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Developing a Precautionary Approach to Fisheries Management in Canada – the Decade Following the Cod Collapses

by

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Abstract

We review the evolution of the precautionary approach in a Canadian context over the decade following major collapses of a number of cod stocks. The collapses of these cod stocks in the late-1980s and early-1990s precipitated evaluations of alternative scientific and fisheries management approaches. Over the 10 years following the collapses, Canada has been engaged in a process of developing a precautionary framework that is consistent with UNFA. This framework adopts a notion of "serious harm" as the definition of a conservation limit reference point. Several approaches for defining conservation limits consistent with serious harm have been applied to three Canadian cod stocks of concern and used in the provision of scientific advice in the most recent assessments. While much has been achieved, work is ongoing to develop robust limit reference points in terms of both spawner biomass and fishing mortality, and to explicitly take into account uncertainty associated with these reference points in relation to uncertainty in the current state of the stock and uncertainty in the projected future states. Approaches for linking a harvest strategy framework to the limits, the current state of the stock, and projected future states, accounting for the associated uncertainties, still need to be developed. However, a broad Canadian framework for the PA is now in place which is consistent with UNFA, and which could provide the basis for management decisions at the present time.

Keywords: Canada, cod fishery, precautionary approach framework, serious harm, limit reference points, harvest strategy framework

Introduction

We attempt to provide a road map outlining the genesis and evolution of the precautionary approach to fisheries management in Canada over the last decade, emphasizing recent events with respect to three Atlantic cod stocks. This decade started against the backdrop of a number of cod collapses in Atlantic Canada, most notably the Northern Cod Stock. Following extension of jurisdiction, groundfish stocks were managed under an $F_{0.1}$ approach established by ICNAF/NAFO. When the cod stocks collapsed, many expressed the concern that the fixed harvest rate strategy of $F_{0.1}$ allowed some removals even when stocks were severely depleted. The collapses precipitated a serious consideration within Canada for the need for a precautionary framework that incorporated reference points and which dealt explicitly with stock assessment uncertainty by quantifying the risk, relative to predetermined reference points, associated with alternative management actions. We show how the development of a precautionary

framework in Canada relates to parallel developments of a management framework by DFO Fisheries Management. We also discuss how the lack of recovery of several cod stocks, combined with the realization that reopened fisheries on three of the four moratorium stocks were unsustainable, precipitated the most recent events in the implementation of the PA on cod stocks in Atlantic Canada.

Road map to the development of the Canadian PA approach

Extension of jurisdiction to collapse

Canada opted for a fixed harvest rate management strategy of $F_{0.1}$ for its Atlantic groundfish fisheries when coastal state jurisdiction was extended to 200 n. miles in 1977. For the major Atlantic groundfish stock, Northern Cod, assessments were carried out annually at NAFO from extension of jurisdiction to 1986, initially setting TACs below $F_{0.1}$ to promote stock rebuilding. Starting in 1987, Canada conducted northern cod assessments independently of NAFO, although STACFIS continued to review the Canadian results each year. The $F_{0.1}$ approach continued to be implemented in 1987 and 1988. However, when substantial declines in the size of the stock became apparent in the late-1980s, the $F_{0.1}$ rule was relaxed in the face of economic and social pressures, fishing mortality rates soared and the stock collapsed (Bishop and Shelton, 1997; Shelton, 1998).

The apparent failure of $F_{0.1}$ spurred Canada to examine new approaches in the provision of scientific advice in support of fish stock management. In November 1991, a major international workshop was sponsored by DFO in Halifax on Risk Evaluation and Biological Reference points for Fisheries Management. The workshop reviewed existing approaches such as $F_{0.1}$, examined methods for identifying and quantifying the uncertainties associated with using various reference points, and considered alternative management strategies which incorporated reference points and the evaluation of uncertainty (Smith *et al*., 1993). A central theme in the workshop was the responsibility of fisheries scientists to evaluate alternative management strategies and for fisheries managers to develop objectives against which these strategies could be evaluated.

The impetus for the 1991 DFO workshop was obtained from NAFO's own Special Session on Management Under Uncertainties held in Halifax in September 1990. (NAFO Sci. Coun. Studies 16, 1991). This special session emphasized the need to adopt objective methods which accounted for uncertainties in the stock assessment and for the need for these uncertainties to be evaluated in terms of the risk of *SSB* falling below clearly defined critical levels (Shepherd, 1991). In particular, SSB reference points based on an approach suggested by Serebryakov (1991) and Shepherd (1991), and 20% of B_{max}, proposed by Beddington and Cooke (1983), were put forward as candidates.

The 1990 and 1991 workshops gave considerable momentum for a movement by Canadian fisheries science towards new and improved approaches based on a foundation of objective methods, quantification of uncertainty, establishment of management objectives, definition of reference points and the quantification of risk associated with alternative management options. This momentum served to establish the scientific basis for risk quantification and the development of reference points in the context of risk management. These became important elements in the way Canadian fisheries scientists approached the initiatives on "precaution" that emerged in the mid-1990s through various international initiatives. The notion of precaution was still embryonic and taking shape in national and international arenas, consequently there was little tangible progress on the implementation of an explicit precautionary approach risk management framework for marine fisheries within Canada over the next few years.

During this period (mid-1990s), DFO Fisheries Management initiated discussions on a new approach called the Integrated Fisheries Management Plan (IFMP) to replace the Fisheries Management Plans (FMPs) which were in operation when the cod stocks collapsed. IFMPs had the goal of greater integration of the functional and technical expertise within DFO, standardizing the fisheries management plan process and identifying performance outputs for individual fisheries management plans. This integrated approach served to formally recognize the role of quantitative stock assessments in the decision-making process, particularly scientific advice on the risks relative to biological reference points for alternative management options, and to put this role in the context of conservation objectives.

As international fisheries organizations such as NAFO, ICES, NASCO and ICCAT were actively developing frameworks for implementation of a precautionary approach as outlined in UNFA, Canada initiated a number of initiatives at the policy, science and management level. A planning meeting was held at BIO in Dartmouth June

1997 at which a High Priority Project on the Precautionary Approach (HPPPA) was initiated. It was decided to adopt a "case study" approach and several domestic stocks were identified. These stocks included Northern Cod, St. Pierre Bank Cod and Southern Gulf Cod. Funding was approved in 1998 and a first National Workshop on Implementing the Precautionary Approach in Canada was held in Nanaimo in October 1998 (Rice and Schnute, 1999). The Workshop reviewed progress on the case studies and activities related to the PA by NAFO and ICES. A number of the analytical problems that had to be overcome in the implementation of the PA in the Canadian case studies were examined. Issues related to implementation uncertainty, evaluation of harvest control rules, evaluation of controls other than catch and effort limits, and ensuring overall ecosystem health were also considered. It was noted that successful implementation of the PA is dependent on effective management structures and consultations among stakeholders, managers and scientists to achieve consensus on principles, objectives, operational definitions of performance measures and unacceptable outcomes.

