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Example application of candidate precautionary approach limit reference points to the 3Ps cod stock

Exemple d'application de points de référence limites d'approche préventive au stock de morue de 3Ps

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Abstract

The cod stock off southern Newfoundland (3Ps) is thought to be within safe biological limits and supports the only significant commercial fishery (>10,000 t) on cod in Atlantic Canada. Currently there are no precautionary approach spawner biomass limit reference points in place. This study provides example application of candidate limit reference points to population estimates derived from the 2002 assessment, extended back to 1959. The candidates include five approaches/variants which were applied by DFO to three severely depleted cod stocks in February 2003 and incorporated in scientific advice which was used as a basis for the closure of the directed fisheries on these stocks. In addition, two new approaches based on non-parametric estimates of the probability of poor recruitment for a range of spawner biomass values and an approach in use in ICES called segmented regression are applied. While it is possible to develop a number of ways of deriving limit reference points, it is essential that both the biological and statistical properties be thoroughly evaluated through a process which includes simulation testing.

Résumé

On croit que le stock de morue retrouvé dans les eaux au sud de Terre-Neuve (3Ps) se situe en deçà des limites biologiques permettant d'assurer sa conservation, car elle alimente la seule importante pêche commerciale (> 10 000 t) de ce poisson de fond dans le Canada atlantique. Aucun point de référence limite de précaution pour la biomasse de géniteurs n'a par contre encore été établi pour ce stock. La présente étude donne un exemple d'application de points de référence limites à des estimations des effectifs de la population tirées de l'évaluation de 2002 et rétrocalculées jusqu'en 1959. Ceux-ci incluent cinq approches/variantes, appliquées par le MPO, en février 2003, à trois stocks de morue fortement appauvris et incluses dans les avis scientifiques qui ont servi à justifier la fermeture des pêches dirigées de ces stocks. De plus, deux nouvelles approches reposant sur des estimations non paramétriques de la probabilité d'un recrutement médiocre pour une gamme de valeurs pour la biomasse de géniteurs et une approche utilisée par le CIEM, appelée régression segmentée, sont appliquées. Bien que des points de référence limites peuvent être établis de diverses manières, il est essentiel que leurs propriétés biologiques et statistiques soient évaluées sous tous les angles à l'aide d'un processus qui inclut aussi un essai de simulation.

Introduction

Of the three commercial cod fisheries currently in existence in Atlantic Canada (eastern Georges Bank, Southern Scotian Shelf /Bay of Fundy, and southern Newfoundland, the cod fishery in NAFO Subdivision 3Ps off southern Newfoundland is the only one supporting a significant (>10,000 t) commercial fishery. Spawning stock biomass (SSB) appears to be at a relatively high level at the present time (Brattey et al. 2002). This is despite the fact that (based on Model D in the 2002 assessment) recruitment has been declining over time and recruits per spawner (RPS) has been below average since 1994, with the exception of the 1998 year class. SSB has been maintained largely through high spawner per recruit (SPR), a consequence of early maturation and rapid growth rates and initially reduced fishing mortality from about 1993 onwards.

Although the stock is vulnerable to any reduction in SPR, and there are concerns about high exploitation rates in part of the stock area (Placentia Bay), 3Ps cod is thought to be within "safe biological limits" at the present time. The current TAC is 15,000 t and the Fisheries Resource Conservation Council has recommended that if adjustments are required, these should be made in 5,000 t increments or decrements. Beyond this there is no structured approach to the management of the stock. DFO Fisheries Management has in principle adopted a structured approach to fisheries management termed Objective-Based Fisheries Management (OBFM), but this approach has yet to be implemented on groundfish stocks. OBFM includes the adoption of clear and measurable fisheries management objectives based on biological and socio-economic factors; the introduction of risk management principles in developing fisheries management strategies and operational management plans; and the "operationalization" of the precautionary approach (PA) including the specific identification of conservation limits (Shelton and Rivard 2003). While some progress in the implementation of the PA was made in recent assessments for three depleted cod stocks (northern cod, northern Gulf cod, southern Gulf cod; Shelton et al. 2003), there has been little progress in implementing the precautionary approach in Canada on other groundfish stocks, including stocks considered to be within safe biological limits. For example, the remits for the fall 2003 assessments of 3Ps cod and 4X/5Y cod do not contain any reference to the precautionary approach or the determination of limit reference points. Canada's Oceans Act of 1996 however states that "… Canada promotes the wide application of the precautionary approach to the conservation, management and exploitation of marine resources in order to protect these resources and preserve the marine environment…". It is therefore anticipated that elements of the precautionary approach will begin to be more widely applied in the provision of scientific advice and in the management of Canadian groundfish stocks and other living renewable marine resources in the future.

Defining serious harm for stocks that are currently relatively healthy, and the management action that would be taken should risk of serious harm rise above some risk tolerance level in the future, would be consistent with implementing both OBFM and the PA. Shelton and Rice (2002) reviewed a number of potential limit reference points, some of which had been considered previously in the context of 3Ps cod by Shelton (2000). In a November 2002 DFO workshop (Rivard and Rice 2003) and in the February 2003 assessment of 3 depleted cod stocks, 5 limit reference point approaches/variants were given consideration (Shelton and Rivard 2003, Shelton et al. 2003). All three stocks were found to be below the estimated spawner biomass limit reference points (B_{lim}) and, based on DFO scientific advice, the Minister of Fisheries and Oceans closed the fisheries in 2003, stating that the stocks were "below the levels where the harm is serious".

