

Recovering Canadian Atlantic Cod Stocks: The Shape of Things to Come?

Jake C. Rice¹, Peter A. Shelton², Denis Rivard¹,
Ghislain A. Chouinard³ and Alain Fréchet⁴

¹ Fisheries Research Branch, Department of Fisheries and Oceans, 200 Kent Street,
Ottawa, Canada, K1A 0E6

² Northwest Atlantic Fisheries Centre, Department of Fisheries and Oceans, PO Box 5667,
St John's, Newfoundland, Canada, A1C 5X1

³ Gulf Fisheries Centre, Department of Fisheries and Oceans, PO Box 5030,
Moncton, New Brunswick, E1C 9B6

⁴ Institut Maurice-Lamontagne, Department of Fisheries and Oceans, P.O. Box 1000,
Mont-Joli, Quebec, G5H 3Z4

Abstract

Between 1989 and 1993 science advisors in Canada recommended major quota reductions for many Atlantic cod stocks. Government response to the advice was initially slow and insufficient to arrest the stock declines. Declines became collapses and complete closures had to be implemented for a number of fish stocks between 1992-1994. At the time of closure, expectations were widespread that it might require as many as 3-4 years for stocks to recover to states capable of supporting substantial fisheries. Those supporting such expectations were helped by some conventionally structured forecasts, which used the past as a guide to the future and implied a rapid recovery for the stocks. Projections with much more pessimistic messages were also provided at that time, but optimistic messages were the basis for much of the planning. The social assistance, industry restructuring, and science augmentation programs were all designed or adapted to extend a maximum of five years. The expectations were that by that time coastal communities and the industry would have restructured to prosper with more modest harvesting of recovered stocks, and that science would have the answers for why the stocks had collapsed.

The last decade has been very different from those expectations. After five years of moratoria, stock recoveries were highly variable. A few stocks did return quickly to historic levels, but these were ones where the declines had been modest at the time that moratoria were instituted. Stocks that had declined severely showed evidence of very weak improvement at best. However, when funding for social assistance programs was exhausted, fisheries were reopened. Although TACs were very small compared to historic harvests, the very modest stock gains during the moratoria were rapidly dissipated. Moreover, the social and community needs for fishing were still present and the restructuring and retraining funds had not resulted in reduced capacity and demand for fish. Therefore the reintroduction of moratoria in 2003 have been resisted just as strongly on the grounds of social and economic impacts, although the states of these stocks are as poor or poorer than in the early 1990s. The big difference is that this time there are no expectations that things will get better in the near future.

There are a number of lessons to be learned from this experience. Based on an examination of 47 alternative hypotheses for why these cod stocks did not recover strongly through the 1990s, it was a suite of biological and fishery properties, and not just bad luck that led to the failures of stocks to recover. Stock recovery trajectories based on productivity measured when a stock is healthy were a misleading guide to

true stock trajectories of depleted stocks. The paper documents some of the ways in which productivity of the depleted Canadian cod stocks differed from productivity of the same stocks when they were large. It will apply some of the lessons learned from the Canadian experience to the general theme of recovery planning.

INTRODUCTION

This paper considers the status and management of Canadian cod stocks over the past 50 years, focusing primarily on the past decade. When looked at in detail there are many differences among the trajectories of the individual stocks, and among the reasons thought to account for details of those differing patterns. Some of the specific cases are examined carefully in other papers at this ASC (Chouinard et al. 2003, Shelton et al. 2003). However, there are some common patterns and inferred processes across stocks as well. As with the biological characteristics and trajectories of the individual stocks, there are also regional differences in the fisheries for these stocks. Likewise there are some commonalities at a coarse level – diverse and competing fleet sectors in almost all areas, significant economic dependency (direct and through generous (Un)Employment Insurance programs) and cultural heritage associated with cod fishing, and technological creep in all fishing sectors. In this paper we seek general messages for those planning and implementing programs for recovery of depleted stocks. Such generalities do not free managers and science advisors from considering the distinctive characteristics of each stock and fishery, but might contribute to a general framework for recovery planning.

EVENTS

1950s (and earlier) through 1980s.

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). Many of these stocks have supported fisheries for centuries, and although they demonstrated wide fluctuations in yield over the entire time period (Fig 2 for catches from stocks around Newfoundland cf Lear 1998), these cod fisheries are inseparable from the history of Atlantic Canada (Kurlansky 1997). All of these stocks were severely overfished in the 1950s to the mid-1970s. Although details of timing and magnitude of declines vary among stocks, for each of them non-Canadian fleets exploited offshore spawning aggregations intensively as suitable technologies developed and the aggregations were discovered (Parsons 1993, Halliday and Pinhorn 1996). Estimates of stock abundance, biomass, and trajectories over that period are dependent on highly suspect catch data, but declines of 80% or more are thought to have occurred for most stocks (Fig 3), and age and size compositions became severely truncated.

The differences in detail of the stock declines are not important for the current messages on stock recovery. However, the similarity among stocks in the rapidity with which recovery commenced following extension of jurisdiction is an important part of the story. At the time and well into the 1980s, stock recovery was attributed to careful management

of the fisheries; for example, [by 1988] “Federal intervention put the industry on the road to recovery. The groundfish resource had recovered significantly since 1977” (Parsons 1993, page 375). A target fishing mortality of $F_{0.1}$ had been adopted in 1979 (Parsons 1993), and the policy was believed to be restricting exploitation to rates that allowed steady increases in abundance and biomass.

It is now clear that this pattern of rapid and secure initial recovery was facilitated by particularly high productivity in terms of both spawner per recruit (SPR) and recruits per spawner (RPS or R/S) (Fig 4-6; CSAS 1996, Shelton et al 2003). It is still unresolved to what degree this high productivity was due to environment and what degree the innate vigour of the stock, and the variable pattern among stocks (cf. Sinclair 1993, Chouinard et al. 2003) is also not explained convincingly as yet. Nonetheless, the belief that stock recoveries could be planned, implemented, and achieved through management became entrenched in science, management, policy, and much (but not all) of the fishing community (Gough 1993, Finlayson 1992).

Moratoria - the mid-1990s

By the end of the 1980s stock recovery was seen to be over. Stock trajectories were either stable or already turning downward (CAFSAC 1989), and a strong retrospective pattern in many assessments, detected by 1986 (CAFSAC 1986) meant that the rate of deteriorating stock condition was consistently underestimated (Sinclair et al. 1991). Response of policy and management to science advice depicting stocks in rapid decline initially was slow and incomplete, although eventually unprecedented measures were implemented. The collapses of several of these stocks in the early 1990s have nearly become modern folklore in the world of fisheries science and management. Masters of hindsight have produced many, publications on the causes of these collapses, with enough blame to spread liberally among poor science, poor management, irresponsible fishing practices, adverse physical oceanographic conditions, excessive predation and inadequate prey (summary in Rice 2002). Despite intensive efforts of a large, diverse, and skilled science team, the role of the various causal factors in the collapses cannot be partitioned fully and accurately for any stock, let alone for all of them (unpublished summary of cod mortality project). There is consensus that overfishing played a significant role in declines of all stocks, although the relative contributions of overly-optimistic science advice, ineffective management, slothful policy responses, and wasteful, aggressive fishing is debated among even highly knowledgeable experts. Moreover, contrary to early claims (Hutchings and Myers 1994), overfishing was not the sole cause of the declines, although the precise role of adverse environmental conditions and the mechanisms through which the environment affected stock productivity are also still debated among experts.

Whatever the causes of the declines, seven of the ten Canadian cod stocks had undergone collapses of 90% or more by 1992-1994. By 1994 eight of the ten stocks were under moratoria for directed fishing (Table 1). 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). At its peak, the

moratoria were estimated to have eliminated more than 40,000 jobs in Atlantic Canada, which aside from parts of the far North, was already considered to be Canada's most economically disadvantaged area.

