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# Management strategies for recovery of northern cod

# Stratégies de gestion pour le rétablissement de la morue du Nord

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## ABSTRACT

Current management plans for depleted cod stocks in the Canadian portion of the Northwest Atlantic do not contain specific recovery strategies. This paper suggests a recovery strategy based on achieving 5% spawner biomass growth per annum. Only TAC options with a very low risk (<0.1) of not achieving this level of biomass growth would be considered under this recovery strategy. Application of this approach in short-term projections of the inshore component of northern cod gives TAC options>0. However, long-term projections suggest little or no rebuilding of the stock as a whole under current natural mortality rates even with no fishing. If cod currently inshore have a tendency to move to the offshore and successfully spawn there, and there is a decline in mortality rate, then the inshore could make a substantial contribution to recovery of northern cod.

## RÉSUMÉ

Les plans de gestion actuels des stocks de morue décimés de la portion canadienne de l'Atlantique Nord-Ouest ne renferment pas de stratégie de rétablissement particulière. Le présent document propose une stratégie de rétablissement basée sur une croissance de la biomasse génitrice de 5 % par année. Seuls les TAC dont le risque de ne pas atteindre ce niveau de croissance de la biomasse est très faible (<0,1) seraient envisagés dans le cadre de cette stratégie. L'application de cette approche dans les projections à court terme de la composante côtière de morue du Nord donne des possibilités de TAC de >0. Toutefois, les projections à long terme semblent indiquer un rétablissement faible ou nul du stock dans son ensemble si le taux de mortalité naturelle actuel est maintenu, même sans pêche. Si les morues actuellement en zone côtière ont tendance à se déplacer vers la haute mer pour y frayer avec succès et que le taux de mortalité diminue, la composante côtière pourrait apporter une contribution substantielle au rétablissement de la morue du Nord.

## INTRODUCTION

Current management plans for depleted cod stocks in the Canadian portion of the Northwest Atlantic do not contain specific recovery strategies. Under the Precautionary Approach, fishing mortality for stocks below the spawner biomass limit reference point should be kept to the lowest possible level to promote stock growth. So far this has not been implemented. This paper promotes a science-based recovery strategy with a target SSB rebuilding rate of 5% per annum, based on a review of current cod productivity conditions in the northwest Atlantic (Shelton *et al*. 2006). Only TAC options with a very low risk (<0.1) of not achieving this level of biomass growth would be considered under this recovery strategy. Adoption of a specific rate target and risk tolerance combination may result in a zero TAC in some years, but would promote stock rebuilding and, while not completely compliant with the Precautionary Approach for stocks below the limit reference point, would be a step in the right direction. It would also be supportive of Canada's undertaking with regard to sustainable fisheries which, in terms of the Johannesburg Accord (2002), requires depleted stocks to be rebuilt to $B_{msy}$ by 2015.

Choices related to rebuilding rates and risk tolerances are to some degree national societal issues with feedback provided by the public to the political process of decision making. These choices may be constrained to some degree by international commitments made on behalf of Canadian society with global best interests in mind. The task of fisheries science is to quantify rates and risks as best as possible and to present this information to fisheries managers, public and the global community, as a basis for decision-making. While the decision-making process may dictate a low rebuilding rate or a high risk of not meeting a target in order to meet perceived societal needs, the scientific information on rates and risks provides an objective baseline for national public auditing and global evaluation of management performance with regard to stated objectives. Such an approach is required in terms of the United Nations Fish Stocks Agreement and the St John's Decleration (http://www.dfo-mpo.gc.ca/fgc-cgp/declaration_e.htm ), both of which imply Government will implement a decision-making process which relies on the best scientific information available and incorporates the Precautionary Approach.

This study has two parts. In the first part TAC options for 2006 for the remnant of northern cod, those fish occupying the inshore central area off the east coast of Newfoundland (southern 3K and northern 3L), are explored using short-term (1-3 years) stochastic projections to determine the risk of not attaining specified target SSB rebuilding rates such as 5%. The three year projection assumes a constant TAC. In the second part long-term deterministic scenario simulations are carried out to investigate the possible impact of an inshore fishery on the recovery of the stock as a whole.

## METHODS

*Short-term projections*

Projections were carried out to January 1, 2009 (3 years), based on bootstrap samples of estimates of survivors on January 1, 2006 generated from the final ADAPT applied in the 2006 stock assessment to the inshore central commercial catch and tuning data (southern 3K and northern 3L; Lilly *et al*. 2006). The bootstrap samples were obtained by randomly resampling index residuals and adding these to model predicted indices to generate new replicate pseudo-data sets. Note that resampling is across indices and ages, i.e. a residual from a sentinel gillnet index at age 3 could be randomly allocated to be added to the predicted sentinel linetrawl index at age 6 to obtain the new bootstrap replicate data point. This is consistent with the assumption of independent and identically distributed (iid) residuals made in ADAPT estimation. The least squares minimization (fitting of the ADAPT) is repeated for each replicate data set to obtain the non-parametric bootstrap estimates of survivors on January 1, 2006. Although bias-corrected bootstrap was explored in the study, peer-review at the assessment meeting concluded that at the present time results should be presented without bias-correction.

Biological inputs and partial recruitment were adopted from the deterministic projection carried out as part of the assessment (Lilly *et al*. 2006) and are given in Table 1. Weights at age are the geometric means (GM) for the period 2003-2005. Maturity values are cohort model estimates for 2006-2009 from the assessment. Partial recruitment at age is obtained from the GM of fishing mortality estimates at age for 2000-2002 from the final 2006 ADAPT, rescaled to have a maximum of 1 for the fully selected age. There was a limited fishery in the inshore over this period before a return to moratorium on directed fishing in 2003. Bootstrap estimates in the 2006 ADAPT are for ages 4-10. Numbers at age 1-3 were generated by first back-calculating preceding numbers at age in the cohort from bootstrap survivors at ages 4-6 in 2006, based on the assumed value of *M* and the reported catch at age. The GMs of the most recent 3 estimates in each age were then used to generate a bootstrap sample of survivors for ages 1-3 in 2006. Thus for age 1 in 2006, the GM was computed on back-calculated bootstrap estimates for age 1 in 2001-2003. Similarly the value for age 2 in 2006 was the GM of age 2 values in 2002-2004 and for age 3 in 2006, the GM of age 3 in 2003-2005.