In this document the same 5 approaches applied in the February 2003 assessments of three severely depleted cod stocks are applied to data on 3Ps cod from Model D in the 2002 assessment (Brattey et al. 2002), extended back to 1959. In addition, two new approaches for deriving B_{lim} are considered. The 2002 assessment found inconsistencies in the catch at age data prior to 1977 and consequently the assessment only considered data from 1977 onwards. Earlier data are useful to illustrate the application of limit reference points, but the results cannot be applied directly to the current assessment of 3Ps cod and the calculations would have to be repeated if and when the inconsistencies in the catch at age data are resolved. Further, five different SPA approaches/formulations are considered in the current assessments for 3Ps cod (Brattey et al. 2002), an expression of model uncertainty, and consequently limit reference points would have to be derived for all five sets of model estimates.

Methods

The November 2002 DFO workshop on the precautionary approach (Rivard and Rice 2003) selected 5 methods or variants for estimating spawner biomass limit reference points. These included three variants of the method of determining B_{lim} as the SSB corresponding to point where the expected value of recruitment based on a fitted model, either Beverton-Holt, Ricker or non-parametric smoother, is half the maximum, denoted as BH50, RK50 and NP50 respectively. The fourth method was Serebryakov's approach where B_{lim} is defined as the SSB corresponding to the intersection of the 50^{th} percentile of recruitment and the 90^{th} percentile of the ratio of recruits to spawner biomass, denoted as SB50/90 (Serebryakov 1991; Shepherd 1991). The fifth method was Brecovery, the SSB from which the stock had previously achieved a rapid recovery. These approaches, and application to three cod stocks (northern cod, northern Gulf cod and southern Gulf cod), are briefly reviewed in Shelton and Rivard (2003) and Shelton et al. (2003). In this study the same 5 approaches/variants are applied to 3Ps cod. In addition, a segmented regression approach (O'Brien et al. 2003) and an extension of a non-parametric kernel method (Rice and Evans 1988; ICES 2003) are also considered in the present study.

The segmented regression approach involves fitting a piecewise linear regression constrained to pass through the origin with zero slope beyond a single change point. In ICES B_{lim} is considered to be determined by the SSB corresponding to the change point, whereas in the development of a domestic Canadian PA, the SSB corresponding to a point on the slope to the left of the change point, determined by a model predicted recruitment value equal to half the recruitment value at the change point, would be consistent with BH50, RK50 and NP50, and hereafter is termed SR50.

The extension of the non-parametric kernel method involves applying the fitted kernel to determine the probability of poor recruitment. This requires a definition of poor recruitment. In the current application the 10^{th} percentile of observed (estimated from sequential population analysis) recruitment (R) value is used to define poor recruitment. The probability of poor R is computed, based on the kernel weighting, for a range of SSB values. In general the probability of poor recruitment is low at high SSB but increases with decreasing SSB. In the present application B_{lim} is considered to correspond to the SSB below which the probability exceeds 10%, consistent with the Canadian PA notion of a low probability of serious harm, and is hereafter referred to as BRpoor.

Results

The stock-recruit scatter for Model D, extended back to 1959, is shown in Fig. 1. In the 2002 assessment it was considered that inconsistencies in the catch at age prior to 1977 precluded using the earlier data. In this illustrative application of B_{lim} approaches to 3Ps cod, it is desirable to consider a longer time series, while recognising that these inconsistencies need to be resolved if historic estimates are to be given credence. The stock-recruit scatter (Fig. 1) shows that a range of SSB has been explored and that recruitment generally appears to be higher at high SSB and lower at low SSB. The fit of a Beverton-Holt stock-recruit model to the data, assuming lognormal error and no constraint on the asymptote, estimates that maximum R is approached at very high SSB and consequently BH50 is estimated to be to the right of all estimates of SSB back to 1959 (Fig. 2). RK50 estimated from the fit of the Ricker model to the data is 53,000 t and appears to reasonably define an SSB level above which poor recruitment does not occur and below which poor recruitment is quite frequent (Fig. 3). However, there is not much evidence in the 3Ps cod data for super-compensation as implied by the Ricker function.

In order to estimate NP50, a kernel function needs to be selected and the shape parameter estimated. In the current application a Gaussian kernel was used and the shape parameter was estimated by a grid search to find the value that minimized the cross-validated prediction sums of squares, where the prediction is the kernel weighted mean recruitment. Other kernel functions could be explored (e.g. Cauchy) and other predictors considered (e.g. kernel weighted median). The minimum on the SS surface was found at a shape parameter value of 7,328 t SSB (Fig. 4). Given the choice of kernel and the estimated shape parameter, a smoother is produced which, in this case, constitutes the kernel weighted mean recruitment which would be predicted at any value of spawner biomass from the range of observed values (Fig. 5). Based on the maximum predicted recruitment from the smoother, the SSB corresponding to half the maximum model predicted value can be computed to get NP50. The estimate is 43,000 t, slightly lower than RK50.

In the extension of the kernel smoother approach, the fitted kernel is used to predict the probability profile of poor recruitment with decreasing SSB (Fig. 6). If poor recruitment is defined as the 10^{th} percentile value (18425×10^3 age 3 fish) and the probability threshold is 0.1, then BRpoor is estimated to be 55,000 t.