In September 1999, the Newfoundland Region of DFO held a joint Science-Fisheries Management workshop on the precautionary approach (Atkinson, 2000), the impetus coming from Science as a consequence of participation in the HPPPA and the need to make progress on the Subdiv. 3Ps Cod case study. The focus was the current status and future direction of the PA in the Newfoundland Region. Progress on implementing risk analysis on 3Ps Cod was summarized at this workshop, although the only reference points considered at this time were $F_{0.1}$ and an arbitrary *SSB* level of 100 000 tons.

A second DFO National workshop under the HPPPA was held in Nanaimo in November 1999 (Richards and Schnute, 2000). Progress on the PA by NAFO, ICES, NASCO, ICCAT, FRCC (Fisheries Resource Conservation Council) and the USA were reviewed as well as regional developments and progress on the case studies. It was noted at the Workshop that Canada had ratified the United Nations Fisheries Agreement (UNFA, on 3 August 1999), which explicitly acknowledged the precautionary approach (the required 30 states had ratified UNFA by 11 November 2001 and the Agreement came into force on 11 December 2001). The Workshop therefore attempted to formulate a general framework on the PA in Canada that was consistent with UNFA. This framework characterized the relationship between removal rate and stock size into four zones (Fig. 1). In zone 1, the stock index is above the stock size reference level and the removal rate is lower than the removal reference level – this is the desirable state and in this situation the *status quo* with respect to harvest strategies is acceptable. In zone 2, the stock is above the stock size reference, but the removal rate is above the removal reference level – this is an undesirable state and measures should be taken to reduce the removal rate to a level that is below the pre-agreed reference level. In zone 3, the stock is below the stock reference level – this is an undesirable state and removals should be restricted to allow a high probability of moving to zone 1 (desirable state). In zone 4, the stock is below the minimum acceptable level – a very undesirable state and removals should be kept as low as possible.

The 1999 HPPPA Workshop again recognized the need to communicate the current scientific thinking to DFO managers, scientists, fisheries managers, Fisheries Resource Conservation Councils and stake-holders. It was agreed that a discussion paper would be developed for DFO Management consideration clearly outlining the developments and current thinking on the PA within DFO Science. This was included as an appendix to the workshop report (Appendix E. PA Implementation for Canadian Harvest Fisheries - Rivard). The discussion paper described the PA framework that had been developed within the HPPPA and emphasized that the next step was to hold discussions on implementation with stakeholders, managers, scientists and Fisheries Conservation Councils. It was noted that the Atlantic Fisheries Conservation Council had recognized the need to adhere to a precautionary approach and that they were working on their own precautionary framework. It was suggested in the discussion paper that the leadership role in initiating the process of implementation resided naturally with DFO Fisheries Management and that regional workshops were key instruments for the design and implementation of a precautionary approach. It was felt that the strategies identified in the precautionary approach could serve to guide the development of IFMPs.

In 1997 IFMPs on groundfish came under criticism by the Auditor General of Canada. Objectives of the IFMPs were often not stipulated, were unclear or were set at such a high conceptual level that they were not measurable. Risks associated with achieving objectives were not identified and assessed and strategies were lacking to ensure that objectives were not compromised. Management strategies were not directly linked to the objectives of the fisheries and performance measures were not clearly linked to the management objectives. The roles of Science and Fisheries Management were unclear or not well understood. The precautionary approach and ecosystem considerations were not incorporated. To address these acknowledged shortcomings, DFO embarked on a new approach termed Objective-Based Fisheries Management (OBFM). The development of OBFM was coordinated

from the beginning by a DFO Headquarters working group which included both Science and Fisheries Management Sectors, and a National Steering Committee of Regional Directors of Fisheries Management and Science was formed to guide the process regionally.

The goals of OBFM were to:

(1) adopt clear and measurable fisheries management objectives based on biological and socio-economic factors,
(2) introduce risk management principles in developing fisheries management strategies and operational management plans,
(3) operationalize the PA and explicitly identify conservation limits in fisheries management plans,
(4) introduce ecosystem concerns into the fisheries management process,
(5) incorporate the principles of Performance Measurement,
(6) advance the development of stakeholder partnerships.

It was felt that meeting these goals would enhance conservation and stock rebuilding, and provide for adaptive responses based on performance and rational feedback. Under OBFM, conservation was to be approached in terms of an explicit measurable goal. Consideration was also to be given to developing a concept of ecosystem-based management with defined ecosystem limits. OBFM would ensure that sound principles and due diligence were applied in developing conservation measures for resources and ecosystems.

National workshops on the OBFM with participants from DFO Science and Fisheries Management were held in May and October of 2000 and, by December of 2000, a third draft of the OBFM Guidelines had been developed, a framework for pilot projects had been agreed on and regional pilot stocks had been identified. For Newfoundland Region, Subdiv. 3Ps cod was the agreed on pilot stock. In February 2001, a Pre-Pilot Workshop was held in St John's for the Newfoundland Region of DFO and other regions held similar workshops around the same time. The Pre-Pilot Workshop was aimed at bringing regional Science and Fisheries Management up to speed on developments with OBFM. Topics covered included preparation of an IFMP, setting conservation limits for target species and the ecosystem, setting the fisheries management objectives, setting the fisheries management strategy and developing the fisheries management operational plan. The Pre-Pilot stopped short of outlining a specific step-by-step implementation plan for the regional pilot stock, 3Ps cod, for the next stock assessment cycle, although Science had already made some initial steps in defining conservation limits (Shelton, 2000).

During the period of June 2000 to May 2001, while discussions were being held within the Department on the OBFM approach, DFO Science was carrying out a Stock Assessment Review (SAR). SAR concluded that certain areas of research should be selected for expanded activities. PA issues related to conservation limits and targets, and species at risk issues were identified, together with several other areas of research. SAR noted that annual changes to stock assessment model formulations, often addressing minor issues, were costly and were in danger of causing "see-saw" TAC adjustments based on "noise" rather than "signal" in the data. It was suggested that a new approach of Intensive Fishery Assessments (IFAs), constituting comprehensive evaluations of the population dynamics, fishery, ecosystem considerations, alternative management strategies and risk to longer-term objectives be carried out less frequently (3-5 years). Between these periods, monitoring would continue and indices would be updated annually. Under this approach Fisheries Management would take a more strategic long-term approach and IFMPs would remain unchanged for 3-5 years, facilitating the implementation of OBFM. It was noted that this would require stocks to be managed further away from the "edge" – a notion consistent with the PA.