The risk of SSB not growing or growing by less than 5% and 10% per year was computed after 1 and 3 years from 1000 projections of the bootstrap survivors. It should be noted that this risk calculation is based on fitting an observation error model. Process error, such as uncertainty in *M*, is not considered.

*Long-term scenario simulations*

The long-term scenario simulations modeled inshore and offshore northern cod components linked through migration of inshore fish to the offshore. This allows consideration of possible impacts of an inshore fishery on the rebuilding of the stock as a whole, an important consideration identified in previous recent assessments of this stock. Weights and proportion mature at age were based on the GM of the last three years data in the 2005 assessment, with the PR calculated from the average of the 2000-2002 *F* values estimated in the 2005 assessment of inshore cod. The same values of biological inputs and PR were used for both inshore and offshore components in these preliminary runs. Inputs are given in Table 2. Natural mortality and fishing mortality on the inshore and offshore components, as well as the migration rate of inshore fish to the offshore, were varied to create different scenarios. Total mortality on this stock estimated from RV data is currently considered to be extremely high (DFO 2006a; instantaneous rate of total mortality of about 0.9). At this high mortality rate, modeled biomass in the offshore is rapidly depleted. Given that some of this mortality may be fishery induced through unreported deaths, an arbitrary base value of $M$=0.6 was adopted for the offshore component in the simulations.

The starting population size for the inshore was set at the numbers at age estimated in the final ADAPT in the 2005 assessment. Estimates of fish age 1-3 in 2005 were assumed to equal the average of back-calculated estimates from older cohorts in 2005. Starting population for the offshore was based on the fall 2004 RV index of numbers at age. To convert the index to population numbers at age, the Campelen-equivalent indices at age for the period 1983-1992 from Lilly *et al*. (2003) were compared with the 1992 assessment ADAPT estimates of numbers at age over the same years from Baird *et al*. (1992) to obtain a median catchability $q$ at age. Younger ages missing in the ADAPT were back-calculated taking into account reported catches and $M$=0.2. The resulting vector of catchabilities for ages 2-10 (12709, 11587, 10676, 10993, 11564, 14686, 13976, 11429, 12422) was then used to convert the 2004 fall RV index at age (Lilly *et al*. 2006) into numbers at age. Before the conversion, the RV estimate at age for 2004 was smoothed by fitting a regression model to the logarithm of the survey indices at age for each cohort separately and using the estimates of the slope and intercept to obtain a predicted value for 2004. For ages younger than age 4, the average of the RV index at age for the last 5 years was used instead. These values were then moved forward by one year and age to represent the population at the beginning of 2005. Recruitment was generated from segmented regression model fits to the SR data obtained using the Julious algorithm (see Shelton 2006 for details; Figs. 1 and 2). For the offshore, SR data are from the 1992 ADAPT assessment of the stock as a whole and for the inshore from the 2005 assessment of the inshore remnant.

## RESULTS

*Short-term projections*

Table 3 and Fig. 3 provide estimates of the risk of SSB not growing by at least 5% or 10% per annum over a 1 and 3 year time horizon for different TAC options. At a TAC of 1000 t the risk of SSB growing by less than 5% is under 0.05 for both 1 and 3 year projections, but increases rapidly with TAC options above 1000 t. At 3000 t the risk is 0.5 or greater over both 1 and 3 year time horizons. The risk of SSB growing by less than 10% increases to more than 0.5 above a TAC of 1000 t and is about 0.9 for both 1 and 3 year projections at a TAC of 3000 t.

*Long-term scenario simulations*

The long-term scenario simulations show that under assumptions of $M$=0.4 in the inshore and $M$=0.6 in the offshore (and assumptions about SR and other biological properties), the inshore component will not grow after the initial few year years and the offshore component will decline in the long term even in the absence of fishing (Run#1, Fig. 4). Initial growth in SSB in both the inshore and offshore is attributable to a "bulge" in numbers at age estimated for ages 5 and 6 which moves through the population (i.e. an unstable age composition). This initial growth in the inshore is consistent with the results from the short-term projections, but it is of some concern that under $M$=0.4 biomass in the inshore is not predicted to continue to grow based on recruitment generated from the segmented model fit.

An arbitrary 15% per annum migration of inshore fish to the offshore increases the initial response in the offshore SSB, but does not prevent a long-term decline in the offshore (Run #2, Fig. 5). The movement of fish from the inshore to the offshore creates a marked declining trend in the inshore with little positive effect in the offshore.

Halving $M$ in both the inshore and the offshore has a positive effect in terms of SSB growth in the absence of any fishery (Run #3, Fig. 6) with both components continuing to increase though the simulation period. Halving $M$ and including a 15% per annum migration of inshore fish to the offshore substantially increases the growth of SSB in the offshore to the detriment of the inshore (Run #4, Fig. 7), although inshore SSB does not fall below current levels.

Halving $M$, switching off migration and including inshore $F$=0.2 causes the inshore to reach an SSB in 2020 of about half of what is achieved in the absence of any fishing under the same $M$ (Run #5, Fig. 8). If, under this scenario, inshore fish also migrated to the offshore at a rate of 15% per annum, this would result in no growth in the inshore SSB but considerably enhanced growth of the offshore biomass (Run #6, Fig. 9). Run #6 is not that different from results obtained under the same natural mortality and migration rates, but with no fishing on the inshore (Run #4, Fig. 7).

# DISCUSSION

*Management context*

For a collapsed fish stocks such as northern cod and other collapsed Canadian Atlantic groundfish stocks, recovery rate should be an important consideration in any management strategy. Trading off some of the potential recovery to address immediate social and economic pressures is a political decision nationally, but one that has to be increasingly justified globally in terms of the Precautionary Approach (PA) and sustainable fisheries objectives. Quantitative analysis of recovery potential can provide an objective context for making such decisions and serve as an evaluation reference for audits and checklists of management progress, both nationally and in the international community, for example with respect to meeting sustainability targets outlined in the Johannesburg Accord.

