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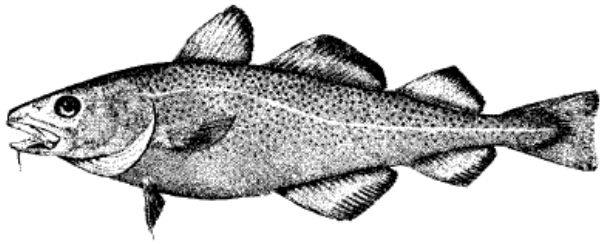
ACCOUNTING FOR CHANGES IN NATURAL MORTALITY IN GULF OF ST LAWRENCE COD STOCKS



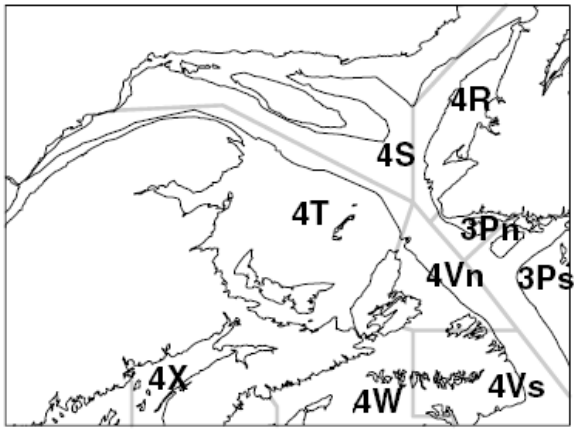


Figure 1: Map of the Gulf of St. Lawrence showing NAFO divisions.

Context

*The decision to increase the values of natural mortality (M) for northern and southern Gulf of St Lawrence cod stocks (*Gadus morhua*) from the traditional value of 0.2 to 0.4 retrospectively to 1986 was made at a DFO Zonal Assessment Process (ZAP) meeting in Newfoundland in 1998 based on an analysis of the available data. Following further analyses, a decision was made at the 2005 Regional Assessment in Mont-Joli to lower M for northern Gulf cod from 0.4 to 0.3 for 1997 to 2000, and to 0.2 from 2001 onward. However, for southern Gulf cod, data examined in Regional Assessments have suggested that no recent decline in M is apparent and a value of 0.4 continues to remain appropriate. A Zonal Review (M-Review) was held at the DFO Maurice Lamontagne Institute Mont-Joli Quebec 31 January – 1 February 2007 to examine the data, methods and results associated with determining changes in values of M in both stocks, as well as information from related studies, and to provide advice on the appropriate treatment of M in the 2007 Regional Assessments of Gulf cod stocks.*

SUMMARY

- Trends in lengths at age (growth), condition, and age at maturity were compared between the two Gulf of St. Lawrence cod stocks as these may be related to changes in natural mortality. The main difference in these parameters is that after a period of decline, growth in northern Gulf cod appears to have recovered to 1970s levels while it has not in southern Gulf cod.

- Total mortality (Z) estimated from survey data during the period of the moratorium in the mid to late 1990s was 0.56 and 0.58 for northern and southern Gulf cod respectively. Given that

fishing mortality (F) was minimal, this indicates an *M* of about 0.4 on both stocks during the moratorium.

- It is possible to estimate *M* in age-structured population models based on survey and catch data (e.g. ADAPT). When identical formulations of ADAPT were applied to each stock, estimates of *M* obtained were consistent with values assumed in the 2006 assessments. These analyses indicated that over the last decade *M* has declined to about 0.25 in northern Gulf cod but remains high (about 0.4 - 0.5) in southern Gulf cod.

- The 2007 assessments for northern and southern Gulf cod should be generally consistent with respect to methods for estimating *M* in ADAPT. However, details will differ between the two stocks. For both stocks *M* should be fixed for a period prior to 1985 at 0.2 to be consistent with earlier studies that show *M* to be at this value or lower. For both stocks *M* should be fixed at 0.4 for the years comprising the moratorium - northern Gulf cod 1994-1996, southern Gulf cod 1994-1997. Periods of fixed *M* are necessary to anchor the ADAPT estimation.