Developments in the recent period – 2001 to 2003

In December 2001, DFO Science held a Workshop on Implementing the Precautionary Approach in Assessments and Advice (Rice and Rivard, 2002). The HPPPA and OBFM provided a climate that many in the Department thought was conducive to implementing the elements of a precautionary approach in the actual management of Canadian fish stocks. A draft of a discussion paper by the Privy Council Office (PCO) of the Canadian Federal Government entitled "A Canadian Perspective on the Precautionary Approach/Principle" (http://www.pco-bcp.gc.ca/raoics-srdc/docs/precaution/Discussion/discussion_e.pdf) had a substantial impact on the direction and emphasis of the December 2001 Workshop. The PCO discussion paper noted that Canada has a long-standing history of implementing the precautionary approach/principle in science-based programs of health and safety,

environmental protection and natural resources conservation. The discussion paper stated that the PA is a distinctive approach within science-based risk management that recognized that the absence of full scientific certainty should not be used as a reason to postpone decisions where there is a threat of serious or irreversible harm. The discussion paper outlined broad guiding principles to support consistent, credible and predictable policy and regulatory decision making when applying the PA. It stated that enunciation of the PA principles would clarify how Canada makes decisions in circumstances of scientific uncertainty where there is a threat of serious or irreversible harm. It would provide a firm basis for Canada to more actively engage in international discussions in a clear, coherent and consistent manner. The framework described in the PCO discussion paper is in the final stages of being readied for endorsement by Cabinet and is currently scheduled for submission in May 2003.

Using the PCO discussion paper as a basis, the December 2001 Workshop concluded that the term "precautionary approach" should be used only to refer to situations that can result in harm that is serious or difficult to reverse. Activities which simply reduced yield were economically inefficient, but could not be interpreted as serious harm (Shelton and Rice, 2002). The PA would apply in situations of high scientific uncertainty and would promote fisheries management actions that would result in low probability of serious harm. In defining limit reference points, it was agreed that a serious reduction in reproductive capacity of a stock would constitute serious harm, but it was noted that there is no unequivocal way to determine the point at which serious harm has occurred. While recognizing that advice in terms of the precautionary approach would usually be framed in terms of *SSB* and *F*, there was consensus that these were not the only properties of a stock that could be used for determining harm.

The December 2001 Workshop reviewed progress on the PA within NAFO and the conclusions from the HPPPA. A synthesis of existing knowledge on limit reference points prepared for the workshop (Shelton and Rice, 2002) was evaluated. In addition, consideration was given to whether or not there was a need for precautionary or buffer reference points and rebuilding targets which focus on stock states which are some distance away from a situation of serious harm. Some suggested that serious harm could be defined in terms of the time it would take for the population to recover to a target level, while others felt that the PA should focus only on the "serious harm" aspect and define appropriate limits for each stock in keeping with the PCO discussion paper.

There was some discussion in the December 2001 Workshop of the use of harvest control rules in the implementation of the PA. This would require the development of a procedure (estimation models and control rules, tested by extensive simulation trials) which could be demonstrated to achieve the desired low probability of serious harm while still satisfying desired management objectives most of the time. The inputs to such a procedure would be updated annually but major analytical reviews and any required alterations to the procedure would happen less frequently. While it was recognized that this approach was in keeping with the SAR recommendations regarding IFAs, and also with Fish Management's OBFM approach, it was realized that such an undertaking would require considerable concerted effort and the pooling of limited quantitative resources. It could also be held up indefinitely while resource managers attempt to resolve the difficult problem of dealing with multiple conflicting objectives associated with the management of each fish stock. The Workshop concluded that implementation of the PA nationally would require direction from DFO line management and further discussion with other sectors.

While DFO was addressing these aspects of implementation of the PA, new legislation for conserving species was introduced in the House of Commons by the Environment Minister on April 11, 2000. The proposed Species at Risk Act (SARA) aimed at providing the authority to prohibit the destruction of endangered or threatened species and their critical habitat on all lands in Canada. SARA would legally recognize the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and provide for rigorous, independent and public scientific assessments by COSEWIC. The Act would require considered responses by Government to COSEWIC determinations of species at risk status. SARA received Royal Assent on 12 December, 2002 and is expected to become law in 2003. Atlantic Cod was classified by COSEWIC as "special concern" (particularly sensitive to human activities or natural events) in April 1998. It is currently again under review, with the new determination of status expected in May 2003. Although the exact implications of various designations under SARA are not yet clear, it seems likely that designations of "threatened" or "endangered" would have considerable impact on commercial exploitation of cod and other fisheries in which there is a significant bycatch of cod.

The status of three of the four cod stocks which had been under moratorium for a period in the mid-1990s, but on which commercial fisheries had reopened in the late-1990s (Northern Cod, Northern Gulf Cod and Southern Gulf Cod), were assessed regionally in early 2002 as part of the annual DFO stock assessment advisory process (Northern

Cod, CSAS SSR A2-01, 2002 (update, not a full assessment); Northern Gulf Cod, CSAS SSR A4-04-01, 2002 and Southern Gulf Cod, A3-01, 2002; http://www.dfo-mpo.gc.ca/csas). These assessments provided evidence that post-moratorium TACs, albeit small relative to historic removals, had been unsustainable over the recent period and that *SSB* was expected to decline further if these fisheries were not reduced.

In March 2002, DFO Science carried out a major review of all 10 Atlantic Canada cod stocks in relation to the criteria used by COSEWIC in determining species at risk status (Smedbol *et al*., 2002). This review noted that the most recent assessments had indicated that current TAC levels on Northern Cod, Northern Gulf Cod and Southern Gulf Cod were probably unsustainable and had a high risk of causing further depletion of the remaining spawner populations which were already below levels which would result in high species at risk designations under the COSEWIC population decline criteria.