The fit of a segmented regression to the stock-recruit data for 3Ps cod and the derivation of SR50 is given in (Fig. 7). The ICES code used in this application computes a bootstrapped F statistic for the null hypothesis that recruitment can be described by a one line model corresponding to the mean of the logarithm of the recruitment values (i.e. the geometric mean). In this application the null hypothesis was rejected with $P<0.01$. The estimate of SR50 is 46,000 t, i.e. between RK50 and NP50. A more appropriate null hypothesis would be a straight line through the origin, but this has not yet been codified and applied.

Application of Serebryakov's SB50/90 to 3Ps cod is illustrated in Fig. 8. This is a purely graphical, nonparametric technique. Where interpolation is required to determine the 90^{th} percentile R/S or the 50^{th} percentile R, the default interpolation in Excel was used. The estimate of SB50/90 for Model D is 38,000 t.

Brecovery for 3Ps cod based on model D from the 2002 assessment, extended back to 1959, is illustrated in Fig. 9. The estimate is 30,000 t corresponding to the SSB in 1976. Note however that the stock also recovered from a lower SSB of 16,000 t in 1994 under a moratorium in the 1990s.

The 7 estimates of B_{lim} (rounded to the nearest 1,000 t) are summarized in Table 1.

Discussion

The seven candidate B_{lim} approaches applied to 3Ps cod in this study do not comprise an exhaustive list and none of them have been rigorously evaluated in terms of their biological and statistical properties. Nevertheless, a cursory review of the estimates may be enlightening. BH50 can probably be discarded in the present example application because it occurs at a higher SSB level than any of the observations in the data set. This is likely to be a problem for any stock-recruit data set that is relatively uninformative about maximum recruitment. In the recent DFO assessment of three cod stocks of special concern, some analyses were carried out on Beverton and Holt models in which the asymptote was constrained to be less than or equal to the maximum observed (SPA estimated) recruitment. This approach requires further evaluation. Although RK50 provides reasonable estimates, there is not much evidence of super-compensation in the data.

Brecovery is the only reference point under consideration in this study that does not relate directly to recruitment overfishing. Fish populations may recover rapidly for a variety of factors governing production, including good recruitment, fast growth, early maturation and good survival. These processes can be captured in terms of recruits per spawner (RPS) and spawner per recruit (SPR). The 3Ps cod stock has recovered from two periods of low SSB – the first in 1976 just before extension of jurisdiction, and the second in 1994 coinciding with the introduction of the moratorium which lasted until the end of 1997. These periods coincided with reduced fishing mortality. The first of these periods also coincided with high recruits per spawner (RPS) levels, whereas the second did not (Fig. 10). Spawner per recruit (SPR) under the prevailing levels of F was not high but was increasing in the first period, and in contrast was very high in the second period, even though the SPR at F=0 was not that different (Fig. 10; i.e. the innate capacity of the population to produce spawner biomass was not that different). Clearly different stock productivity conditions in association with reduced F led to the two recovery periods in 3Ps cod. There is no particular reason to choose the first event to determine Brecovery, except perhaps that the stock clearly retained the capacity of high recruitment rates at that time, although recruitment overfishing had already been taking place to some degree.

In the November 2002 DFO workshop on the precautionary approach at which limit reference points for the three cod stocks of special concern were developed, it was considered a desirable outcome if the 5 approaches/variants gave B_{lim} estimates that were clustered rather than wide-spread. Estimates were very closely clustered for southern Gulf cod, but not so for northern Gulf cod and northern cod. The estimates for 3Ps cod (Table 1) are somewhat spread out, suggesting that B_{lim} lies in the range of 30,000 – 55,000 t SSB, based on the estimated from Model D extended back to 1959. Estimated have not been computed for the shorter time-period in which the earlier years with inconsistent catch at age data are omitted, nor for the alternative models applied in the assessments. In assessments where no single model is thought to provide a best representation of the true trajectory of the stock, and where alternative models give estimates that differ substantially in magnitude, it might be better to evaluate the status of the stock against limits in relative terms, e.g. current or projected biomass as a percentage of the limit.

Defining serious harm is important in providing a cornerstone for the application of the precautionary approach to Canadian fish stocks. Once defined, this state should be avoided with high probability. For stocks already in a state where serious harm has been done, rebuilding plans are required to facilitate recovery to within safe biological limits. Northern cod, northern Gulf cod and southern Gulf cod were all recently assessed to be in a state where serious harm has already been done and the directed commercial fisheries were closed. This sets a precedent for rebuilding plans to include fishery closures when the harm that has been done through overfishing is judged to be serious. In some cases even cessation of directed fishing may be insufficient to precipitate a recovery if bycatches and other forms of elevated mortality continue, or low stock productivity conditions (low SPR and RPS) prevail.