Conditions were bleak, and science advice pessimistic (CAFSAC 1993, Sinclair 1993) but optimism for recovery was widespread (cf FRCC 1993a,b). Typical statements from Ministry officials, politicians, the Conservation Council, and community leaders included:

“Our scientists advise that with a moratorium on Northern cod for two years, the size of the stock should increase significantly, and the spawning stock should no longer be at dangerously low levels. In short, if there is a two year moratorium, we should be able to begin safely the fishery for Northern Cod inshore in 1994 and have made a strong start on rebuilding the stock” (John Crosbie, Minister of Fisheries and Oceans, in announcement July 2, 1992.)

A few months later, the succeeding Minister of Fisheries and Oceans, Brian Tobin stated “I remain confident, in the face of such a sobering fisheries assessment, that we can and will over time restore this important sector in Atlantic Canada to good health.” November 29, 1993.

The Fishery Resource Conservation Council, in its recommendations for fisheries management in 1994, stated that “These changes [the 1993 in-season closures] represented an important step toward arresting the decline and beginning the process of rebuilding stocks” (FRCC 1993b, pg 5). However the FRCC also repeated their earlier warning that “... there is no guarantee that it [rebuilding] can be done nor precedent as to how to do it.” (FRCC 1993b, pg 3).

Cod fishing had been the cultural foundation of much of coastal Atlantic Canada for four centuries, and had seen hard times in the past (Lear 1998). Cod had declined previously and recovered, and done so most recently in the lifetime of many fishers, scientists, and managers. The issue was how to survive hard times again. This expectation of recovery shaped the policy and decision-making climate throughout the period of recovery planning, despite no clear indication of how the recovery was to be achieved.

With many coastal communities of Atlantic Canada largely, if not solely, dependent on cod fishing, and the major processing companies also dependent on cod, an economic and social assistance package was inevitable. A short-term relief package for Newfoundland in 1992, accompanying the first moratorium (Announcement by J. Crosbie, July 2, 1992), was followed rapidly by the coast-wide Atlantic Fisheries Adjustment Package in 1993 (known variously as AFAP and TAGS – the Atlantic Groundfish Strategy), as the moratoria spread to many other stocks. As indicated by its name, the AFAP was intended to “adjust” the fisheries, because the problems of overcapitalisation and over-capacity were widely recognised. A minimal income support (under 400\$ Can per month) was provided to fishers and plant-workers who had lost their jobs with the moratoria, however, the income support could as much as double if the beneficiary would register

for an approved “retraining” course. There was also a vessel buy-back and license retirement program. The goal was a smaller, more professional industry, but nonetheless an industry where cod-fishing would still be a cornerstone economically and culturally.

The planning and implementation of AFAP was predicated on timely recovery of the cod stock, supported by a few very optimistic estimates of the growth potential of some cod stocks (e.g. 30% per annum for 2J3KL cod – Myers et al. 1997); a recovery we all know now did not occur. The scientific basis for expecting a rapid and secure recovery was not examined in detail at any time, despite regular stock assessments showing that the recovery was not being realised. Expectations based on historical “experience” or traditional knowledge proved difficult to change, although with the benefit of hindsight essentially all parties associated with Canadian Atlantic cod disavow responsibility for creating the expectations. Even before the current increased awareness of how uncertain analytical assessments usually are (Patterson et al. 2001) DFO Science Branch had been reluctant to conduct and publish medium-to-long-term stock projections. During the recovery in the 1980s Science came to argue increasingly strongly that such projections were both highly uncertain, even when done stochastically (see evolution from DFO 1978 & 1980 to 1988, and were likely to be mis-interpreted. This did not prevent such projections from being conducted at the request of Task Groups, managers and policy makers, with products used by policy and economic sectors (e.g. Munro 1980).

The lesson for planning stock recoveries is the same whether expectations were the result of formal projections or just intuitive extrapolations of the experience during period immediately following extension of jurisdiction. In the planning for AFAP, expectations were built on the full past experience with these cod stocks – expectations based on assuming past stock recruit relationships, past growth rates, historic natural mortality (e.g. Myers et al. 1997). Moreover, at the time of *planning* for the recovery of these stocks, there would have been few data on which to argue for more pessimistic assumptions. (The reality was bad enough, without assuming worse.)

Re-openings – The Late 1990s

We now know that all these assumptions were an unsound basis for planning for cod recovery. At the first cod Zonal assessment meeting in 1997, assessments concluded that stock status probably had improved for all stocks since their respective moratoria were implemented, but gains for several stocks were very small (Table 2). Rather, at the Zonal meeting it became clear that productivities of several of the stocks were far lower than had been assumed (formally or informally) in 1992-1994, and natural mortalities likely higher (CSAS 1997). It was difficult to reach consensus among technical experts on these points, however, and the final wordings were highly qualified. Merely a year later it proved impossible to produce any Overview addressing the causes of the disappointingly slow recovery of these stocks, due to a failure of the technical experts to agree on the relative importance of various factors. There was an even stronger consensus that stock recovery was not going well (Rivard 1999), but spirited disagreements on details. These disagreements ensured that the scientific advice was extensively qualified, but nonetheless clearly pessimistic about stock status:

“Nous n’avons pas le moindre signe que les stocks sont en train de se reconstituer” J. Rice quoted in *Encart Geographica* 1998.

“The spawning biomasses of the five stocks that were assessed remain very low compared to the states of these stocks prior to the collapses. ... Because recruitment of new spawners to the mature biomass of most stocks is very low, most of the small increases observed in spawning biomass of some stocks is due to growth of surviving fish. Increasing harvests based on this growth would reduce the number of spawners further and cause further reductions in the already low spawning potential of the stocks” Quotes from press release following Zonal Assessment meeting in Rimouski, Feb 1998.

“Cod stocks on Georges Bank/Bay of Fundy [5YZ], Southwest Scotian Shelf [4X], and St Pierre Bank [3Ps] have recovered from lower biomasses earlier in this decade. Fisheries are sustainable and stocks are stable or increasing. Other cod stocks remain depressed. Low recruitment and high mortality ... contribute to the failure of those stocks to rebuild.” Bullets points from SSRs. Feb 1998.

4TVn – The assessment concluded that “... the spawning biomass remained near record low levels, recruitment remained poor, and natural mortality was high. ... risk analysis reports that there is a 93% chance that the spawning biomass will decline, even if there is no catch in 1998. An implication of the analyses is that any fishery in 1998 is likely to reduce the spawning biomass further, from its presently depressed state.” Statement of Meeting Conclusions for Press Feb 1998.

2J3KL – “The overall stock size remains very low relative to historic levels, and recruitment continues to be poor. Mortality rates ... remain very high, even though there is a moratorium.. ... spawning biomass could decline further, even in the absence of a fishery. Statement of Meeting Conclusions for Press Feb 1998.

4VsW - The spawning biomass is at or near the lowest seen, between 5 and 16% of the average from 1979-1989. ... the biomass is projected to decline 5-20%, even in the absence of a fishery” Statement of Meeting Conclusions for Press Feb 1998.

It was against this background that AFAP completed its 5 years of funding. The Office of the Auditor General of Canada reviewed the costs and benefits of the programs (<http://www.acoa.ca/e/library/audit/>). Costs were readily quantified – approximately 3.9 billion dollar Canadian had been spent on all aspects of vessel and license retirement, social assistance, and retraining. Benefits were harder to measure. Coastal communities survived, but the relative role of income support from AFAP and income from new, lucrative fisheries for shrimp and crab were difficult to partition. More importantly, the Auditor General’s review concluded that vessel and license retirements had been concentrated in the older boats and fishers, and the profits from invertebrate fisheries were being reinvested in new, technologically sophisticated vessels designed to be capable of participating in many fisheries, including cod. It also concluded that participants in retraining programs very often had chosen training programs in skills and technologies that would readily transfer to improved efficiency at fishing, and based on interviews, a large majority of participants said that they intended to return to fishing as their primary job, just as soon as it was possible to do so. Overall the Auditor General’s report concluded that, after spending 3.9 billion dollars to “adjust” the Canadian Atlantic groundfish fishery, effective fishing capacity was 160% of what it had been in the early 1990s.