In February 2003 three of the four cod stocks on which fisheries had reopened after moratorium were assessed by DFO Science to be below their respective PA spawner biomass limit reference points. Despite contrary advice from the Fisheries Resource Conservation Council (FRCC) to keep the fisheries open (http://www.frcc.ca/2003/EGulf.pdf ; http://www.frcc.ca/2003/2j3kl.pdf ), in April 2003 the Minister of Fisheries and Oceans announced "All three of these stocks are below the levels where the harm is serious and it may be very hard to reverse this trend. It is clear that rebuilding is a long process but we must begin now." (Canadian Broadcasting Corporation, Video Archives). The decision to close the directed fisheries on the basis that the stocks were below their respective limit reference points was taken to imply Canada had begun to implement the PA in 2003 (Shelton *et al*., 2003). However it later became clear that this was a "once-off" decision and did not imply PA implementation by DFO. Directed fisheries reopened again on the two Gulf cod stocks in 2004 despite no improvement in the status of these stocks and a bycatch "allowance" of northern cod was introduced in a fishery for winter flounder, a species of limited commercial value. Cod catches exceeded those of winter flounder in this fishery by a large factor (Lilly *et al*., 2006), making it *de facto* a directed commercial cod fishery. Recent DFO scientific assessments have determined that there will be little or no recovery of these three cod stocks under current removal levels ( http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_010_E.pdf ; http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_014_E.pdf ; http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_015_E.pdf ).

In May 2003 the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), charged with determining species at risk status under the Species at Risk Act (SARA), concluded that northern cod is Endangered, northern Gulf cod is Threatened and southern Gulf cod is of Special Concern. If DFO had in place a science-based rebuilding strategy, it is possible that COSEWIC may have expressed less serious concern regarding the fate of these stocks. If accepted by Government, determinations of Endangered and Threatened would, under SARA, place heavy restrictions on any form of harm to the population or habitat and require formal rebuilding plans to be developed and implemented. Three years later, in April 2006, Government announced that it would not list the three cod stocks under SARA. Instead, comprehensive recovery plans for cod would be completed and DFO would continue to pursue strong conservation measures with the provinces, fishers and key stakeholders (http://news.gc.ca/cfmx/view/en/index.jsp?articleid=205909 ). Reasons given by Government for not listing included economic and social costs which were considered to outweigh the benefits (http://canadagazette.gc.ca/partII/2006/20060419/html/si61-e.html ), based on results from bio-economic models (http://www.dfo-mpo.gc.ca/species-especes/cod/main_e.asp ). These models included arbitrary cod population scenarios that have not been peer reviewed. The socio-economic aspects have also not been peer reviewed. Consequently, the strengths and weaknesses of the analysis are as yet undetermined. The analyses exclude any non-use value that Canadians might place on protecting species from extinction and rebuilding them to healthy states, and there has been no accounting for uncertainty and risk in future states.

The comprehensive recovery plans alluded to in the decision on SARA listing refers to the products of three federal-provincial-industry Cod Action Teams (CATs) that were established in Newfoundland/ Labrador, Maritimes, and Quebec in 2003 (http://www.dfo-mpo.gc.ca/media/infocus/2005/20051123_e.htm ). These teams have developed long-term "rebuilding strategies" which DFO anticipates will play a major role in the management of cod stocks in the coming years. However, there were no quantitative analyses carried out to support this exercise and the rebuilding strategies are expressed in general terms only, with no specific goals or target rebuilding rates. It should be noted that specific recovery goals and target rebuilding rates would have been required had the populations been listed under SARA.

*Recovery strategies*

The current research document provides an evaluation of short-term risk associated with TAC options for the inshore remnant of northern cod and explores longer-term rebuilding scenarios for the stock as a whole, some of which involve inshore fish recolonizing the offshore. The inshore remnant that overwinters mainly in Smith Sound, Trinity Bay (northern 3L) and disperses in the spring through the inshore portion of northern 3L and southern 3K may be very important with respect to the future of the northern cod stock. Acoustic surveys have estimated the biomass to be about 20,000 t in recent years (DFO, 2006a). These fish may comprise the best hope for rebuilding northern cod if they have the capacity to move offshore, survive and spawn, i.e. "recolonization". The alternative option of "resurgence" in the offshore seems remote given the continuing high mortality that appears to be occurring and the lack of any known prespawning aggregations. Is there something to preclude inshore cod moving offshore? The degree of separation between inshore and offshore cod has been reviewed a number of times in the past (e.g. Lilly, *et al*. 1999, Smedbol *et al*. 2002). Genetic work on microsatellite loci has suggested that most cod in the inshore are significantly different from most cod in the offshore but, interestingly, fish sampled in Trinity Bay were not significantly different from fish sampled from northern Grand Bank.

Based on population estimates for the inshore and productivity assumptions, there is a low (<0.05) risk that the inshore biomass would increase by less than 10% over both one and three year time horizons if not fished. However, removing 3,000 t annually in a fishery is expected to lead to a probability of 0.5 or more of not increasing by 5%, a high risk of not meeting a relatively modest target rebuilding rate. This is not compliant with the DFO Precautionary Approach for stocks in the Critical Zone (DFO, 2006b). In this zone, fishery management actions must promote stock growth by reducing human removals to the lowest possible level in order to be deemed compliant with the PA.

The short-term risk analysis deals only with uncertainty associated with the index in relation to the true population (observation error). Although observation error may dominate short term projections, uncertainty also exists with regard to natural mortality, growth and recruitment (process error). Process error will tend to dominate long-term projections. Uncertainty exists with regard to mortality, body growth, maturation, and recruitment rates. Uncertainty also exists with regard to the ability of cod from the inshore aggregation to expand over the range of historical high northern cod abundance. Exploration of these and other sources of uncertainty in long-term scenarios is complex. Within the limited constraints of the present analysis, it was not considered possible to carry out a full exploration of the uncertainty. Instead, a number of scenario simulations were undertaken to explore the potential effects of changes in natural mortality, fishing mortality and migration rates. The results should be considered preliminary and not conclusive. However, they do illustrate that long-term growth prospects for northern cod are poor under current high mortality rates. This is consistent with the results in Shelton *et al*. (2006) which estimated very low growth rates (<1%) for northern cod under $M$=0.5. If reduction in mortality occurs, migration of inshore fish to the offshore could considerably enhance offshore recovery and thus recovery of the stock as a whole.

It is not suggested that these long-term scenario results be used to guide management decisions at the present time. They are highly assumption dependent given the large amount of uncertainty regarding potential migration rates and causes of current elevated natural mortality. Also, the segmented regression fits to the spawner-recruit data may not adequately represent this contribution to stock productivity. The six scenarios presented can only be considered to illustrate some possibilities from the set of all possible scenarios. Further exploration could be carried out to realize a representative set of reference scenarios which bracket the range of outcomes. Unlike the deterministic scenarios presented here, these should be stochastic, incorporating subsidiary sources of uncertainty within the major assumptions that define the alternative reference cases. These reference scenarios could form the basis for alternative operating models to which competing rebuilding strategies could be applied to evaluate relative performance. The use of a single arbitrary deterministic scenario as a basis for decision-making, as was done in the case of the socio-economic analysis of the cost of listing northern cod under SARA (http://www.dfo-mpo.gc.ca/species-especes/cod/cod_morue_long_e.pdf ), cannot be supported scientifically. The specific assumptions made to generate such a scenario could predetermine the outcome.