In a Canadian context serious harm has been equated with impaired productivity of the stock and has been considered to be synonymous with (but not restricted to) recruitment-overfishing (Shelton and Rivard 2003). Recruitment overfishing occurs when a declining spawner biomass results in reduced recruitment. In keeping with the concept of logistic population growth, stock-recruit relationships are generally modeled as smooth asymptotic or dome shaped functions. The concept of developing a spawner biomass limit reference point (B_{lim}) is predicated on some method of objectively defining serious harm in terms of recruitment overfishing for what are assumed to be smooth stock-recruit functions. Note that segmented regression approach departs from the notion of a smooth function. There are two requirements for a SSB limit reference point. B_{lim} must be biologically sensible and must be able to be objectively determined from the available data. Further desirable properties are that the estimator of B_{lim} is unbiased with small variance and is robust with respect to single data points (estimates should not vary greatly if one data point is omitted), data outliers and model uncertainties. These biological and statistical properties are not self-evident. They require evaluation through processes such as simulation model testing in which the approach is applied to a modeled fish population and fishery. Ideally such an evaluation would be carried out in concert with the evaluation of other aspects of a precautionary approach framework, including decision risk tolerances, candidate harvest control rules, definitions of safe biological limits and identification of multiple management objectives. This is not a trivial undertaking and will require concerted effort of a number of suitable skilled individuals over a period of time. In the meantime it may be defendable to adopt interim limit reference points and simplified harvest control rules that alter fishing practice in some prescribed manner as the limit is approached. Interim limits and rules could be refined and updated at a later stage when the appropriate analysis has been undertaken.

The set of candidate limit reference point approaches applied to 3Ps cod in this research document are not exhaustive and they have not been evaluated in the Canadian context of the definition of serious harm. Application of limit reference points to shut down fisheries on stocks that are clearly at extremely low levels (sufficiently low to warrant species-at-risk designations) may not be controversial, but *a priori* definitions of serious harm for relatively healthy stocks, or safe biological limits for recovering stocks, are more likely to be critically scrutinized and debated, and must have a sound, scientific and objective basis developed through thorough evaluation.

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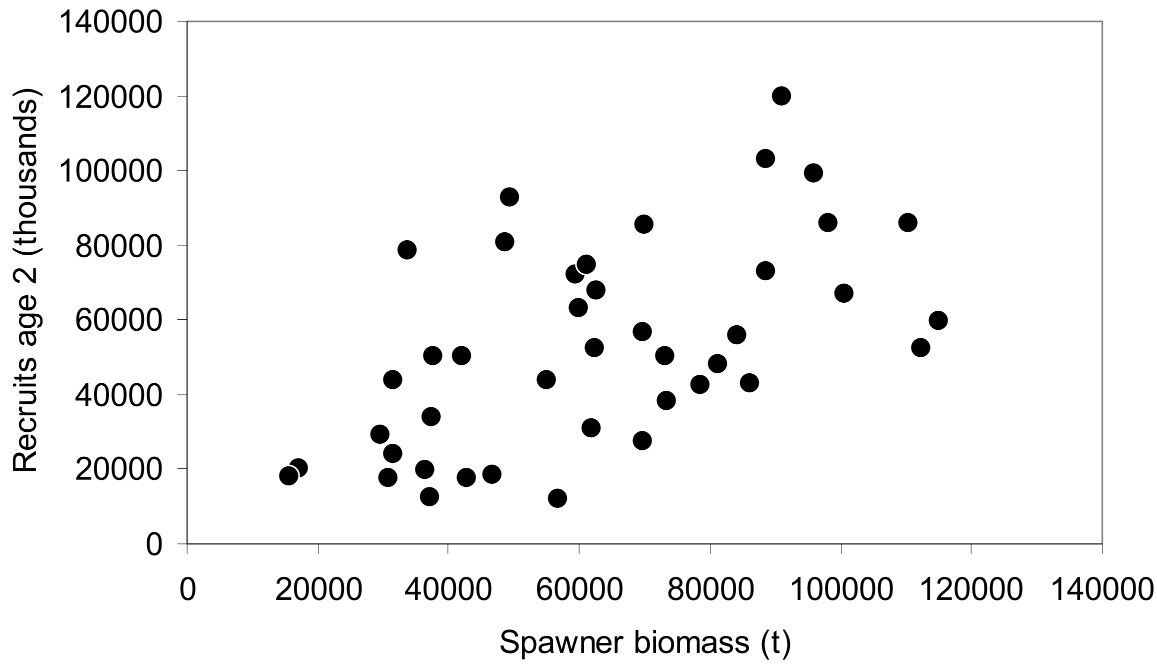

Fig. 1. Stock-recruit scatter for 3Ps cod from Model D in the 2002 assessment, extended back to 1959.

