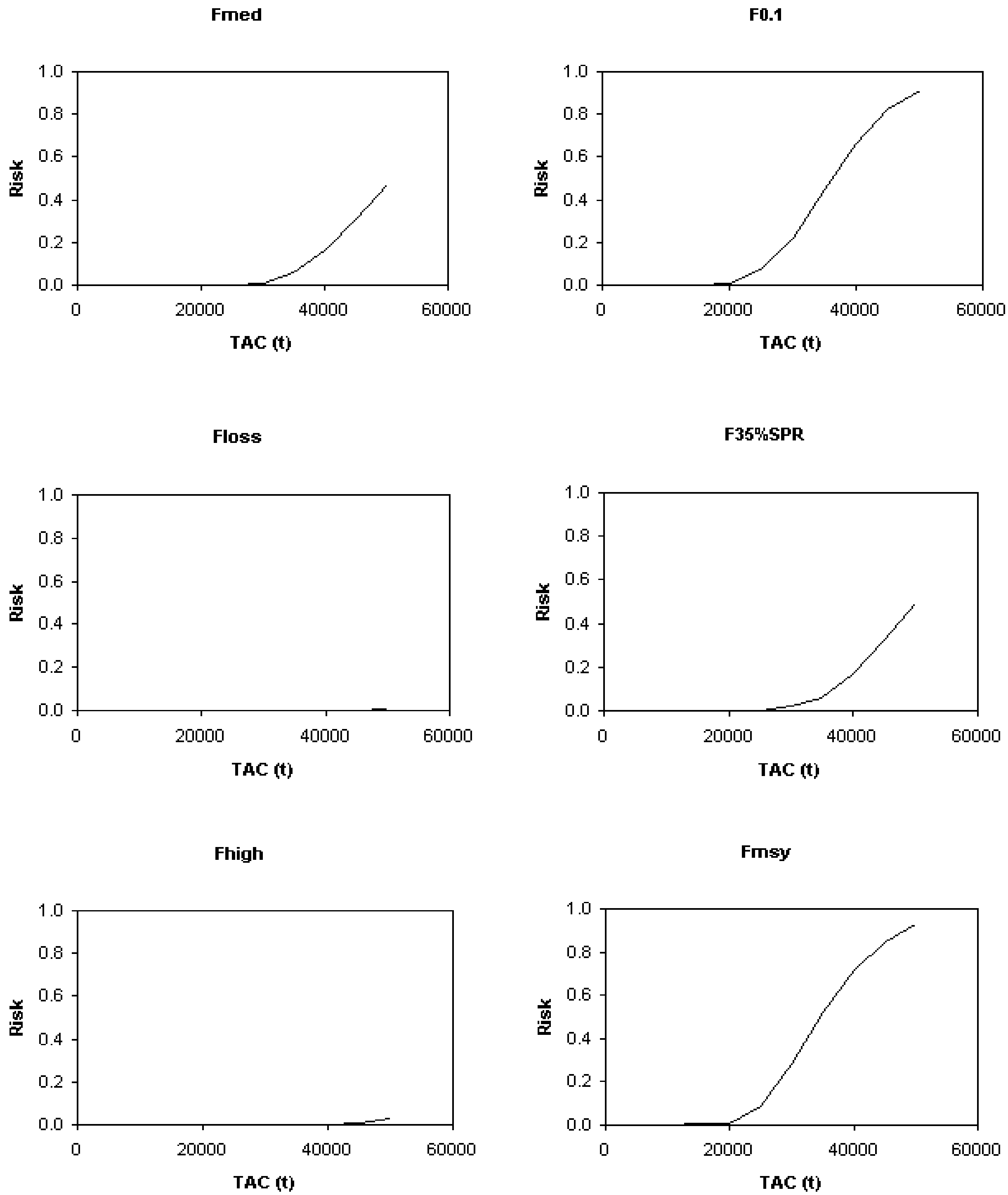

Fig. 4. The risk of exceeding different fishing mortality reference points for a range of TAC options.