Although productivity is currently low for more northerly distributed cod stocks off the east coast of Canada, rebuilding should occur in most cases if fishing mortality can be kept low enough (Shelton, *et al*. 2006). A rebuilding strategy that ensures a low risk of failing to meet a feasible target rebuilding rate less than the maximum, while not completely compliant with DFO's PA framework, and perhaps insufficient to meet the objective of rebuilding to $B_{msy}$ by 2015, would nevertheless be a step forward.

## REFERENCES


Baird, J, Bishop, C and Murphy, E. An assessment of the cod stock in NAFO divisions 2J3KL CAFSAC Working Paper 92/137.

DFO. 2006a. Stock Assessment of Northern (2J3KL) cod in 2006. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/015.

DFO. 2006b. A harvest strategy compliant with the precautionary approach. . DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

Lilly, G.R., Shelton, P.A., Brattey, J., Cadigan, N.G., Murphy, E.F and Stansbury, D.E. 1999. An assessment of the cods stock in NAFO Divisions 2J+3KL. DFO Can. Stock Assess. Res. Doc. 99/42

Lilly, G.R., Shelton, P.A., Brattey, J., Cadigan, N.G., Healey, B.P., Murphy, E.F., Stansbury, D.E., and Chen, N. 2003. An assessment of the cod stock in NAFO Divisions 2J+3KL in February 2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/023

Lilly, G.R., Murphy, E.F., Healey, B.P, and Brattey, J. 2006. An assessment of the cod (*Gadus morhua*) stock in NAFO Divisions 2J3KL in April 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/043.

Shelton, P.A. 2006. Properties of three estimators of recruitment overfishing. DFO Can. Sci. Adv. Sec. Res. Doc. 2006/091.

Shelton, P. A., Rice, J. C., Rivard, D., Chouinard, G. A., and Fréchet, A. 2003. 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.

Shelton, P.A., Sinclair, A.F., Chouinard, G.A., Mohn, R., and Duplisea, D.E. 2006. Fishing under low productivity conditions is further delaying recovery of Northwest Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. 63:235-238.

Smedbol, R.K., Shelton, P.A., Swain, D.P., Fréchet, 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. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/082.

**Table 1.** Fixed inputs for the stochastic projection based on bootstrap estimates of survivors on January 1, 2006. M=natural mortality, PR=partial recruitment to the fishery (PR=1 implies fully recruited), Sw=stock weight (beginning of year), Cw=catch weight (middle of year), Mat=proportion of females mature at age.

| M | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | 2007 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | 2008 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |

| PR | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | 0.001 | 0.053 | 0.218 | 0.470 | 0.771 | 1.000 | 0.871 | 0.933 | 0.634 |
| | 2007 | 0.001 | 0.053 | 0.218 | 0.470 | 0.771 | 1.000 | 0.871 | 0.933 | 0.634 |
| | 2008 | 0.001 | 0.053 | 0.218 | 0.470 | 0.771 | 1.000 | 0.871 | 0.933 | 0.634 |

| Sw | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | 0.278 | 0.434 | 0.688 | 1.171 | 1.800 | 2.417 | 3.042 | 3.679 | 5.186 |
| | 2007 | 0.278 | 0.434 | 0.688 | 1.171 | 1.800 | 2.417 | 3.042 | 3.679 | 5.186 |
| | 2008 | 0.278 | 0.434 | 0.688 | 1.171 | 1.800 | 2.417 | 3.042 | 3.679 | 5.186 |
| | 2009 | 0.278 | 0.434 | 0.688 | 1.171 | 1.800 | 2.417 | 3.042 | 3.679 | 5.186 |

| Cw | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | 0.317 | 0.522 | 0.849 | 1.588 | 2.131 | 2.733 | 3.335 | 4.098 | 5.664 |
| | 2007 | 0.317 | 0.522 | 0.849 | 1.588 | 2.131 | 2.733 | 3.335 | 4.098 | 5.664 |
| | 2008 | 0.317 | 0.522 | 0.849 | 1.588 | 2.131 | 2.733 | 3.335 | 4.098 | 5.664 |

| Mat | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | 0.002 | 0.014 | 0.083 | 0.261 | 0.838 | 0.982 | 1.000 | 1.000 | 0.999 |
| | 2007 | 0.002 | 0.014 | 0.083 | 0.373 | 0.633 | 0.972 | 0.998 | 1.000 | 1.000 |
| | 2008 | 0.002 | 0.014 | 0.083 | 0.373 | 0.778 | 0.894 | 0.996 | 1.000 | 1.000 |
| | 2009 | 0.002 | 0.014 | 0.083 | 0.373 | 0.778 | 0.949 | 0.976 | 0.999 | 1.000 |

**Table 2.** Inputs for the long-term scenario simulations. Note that instantaneous rate of natural mortality (*M*) was set at 0.4 for the inshore and 0.6 for the offshore on all ages although scenarios with lower *M* were also explored. CW=catch weight (middle of year), SW=stock weight (beginning of year), Mat=proportion of females mature at age, PR= partial recruitment to the fishery (PR=1 implies fully recruited)

| Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| CW | | 0.362 | 0.560 | 0.868 | 1.524 | 2.143 | 2.784 | 3.318 | 3.943 | 4.555 |
| SW | | 0.302 | 0.439 | 0.680 | 1.140 | 1.768 | 2.430 | 2.990 | 3.603 | 4.205 |
| Mat | | 0.001 | 0.007 | 0.078 | 0.461 | 0.898 | 0.961 | 0.981 | 0.996 | 1.000 |
| PR | | 0.001 | 0.054 | 0.221 | 0.455 | 0.745 | 1.000 | 0.865 | 0.959 | 0.642 |

**Table 3.** Risk of SSB annual percentage growth being less than specified target rates over 1 and 3 year time horizons.

| TAC kt | Time yrs | 0% | 5% | 10% |
|---|---|---|---|---|
| 0 | 1 | 0.000 | 0.001 | 0.026 |
| | 3 | 0.000 | 0.001 | 0.037 |
| 1 | 1 | 0.000 | 0.018 | 0.207 |
| | 3 | 0.000 | 0.017 | 0.240 |
| 2 | 1 | 0.014 | 0.224 | 0.629 |
| | 3 | 0.008 | 0.141 | 0.607 |
| 2.5 | 1 | 0.076 | 0.426 | 0.803 |
| | 3 | 0.039 | 0.328 | 0.780 |
| 3 | 1 | 0.222 | 0.635 | 0.906 |
| | 3 | 0.123 | 0.500 | 0.884 |


**Fig. 1.** Segmented regression fitted to stock-recruit data points (Julious algorithm) estimated in the 2005 assessment of inshore northern cod. Recruitment is thousands of fish at age 1 and SSB is tons.

