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Reference Point Approaches to Management with the Precautionary Approach

Recent progress on the implementation of the precautionary approach on Canadian cod stocks leading to the re-introduction of the moratorium

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Abstract

Seven out of ten cod stocks in Atlantic Canada have undergone collapses of 90% or more as a result of overfishing combined with changes in stock productivity, most of them in the late 1980s - early 1990s. By 1994, eight of the ten stocks were under a moratorium on directed fishing. The Canadian portion of the Georges Bank was reduced to a bycatch fishery in 1995, leaving only one cod stock supporting a directed fishery. In 1997/98 the directed commercial fishery reopened on four stocks, only one of which had shown any signs of recovery. Although these fisheries were small relative to previous levels, scientific evidence rapidly accumulated to show that they were unsustainable given the recent productivity levels of these stocks. Recognising that unsustainable fisheries on collapsed, non-recovered resources was inconsistent with a conservation-minded approach, Canadian Department of Fisheries and Oceans scientists, with input from fisheries managers, developed a precautionary approach framework which defined spawner biomass limits associated with serious harm to stock productivity. This framework was implemented in the February 2003 assessments for the three stocks of most concern. Medium-term deterministic projections of spawner biomass relative to these limits were sufficiently pessimistic to convince decision makers of the need to place the fisheries back under moratoria despite pressing social and economic considerations. We describe the process leading to the development of the framework, in particular the spawner biomass limit reference points, and the implementation in the most recent assessments. We give consideration to further progress required to develop a fully articulated framework for Canadian cod stocks.

Keywords: precautionary approach, cod, spawner biomass limit reference point, framework, deterministic projections

Introduction

Atlantic cod *Gadus morhua* off Canada's east coast are separated into ten stocks for assessment and management purposes (Smedbol et al. 2002; Fig. 1). Of these, seven have in the past undergone collapses of 90% or more from overfishing and changes in stock productivity. By 1994 eight of the ten stocks were under moratoria on directed fishing. In 1995, the Canadian portion of the Georges Bank cod fishery was reduced to bycatch only, leaving only one stock supporting a directed fishery, 4X/5Y cod (Southwest Scotian Shelf/Bay of Fundy). In 1997/98 directed fisheries reopened on four of the stocks, only one of which, 3Ps cod (St. Pierre Bank-south coast of Newfoundland), had shown any degree of recovery. Fisheries on Northern Gulf Cod (NGC, NAFO Divisions 4RS3Pn), Southern Gulf Cod (SGC, NAFO Division 4TVn) and Northern Cod (NC, NAFO Divisions 2J3KL) were placed back under moratorium in 2003, based on DFO scientific advice provided in the context of a new precautionary approach (PA) framework.

In this paper we briefly review the decline and collapse of NGC, SGC and NC, the imposition of the moratoria and reopening of directed fisheries. We describe the basis for the partially developed PA framework that has been applied and which was instrumental in the decision in 2003 to again close the fisheries on these three stocks. We describe the derivation of limit reference points based on historic data and relate these to the most recent assessment results. We provide the results from medium-term deterministic projections and show how these shaped the scientific advice that led to the reintroduction of the moratorium. Finally, we suggest some further steps that need to be taken to develop a fully articulated PA framework for these stocks.

Decline and 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. Annual assessments were carried out under the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) and, in the case of NC, also under the Northwest Atlantic Fisheries Organization. There was an increasing trend in landings during the post-extension of jurisdiction period in all three stocks (Fig. 2). This occurred during a time of increasing Canadian fishing effort and increasing resource levels as reflected by estimated of spawning stock biomass (SSB) from sequential population analysis (SPA, Fig. 3). In the early part of this period, SPAs were calibrated using *ad hoc* methods but since the late 1980s calibration has been carried out under the ADAPT framework (Gavaris 1988). Fishing mortality (F) levels are estimated to have remained reasonably constant over the period from extension of jurisdiction until the late 1980s, ranging between 0.3 and 0.6 (Fig. 4) despite the increased catches. These estimates exceeded the $F_{0.1}$ target level which is generally found to be in the range of 0.2-0.3 for cod in the Northwest Atlantic. This overrun was partly a consequence of the "retrospective problem" (Sinclair et al. 1991) and partly a consequence of catches in excess of the scientific computations of the TAC corresponding to $F_{0.1}$ in stock projections.

Increases in catches and SSB during the period following extension of jurisdiction were supported initially by increasing stock productivity in terms of spawner per recruit (SPR; Figs. 5 and 6) in combination with high recruits per spawner (RPS) in the mid to late 1970s (Fig. 7). [In this study SPR is computed as the cumulative SSB from a single recruit that would accrue over its lifespan in the absence of fishing at prevailing rates of natural mortality, body growth and maturation. For heuristic purposes, we adopt the convention of Shelton and Morgan (1993) of computing annual SPR (i.e. summed across all ages in a year), rather than cohort SPR. RPS is derived from SPA estimates of number of recruits at age 3 divided by the SSB that gave rise to the recruits. SPR at F=0 can be thought of in terms of the innate spawner production capability of the stock (although effects of fishing on growth or maturation rates, e.g. through genetic changes to the population would be included)].

SPR in all three stocks declined through the 1980s (Figs. 5 and 6). When annual F is accounted for, the decline is from about 2.5 kg of spawners per age 3 recruit around 1980 to about 0.5 kg per recruit in the early 1990s (Fig. 6). Over the same period RPS went from more than 1 recruit per spawner down to less than 0.5 (Fig. 7). The combined effect of decreasing SPR and decreasing RPS resulted in a substantial decrease in stock productivity over this period. A heuristic of the combined effect on spawner production can be obtained by subtracting the spawner biomass required to give one recruit (1/RPS) from the spawner biomass obtained from one recruit (SPR) to obtain “surplus SSB production”. Surplus SSB at F=0 declined precipitously through the 1980s to below zero by 1990 (Fig. 8). Catches continued to increase over the early part of the 1980s against this backdrop of declining stock productivity and after the mid 1980s F rapidly increased to levels well beyond $F_{0.1}$ (Fig. 4), precipitating the collapses in SSB in the late 1980s and early 1990s (Fig. 3). When annual F is taken into account, surplus SSB production is shown to fall below zero by the early to mid 1980s (with the exception of NC in 1987; Fig.9), bottoming out in the late 1980s/early 1990s. Dutil et al. (2003), using a bioenergetics approach, have drawn similar conclusions regarding changes in the productivity of cod stocks in the Northwest Atlantic over this time and have related these changes to environmental conditions.

An analysis of mortality rates derived from research vessel survey data from the moratorium period on SGC (1993-96) indicated that natural mortality (M) in that period was around 0.4. SPAs suggested that an increase in M on this stock likely occurred in the 1980s (Sinclair 2001). Currently, stock assessors for NGC and SGC assume that an increase in M occurred in 1986. This change contributed to a major reduction in the inferred SPR at F=0 for these two stocks from about 6 kg per recruit down to less than 1.5 kg (Fig. 5). There was no corresponding residual problem in NC in the 1980s, but in the early 1990s two year classes (1986 and 1987) decreased at rates that could not be explained by the assumptions of constant M, constant survey catchability (q), and no misreporting of catches. Shelton and Lilly (2000) considered that unreported deaths due to fishing may have been the main contributing factor. However, the 2003 assessment (Lilly et al. 2003) developed an SPA for the coastal component of Northern Cod (NCC) for the period 1995 onwards in which M was assumed to be 0.5 based on results from tagging experiments. A higher level of M is also consistent with analysis of the Research Vessel survey index at age data for NC in offshore strata for the moratorium period. The SPR for NCC for the recent period with M=0.5 is comparable to those obtained for NGC and SGC under the assumption of M=0.4 and F=0 (Fig. 5).