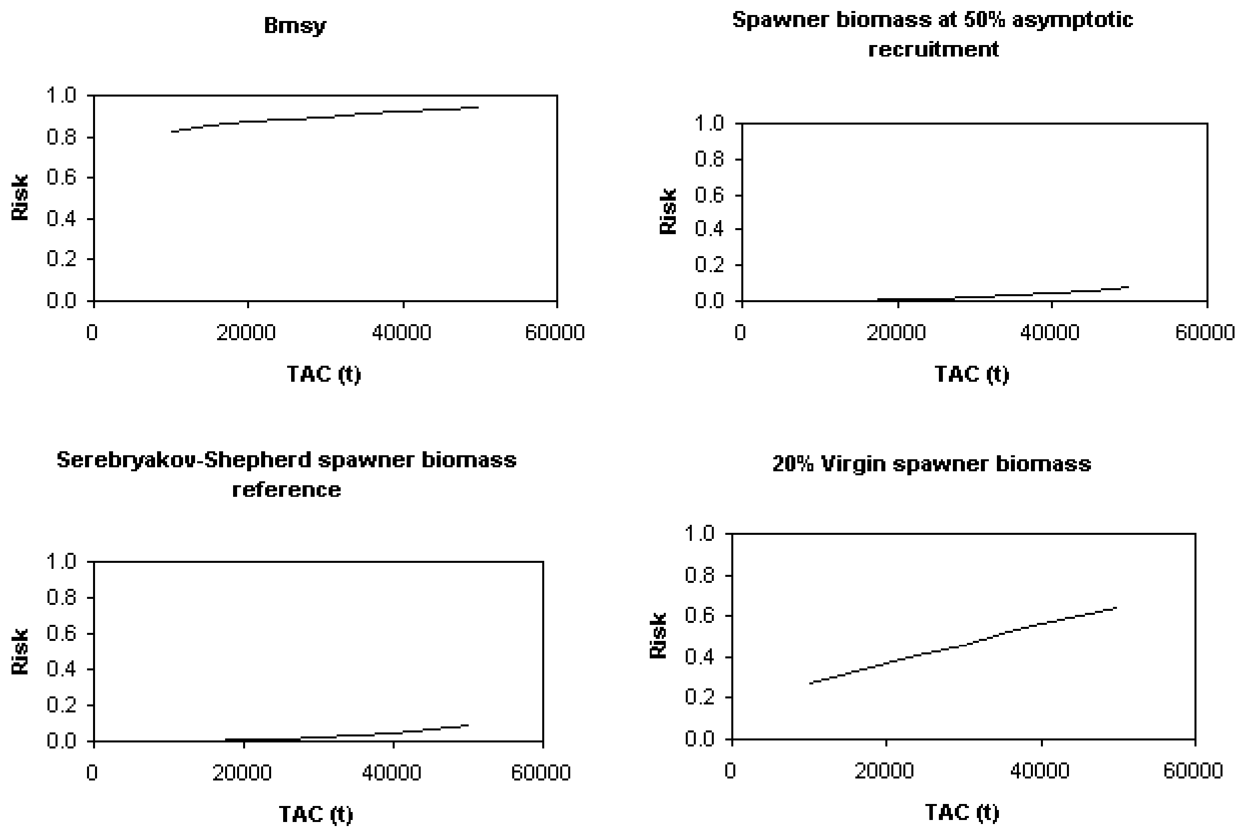

Fig. 5. Risk associated with falling below different spawner biomass reference points for a range of TAC options for year 2000.