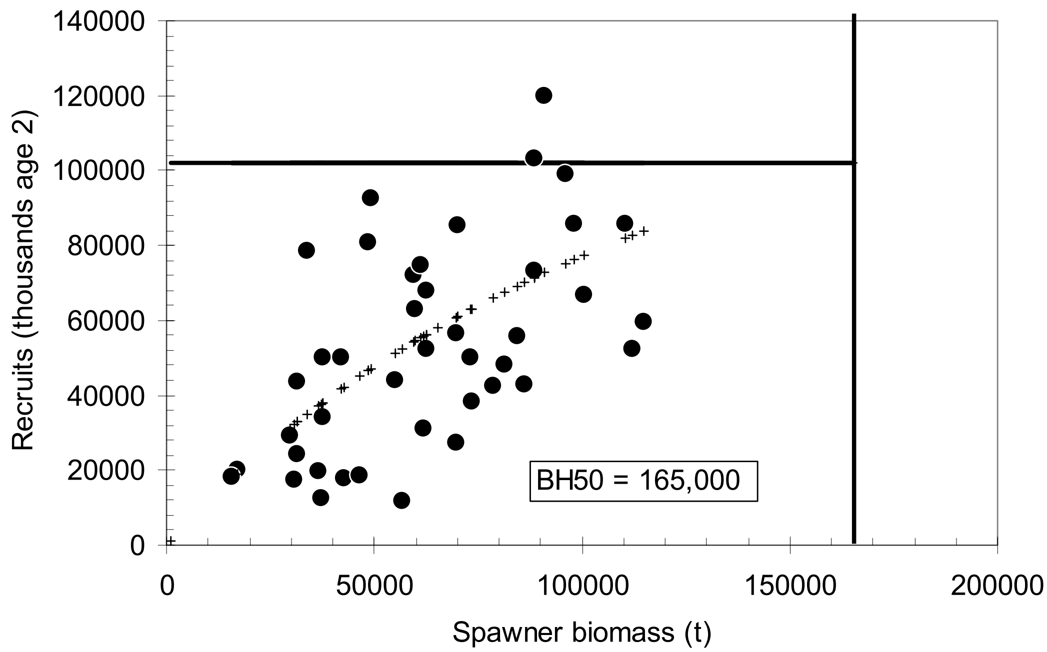

Fig. 2. Fit of a Beverton-Holt stock-recruit model to the stock and recruit estimates for Model D, and the estimation of BH50.

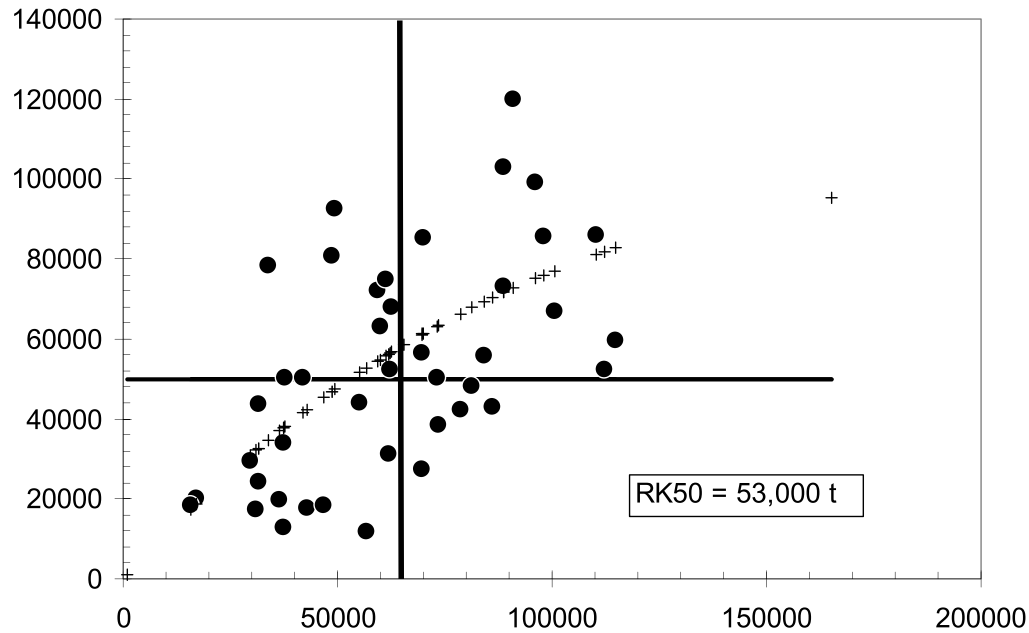

Fig. 3. Fit of a Ricker stock-recruit model to the stock and recruit estimates for Model D, and the estimation of RK50.

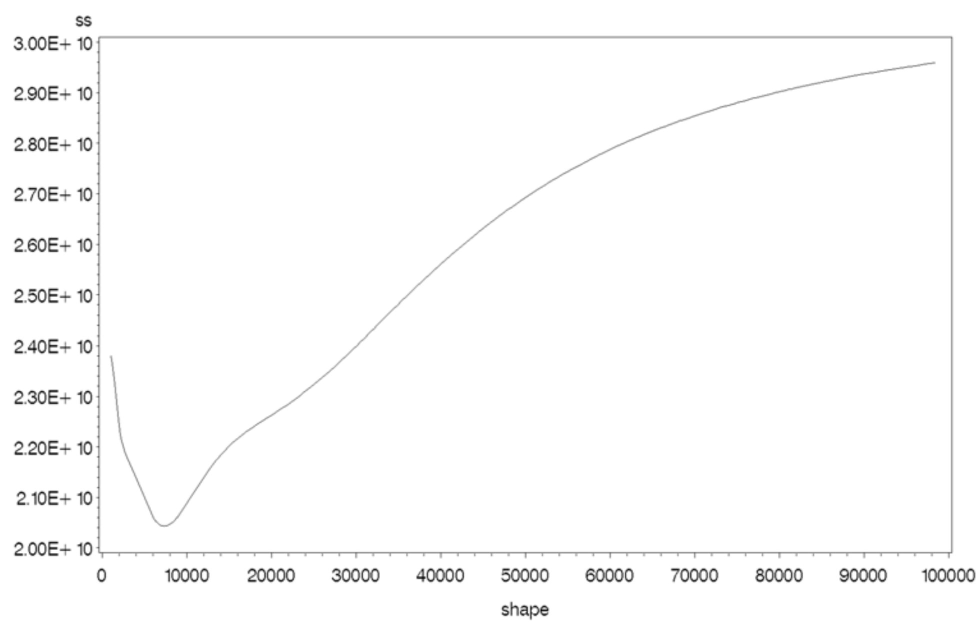

Fig. 4. The cross-validated prediction sums of squares surface from a grid search to find the shape parameter for a Gaussian kernel applied to the 3Ps cod stock-recruit data from Model D in the 2002 assessment.