Not surprisingly, expiration of income from AFAP resulted in an intensification of pressure from coastal fishing communities to be allowed to resume fishing cod. The conclusions of the assessments in 1997 and 1998 expressed pessimism about stock recovery, but generally with many qualifications about the strength of evidence for contributing factors to slow recovery and recent stock trends. This was a volatile combination. Between 1997 and 1999 the Fishery Resource Conservation Council (comprised of academics or private sector experts, industry leaders, and provincial representatives, and designated as the Minister's official advisory body on Atlantic groundfish) recommended reopening commercial fisheries with small TACs on four of the five stocks despite stock assessments not showing any clear signs of improvement in stock status (Table 2) (FRCC 1996, 1998, 1999). They made their recommendations after considering, in addition to the scientific evidence, the views expressed during public consultations. Many pointed at the uncertainties in stock assessment results and the qualified statements in the advice, and argued that small fisheries would "test" the fishing grounds in some unspecified way.

Fisheries for these small TACs proved difficult to manage effectively for several reasons. The (Un)Employment Insurance program for fishers made the industry and policy objective in most areas maximisation of the number of participants, rather than economic indicators such as CPUE or profitability. The combination of low TACs and high participation required very complex regulations which, proved hard to implement, monitor, and enforce. A TAC also created legal markets for cod, and there were widespread (but unverifiable) rumours of extensive unreported harvesting and poor fishing practices. In one Region, eventually Science and Fisheries Management intervened after the FRCC advice was provided, asking for a higher TAC than advised by the FRCC. They hoped that an orderly fishery supported by a higher TAC would actually pose less risk to stock recovery than fishing with a TAC so low that the management task was intractable.

By the early 2000s some aspects of stock productivities might have improved for the unrecovered stocks (Fig 4 again), but fisheries were being prosecuted on the small production and residual standing stocks. Not surprisingly, these fisheries proved unsustainable (2002 assessments; www.dfo-mpo.gc.ca/csas), and another zonal assessment meeting, in February 2003, concluded that four of the five key northern stocks were either again in decline, or at best increase in stock had ceased. Recent NAFO assessments of 3NO have been no more optimistic. The Zonal Assessment made another attempt to account for the poor recovery as well. This time a Planning Group preparing for the meeting posed 47 different (sometimes overlapping) hypotheses for the lack of recovery (Table 3 – hypotheses from planning group), and coordinated preparation of Working Papers for the Zonal Assessment Meeting testing them. The Zonal Meeting reviewed all the information, and concluded that a combination of factors contributed to the decline (Table 4). Key points included:

- Expectations of recovery rates were unrealistic.
- Both growth and reproduction were often poor.

- Natural mortality had increased. Seal predation could not be discounted as a factor, but there was little evidence that cod were not finding enough food.
- Fisheries were unsustainable

The Zonal assessment meeting also evaluated stock status in a Precautionary framework relative to Conservation Limit Reference Points for the first time, and concluded that the four key stocks (2J3KL, 3Pn4RS, 4TVn, and 4VsW) were all at or below their conservation limits (Shelton et al. 2003). Although the FRCC advice to the Minister recommended continuation of fisheries for all stocks except 4VsW (which had never reopened), the Minister opted for moratoria on all four stocks. The Minister's decision was consistent with the federal policy on the application of precaution in government decision-making. There has been strong opposition to the closure in many coastal communities, and by some provincial governments, but the closures have been maintained and public opinion in many places has turned in favour of the decision. A second generation of social support and restructuring funding was demanded by many quarters, but at least up until mid-summer, such programs were small, local, and short-term. The emphasis has been on a message that AFAP provided the means for coastal Atlantic Canada to adjust to new realities about cod fisheries. Now they have to live the consequences of their choices.

The story is not over, however. Medium term projections for the four stocks under moratorium suggest that stock increases over the next five years are unlikely, or at best very small. The message from the February 2003 meeting was that stock status is very unlikely to improved markedly over the next few years, even with total closures, and there was little point to re-evaluating status of these stocks before about 2006. Nonetheless, no formal decision framework for re-opening has been adopted. Therefore decisions about continuation of the moratoria beyond 2003 are not necessarily assured. Rather, "Action Plans" for cod recovery have been called for and have already become the focus of discussions on the future of these stocks.

It is too early to know what the Action Plans will specify for the various stocks. However, regardless of what the Action Plans include, the four stocks that did not rebuild promptly with the first moratoria will require a long time to rebuild. Recovery will require both major changes in some aspects of productivity (recruits-per-spawner and spawners-per-recruit well above historic average, natural mortality returning to at or below the historic levels of around 0.2, improve growth rates), and several years for the benefits of the improved productivity to accumulate in the standing stock biomasses. Based on the Canadian experience in the last decade, even small fisheries on these stocks during the recovery period, however long, could annihilate recovery gains and prevent the benefits from accumulating enough for the stocks to return to their historic biomasses and yields. Regardless of what stage of recovery has been reached when fisheries are reopened, the Canadian experience also supports the conjecture that there will be ample fishing capacity still on hand to take (or exceed) the yields that would be available at that time.

LESSONS

The Canadian experience over the past decade supports several conclusions, which might be taken as lessons for other jurisdictions that are trying to recover depleted or collapsed stocks.

1. Stocks DO differ in their recovery potential. Of the ten Canadian cod stocks, nine were placed under moratoria or bycatch-only limits. At one extreme 3Ps cod recovered to historic levels quickly, whereas at the other extreme 4VsW has shown no improvement despite a decade of effective closure to all harvesting, and is considered to exist only at “background levels” at present. This means recovery planning must take account of stock-specific information, and of the local social and economic pressures on managers and decision-makers. The differences are in detail, though. Some general considerations apply widely.
2. As a generalisation stocks that were less depleted recovered more quickly. However, among stocks that were badly depleted, the difference between 1-3% of historic stock sizes and 5-8% does not appear important. Consistent with all interpretations of the Precautionary Approach in fisheries agreements and literature, swift and decisive conservation actions pay off, long before the uncertainties about how quickly and why the stock is declining have been resolved. Even if the signals of severe decline are a false alarm, few stocks in the North Atlantic are so healthy that a few years of reduced exploitation would fail to repay the sacrifice with improved productivity and yield in the future.
3. The productivity of badly depleted stocks is lower than the productivities of the stocks when they are healthy, and for a variety of reasons. The reasons may be stock specific, but don't matter all that much to planning at the initial stages, anyway. What matters is that projections of recovery times and trajectories will be severely overly optimistic, if projections assume the recruits per spawner, (or components such as rates of growth, maturation, or natural mortality) characteristic of the stock when it was healthy. In the initial planning time horizons for recovery must accommodate the likely poor stock productivity, and the default settings for projections should assume that the stocks will be of low productivity until there is evidence that they are not. There will be plenty of time to refine parameter settings in the projections, as data collected during the recovery phase allow situation-specific parameter estimates to be determined from field data.
4. Planning errors are not symmetric; the costs of over-optimism are more grievous and lasting than the costs of being overly pessimistic. If the planning horizon is actually longer than the recovery time for a stock, managers and decision-makers have to deal with a pleasant surprise. If the planning horizon is shorter than the actual recovery time for the stock, as happened in Canada, everyone – scientists, managers, decision-makers, and the industry participants – find themselves in a situation with few winning choices.
5. Set re-opening criteria early, and have them based on properties of the stock. This is particularly crucial if timeframes for recovery are based on assuming typical productivity for the stocks. If decisions about reopening or expanding restricted fisheries are simply based on a certain number of years passing, the likelihood that there will be unsustainable fisheries on unrecovered stocks is very high.

6. Small fisheries on depleted stocks are NOT compatible with stock recovery. They show a pattern of becoming the only scale of fishery that the stock will ever again support. Based on 3Ps and 5Zj-m, when re-opening waited until stocks were back to well within historic typical sizes, the subsequent fisheries seem to have been sustainable, and even economically viable.