The implementation of the moratorium on directed fishing on NC in 1992, NGC in 1994 and SGC in 1993 coincided with increasing levels of stock productivity in terms of SPR for NC at M=0.2 and slight increases for NGC at M=0.4, but little change in the case of SGC at M=0.4 or NCC at M=0.5 (Fig. 5). When annual F is taken into account, it is evident that there was a major impact of the moratorium on SPR in all three stocks (Fig. 6). RPS also increased to reach peak levels in the mid 1990s for NGC and relatively high levels for SGC (Fig. 7). RPS for NCC in the mid 1990s was estimated to be higher than for NC in the early 1990s, although this is in part a consequence of a higher M value in the NCC SPA. The increasing productivity coinciding with the moratorium can be seen in both surplus SSB at F=0 and F=annual (Figs. 8 and 9). However, surplus SSB production only briefly rose above zero for NGC and SGC during the moratorium period and not at all for northern cod. There was, however, limited growth in SSB of northern cod over the moratorium period as below-average to poor year-classes produced in the years immediately prior to the moratorium were protected from intensive directed fishing. Even these small increases in numbers of spawners were sufficient to increase SSB slightly (Fig. 3).

An advisory body to the Canadian Minister of Fisheries and Oceans, the Fisheries Resources Conservation Council (FRCC), which was created following the cod collapses, advised the reopening of directed commercial scale fisheries on NC in 1998, NGC in 1997 and SGC in 1998. In some cases these were termed "index" fisheries in the expectation that they would yield valuable information for scientific analyses on the state of the stocks as well as providing income to fishermen. The cessation of income support to fishermen and mounting social, economic and political pressures contributed to the decision to reopen. Although the reopened fisheries were small relative to those in existence prior to the moratoria, annual stock assessments carried out by DFO Science subsequent to the re-openings showed that they were, or rapidly became, unsustainable under prevailing stock productivity conditions and that the decline in SSB had resumed (Rice et al. 2003).

Development of a precautionary approach

Canada's Oceans Act of 1996 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…". In the mid to late 1990s Canadian scientists were still adapting and developing tools required for implementation of the PA on DFO managed stocks (Shelton and Rivard 2003). In particular, two DFO National Science workshops in the late 1990s addressed a number of technical aspects related to implementing the precautionary approach. The Workshops came up with a general PA framework that was considered to be consistent with United Nations Fisheries Agreement (UNFA) of 1995 (Fig. 10; Richards and Schnute 1999), but there were noteworthy differences of viewpoint with regard to which aspects of the general framework were the most important ones. These differences in viewpoints regarding the situations in which precaution was to be employed, and the degree of "precaution" necessary, made it difficult to develop the framework to a the level of specificity adequate to guide case-by-case advice and decision-making.

Greater clarity on the degree of conservativeness required under the PA came from a Canadian inter-departmental Working Group, coordinated by the Privy Council Office. This WG was charged with coming up with an approach that ensured a consistent interpretation of "precaution" across all government activities; in human health, in food safety, in environmental protection, as well as in natural resource conservation. The Working Group provided guidelines that nested the PA as a special case of general risk management, with greater risk aversion to be applied when there is both high scientific uncertainty and when the risk is with respect to "serious or irreversible harm" (http://www.pco-bcp.gc.ca/raoics-srdc/docs/precaution/Discussion/discussion_e.pdf). Development of a DFO PA was given further momentum by the ratification of UNFA by Canada and more 30 or more other countries, resulting in it coming into force on December 11, 2001.

In December 2001 a DFO workshop adopted the notion of "serious harm" as the definition of a conservation limit reference point (Rice and Rivard 2002) and reviewed a number of B_{lim} and F_{lim} candidates in this context (Shelton and Rice 2002). In the context of the DFO PA for fisheries management, 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".

NC, NGC and SGC were assessed by DFO regionally in early 2002 as part of the annual DFO stock assessment advisory process (NC - CSAS SSR A2-01, 2002 (update, not a full assessment); NGC - CSAS SSR A4-04-01, 2002, and SGC - A3-01, 2002; http://www.dfo-mpo.gc.ca/csas). These assessments documented the evidence that pos-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. The FRCC advice to the Minister of Fisheries and Oceans was to continue with status quo TACs on all three stocks for 2002, but to review the situation at the begging of 2003, giving consideration to the possibility of further quota reductions if the status of the stocks had not improved.

In March 2002, DFO Science carried out a major review of all 10 Atlantic Canada cod stocks in relation to the criteria used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in determining species at risk of extinction status in Canada (Smedbol et al. 2002). This review noted that the most recent assessments had indicated that current TAC levels on NC, NGC and SGC 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 classification.

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 to determine limit reference points (Rivard and Rice 2003). Limits were developed for NGC and SGC, and for NC a “bench-mark” reference point was decided on, at which point the limit reference point would be re-evaluated.

Although the November 2002 Workshop gave some consideration to the application of the non-parametric kernel smoothing methods applied to SR data by Rice and Evans (1986, 1988) and Evans and Rice (1988) as an approach for defining impaired productivity (ICES 2003), and found the results to be very promising, the immediacy of the problem of developing limit reference points necessitated the adoption of more traditional approaches. From among the B_{lim} candidates reviewed by Shelton and Rice (2002) the Workshop selected $B_{50\%Rmax}$ and Serebryakov’s $B_{50\%R90\%surv}$ for application to the three cod stocks. Empirical evidence exists for the use of $B_{50\%Rmax}$ as a threshold SSB that would be in keeping with the notion of serious harm (Mace 1994, Myers et al. 1994). 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-recruit 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 gives consideration to early stage survival as well as recruitment production. 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 favorable stock productivity conditions as described above, as well as having considerable numbers of fish younger than the age a maturity that were already within the population and which fueled the recovery (e.g. SGC), and in some cases significant numbers of survivors from higher recruitment levels in the late 1960s (e.g. NC). Also, $B_{recovery}$ requires an external decision about what constitutes a secure and rapid recovery – as contrasted with a prolonged state of collapse. 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. Although it was considered that the definition of F limit reference points was desirable, it was considered to be a secondary issue at the time given the severely depleted state of the three stocks.

Implementation and consequences

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. Moreover, in many cases the most aberrant estimates were from one of the methods requiring use of a parameterized stock-recruit relationship which fit the available data poorly, especially at low stock size.

The results from applying the 5 approaches to the three stocks are illustrated in Figs. 11 and summarized in Table 1. The SSB levels were relatively consistent for SGC, but covered a wide range for NGC and NC. For the NGC and the NC, the $B_{50\%Rmax}$ was found to be very sensitive to the computational method used for fitting the stock-recruit relation. Typically, large variances were associated with parameter estimates. NC results were strongly influenced by high recruitment levels in the early part of the time series. Serebryakov's method was found to be relatively robust 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 t for SGC, 200,000 t for NGC and a bench-mark SSB 150,000 t for NC, with carefully chosen text to accompany each value (Table 1). For NGC it was noted that the 200,000 t B_{lim} was not definitive because there were few data in the 100,000 – 200,000 t range of SSB and that the B_{lim} may be revised downward when more data become available. For NC maximum recruitment was poorly defined but it was agreed that B_{lim} would likely be greater than 300,000 t, the SSB level from the Serebryakov method. It was considered that when SSB approaches the bench-mark SSB level of 150,000 t (corresponding to $B_{recovery}$), the data would be reviewed to see if there was more information on defining an appropriate B_{lim}.