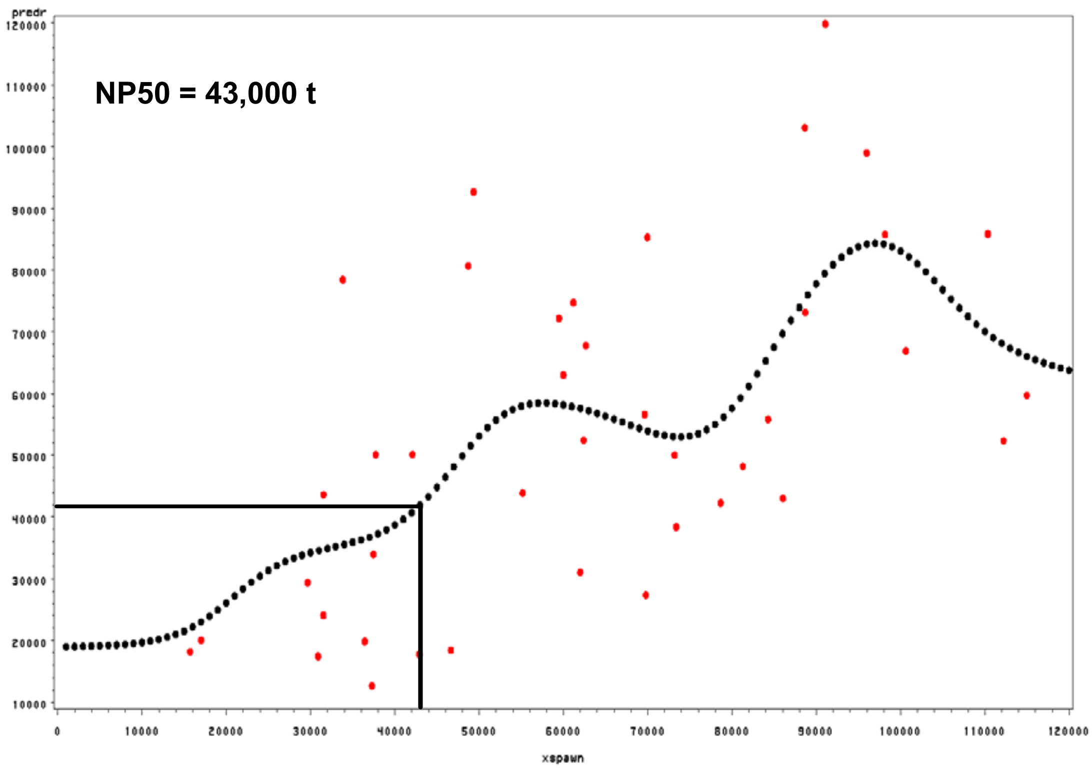

Fig. 5. The Gaussian kernel smoother fitted to the data for 3Ps cod Model D showing the estimation of NP50.

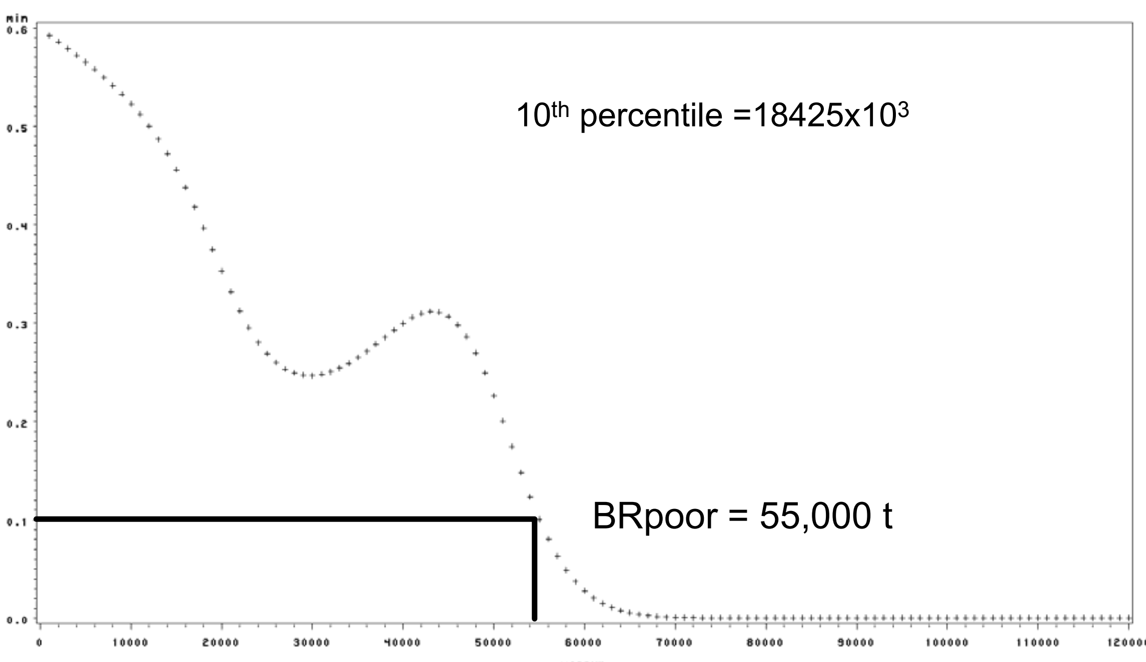

Fig. 6. The estimated probability of recruitment falling below the 10^{th} percentile value for a range of spawner biomass values. BRpoor is defined as the SSB at which the probability of poor recruitment ($\leq 10^{th}$ percentile value) increases above 0.1 with decreasing SSB.