Those involved with the Canadian cod stocks over the past two to three decades have drawn some other conclusions as well. These are less directly relevant to the theme of this session, but are worth sharing.

The scientists and managers associated with a collapsing and recovering stock should record everything they considered, even if it was a recovery measure or hypotheses that was rejected in the end. This might protect their professional credibility from the masters of hindsight. In the days of CAFSAC (the Canadian Atlantic Fisheries Scientific Advisory Committee, 1978-1993), Canadian scientific advice was fairly concise, and Advisory Documents included only the arguments and analyses that survived peer review. Hypotheses and data sets rejected on sound scientific grounds were not included in the final documents – after all, they had been rejected. In the years since, countless authors have castigated the short-sightedness of scientists of the day for “not considering” factors or information, that, with more time and better data, have turned out to be relevant. The thoroughness with which the 2003 Zonal Assessment documented the 47 candidate hypotheses and the reasons for rejecting many of them, shows a desire not to repeat that unpleasant experience.

Fisheries science and management is always challenged to deal with technological creep. Technology will not be frozen during a moratorium or recovery period. In fact, if re-training is offered to fishermen who have been idled during the recovery, the pace of technological change might even be greater during moratoria. Retraining in computers, electronics, and other technologies is readily transferable back to a fishery, should the retrained individual choose to return to the fishery later.

Related to the above point, at least in Canada, fishing is a culture, not just an economic activity. People will come back to the fishery when it reopens, in large numbers and with new skills and high expectations. If part of the reason for the decline or collapse was excess capacity or effort to begin with, unless capacity is *permanently* removed from the fishery early in the recovery period, the problem will be as bad or worse when the biological recovery targets have been reached. *Failure to deal with this reality makes the science and management effort to recovery the stock biologically pointless.*

REFERENCES

CAFSAC. 1986. Advice on the status and management of the cod stock in NAFO Divs 2J, 3K, and 3L. CAFSAC Adv. Doc. 86/25.

CAFSAC 1989. Canadian Atlantic Fisheries Scientific Advisory Committee. Annual report.

- Chouinard, G.A., A. F. Sinclair, and D. P. Swain. 1993. Factors implicated in the lack of recovery of southern Gulf of St. Lawrence cod since the early 1990s. ICES CM 2003/U:04
- CSAS 1996. Overview of the status of Canadian Managed Groundfish Stocks in the Gulf of St. Lawrence and the Canadian Atlantic CSAS SSR 96/40
- CSAS 1997. Overview of the status of Canadian Managed Groundfish Stocks in the Gulf of St. Lawrence and the Canadian Atlantic CSAS SSR 97/G-01
- DFO 1978. Resource Prospects for Canada's Atlantic Fisheries 1979-1985. Ministry of Supply and Services, Govt. of Canada.
- DFO 1980. Resource Prospects for Canada's Atlantic Fisheries 1970-1985. Ministry of Supply and Services, Govt. of Canada.
- DFO 1988. Resource Prospects for Canada's Atlantic Fisheries 1989-1993. Ministry of Supply and Services, Govt. of Canada.
- Finlayson, A.C. 1993. Fishing for Truth *A Sociological Analysis of Northern Cod Stock Assessments from 1977 to 1990*. ISER Press. St. John's.
- Forsey, R. and W.H. Lear. 1987. Historical catches and catch rates of Atlantic cod in Newfoundland 1677-1833. Can. Data Rept. Fish. Aquat. Sci. 662: 52 pp.
- FRCC 1993a. We must stop chasing quotas down to the last fish: 1993 Conservation Requirements for Atlantic Groundfish. FRCC Aug 1993
- FRCC 1993b. Partners in rebuilding fish stocks for our future: 1994 Conservation Requirements for Atlantic Groundfish. FRCC Nov. 1993
- FRCC 1996. Building the Bridge: 1997 Conservation Requirements for Atlantic Groundfish. FRCC Oct 1996
- FRCC 1998. Conservation Must Be Compulsory, not Optional. Annual Report of the Fisheries Resource Conservation Council and Conservation Requirements for Atlantic Groundfish for 1998. FRCC May 1998.
- FRCC FRCC 1999. Fisheries in Transition: Annual Report of the Fisheries Resource Conservation Council and Conservation Requirements for Atlantic Groundfish for 1999. FRCC July 1999.
- Gough, J. 1993. A historical sketch of fisheries management in Canada. pp 5-53. in L.S. Parsons and W.H. Lear, eds. Perspectives on Canadian Marine Fisheries Management. Can. Bull. Fish. Aquat. Sci. 226.
- Halliday, R.G. and A.T. Pinhorn. 1996. North Atlantic fishery management systems: A comparison of management methods and resource trends. J. Northw. Atl. Fish. Soc. 20: 3-135.
- Hutchings, J.A., and Myers, R.A. 1994. What can be learned from the collapse of a renewable resource? Atlantic cod, *Gadus morhua*, of Newfoundland and Labrador. Can. J. Fish. Aquat. Sci. 51: 2126-2146.
- Kurlansky, M. 1997. Cod, A Biography of the Fish that Changed the World Penguin, London.
- Lear, W.H. 1998. History of fisheries in the northwest Atlantic: the 500 year perspective. J. Northw. Atl. Fish. Soc. 23:41-73.
- Munro G.R. 1980. A promise of abundance: extended fisheries jurisdiction and the Newfoundland economy. 111 pp. Economic Council of Canada.

Myers, RA, G. Mertz, and PS Fowlow. 1997. Maximum population growth rates and recovery times for Atlantic cod, *Gadus morhua*. *Fish. Bul. US*, 95: 762-772.

Parsons, L.S. 1993. Management of Marine Fisheries in Canada. *Can. Bull. Fish. Aquat. Sci.* 225: 763 pp.

Patterson, K; Cook, R; Darby, C; Gavaris, S; Kell, L; Lewy, P; Mesnil, B; Punt, A; Restrepo, V; Skagen, DW; Stefansson, G. 2001. Estimating uncertainty in fish stock assessment and forecasting. *Fish and Fisheries* 2: 125-157.

Rice, J.C. Changes to the large marine ecosystem of the Newfoundland-Labrador Shelf. pp 51-103. in K.S. Sherman and H.-R. Skjoldal. (eds) *Large Marine Ecosystems of the North Atlantic*. Elsevier Sci. Press.

Rivard, 1999. Proceedings of the Cod Zonal Assessment Process, Rimouski, Québec. *Canadian Stock Assessment Proceedings Series 99/05*. 140 pages.

Shelton, P.A, J.C. Rice, D. Rivard, G.A. Chouinard and A. Fréchet. 1993. Recent progress on the implementation of the precautionary approach on Canadian cod stocks leading to the re-introduction of the moratorium. *ICES CM 2003/Y:15*

Sinclair, A., Gascon, D., O'Boyle, R., Rivard, D., and Gavaris, S. 1991. Consistency of some Northwest Atlantic Groundfish Stock Assessments. *NAFO Sci. Coun. Studies*, 16:59-77.

Sinclair, A. F. 1993. Report on the assessments of groundfish stocks in the Canadian northwest Atlantic, May 4-14, 1993. *Can. Tech. Rep. Fish. Aquat. Sci.* 1946E: vi + 215 p.

Smedbol, R.K., Shelton, P.A., Swain, D.P., Frechet, A. and Chouinard, G.A. 2002. Review of population structure, distribution and abundance of cod (*Gadus morhua*) in Atlantic Canada in a species-at-risk context. *Can. Sci. Adv. Sec. Res. Doc.* 2002/082, 134p.

Table 1. Status of cod as reported in the assessment done closest in time to the decision to close directed fishing on each stock, relative to peak abundance (four year average) in 1980s (Data from CAFSAC and ASAS Research Documents). Indicators of stock status vary among stocks, due to differences in assessment approaches, but when possible correspond at least roughly to mature biomass or abundance. Some closures were made part way through a fishing year, so the TAC in the year of closure was not zero, and closest assessment could have been *after* the closure. However, information from surveys and catches that was available when the decision was made might have used for the first time in the following, rather than preceding assessment.