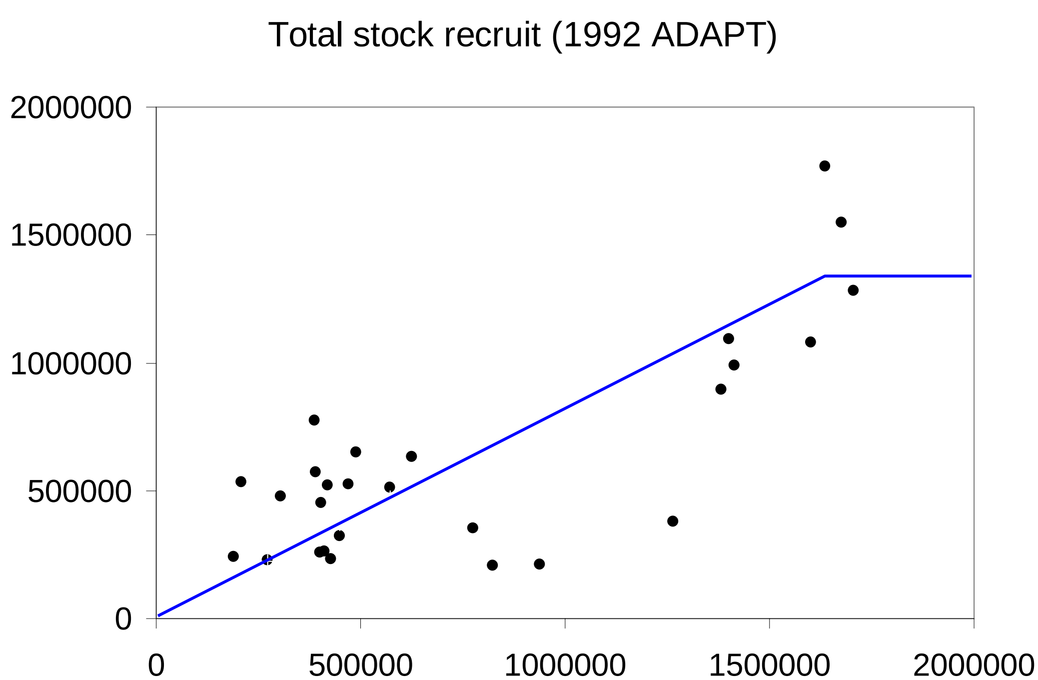
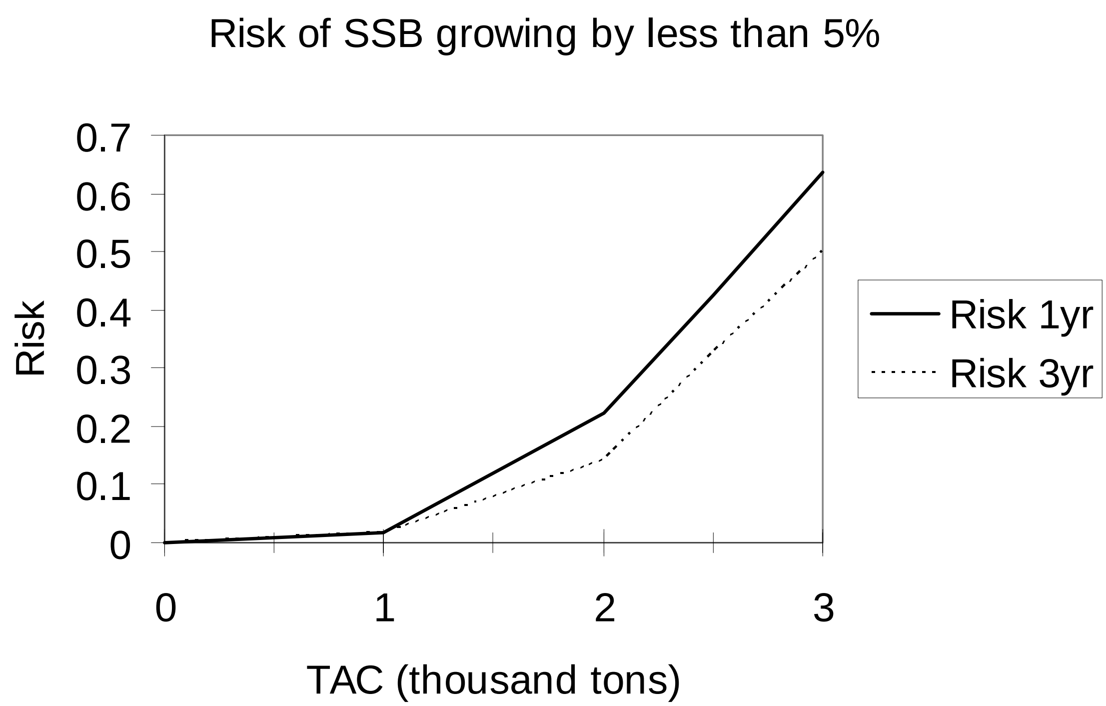



**Fig. 2.** Segmented regression fitted to stock-recruit data points (Julious algorithm) for the stock as a whole estimated in the 1992 assessment of northern cod. Recruitment is thousands of fish at age 1 and SSB is tons.