A cod Zonal Assessment (ZAP) was held in Halifax in March 2003 to evaluate the current status NGC, SGC and NCC based on the available data. SPA assessments were accepted for all three stocks. For NC, although SPA was the main tool prior to the collapse, a severe residual problem had developed in the early 1990s which is 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 March 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 unlikely that it would play any significant role in stock rebuilding in the near future. The SSB estimates from the ZAP for each of the three stocks and the corresponding B_{lim} values are summarized in Table 1.

In addition to determining current status, the ZAP carried out medium-term deterministic projections based on recent average values of recruitment rates, weights at age and proportion mature at age. The emphasis in these projections was a 5 year period and only this portion of the projection was used to provide scientific advice to decision makers. However, it was recognized that the steady state conditions of the stocks (obtained 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. For NC, mark-recapture data suggested that M=0.5 was appropriate for the inshore component over the recent period, rather than the historically assumed value of 0.2. Similarly high values of M were assumed in the NG and SGC assessments as discussed above. These M values were used in the SPAs and in the projections. The 5 year projections suggested that NGC would decline initially 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 as a consequence of transient recruitment effects, but that this would be marginal (Fig. 12). Under *status quo* TAC levels all three stocks showed significant declines in SSB over a 5 year period (Fig. 13). Thus, even in the absence of a fishery the stocks were not projected to reach B_{lim} in the near future and were predicted to move further below B_{lim} under *status quo* fisheries.

The consequence of the March 2003 stock assessment and the ensuing scientific advice resulted in fairly dramatic events. The FRCC mulled over the scientific evidence but were not convinced about the need to close the fisheries. Instead they recommended to the Minister that the TAC for NGC and SGC should be cut in half and that a cap on NC removals of 1,500 t of NC should be put in place. The Minister, despite considerable pressure from various quarters to keep the fisheries open, accepted the DFO scientific assessments and advice provided in terms of the PA, and on the 24th of April 2003 announced the closure of all three fisheries. This precipitated strong reactions from those affected by the measures, their representatives and in one case, a provincial government. However, once the dust had settled, there was a groundswell of support in the media and among the public for acting in a precautionary manner and conserving the remainder of the stocks in the hope of commercial scale fisheries reopening sometime in the future.

The next steps

In the 1980s and early 1990s groundfish management in Atlantic Canada was based primarily on yield per recruit reference points, most particularly $F_{0.1}$. Sinclair (1997) has shown that yield per recruit reference points may not be sustainable in situations where productivity declines, for example through a change in natural mortality. Although $F_{0.1}$ may have been effective when stock productivity levels were high, declining stock productivity and increasing Canadian effort in the 1980s, combined with retrospective error in stock assessments and inertia in the decision-making process, allowed fishing mortality levels to escalate and the stocks collapsed. The magnitude of the declines may have been considerably less and the collapses avoided if the fixed harvest rate management strategy of $F_{0.1}$ had been adhered to (see for example NC in Shelton 1998). Nevertheless, the realities of stock assessment and fisheries management point to the need for a more precautionary approach in which serious harm is defined *a priori* by the setting of limit reference points and fishery harvest levels are reduced well below those indicated by yield per recruit analyses before the risk of violating these limits rises above some very low level, forcing closure of the fishery.

The recent decisions by DFO to close three of the four reopened cod fisheries is a step towards the implementation of the PA, but it is not a strong test of the commitment to do so, given the indisputably poor status of the stocks. Indeed, only a minimal PA framework comprising B_{lim} and deterministic projections was in place to support the scientific advice. Comprehensive PA frameworks need to be developed for all Canadian stocks on which there is a directed fishery and in advance of any of the closed fisheries reopening.

For DFO Science, key tasks include more comparative work on performance of alternative B_{lim} estimators, and particularly on improved quantification of uncertainty. These steps are necessary to set precautionary reference points and to manage the risk of falling below the conservation limits. The Canadian federal framework clarifies that precaution is justified to keep the risk of "serious or irreversible harm" very low, and a variety of legal opinions have supported that, in international contexts, this standard will apply as well. Hence, science must define much more explicitly and objectively exactly what constitutes "serious harm" to stocks and ecosystems. (There is a general consensus that in biological contexts *serious* harm will occur well before truly *irreversible* harm is done to a stock.) Once the biological properties of serious harm are defined empirically and justified objectively, the technical task of developing estimators for those properties will be much more straightforward.

DFO Science is not working alone on implementing a precautionary approach to fisheries management in Canada. DFO Fisheries Management, the Canadian fishing industry and the public each have important roles as well. Fisheries Management, in developing an approach termed "Objectives Based Management" or OBFM, is taking seriously the need for a structured approach incorporating management objectives, risk evaluation, harvest control rules and the implementation of the precautionary approach. Although conservation is of prime importance in OBFM, a number of potentially conflicting management objectives (maximizing employment, economic return, etc.) need to be considered. In designing PA frameworks there is a need for fisheries scientists to be cognizant of the realities of decision making and ensure sufficient flexibility and adequate decision space to allow management objectives to be achieved and fisheries to proceed, without compromising the precautionary approach (see for example the NAFO context in Shelton et al. 2003). Although a certain amount of momentum has been gained, implementation of OBFM and the PA in Atlantic Canada is going to be an ongoing challenge, particularly in the Atlantic groundfish fishery given the apparent overcapacity and lack of many economic alternatives.

The Canadian fishing industry is becoming more familiar with the concepts and literature of precaution, and is beginning to incorporate these ideas into their own deliberations. The interest of industry in having as much predictability as possible in their planning horizons is forming the basis for a new type of dialogue between industry and science, prompting calls from industry for decision-rules that science would apply to itself, for example in the case of divergent B_{lim} estimates. This presents some interesting challenges to the science community.

The Canadian public, having footed the considerable bill for compensation during the cod moratoria of the early 1990s, is now much more aware of the cost to society of stock degradation and hence the need to act in a precautionary manner. Unsustainable fishing practices on stocks close to or below B_{lim} will not garner public support in the future. Indeed, public opinion quickly turned in favor of the Minister's recent decision to close the cod fisheries once it was clear that there was broad scientific consensus on the poor state of the stocks and the detrimental effect to recovery of <u>any</u> ongoing fisheries.

Having made some rapid advances on implementing the PA in the last few years, it is imperative that DFO science retains the momentum. It needs to remain abreast of developments with respect to the PA in ICES, NAFO, ICCAT NASCO and in national agencies. The nascent national framework must mature into a comprehensive approach to precaution, with robust reference points, adequate risk estimation and practical harvest control rules. If this can be achieved it will become an integral part of fisheries management nationally and stock collapses should become a rarity.

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Table 1. Current (2003) estimates of SSB and the corresponding B_{lim} values for Northern Cod, Northern Gulf Cod and Southern Gulf Cod.