STOCK	YEAR OF CLOSURE	INDICATOR OF STATUS	ESTIMATE IN YEAR OF CLOSURE	BEST 4 YEAR MEAN IN 1980s (yrs)	PERCENT CLOSURE vs MEAN
2GH	NA	No analytical assessments			
2J3KL	1992	SSB (t)	72,000	296,000 (84-87)	24.3
3NO	1995	5+ Numbers	8,646	98,185 (84-87)	8.8
3Ps	1993	SSB (t)	108,595	158,447	68.5
3Pn4RS	1993	5+ Biomass	42,540	323,775 (82-85)	13.1
4TVn	1993	5+ Biomass	48,726	237,878 (82-85)	20.5
4Vn(m-o)	1993	RV # per tow	47.67	140.0 (82-85)	34.0
4VsW	1993	3+Biomass	15,600	97,000 (79-82)	16.1
4X/5Y*	<i>Not Closed</i>	<i>3+ Biomass</i>	<i>29,687 in 1994</i>	<i>63,533 (79-82)</i>	<i>49.1</i>
Georges Bank (5Zj-m)	1995	4+ Biomass	9,925	24,965 (79-82)	39.8

- Included for illustrative purposes to show magnitude of change that did not prompt a closure.

Table 2. Status of cod as reported in the assessment done closest in time to the decision to REOPEN directed fishing on each stock, relative to status in the year of closure *as estimated in the year of reopening*. (http://www.dfo-mpo.gc.ca/csas/Csas/English/Publications/Research_Doc_e.htm). Indicators used highly variable, because assessments changed substantially when commercial catches were no longer available. (This could be quite different from the estimate of the parameter in the year of closure. Indicators of stock status vary among stocks, due to differences in assessment approaches, but when possible correspond at least roughly to mature biomass or abundance.

stock year of reopening indicator estimate at reopening percent of estimate at closure

STOCK	YEAR OF REOPENING	INDICATOR	ESTIMATE IN YEAR OF REOPENING	PERCENT OF ESTIMATE IN YEAR OF CLOSURE
2J3KL	1998	Offshore Survey Biomass Inshore Survey biomass	21,158 130,000	41.8 Not recorded
3NO	Not reopened			
3Ps	1997	3+ Biomass	124,946	116
3Pn4RS	1997	SSB	25,283	96.0
4TVn	1998	SSB	73,000	109
4Vn(m-o)	Not reopened			
4VsW*	<i>Not Reopened</i>	<i>3+ Biomass</i>	<i>13,461</i>	<i>106</i>
4X**	<i>Never closed</i>	<i>3+ Biomass</i>	<i>41,752</i>	<i>141</i>
Georges Bank	1996	SSB	19,786	109

* 4VsW has not been reopened. Last value from 1998 assessment contrasted with 1993 value from the same assessment to illustrate an increase that did not result in reopening.

** 4X was never closed. Last value from 1998 assessment contrasted with 1993 value from the same, to illustrate trend in stock supporting a managed fishery.

Table 3: Inventory of the Hypotheses for failure of several Canadian cod stocks to rebuild that were considered at the cod Zonal Assessment Meeting in February 2003. The goal was to conduct a comprehensive review of potential causal factors, and some interaction or overlap of hypotheses was not considered a serious problem. It was acknowledged that data would not be sufficient for rigorous testing of all hypotheses, and the meeting took a “weight of evidence” approach to evaluating the alternatives.

Hypotheses regarding failure to rebuild because recruitment has been inadequate to promote increase in stock size.

General

H1. The Spawning Biomass is very low. (i.e, there is a stock recruit relationship, and the stock is way down on the ascending limb).

H47. Patterns of distribution in space and time have changed, even of the mechanisms causing the changes cannot be documented, and the consequences of the new patterns are not known (WEAK explanation of anything).

Low recruits per spawner

H8. Physical oceanographic conditions for development are less favourable than they used to be. (We would have to document which oceanographic properties have changed – temperature, salinity, etc. It would be helpful but not essential to also have a mechanism that linked the property to successful development.)

H9. Transport paths have changed such that eggs and larvae travel through or end up in areas less suitable for development. (As with 8, we would have to document the changed paths, and the test would be stronger if we had a mechanism by which development was impaired).

H10. Oxygen content of the water has become lower, leading to increased direct mortality of eggs or larvae.

H11. Predation on eggs and larvae has increased. (We would have to document which predators, ideally with both coincident trends in populations and diet data. Having both would be much stronger than having either alone.)

H12. Productivity of key foods for larvae has deteriorated leading to increased direct mortality due to starvation. (Which foods – both trends and cod diet data?)

H13. Productivity of key foods for larvae has deteriorated, leading to reduced larval growth rate (have to document which foods from trends and diets). The reduced growth rate means size dependent mortality (any cause, but predation is an obvious one) at a constant rate over time will lead to greater mortality of the cohort.

H14. Competitors for larval food have increased their abundance and/or consumption of shared foods, reducing the cod food supply, allowing consequences in 12 and/or 13.

Reproductive biology is disrupted

H2. Kilogram for kilogram small/young spawners are less effective (fecundity and/or viability of products) spawners than old/large spawners, and the age/size composition of the SSB is very young/small.

H3. The condition of the spawners is poorer than “usual”, such that per capita or per kg fecundity is impaired (either fewer eggs per kg or lower lipid/energy content per egg).

H4. The abundance of spawners is reduced so low that spawning behaviour has been disrupted (“Allee effect”), disproportionately reducing the fecundity per kg of SSB. (Behavioural depensation – even if the specific mechanisms are not known)

H7. Human activities that interfere with successful spawning now are occurring in cod spawning areas, at levels greater than they did when recruitment was better.

H40. Body burdens of contaminants have increased, with possible (documentable?) detrimental effects on fecundity.

H44. The life history of cod has changed (due to directional selection by fishing?) such that energy allocation among reproduction and growth is different. (It would be necessary to carry on to population dynamics consequences of the changes)

H45. Intensive selective fishing has resulted in a population of cod with smaller quasi-terminal size, and corresponding consequences for *m* and fecundity. (could be considered a special case of 44.)

Population biology of reproduction is disrupted

H5. Spawning components have been lost from the population, with detrimental impacts on stock productivity. (Spatial depensation - We could but would not have to specify the mechanism by which

productivity is impacted. Just documenting lost components would probably be accepted as a reason why recruitment could be impaired).

H6. Spawning now takes place in non-traditional places, resulting in less effective release of reproductive products. (We would probably have to provide more in the way of causes and mechanisms than in 4. Is the timing of migration disrupted? Are suitable water temperatures now distributed differently than in the past? Are the places where the eggs are likely to be transported now different from where they used to be transported?)

Hypotheses regarding failure to rebuild because growth and production have been inadequate to increase biomass significantly

General

H44. The life history of cod has changed (due to directional selection by fishing?) such that energy allocation among reproduction and growth is different. (It would be necessary to carry on to population dynamics consequences of the changes)

Environmental effects on juvenile or adult growth

H16. Growth is temperature dependent and temperatures have been less favourable in recent years.

H17. Some other physical oceanographic conditions for development are less favourable than they used to be. (We would have to document which oceanographic properties have changed – salinity, oxygen etc. It would be helpful but not essential to also have a mechanism that linked the property to successful development.)

H39. Physical environmental conditions have altered in ways that reduce growth rate of cod, (whether or not the mechanism can be documented). Reduced growth rate combined with size-dependent mortality and / or fecundity have detrimental population consequences.

H26. Habitat quality for juveniles has been reduced, especially due to human activities (trawling). (Necessary to document what habitat features have been changed, and how widespread the changes are).

Hypotheses regarding failure to rebuild because Mortality has been too high to allow populations to grow

Impacts of Fishing (examine for adults and juveniles separately when possible)

H30. Fishing mortality due to recorded catches (by fleet sector) has slowed population growth

H31. Mortality due to unreported catches and/or discards has slowed population growth.