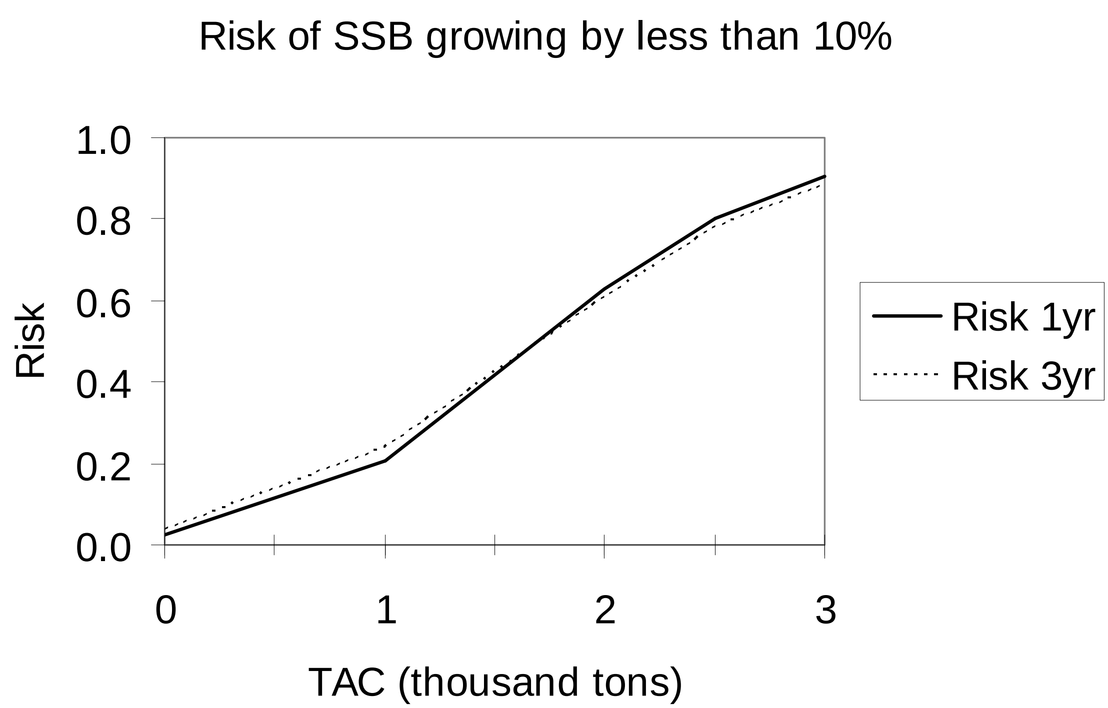




**Fig. 3.** Risk of SSB annual percentage growth being less than specified target rates over 1 and 3 year time horizons.

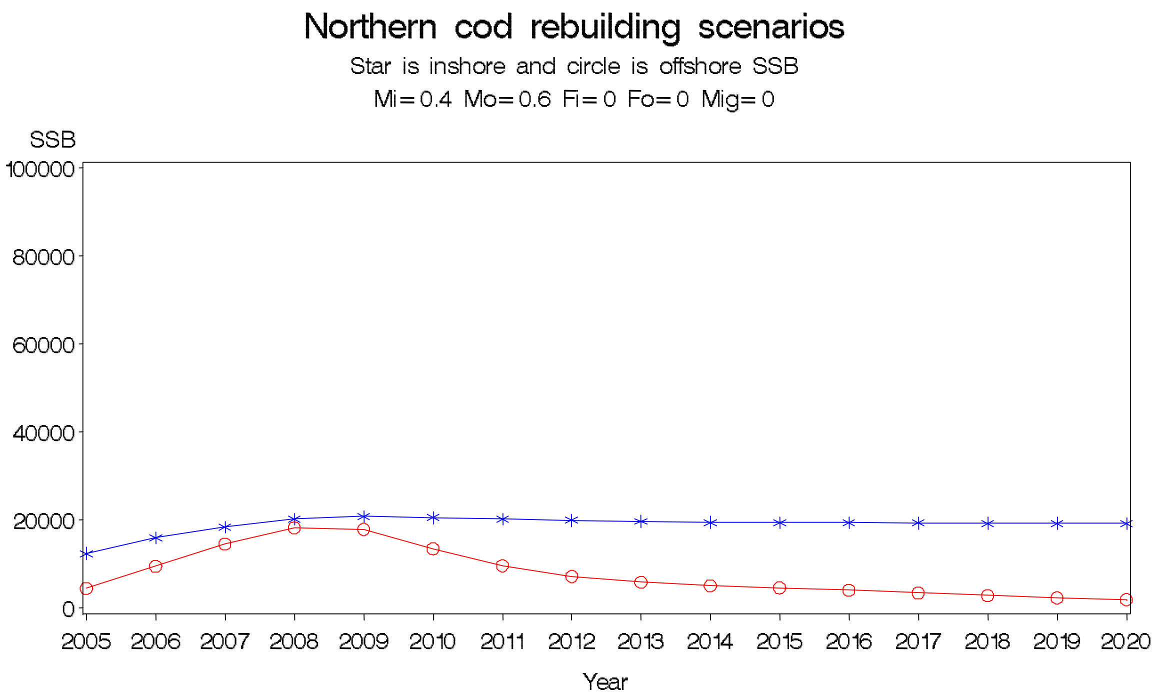



**Fig. 4.** Run #1 of the long-term scenario simulation model with natural mortality in the inshore set at 0.4 and in the offshore at 0.6. There is no fishing mortality and no migration of inshore fish to the offshore.