Stock	*Current SSB (tonnes)*	*Conservation Limit Reference Point*
Northern Cod	Less than 50,000	Between 300,000 and 800,000 t. With little historic information on stock productivity in this range of SSB, as the SSB rebuilds between 150,000 and 300,000 t, information on stock productivity may allow the limit to be determined with greater precision.
Northern Gulf Cod	39,000	Around 200,000 t. With little historic information on stock productivity between 100,000 t and 200,000 t, stock recovery to SSB greater than 150,000 t may allow the current limit to be revised.
Southern Gulf Cod	72,000	Clustered around 80,000 t.

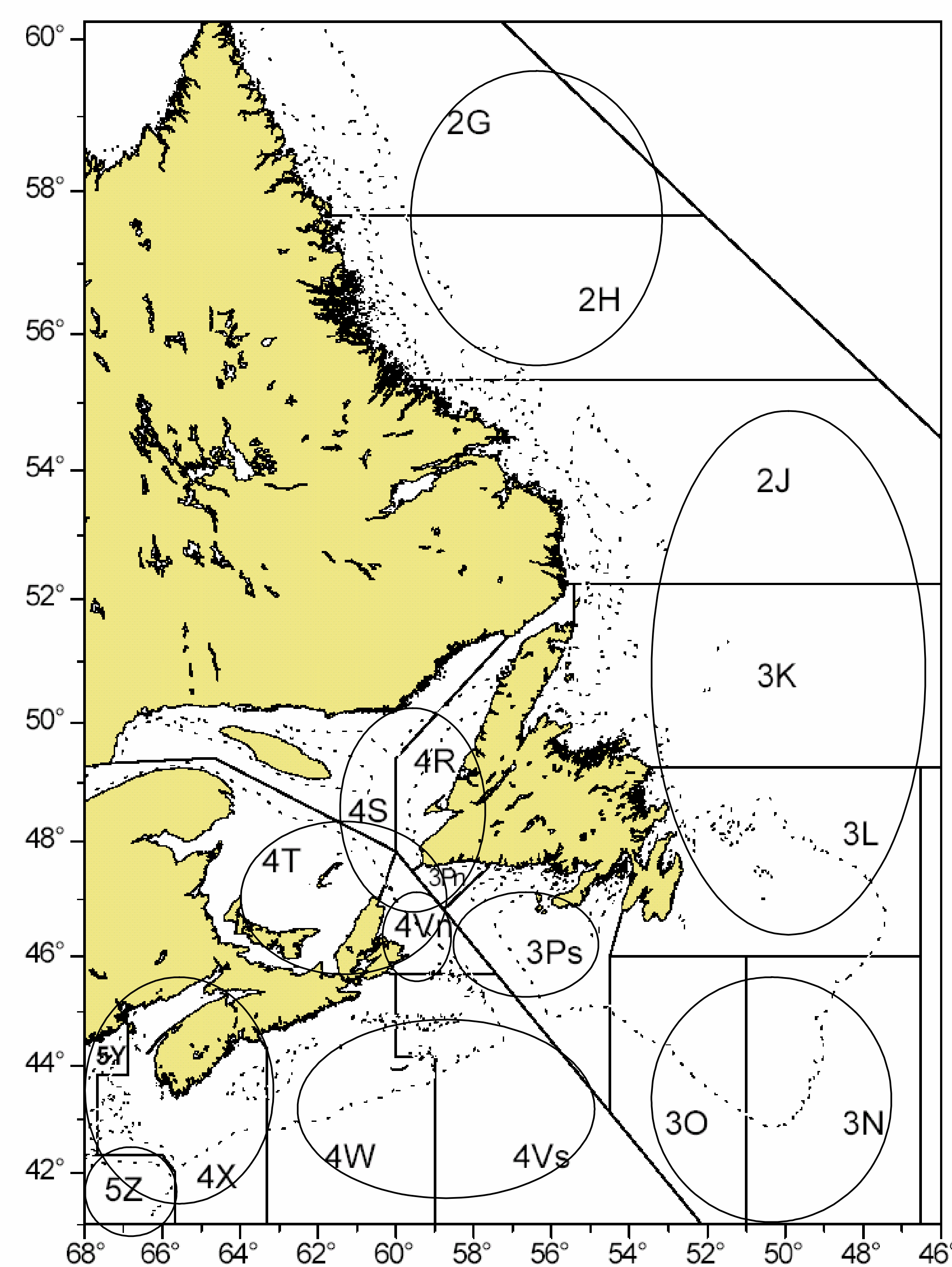

Fig. 1. Schematic showing the general location (not exact) of the 10 cod stocks recognized by Canada for management purposes in the Northwest Atlantic.

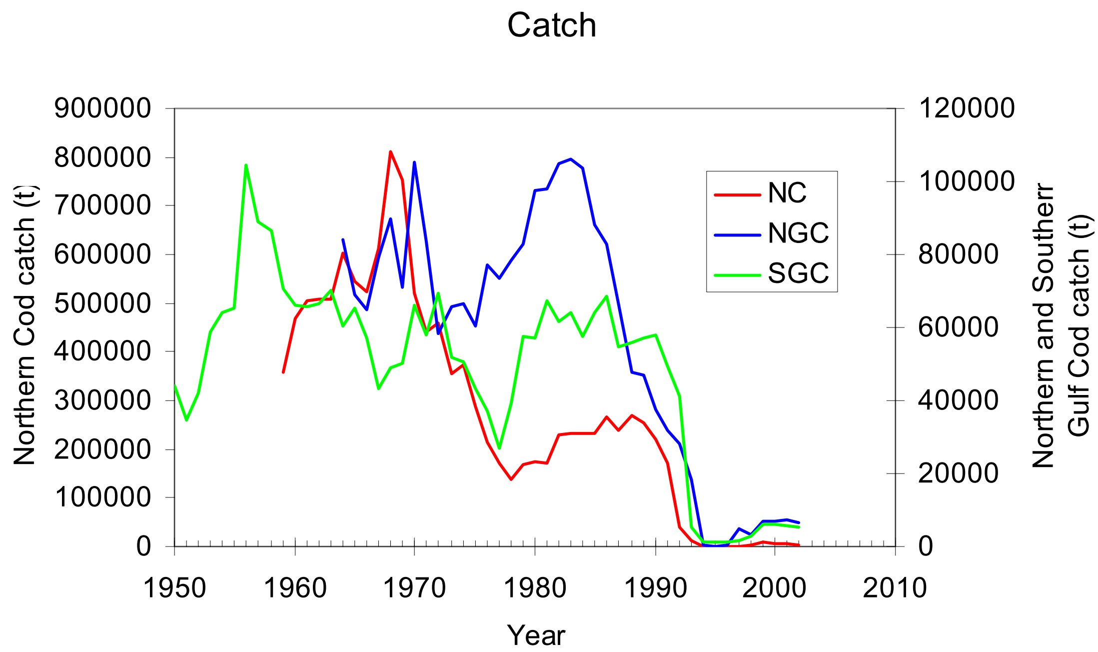

Fig. 2. Timeseries of commercial catches for Northern Cod, Northern Gulf Cod and Southern Gulf Cod.