H32. Mortality due to non-retention in fishing gears has slowed population growth.

H27. Mortality rates of juveniles have increased due to bycatch and discards in fisheries for small pelagics (capelin, herring?) or invertebrates (shrimp). (Necessary to document bycatch rates and effort in the fisheries).

H28. Mortality rates of juveniles have increased due to non-retention mortality in groundfish gears. (Necessary to document bycatch rates and effort in the fisheries).

H15 and H23. The intrinsic (genetic?) growth rates of individuals has been reduced, such that even with sufficient food, mortality factors at a constant rate over time result in greater mortality on the cohort. This is accentuated if mortality sources are size dependent.

Changes in Natural Mortality – General (examine for juveniles and adults separately when possible)

H29. Natural mortality has been documented to have increased, but the mechanism is unknown.

H42. Body burdens of contaminants have increased, with possible (documentable?) detrimental effects on survivorship.

H43. Body burdens (or species composition) of parasites or disease organisms have increased, with possible (documentable?) detrimental effects on survivorship (or fecundity?)

H46. Post spawning mortality has increased, whether or not the mechanism responsible for the increase can be documented. (More convincing, of course, if it can be).

Changes in Natural Mortality - Trophodynamic causes

H18. Predation by marine mammals has increased, and reduced cohort survivorship compared to historic rates. (Should be supported by both population and diet data.)

H33. Predation mortality by marine mammals has impaired population increase.

H19. Predation by a specified other predator or suite of predators has increased, and reduced cohort survivorship compared to historic rates. (Should be supported by both population and diet data.)

- H20. Productivity of key foods for juveniles has deteriorated leading to increased direct mortality due to starvation. (Which foods – both trends and cod diet data?)
- H21. Productivity of key foods for juveniles has deteriorated, leading to reduced juvenile growth rate (have to document which foods from trends and diets). The reduced growth rate means size dependent mortality (any cause, but predation is an obvious one) at a constant rate over time will lead to greater mortality of the cohort.
- H22. Competitors for juvenile food have increased their abundance and/or consumption of shared foods, reducing the cod food supply, allowing consequences in 20 and/or 21.
- H24. Timing of food availability has changed such that annual cycle of feeding and growth are disrupted. (This would require documenting change in timing such as earlier or later spring bloom, and would be helped documenting some relationship of feeding or growth to the food items whose temporal availability has changed.)
- H35. The timing of food availability changed in ways that are detrimental of the annual cycle of feeding, energy storage, growth and/or reproduction.
- H34. The quantity of food is insufficient to maintain growth and/or survivorship. (Necessary to document which foods with trends and diet data).
- H25. Although the *quantity* of food has remained at historic levels, the *quality* of food has deteriorated in some way, which would have to specify, such as reduced lipid levels in prey.
- H36. The *quality* of food has declined, either through changed species composition of diet or lower lipid or nutrient content of traditional prey.
- H37. The spatial distribution of prey has changed in ways such that even if amounts have not declined, availability to cod has declined.
- H38. Condition factor has been reduced for some or all parts of the year, whether or not any changes in feeding conditions have been documented. (This would benefit from some demonstrated consequences of poorer condition on growth, survivorship, or fecundity.)
- Changes in Natural Mortality - Environmental causes*
- H41. Physical environmental conditions have altered in ways that directly increase the mortality rate of adult cod (winter lethal temperatures or other mechanisms.)
- H42. Physical environmental conditions have altered in ways that affect the distribution and/or migration of cod, such that they spend parts of their annual cycle in non-traditional (can it be demonstrated less suitable) places. (whether or not we can document consequences of being displaced from traditional locations).
- H26. Habitat quality for juveniles has been reduced, especially due to human activities (trawling). (Necessary to document what habitat features have been changed, and how widespread the changes are). Table 4 – conclusions of ZAP regarding causes of lack of recovery

Table 4: Conclusions of the Zonal Assessment Meeting regarding the slow recovery of several Canadian Atlantic cod stocks. All text are quotes extracted from the Press Release at the end of the meeting.

Expectations of rapid recovery were unrealistic, given the low spawning biomass and typical productivity of these stocks.

All these stocks live in cold environments and show low productivity compared to many other cod stocks further south, and in the Northeast Atlantic. During at least the first half of the 1990s the ocean climate was particularly unfavourable for cod, and cod productivity worsened.

In addition to effects of fishing, adult mortality from other causes is very high for all these stocks.

Although causes of this elevated mortality are not fully known, it was possible to conclude that:

- ❑ Estimates of cod consumed or otherwise killed by seals are high enough that such mortality contributed to the lack of recovery in all areas.
- ❑ For at least of the some stocks, the energetic condition of cod following spawning was particularly low in the early 1990s, and may have been low enough to result in mortality.
- ❑ A number of other factors were considered, but the evidence available does not suggest that they contributed importantly to the high adult mortality.

Mortality due to fishing is also a factor in the failure of these stocks to recover:

- On stocks where fisheries were reopened, removals reached levels that took or exceeded surplus production, contributing to the cessation of stock rebuilding and reversals of what increases had occurred.
- Discarding, misreporting, poaching, and unreported catches occur in both commercial and recreational fisheries. However, the likely scale of these removals is such that fixing them alone would not be sufficient to ensure recovery.

In offshore 2J3KL, bycatches in a number of foreign and domestic fisheries are poorly monitored, and could be a factor in the failure of this stock to increase.

Size at age was low at the beginning of the moratorium for all stocks, contributing to slow initial rebuilding

Studies of the reproductive potential of cod stocks indicate that first time spawners are generally less successful than repeat spawners; fish in poor energetic condition have lower fecundity; and small spawners have shorter duration of spawning. All of these factors mean that larger, older spawners contribute more per kilogram to the reproductive potential of a stock.

- At the beginning of the moratorium all stocks had very few older fish and a high proportion of first time spawners, contributing to the slow initial rebuilding
- The lack of older spawners and poor energetic condition of fish, for the periods when those circumstances occurred in each stock, contributed to the disproportionately low reproductive potential of the depleted spawning biomass.