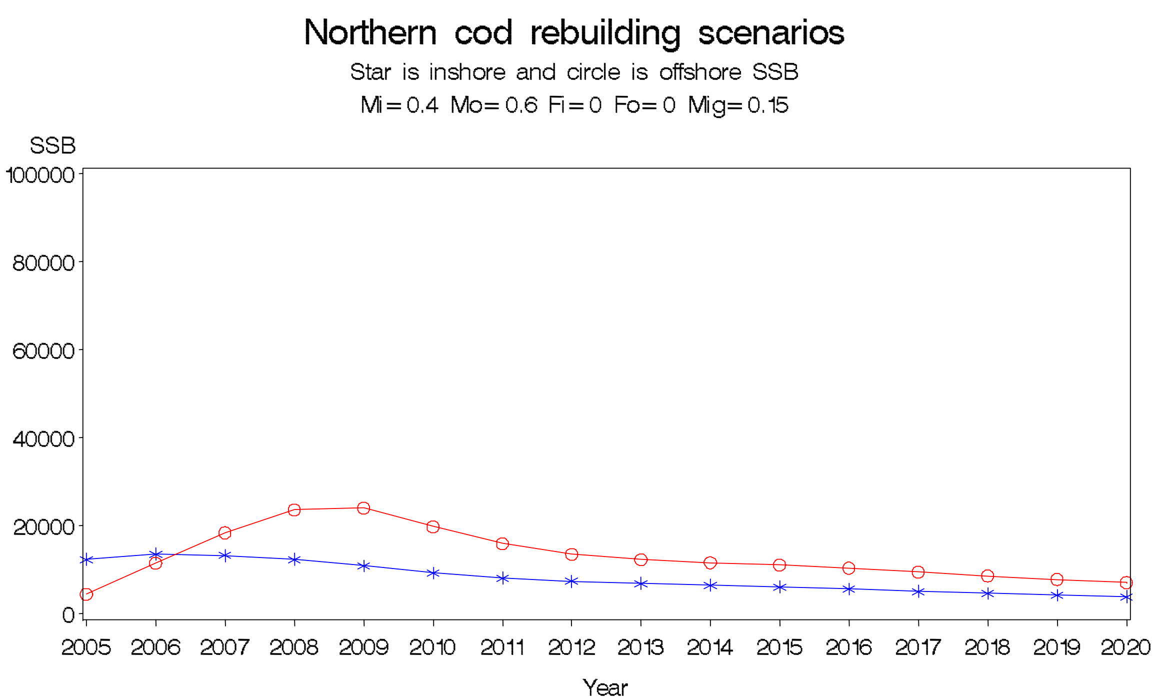



**Fig. 5.** Run #2 with the same conditions as Run #1 but with a 15% annual migration rate of fish from the inshore to the offshore.

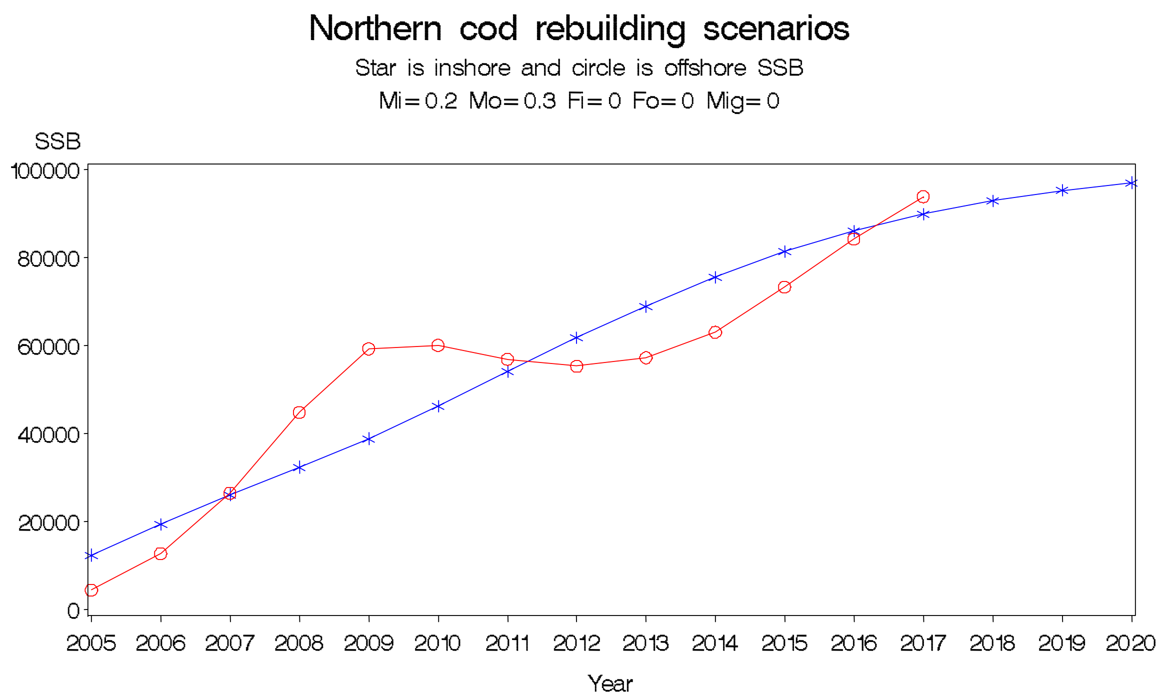



**Fig. 6.** Run #3 with natural mortality set to 0.2 in the inshore and 0.3 in the offshore, with no fishing or migration. The SSB for the offshore exceeds 100,000 by year 2018.

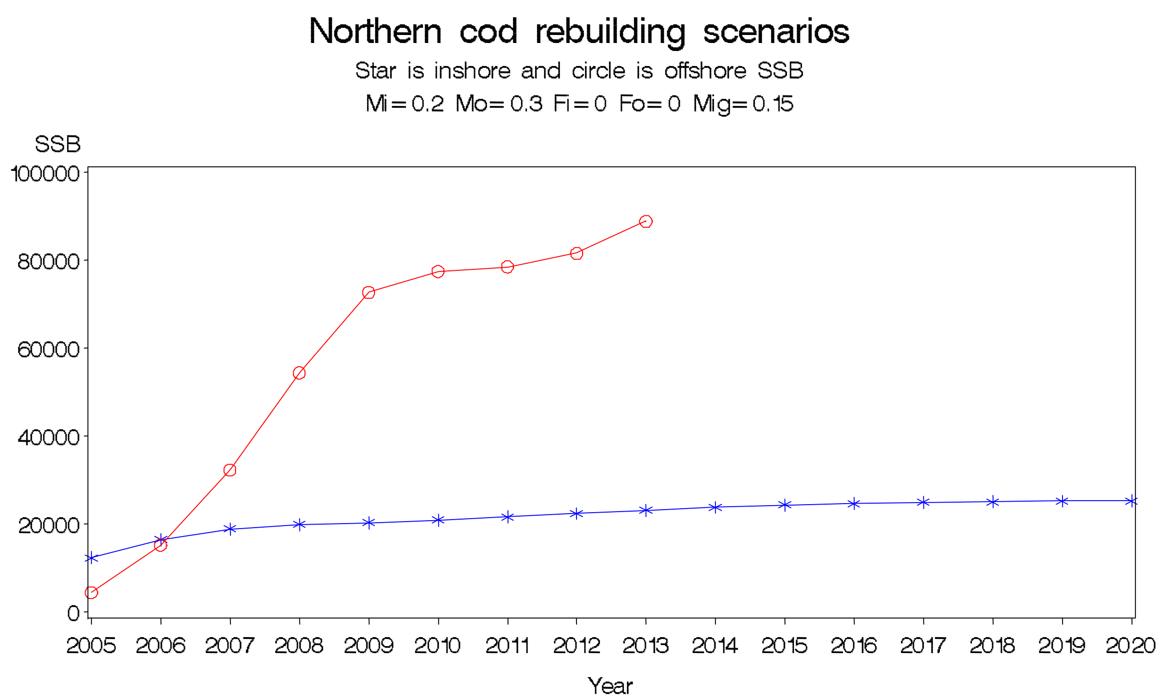



**Fig. 7.** Run #4 – same conditions as Run #3 but with a 15% annual migration of inshore fish to the offshore. The SSB for the offshore exceeds 100,000 t by year 2014.