The concerns raised by scientists and managers on the state of many gadoid stocks in the Atlantic and the Pacific highlighted the need to proceed as quickly as possible with the implementation of the PA and a National Workshop on Reference Points for Gadoids was convened in Ottawa in November 2002 (Rivard and Rice, 2003). The objectives of this Workshop were to define limit reference points, propose guidelines for consideration of uncertainties in a risk management context, and to discuss harvest strategies that were consistent with a precautionary approach. Limits were developed for the Northern Gulf and Southern Gulf Cod stocks and a "bench-mark" reference point for Northern Cod was decided on, at which point the limit reference point would be re-evaluated. The workshop was conceived as a joint Science/Fisheries Management initiative and fishery managers developed a parallel framework of harvest strategy zones based on the status of the stock relative to their limit reference points. The November 2002 Workshop was followed in February 2003 by a special Zonal Assessment (ZAP) in Halifax to determine the current stock status of the three cod stocks of concern, relative to their limit reference points, and to provide scientific advice consistent with the PA. Given that the setting of limit reference points at the November 2002 Workshop and the use of these in the provision of scientific advice in the February 2003 Cod ZAP represent the most tangible developments in the implementation of Canadian PA framework to date, more detail on these events is provided below.

Implementing the Canadian PA framework

The Canadian precautionary approach framework that was developed in the 2001 and 2002 Workshops (Rice and Rivard, 2002; Rivard and Rice, 2003; see also Shelton and Rice, 2002; Shelton *et al*., 2003) focuses on evaluating the risk of serious or irreversible harm. Serious harm is interpreted in terms of "impaired productivity" and the conservation limits are related to definitions of what constitutes impaired productivity for each stock as determined by scientific experts applying "best science practice". While limits are determined by science, the framework allows for societal input regarding risk tolerances relative to these limits.

Shelton and Rice (2002) reviewed candidate limit reference points in terms of both *F* and *SSB*. Although *F* reference points are considered to be potentially useful under the Canadian framework (Richards and Schnute 2000, see Fig. 1), only *SSB* limits have been considered in any detail thus far. Serious harm is defined as the *SSB* below which productivity is impaired, rather than just sub-optimal. Shelton and Rice (2002) rejected many of the candidate *F* limits because they were clearly not consistent with serious harm, although they might be associated with reduced yield or with "growth overfishing".

The Canadian framework defines impaired productivity in terms of impaired ability of the stock to reproduce itself. Impaired stock productivity could be linked to combinations of reduced body growth rates, decreased maturation rates, increased mortality rates or decreased recruitment rates. In terms of recruitment, impaired productivity is consistent with the notion of "recruitment overfishing" and this has been the initial emphasis in the implementation of the Canadian PA. To define recruitment overfishing, one needs to find the *SSB* level consistent with a marked decrease in recruitment. However, most *S-R* models have only two parameters and recruitment is a smooth continuous function of *SSB*. Three parameter recruitment models have been developed, such as the depensatory form of the Beverton-Holt model (Myers *et al*., 1995), which allow for discontinuities, but fitting such models is seldom attempted and simulation studies suggest that depensation will be hard to detect in most stock-recruit data (Shelton and Healey, 1999).

An alternative way of thinking about impaired productivity and recruitment overfishing was developed in the November 2002 DFO Workshop. It is expressed in terms of the depletion of the spawner biomass to a level so low that the probability that the stock will produce good recruitment is diminished, or the probability that the stock will produce poor recruitment is increased. The non-parametric kernel smoother approach applied to modeling stock-recruit data by Rice and Evans (1986, 1988) and Evans and Rice (1988) is particularly suitable for this kind of analysis because the kernel is a pdf (e.g. Gaussian, Cauchy, etc.) that gives the probability of any previously observed *R* at any specified level of *SSB*. Cross-validation prediction sums of squares methods for determining the optimal shape parameter for the pdf generally find clear minima (see for example, Shelton and Morgan 1993, 1994). Having determined what constitutes good recruitment (for example the 90^{th} percentile), and/or poor recruitment (for example the 10^{th} percentile), the probability that recruitment will fall into the good recruitment range or into the poor recruitment range can be computed directly from the *S-R* data and the kernel smoother fit to the data. These probability profiles generally show a marked decrease or increase over a narrow range of *SSB* (not necessary over the same *SSB* range – depends on definition of poor and good recruitment) which can be used to determine B_{lim}. Alternatively, B_{lim} could be defined as the point along the decreasing *SSB* axis at which the probability of good recruitment falls below a predetermined probability level, or the probability of poor recruitment rises above a predetermined level, for example 0.5. We illustrate this approach for Southern Gulf Cod (4TVn) using work carried out and presented at the November 2002 Workshop (Fig. 2). The recruitment probability approach looks very promising and the November 2002 Workshop felt that it needed to be investigated further in the context of the definition of serious harm under the Canadian PA framework.

More conventional approaches to defining B_{lim} that are consistent with the notion of demarcating serious harm are available in the fisheries literature (see Shelton and Rice 2002 for a review). The 2002 Workshop selected two of these – $B_{50\%\text{Rmax}}$ and Serebryakov's $B_{50\%\text{R90\%surv}}$ (Fig. 3) for application to the three cod stocks. Empirical evidence exists for the use of $B_{50\%\text{Rmax}}$ as a threshold SSB that would be in keeping with the notion of serious harm (Mace, 1994; Myers *et al*., 1994). $B_{50\%\text{Rmax}}$ is defined as the point below which the population fails, on average, to produce half the maximum recruitment. Three variations of this approach were considered: BH50 based on the fit of a Berverton-Holt stock-recruit model, RK50 based on the fit of a Ricker stock-recuit model, and NP50 based on a nonparametric smoother. The Serebryakov approach (Serebryakov, 1991; Shepherd, 1991) has the advantage of not requiring the fitting of a stock-recruit model and it incorporates information on early stage survival as well as recruitment production. The B_{lim} is defined under the Serebryakov approach as the point below which the population fails to produce average recruitment even under good early-stage survival conditions. A third approach was also considered as a spawner biomass limit, B_{recovery}, the *SSB* level from which the stock has previously sustained a rapid recovery. This limit reference point is somewhat contentious because it is not clear that B_{recovery} will necessarily produce a recovery under average stock productivity conditions. The recoveries that took place in Canadian cod stocks around the time of extension of jurisdiction all occurred under what might be termed favorable stock productivity conditions, including good body growth rates and having considerable numbers of fish younger than the age a maturity that were already within the population and which fueled the recovery (e.g. Southern Gulf Cod), and in some cases significant numbers of survivors from higher recruitment levels in the late-1960s (e.g. Northern Cod). Nevertheless, B_{recovery} was retained as a potential candidate for B_{lim}, recognizing that its value has to be considered in the context of the degree to which past recoveries were the result of particular circumstances.