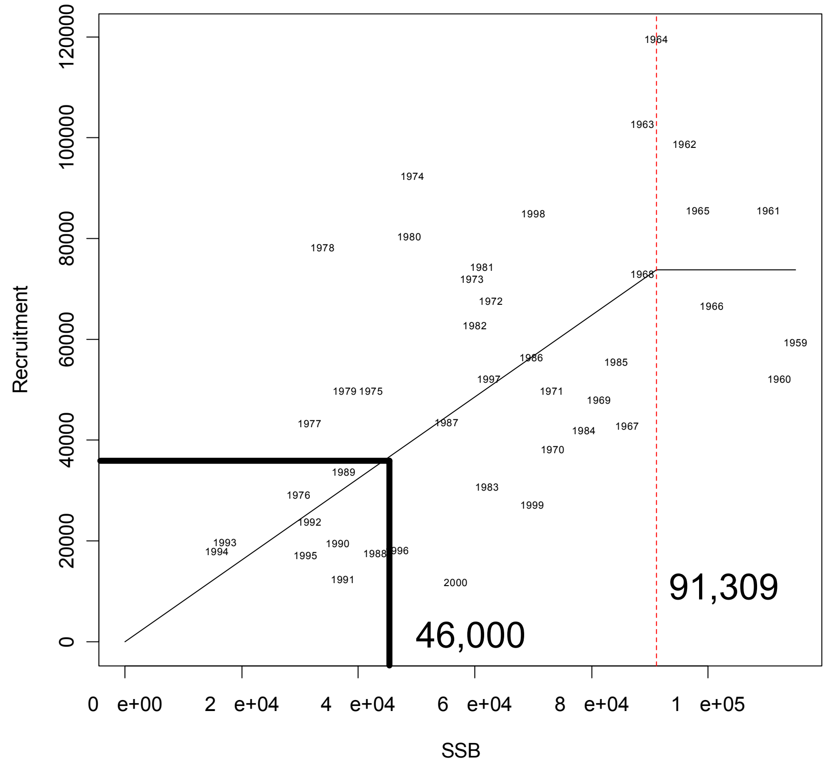

Fig. 7. Segmented regression model fit to the stock-recruit data for 3PS, and the estimation of SR50.

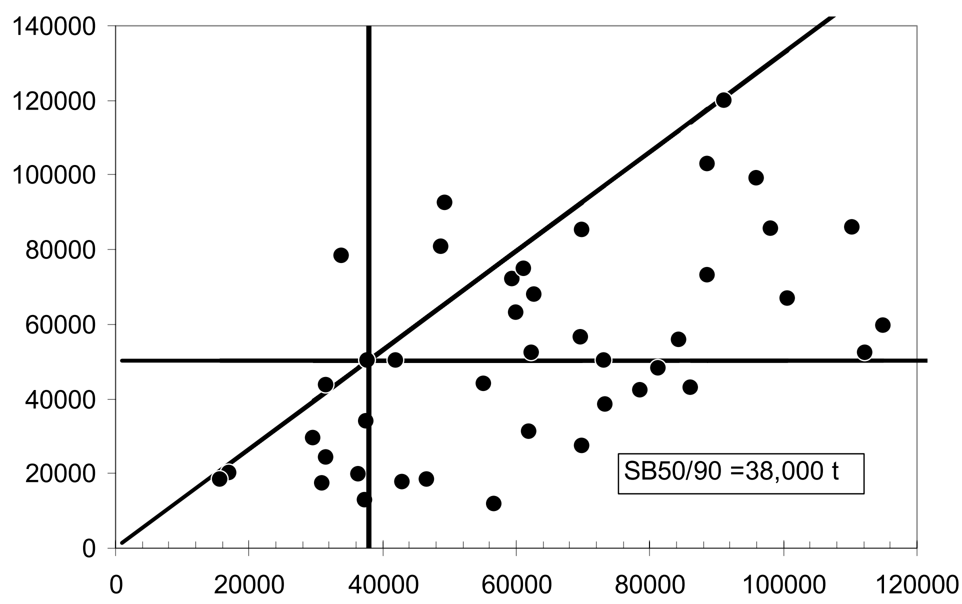

Fig. 8. Application of Serebryakov's approach to 3Ps cod to estimate SB50/90. The lines demarcate the 50^{th} percentile of recruitment and the 90^{th} percentile of the survival rate (in terms of eggs to recruits with SSB as a proxy for egg production).