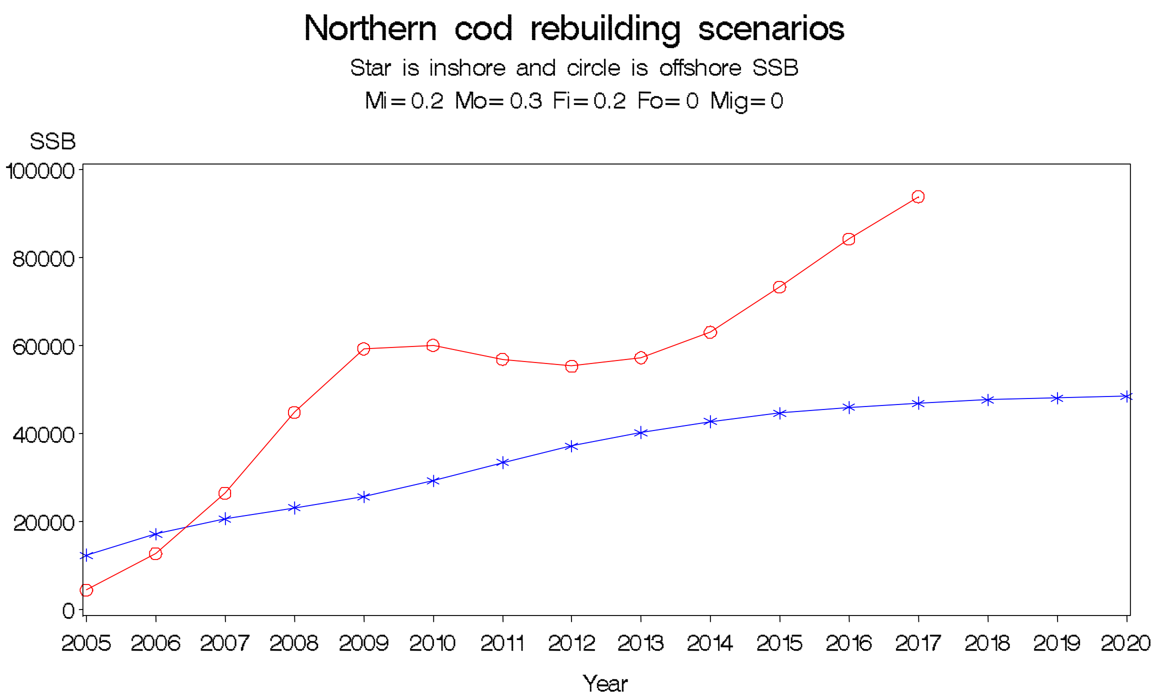



**Fig. 8.** Run #5 – same conditions as Run #3 but with a fishing mortality of 0.2 on the inshore. The SSB for the offshore exeeds 100,000 t by the year 2018.

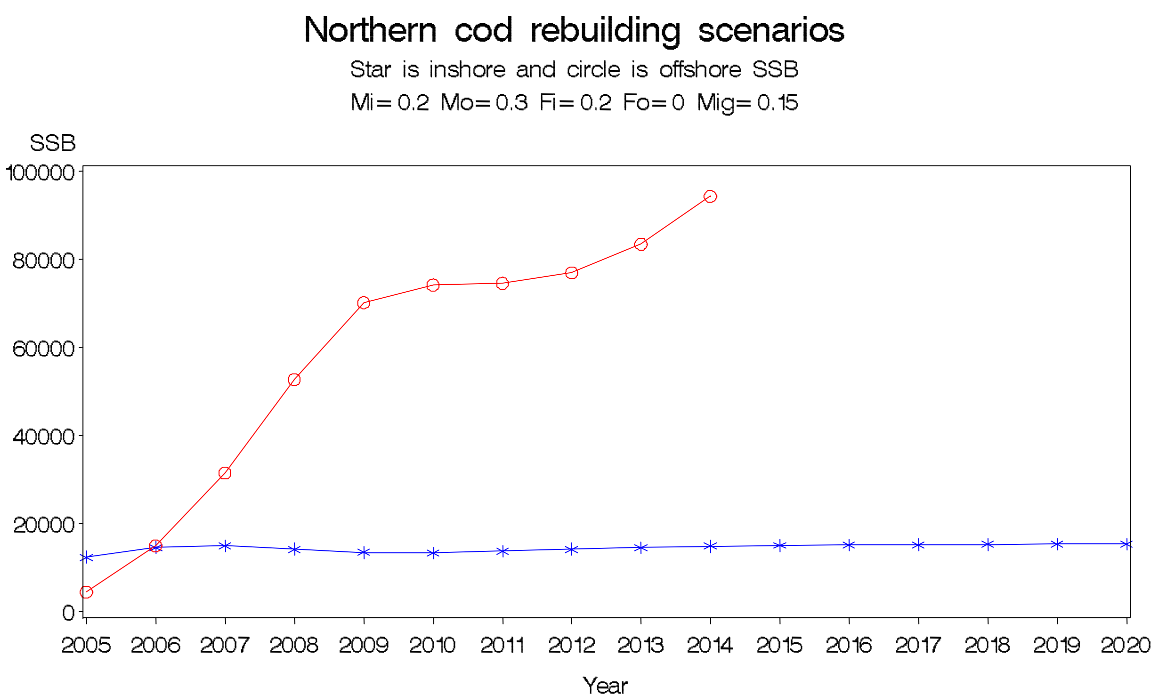



**Fig. 9.** Run #6 – same conditions as Run #5 but with a 15% annual migration rate of inshore fish to the offshore. The SSB for the offshore exeeds 100,000 t by the year 2015.