The 5 approaches/variants were applied to the three cod stocks. Where the estimates of B_{lim} appeared to be sensible and particularly where they appeared to be clustered at roughly the same *SSB* level, it was considered that a reasonably strong case could be made for defending the associated *SSB* level as a limit reference point. Where the estimates covered a wide range, it was considered that, although B_{lim} was poorly defined, an argument could be made for keeping the *SSB* above all "plausible" candidate B_{lim} values until better estimates have been obtained.

The results from applying the 5 approaches to the three stocks are illustrated in Fig. 4 from the November 2002 Workshop report (Rivard and Rice, 2002). The SSB levels were relatively consistent for Southern Gulf Cod, but covered a wide range for Northern Gulf Cod and Northern Cod. For Northern Gulf Cod and Northern Cod, the $B_{50\%\text{Rmax}}$ was found to be very sensitive to the computational method used for the stock-recruit relation. Typically, large variances were associated with parameter estimates and therefore maximum recruitment was poorly defined. Northern Cod results were strongly influenced by high recruitment levels in the early part of the time series. The Serebryakov's method was found to be robust (not too strongly influenced by only one or two data points) and scaled well across the three stocks considered, in the sense that it gave reasonable estimates relative to historical *SSB* and stock productivity levels.

Despite some of the difficulties encountered, the 2002 Workshop reached consensus on B_{lim} values of 80 000 tons for Southern Gulf Cod, 200 000 tons for Northern Gulf Cod and a bench-mark *SSB* 150 000 tons for Northern Cod. For Northern Gulf Cod it was noted that the 200 000 tons B_{lim} was not definitive because there were few data in the 100 000-200 000 tons range of *SSB* and that the B_{lim} may be revised downward when more data become available. For Northern Cod, maximum recruitment was poorly defined, but it was agreed that B_{lim} would likely be greater than 300 000 tons, the *SSB* level for B_{lim} from the Serebryakov method. It was considered that when the *SSB* approaches the bench-mark *SSB* level of 150 000 tons (corresponding to $B_{recovery}$), the *S-R* data would be reviewed to see if there was more information for defining B_{lim}.

An example harvest strategy framework was developed by Fisheries Management at the November 2002 Workshop which would operate in concert with conservation limits within the Canadian PA framework (Table 1). The harvest strategy framework recognizes that risk of a stock reaching B_{lim} must be kept very low. Four zones were established. For a stock that is well below the conservation limit, a "Monitoring Zone" would apply in which fishing mortality would be limited to approved scientific activities only with no significant bycatches allowed in other fisheries. The next zone is the "Incidental By-catch Zone – below the conservation limit". In this zone incidental bycatch would be allowed so that other directed fisheries could be pursued, providing the bycatch is not significant and all reasonable measures are taken to minimize bycatch. Stocks above the limit would be in a "Bycatch Zone" in which normal bycatch levels incurred in the pursuit of other directed species would be acceptable. For stocks well above the conservation limit, a "Normal Fishing Zone" would apply with moderate fishing mortality from a directed fishery considered acceptable.

Stock assessments carried out under the Zonal Assessment Process (ZAP) in Halifax in February 2003 evaluated the current status Northern Gulf Cod, Southern Gulf Cod and Northern Cod based on the available data. SPA-based assessments were accepted for all three stocks. For Northern Cod, although SPA was the main tool prior to the collapse, a severe residual problem that had developed in the early-1990s has yet to be resolved (Shelton and Lilly, 2000). This problem, coupled with low catch levels and poor sampling during the moratorium, as well as the change in the overlap of the survey area with the area where the fishery took place after reopening in 1998 (near-shore), was not conducive to a whole stock SPA. However, in the February 2003 ZAP it was decided that sufficient inshore indices were now available to calibrate an inshore SPA based on the catch from 1995 onwards (almost entirely inshore). While some fish continue to exist in the offshore (estimated to be about 20,000 t) and appear in both the survey catches and in commercial bycatches, the mortality rate on this component was found to be extremely high, suggesting it is unlikely that it would play any significant role in stock rebuilding in the near future. The *SSB* estimates from each of the three stocks and the information considered at the ZAP on B_{lim} is summarized in Table 2.

In addition to determining current status, the ZAP carried out medium-term deterministic projections based on recent average values of recruitment rates, weight at age and proportion mature at age. The emphasis in these projections was a 5 year period, but it was recognized that the steady state conditions of the stocks (e.g. by running the projection out further to allow transient age structure effects to shake out) were also of interest. The SPAs for each of the stocks incorporated an assumption about natural mortality (*M*). For Northern Cod, mark-recapture data suggested that an M=0.5 was appropriate for the inshore component over the recent period, rather than the historically assumed value of 0.2 and this value was used in the SPA. Values of *M* greater than 0.2 have been applied in Northern Gulf and Southern Gulf cod SPAs for a number of years.

Projections suggested that Northern Gulf cod would decline over the next five years even in the absence of fishing, that Southern Gulf cod would show no growth in the absence of fishing and that Northern Cod would show some growth over five years in the absence of fishing as a consequence of transient recruitment effects, but that under average R/S there would show only marginal growth in the longer term. At *status quo* TAC levels, all three stocks were projected to have significant declines in *SSB* over a 5 year period. Even in the absence of a fishery the stocks are not projected to reach B_{lim} in the near future and are predicted to move further away from B_{lim} under *status quo* fisheries. In terms of the Fisheries Management example harvest strategy framework developed in the November 2002 Workshop (Table 1), Northern Cod and Northern Gulf Cod would fall into the Monitoring Zone and Southern Gulf Cod into the Incidental By-catch Zone.

The road ahead

While much has been achieved in developing a Canadian PA framework, there is still some distance to travel before the destination of a fully articulated PA framework is arrived at. Science needs to develop robust limit reference points in terms of both spawner biomass and fishing mortality, and to explicitly take into account uncertainty associated with these reference points in relation to uncertainty in the current state of the stock and uncertainty in the projected future states. Further work is required in developing a more definitive harvest strategy framework. Approaches for linking the harvest strategy framework to the uncertainties in the limits and in the current state and future projected states need to be developed.

There has been rapid movement towards implementing a PA approach to cod stocks in Canada over the recent period. Similar work is going ahead with respect to invertebrate fisheries (Smith, 2003). Although it is true that the Canadian framework has yet to deal explicitly with competing risks, ecosystem considerations, or socio-economic aspects of fisheries management objectives, a broad Canadian framework for the PA is now in place which is consistent with UNFA and other international fisheries agreements, and which could provide the basis for management decisions at the present time.