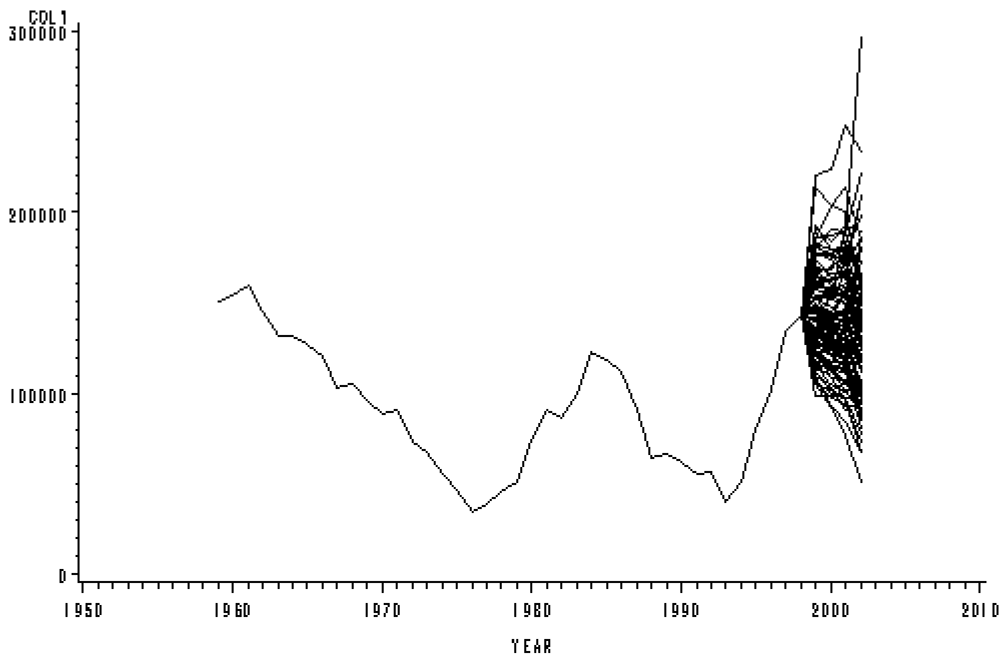

Fig. 6. Plot of 100 simulations of 3Ps cod spawner biomass to January 1, 2002 under a 30,000 t TAC. Each realization represents a random draw from the probability distributions of survivors at age on Janaury 1, 1999 based on the variance-covariance matrix from the final model accepted in the October 1999 RAP.

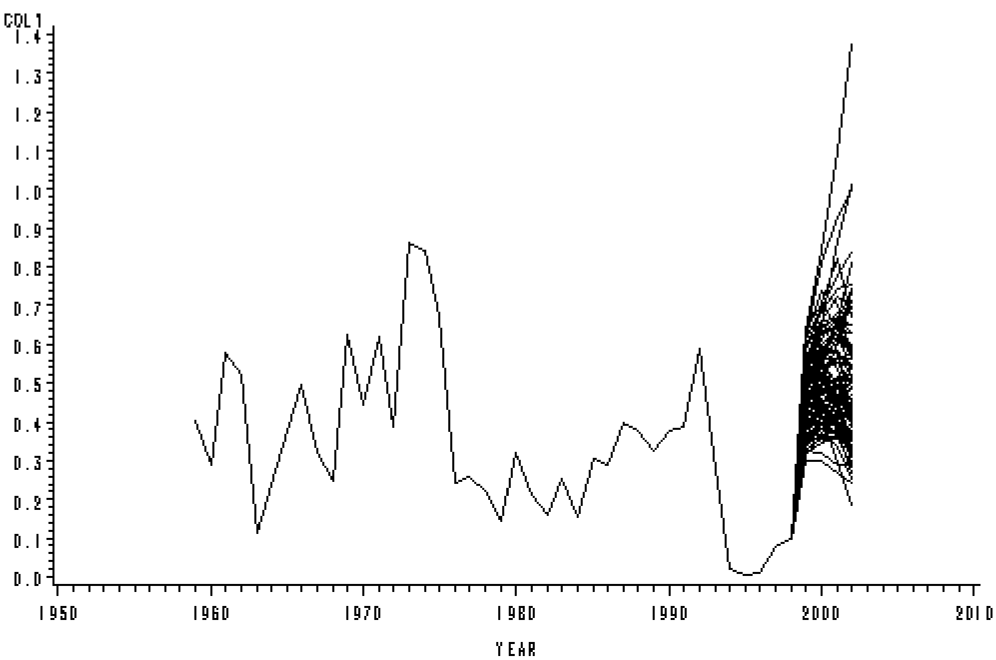

Fig. 7. Plot of 100 simulations of 3Ps cod fishing mortality to January 1, 2002 under a 30,000 t TAC.