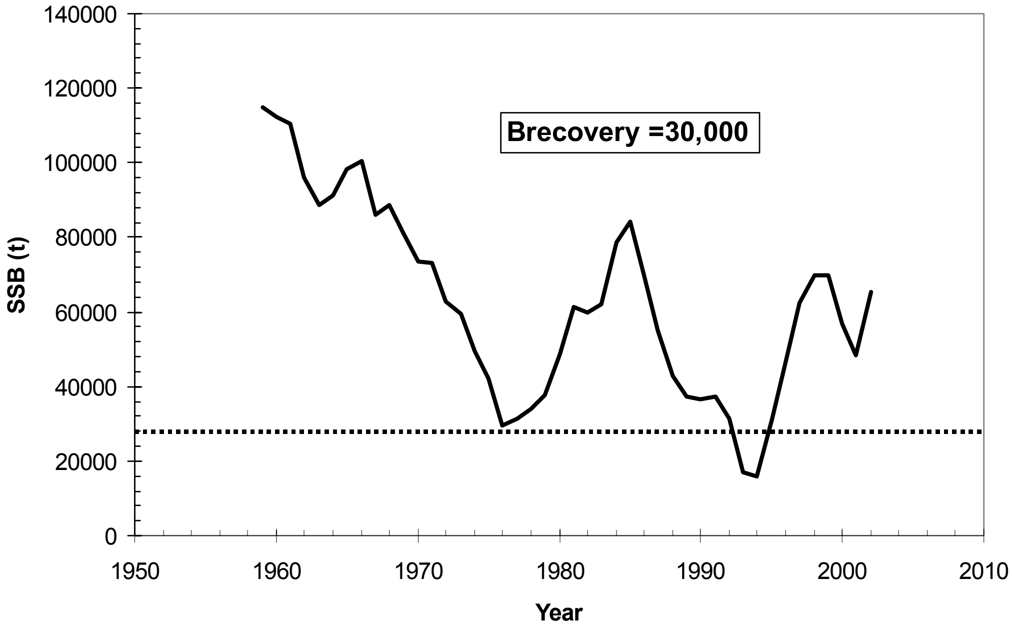

Fig. 9. Application of Brecovery to 3Ps cod Model D from the 2002 assessment, extended back to 1959.

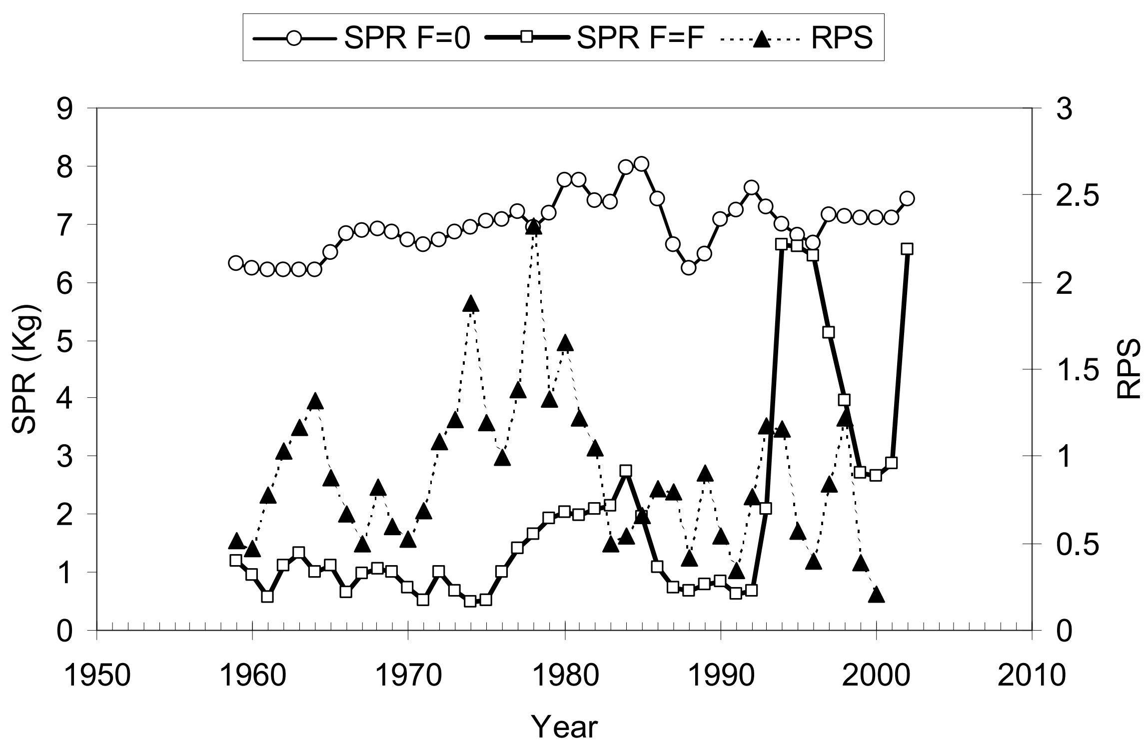

Fig. 10. Recruits per spawner and spawner per recruit at F=0 and actual F for 3Ps cod relative to a reference recruit age of 2.

Table 1. Summary of the estimates of spawner biomass limit reference points for 3Ps cod from the application of the 7 methods/variants.

Blim	SSB
BH50	165,000 t
RK50	53,000 t
NP50	43,000 t
SR50	46,000 t
PRpoor	55,000 t
SB50/90	38,000 t
Brecovery	30,000 t
B2002	65,422 t