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Table 1. An example harvest strategy framework developed by DFO Fisheries Management at the November 2002 Ottawa Workshop which would operate in concert with science-based conservation limits within the Canadian PA framework.

Fisheries Management Benchmarks

From an access perspective, it is useful to define fisheries management benchmark zones for specific fisheries which would allow clear rules to be developed to guide decision-making. These rules would then describe how the available fish can be utilized to meet various needs. For example, the following key progresses from no fishing through a full commercial fishery:

Monitoring Zone – well below the conservation limit

- Fishing mortality severely limited to RV and perhaps sentinel fisheries catch. Fishing mortality will be relatively constant at an extremely low level.

Incidental By-catch Zone – below the conservation limit

- Additional fishing mortality limited to incidental catch to permit other directed fisheries to occur where the catch of the by-caught species is not significant.
- Additional fishing mortality could also include a "Sparrow-type" fishery for aboriginal participants.
- Fishing mortality will vary, to a cap at a very low level.

By-catch Zone

- Additional fishing mortality limited to by-catch normally caught in other directed fisheries without a specific cap.
- Fishing mortality at a low level, catch varies relative to biomass of stock as well as biomass of stock of directed species.

Normal Fishing Zone

- Additional fishing mortality subject to commercial/recreational fisheries occurring, limited by a TAC and defined by the above characteristics.
- Above this point, fishing mortality would be held at a moderate level, and a stepped approach to changing TACs would be used.

Table 2. Summary of the SSB estimates from each of the three stocks and the information considered at the February 2003 ZAP on B_{lim}.

Stock	Current SSB	B_{lim}
Northern Cod	<50 000 tons	150 000 tons bench-mark B_{lim} >300 000 tons
Northern Gulf Cod	39 000 tons	200 000 tons
Southern Gulf Cod	72 000 tons	80 000 tons

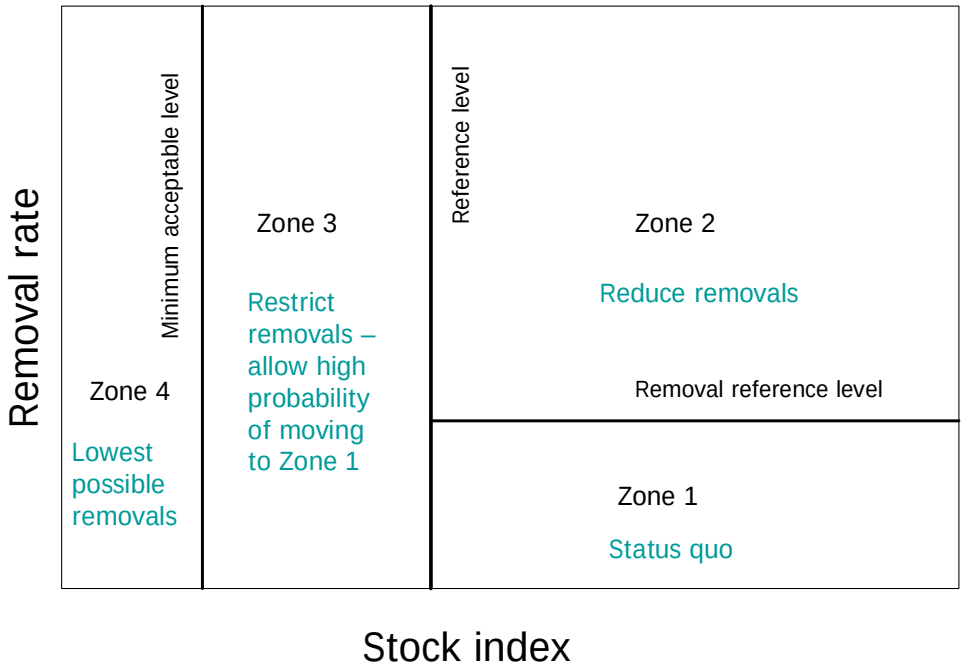


Fig. 1. Generic framework for implementing the PA from the November 1999 Nanaimo High Priority Project on the PA Workshop.

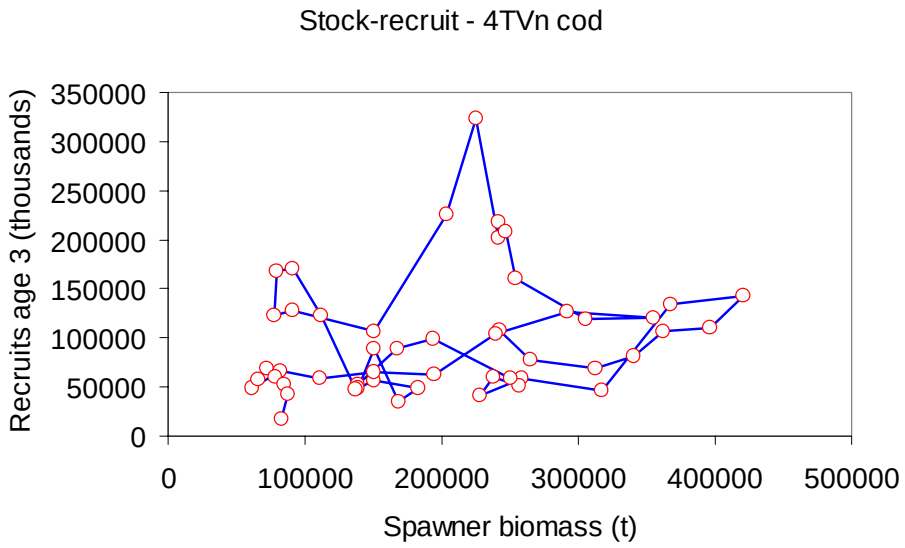


Fig. 2a. Stock-recruit scatter for 4TVn cod from the November 2002 Ottawa Workshop on Reference Points for Gadoids.