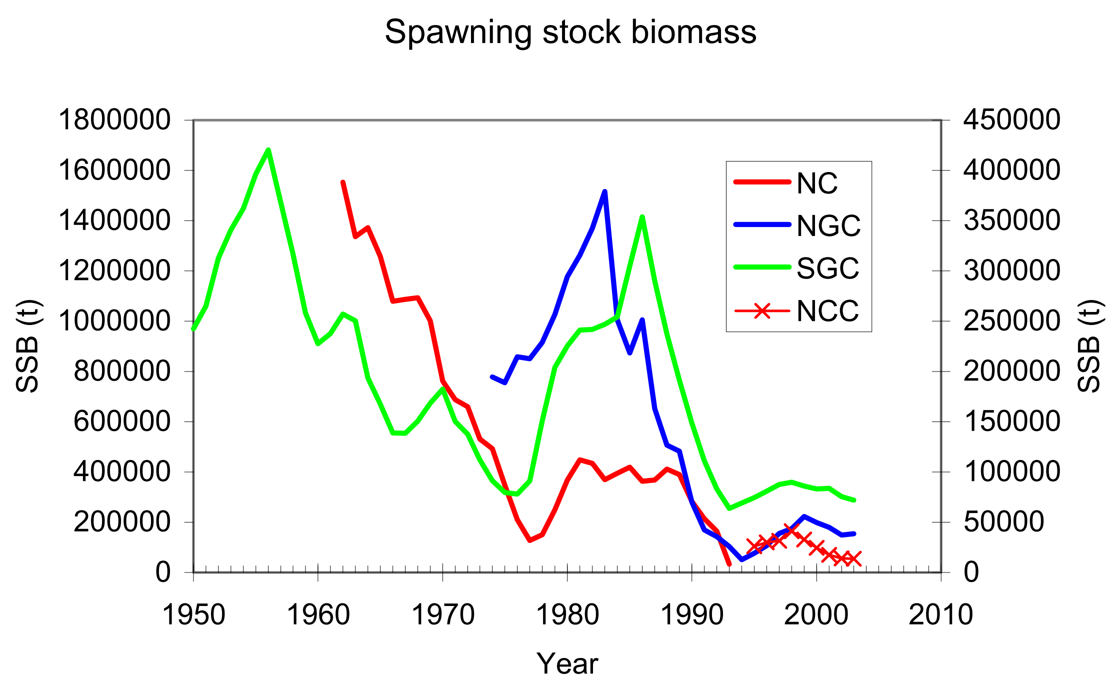

Fig. 3. Timeseries of spawner biomass estimates for Northern Cod, Northern Gulf Cod and Southern Gulf Cod. Included is a recent short timeseries for Northern Cod Coastal Component.

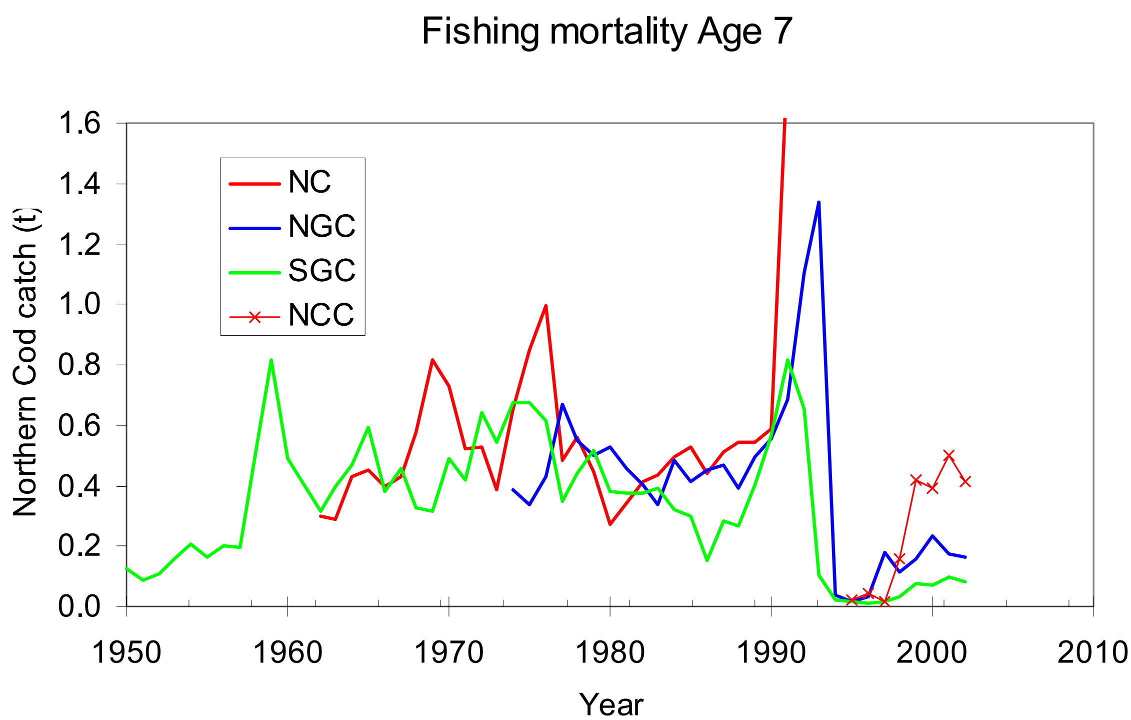

Fig. 4. Estimates of fishing mortality for Northern Cod, including the Coastal Component, Northern Gulf Cod and Southern Gulf Cod.

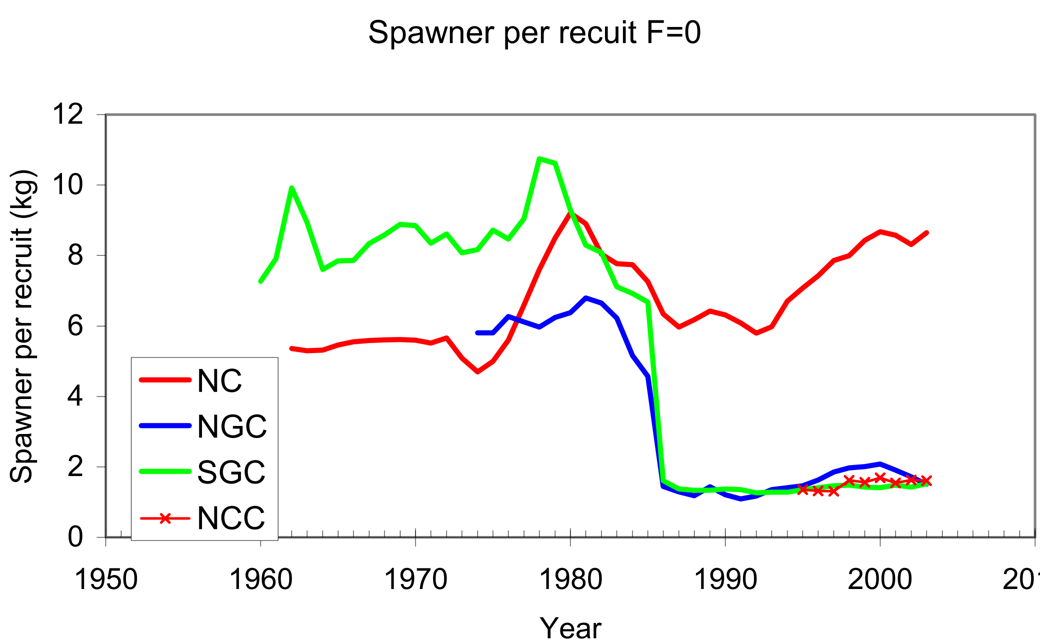

Fig. 5. Spawner per recruit at F=0 for Northern Cod, including the coastal component, Northern Gulf Cod and Southern Gulf Cod.