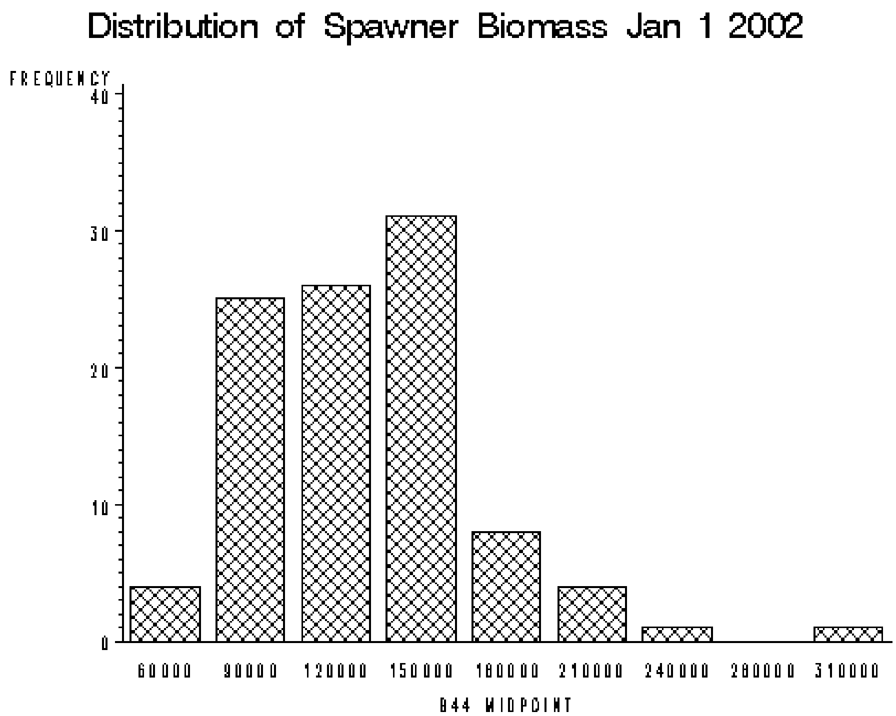

Fig. 8. Frequencey distribution of simulated spawner biomass on January 1, 2002 under a constant 30,000 t TAC.

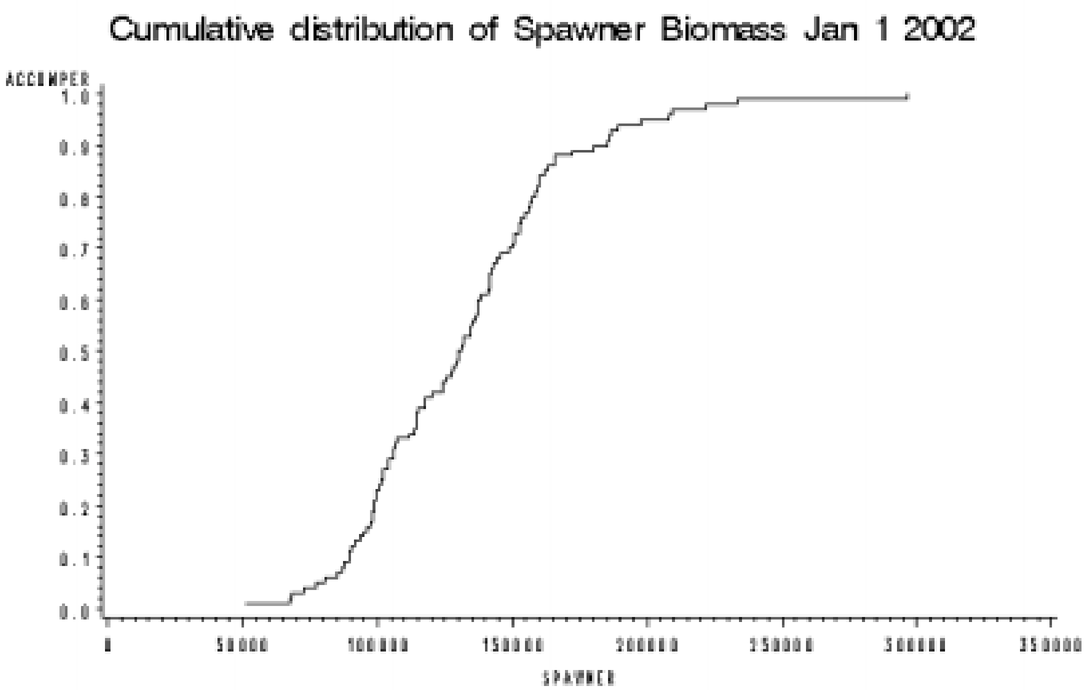

Fig. 9. Cumulative distribution of simulated spawner biomass on January 1, 2002 under a constant 30,000 t TAC.