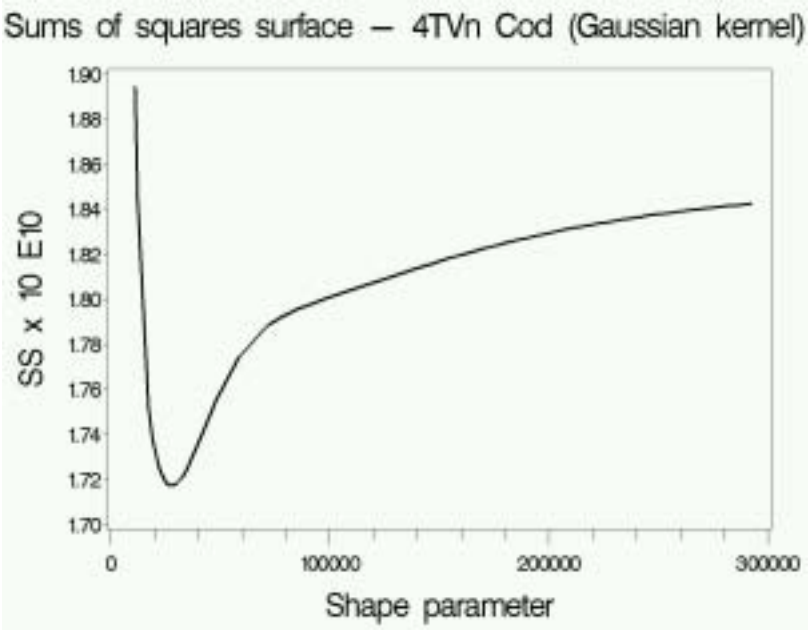


Fig. 2b. Cross validated prediction sums of squares for the shape parameter for a Gaussian kernel for Southern Gulf Cod *S-R* data, illustrating the first step in the approach proposed in the November 2002 Workshop on Reference Points for Gadoids – estimating the shape parameter.

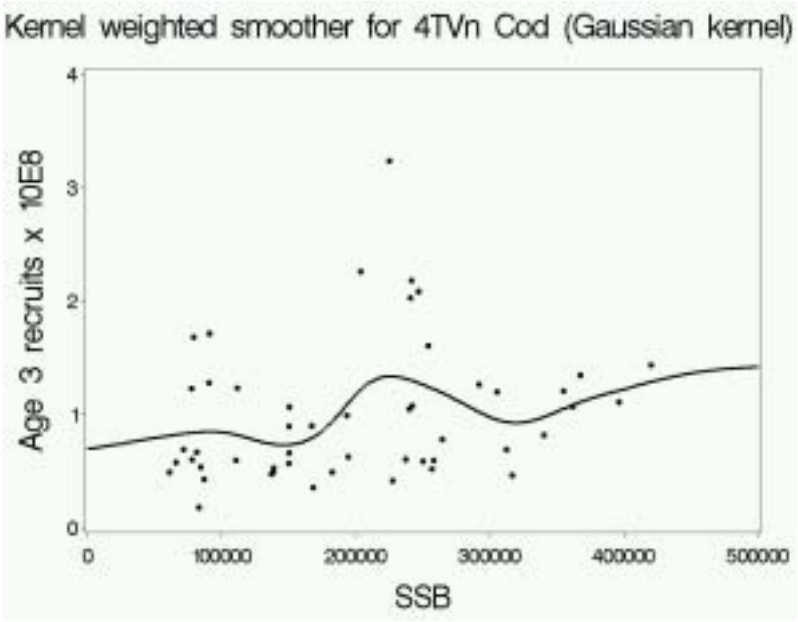


Fig. 2c. Kernel smoother applied to *S-R* data for Southern Gulf Cod using the shape parameter estimated in Fig. 2b, illustrating the second step in the approach proposed in the November 2002 Workshop on Reference Points for Gadoids.

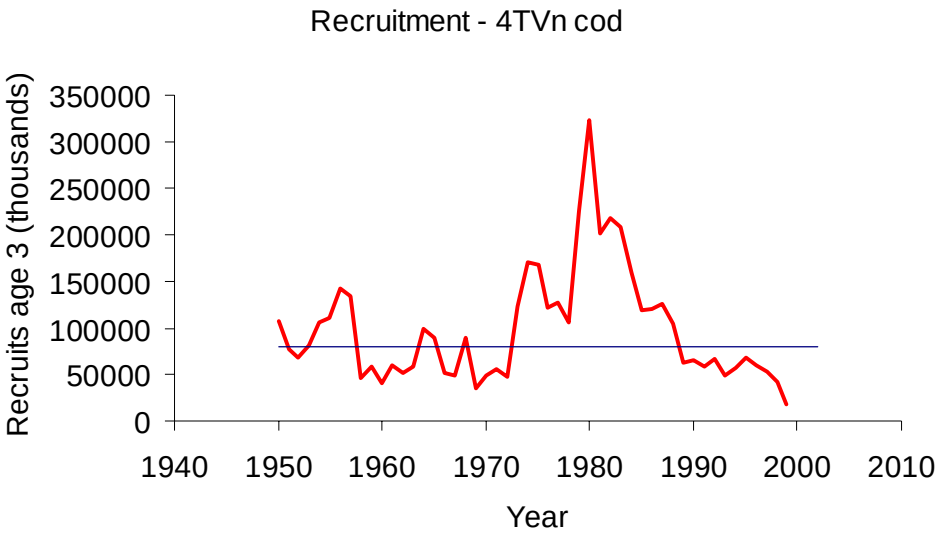


Fig. 2d. Examination of the recruitment data for Southern Gulf Cod to determine poor recruitment, illustrating the third step in the approach proposed in the November 2002 Workshop on Reference Points for Gadoids. Poor recruitment is represented by the horizontal line, demarcating the 10^{th} percentile.

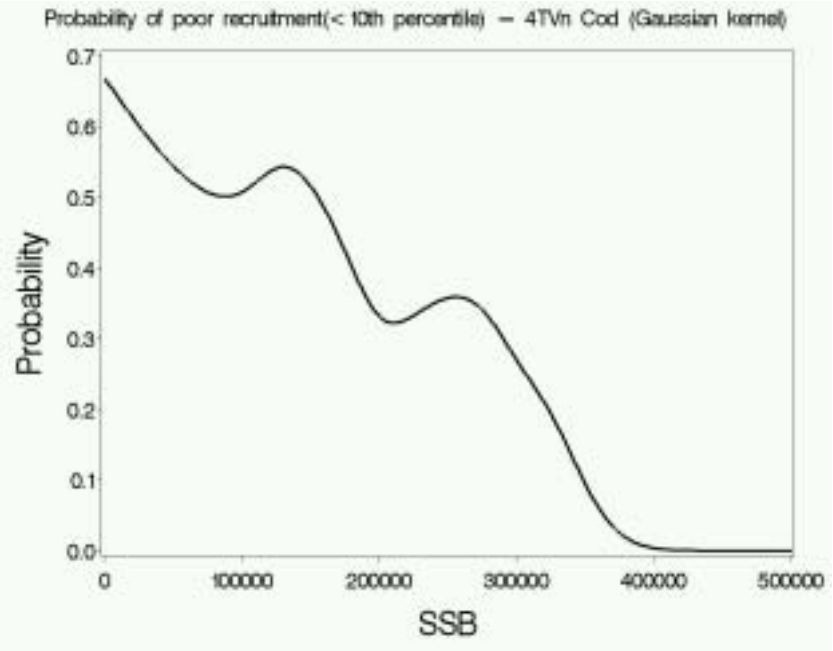


Fig. 2e. Probability of poor recruitment ($<80{,}00 \times 10^3$ = 10^{th} percentile, as an example) as function of *SSB* for Southern Gulf Cod, illustrating the fourth step in the approach proposed in the November 2002 Workshop on Reference Points for Gadoids.