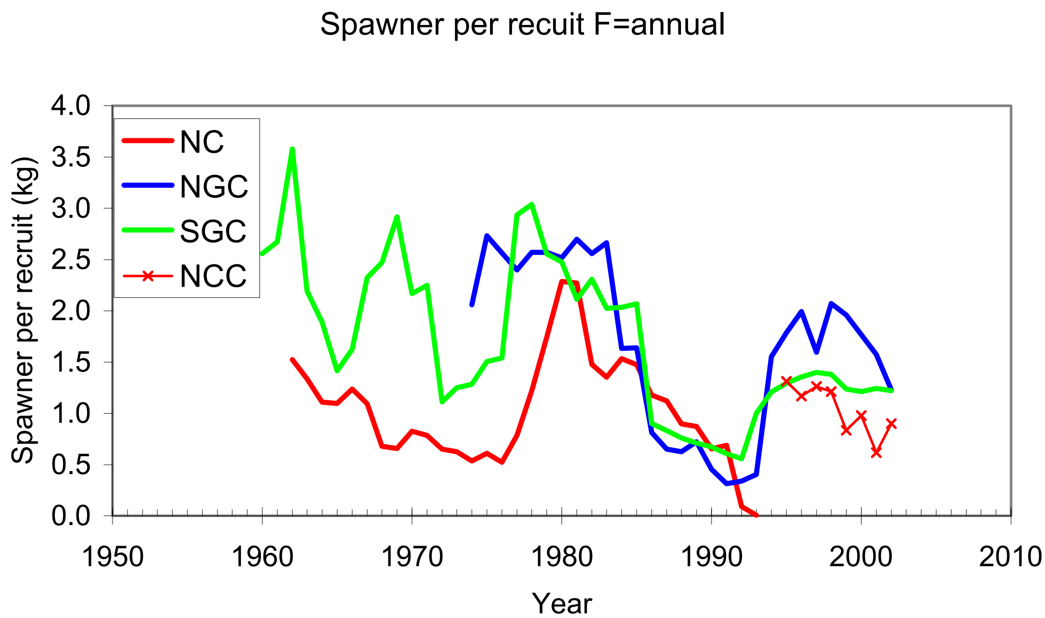

Fig. 6. Spawner per recruit at annual F for Northern Cod, including the Coastal Component, Northern Gulf Cod and Southern Gulf Cod.

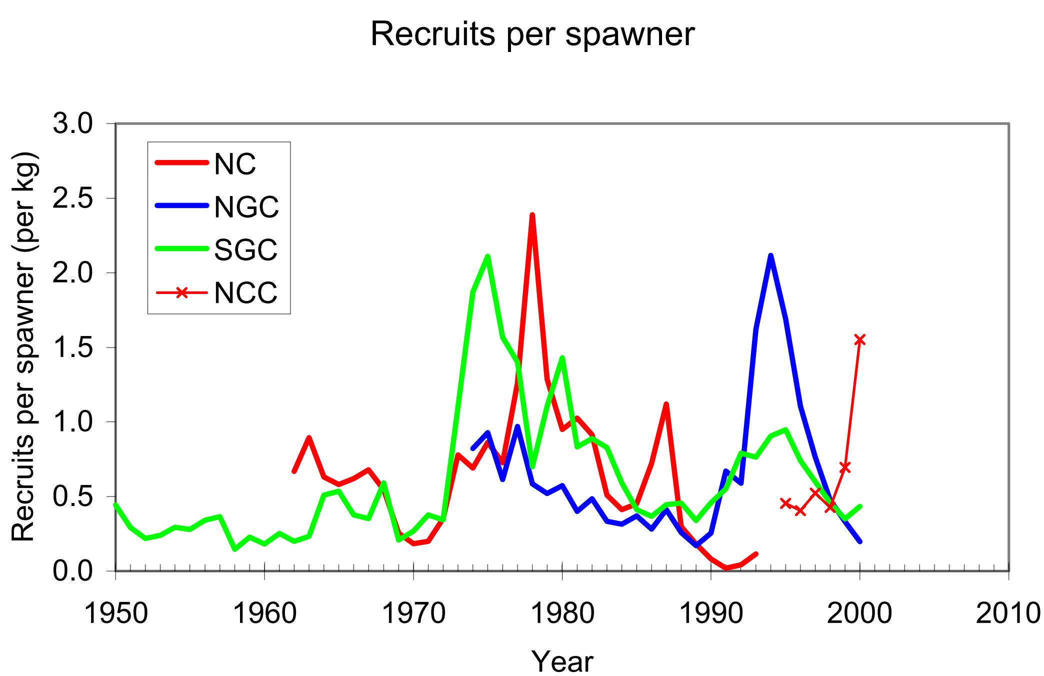

Fig. 7. Recruits per spawner for Northern Cod, including the coastal component, Northern Gulf Cod and Southern Gulf Cod.

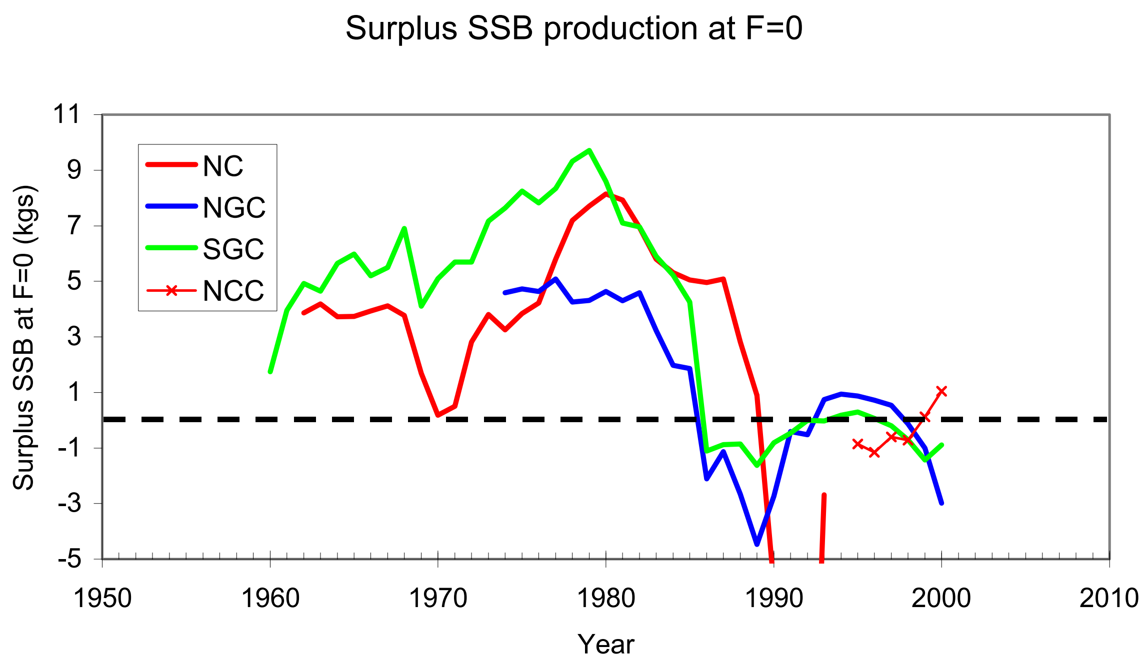

Fig. 8. Surplus SSB production at F=0 computed by subtracting the spawner biomass required to give 1 recruit (1/RPS) from the spawner biomass obtained from one recruit (SPR).