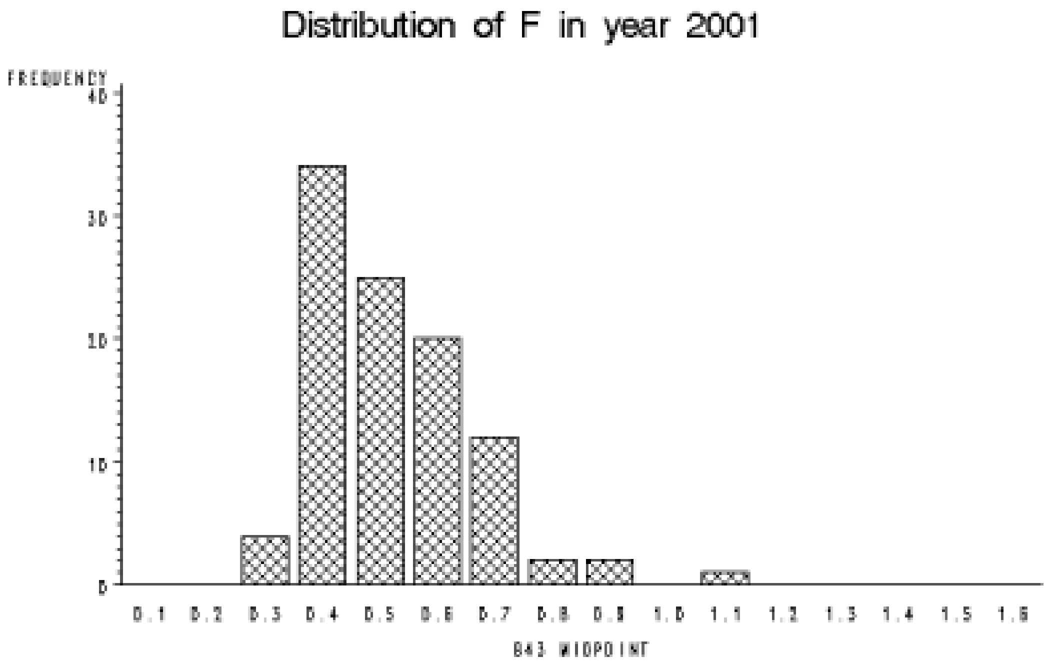

Fig. 10. Frequency distribution of fishing mortality for the year 2001 under a constant 30,000 t TAC.

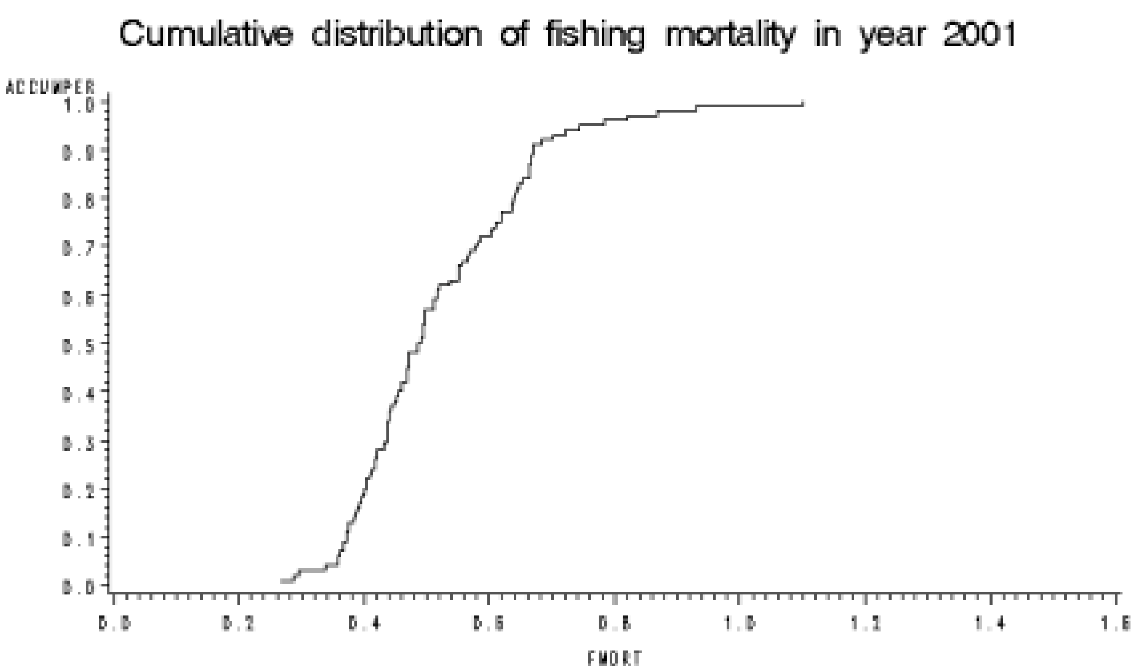

Fig. 11. Cumulative distribution of simulated fishing mortality in 2001 under a constant 30,000 t TAC.