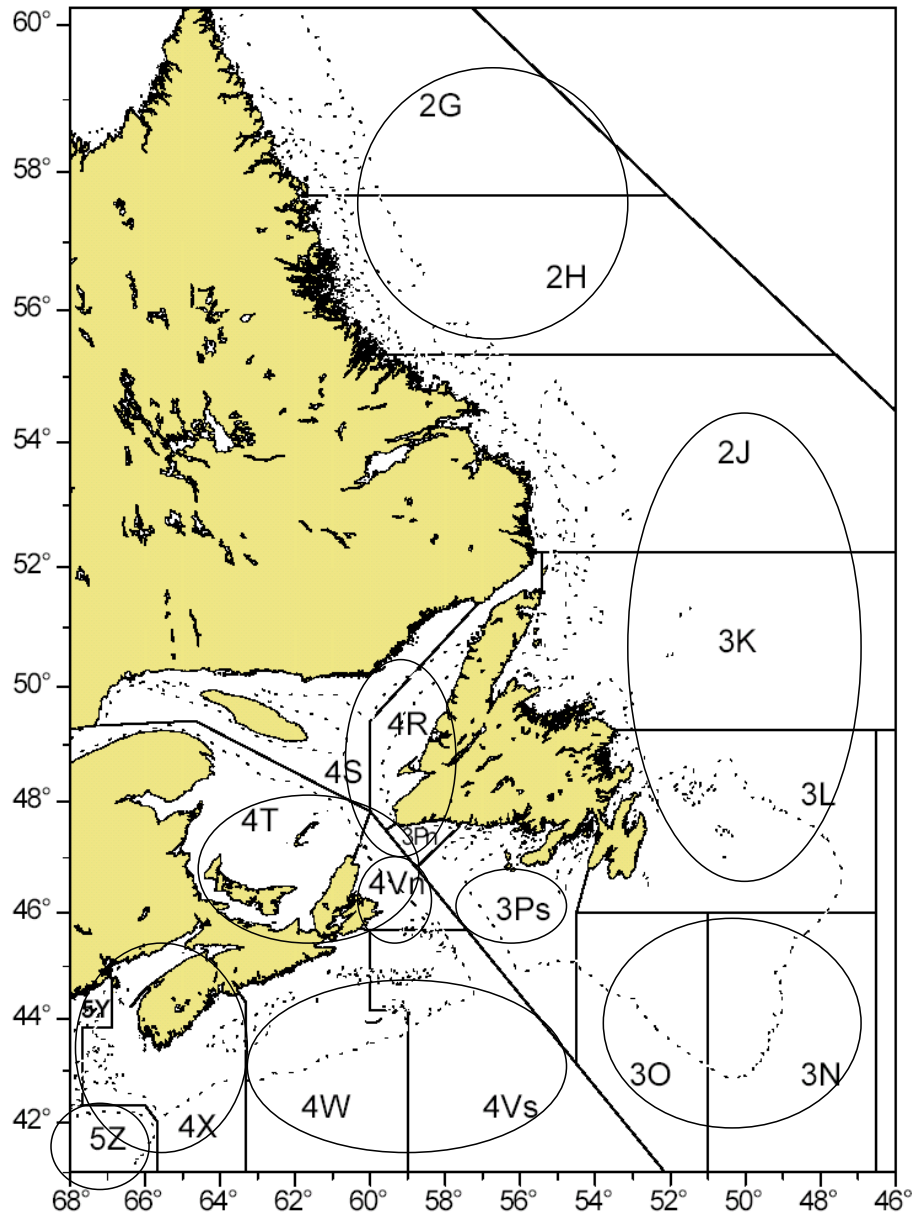
In the southern Gulf increasing abundance of mackerel and herring are expected to result in high predation on cod eggs and larvae in the coming years. This source of predation may also decrease cod productivity in the northern Gulf.

For stocks where the distribution of spawning components has been examined, severe reduction of the size of some spawning components or reduced area of spawning are contributing to the poor recovery of cod stocks.

Where maturation rates have been monitored, cod are maturing at younger ages. This has not resulted in recovery of any of these stocks.

Taken together, these factors strongly suggest that there will not be a prompt recovery in any of these stocks.

Fig 1 – Stock distributions for Canadian Atlantic cod stocks.



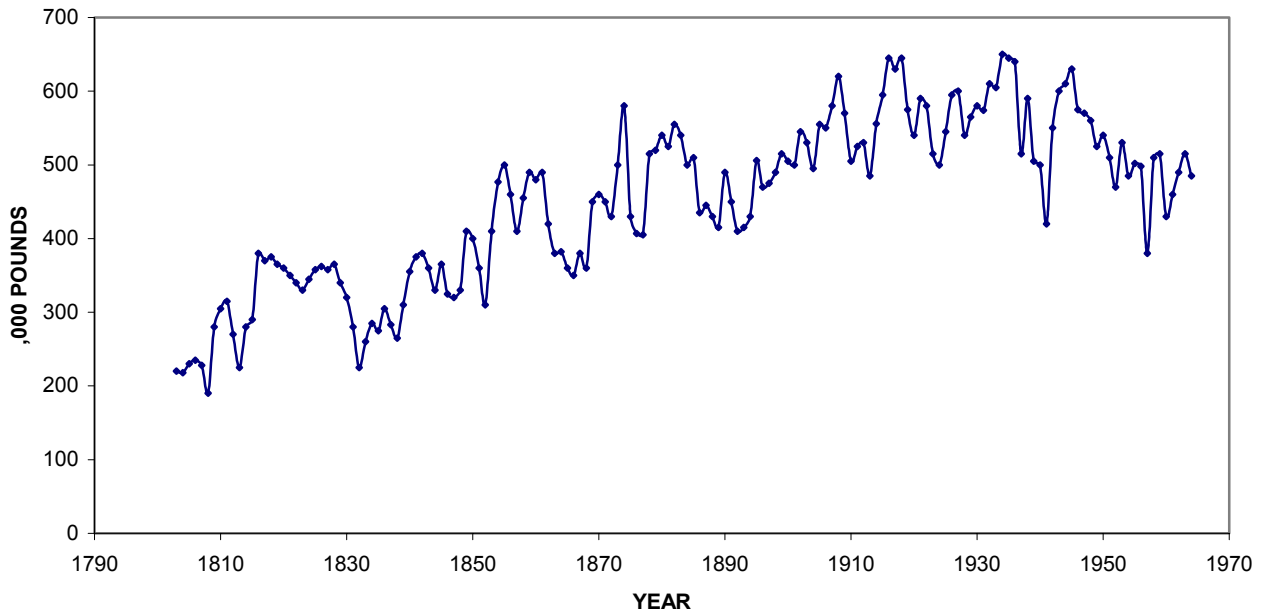


Fig 2 Reconstruction of catches of Newfoundland cod from Divisions 2HJK3LNOP from late 1700s to 1970, based on archived export records (data from Lear and Forsey 19xx)

Fig 3 – SPA biomasses for most Canadian cod stocks. Axes are in tonnes, and 2J3KL cod (dashed line) is scaled on the secondary (right) axis. All others are on primary (left) axis.

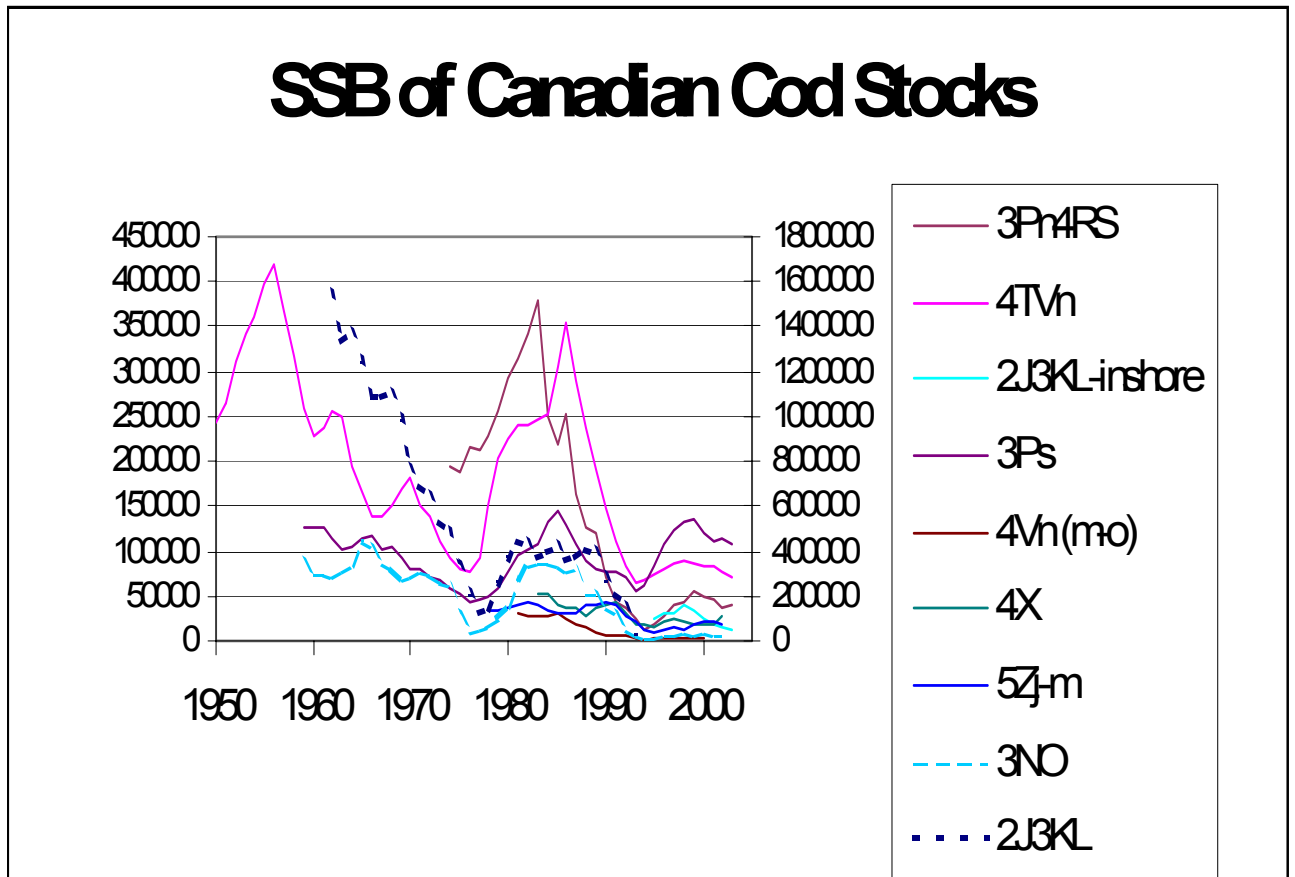


Fig 4 – Recruits per spawner for several Canadian Atlantic cod stocks, during two periods of decline and recovery. (See Shelton et al. 2003 for computational details.)