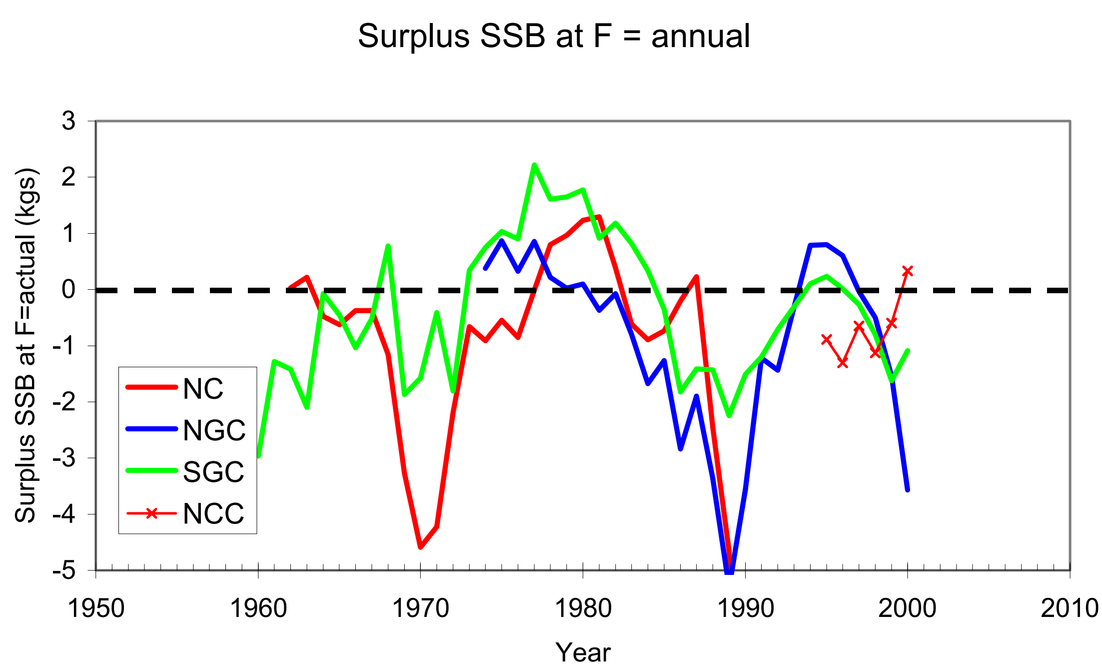

Fig. 9. Surplus SSB production applying annual F, computed by subtracting the spawner biomass required to give 1 recruit (1/RPS) from the spawner biomass obtained from one recruit (SPR).

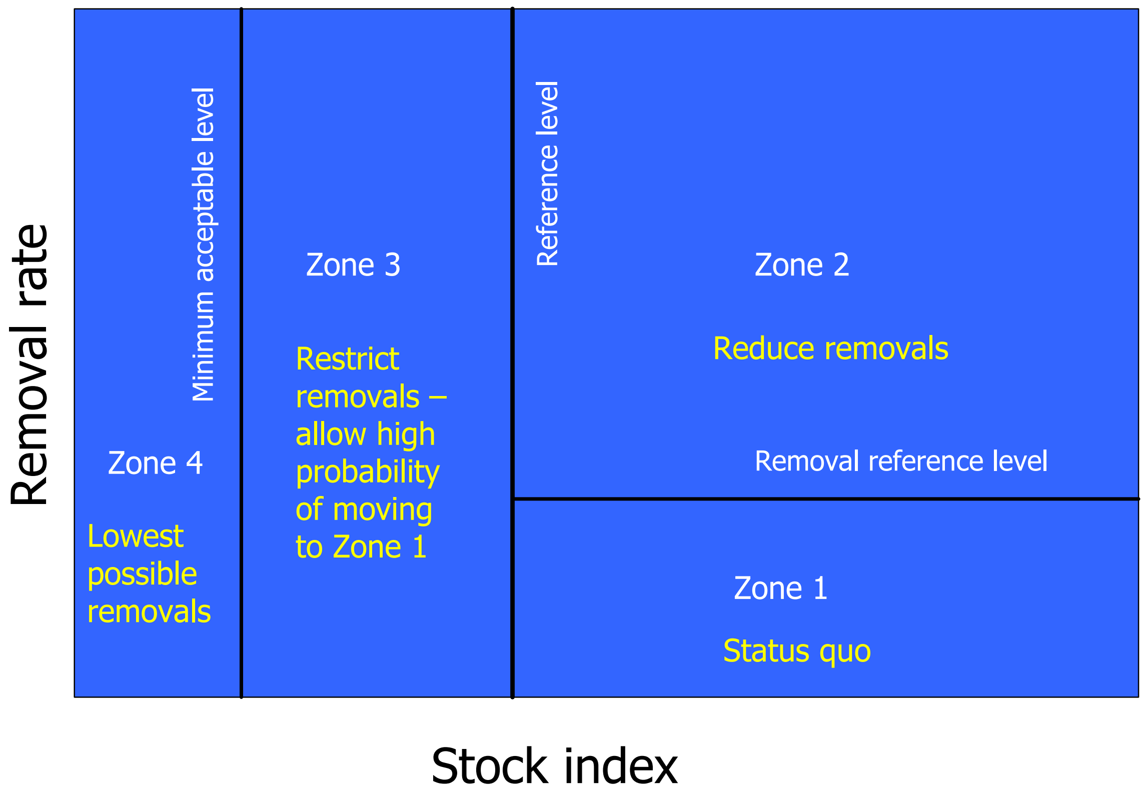

Fig. 10. A general PA framework considered to be consistent with United Nations Fisheries Agreement (UNFA) developed in a DFO workshop in November 1999 (from Richards and Schnute, 1999).