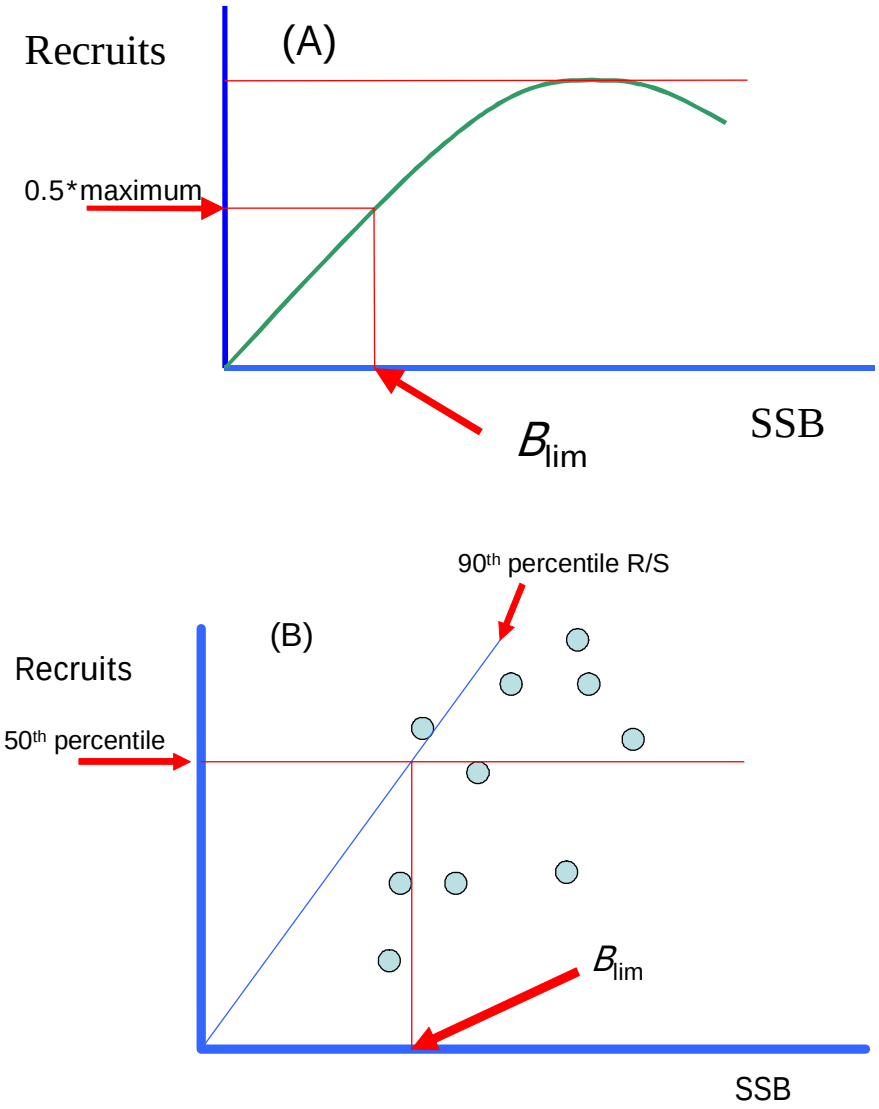
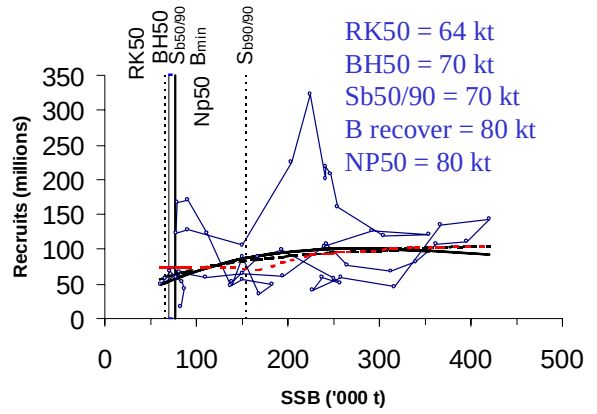
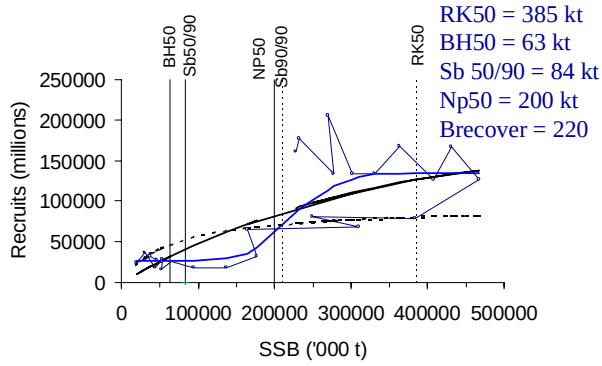


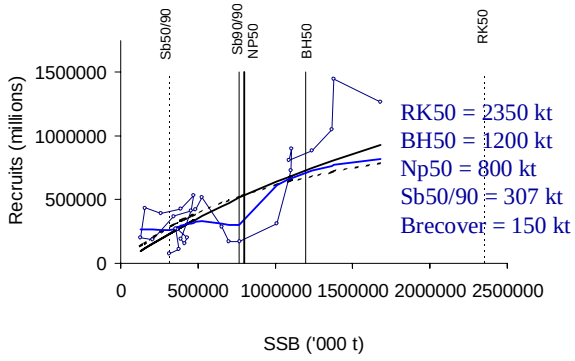
Fig. 3. Illustration of the application of two B_{lim} approaches, (A) $B_{50\%Rmax}$ and (B) Serebryakov's $B_{50\%R90\%surv}$, evaluated in the November 2002 Ottawa Workshop.



Southern Gulf cod



Northern Gulf cod



2J3KL cod

Fig. 4. Results from the 5 approaches/variants for determining B_{lim} applied to the three cod stocks in the November 2002 Ottawa Workshop.