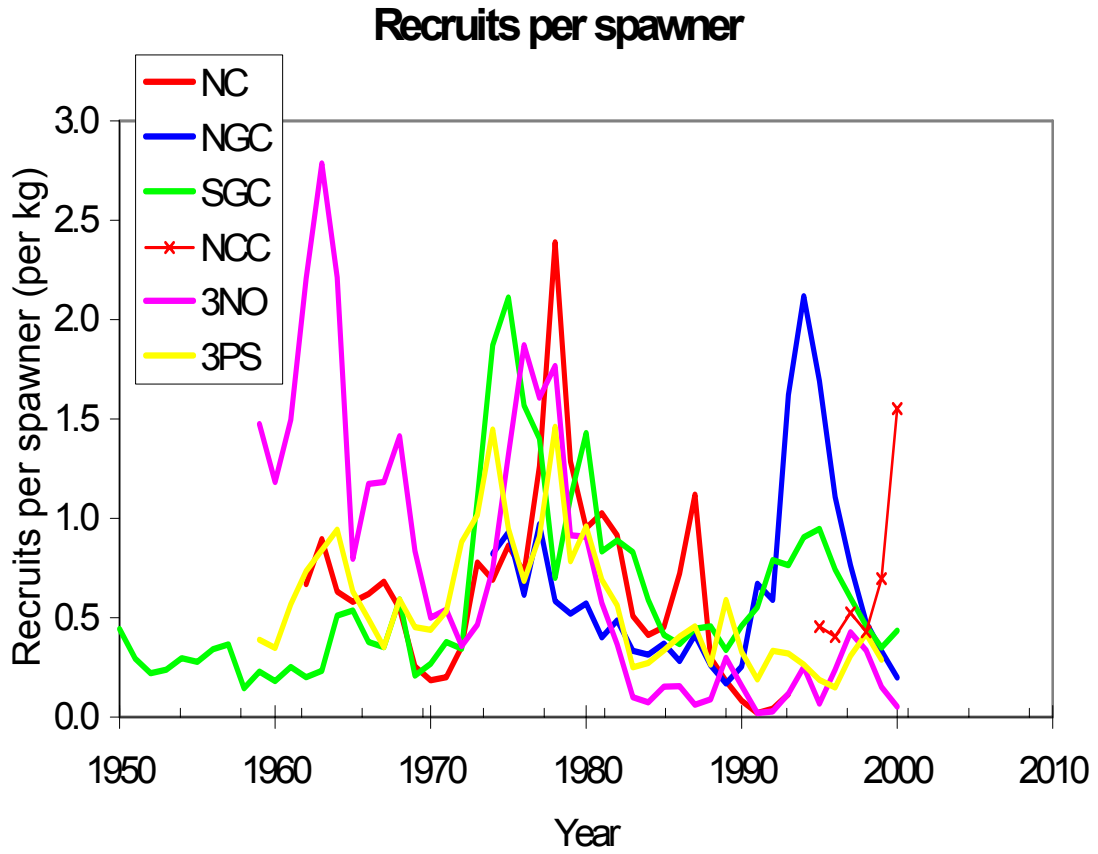


Fig 5 – Surplus SSB production of four Canadian cod stocks subjected to strong management efforts at recovery. (See Shelton et al. 2003 for details of the measure of productivity).

Surplus SSB production under annual F

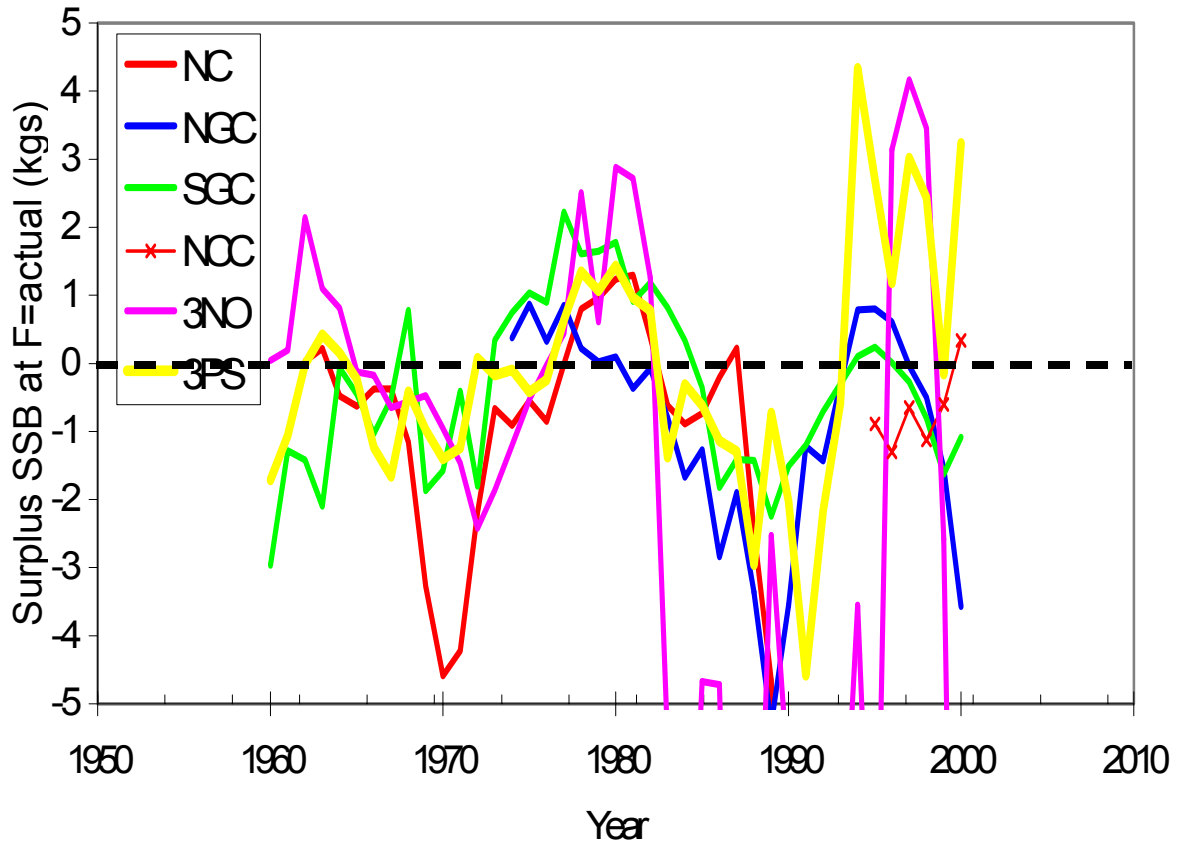


Fig 6 – Estimate production of Canadian cod stocks in Fig 4, had no harvesting been allowed (top), and with actual harvesting rates (lower). (See Shelton et al 2003 for details of the measure of productivity).