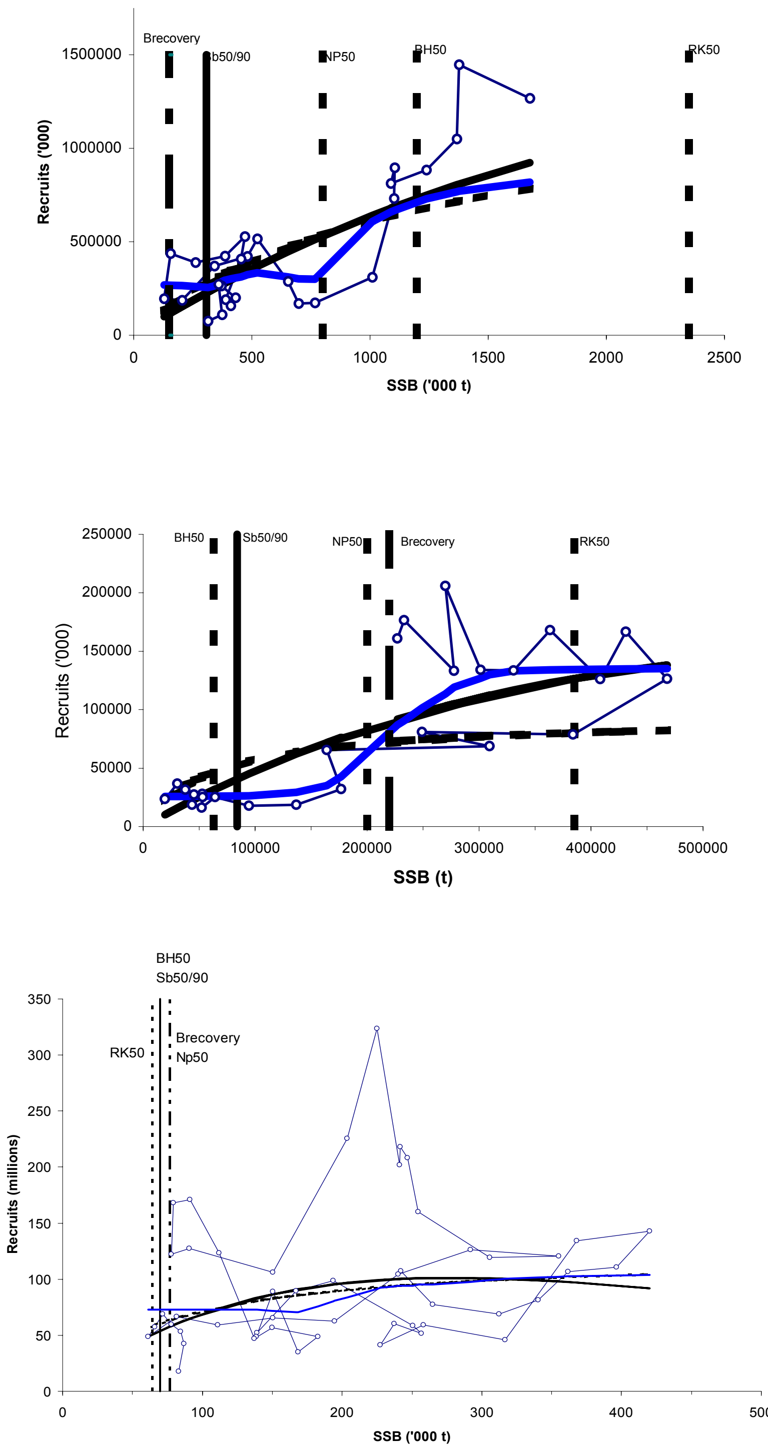

Fig. 11. B_{lim} reference points estimated for Northern Cod (top), Northern Gulf Cod (middle) and Southern Gulf Cod (bottom). Fitted models include Ricker, Beverton-Holt and non-parametric smoother. See text for details.

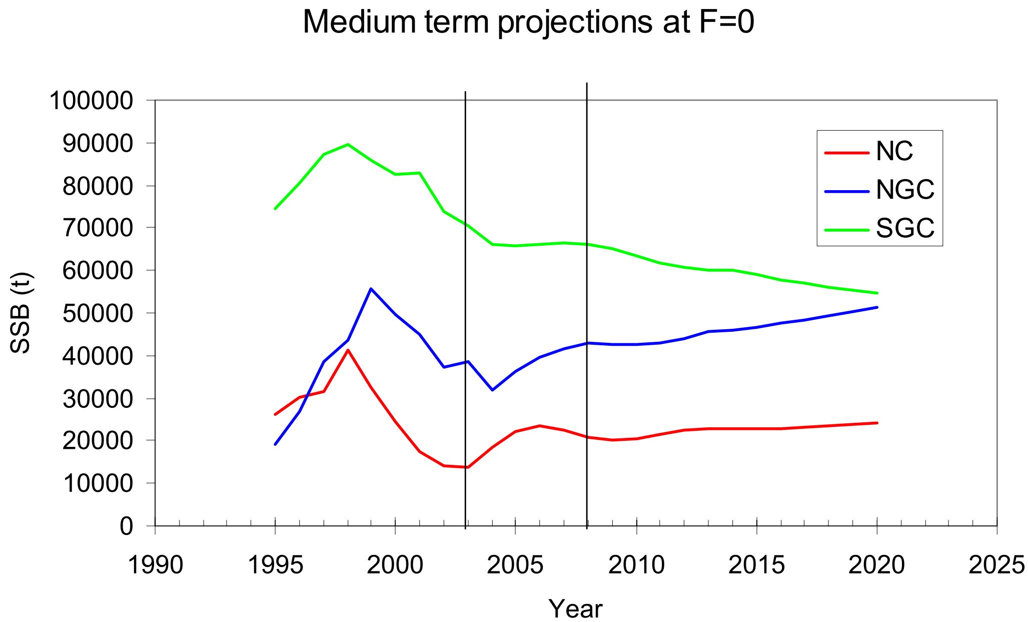

Fig. 12. Medium term projections of Northern Cod, Northern Gulf Cod and Southern Gulf Cod under current RPS and SPR conditions at F=0. The vertical lines demarcate the 5 year time horizon used in the provision of scientific advice.

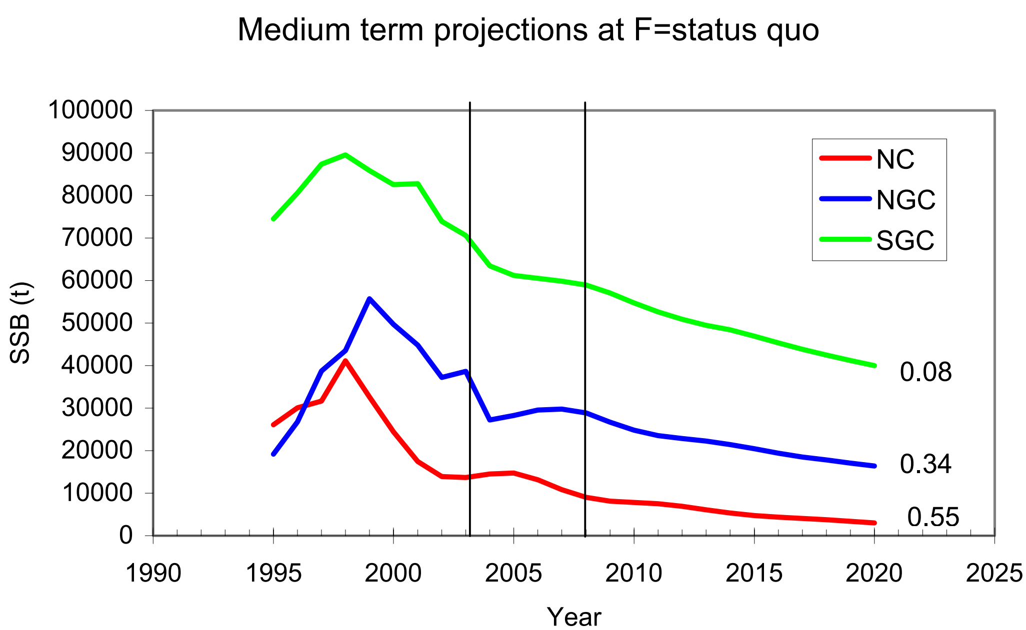

Fig. 13. Medium term projections of Northern Cod, Northern Gulf Cod and Southern Gulf Cod under current RPS and SPR conditions and at *status quo* F. The vertical lines demarcate the 5 year time horizon used in the provision of scientific advice.