- For the period from 1980 to 1993 *M* can be estimated in the southern Gulf. For northern Gulf *M* should be fixed at 0.2 up to 1985 and at 0.4 from 1986 to 1996. For the period from 1997/8 to 2006 *M* should be estimated in two blocks for both stocks unless there is statistical justification for three blocks.

- Scientific advice on the management of both northern and southern Gulf cod stocks is based on risk analysis. Uncertainty in the estimate of *M* must be formally included in the risk analysis.

- It is recommended that further analysis be carried out with respect to the estimation of *M* for these and other cod stocks taking into account variability in survey catchability, uncertainty in reported catches and sensitivity to assessment model assumptions and constraints.

- Reasons for the recent difference in natural mortality between the two stocks remain unclear.

BACKGROUND

Natural mortality (*M*) is an important component of any age-structured stock assessment. Traditionally *M* has been fixed at a constant value of 0.2 in analytical assessments of cod stocks off the east coat of Canada based on the natural life history characteristics of the populations. The moratorium provided a unique opportunity to examine *M* under conditions in which fishing mortality (F) could be assumed to be close to zero for a number of stocks. Analysis of survey data indicated $M > 0.2$ for some stocks over the moratorium period and, based on further analysis, values of 0.4 were considered valid for both northern (3Pn4RS) and southern (4TVn(Nov-Apr)) Gulf cod for the period from 1986 onwards. In 2005, at a regional assessment process (RAP) meeting in Mont-Joli, a decision was made to lower *M* on northern Gulf cod from 0.4 to 0.3 from 1997 to 2000 and to 0.2 in 2001 onward. This was based on model estimates using ADAPT, an increase in the percentage of older fish, a decrease in misreporting and an increase in water temperatures. In the southern Gulf regional assessments the data supported the assumption that *M* had not decline and a value of 0.4 has been used. The differences in the treatment of *M* in the two assessments have implications with regard to perceived stock productivity and the risk associated with alternative TAC options. The objective of the Zonal Review was to determine if current values of *M* used in both stock assessments are supported

by the best scientific evidence available and to advise on the most suitable treatment of *M* in the assessment of both northern and southern Gulf cod stocks in 2007.

ASSESSMENT

Approaches

A number of aspects of the biology and the environment could affect *M*. There could also be indirect effects of fishing. These were briefly reviewed. There are a number of alternative methods for estimating *M*. These were considered in the context of available data for the two Gulf cod stocks. Treatment of *M* for Gulf cod stocks in the 2006 assessments was also reviewed. In addition, data and analyses for northern cod and eastern Scotian shelf cod were briefly examined to give a broader context to the problem. Near-identical ADAPT formulations were specified for Gulf cod and applied in the meeting to compare changes in *M* in the two stocks. Based on these results, recommended formulations were prescribed for the 2007 assessments of northern and southern Gulf cod stocks. These formulations were very similar. Suggestions were made regarding the carrying forward of uncertainty in *M* in the projections to evaluate risk with respect to TAC options.

Potential causes for changes in *M*

It is recognised that the life-history strategy of each fish species is tuned through evolution to the conditions it experiences in order to optimise fitness. This optimization involves trade-offs of life-history characteristics. Some of these trade-offs are captured at the phylogenetic level by the Beverton-Holt life-history "invariants". These invariants predict that natural mortality rate increases with decreased age at maturity and increased individual growth rate across phylogenetic groups. The degree to which these invariants will hold within taxa or stocks is not known and factors such as food availability and other environmental effects could be important.

In the northern Gulf, the mean length at age 6 in commercial catches decreased from the mid 1970s to the early 1990s and then recovered to 1970s levels. Lengths at age from research vessel surveys are consistent with trends in commercial data, as the FV *Gadus Atlantica* 1978-1994 series indicates a gradual decline while the CCGS *Alfred Needler* 1990-2005 series shows the reverse. In the southern Gulf, the mean length at age 6 decreased substantially through the late 1970s to mid 1980s but subsequently showed only a slight increasing trend and has essentially remained very low. In the northern Gulf, age at maturity decreased from the mid 1980s to the mid 1990s and has subsequently shown a partial return to older ages. In southern Gulf cod age at maturity declined in the 1960s and 1970s and has changed little since then. In the northern Gulf the increasing growth rate and decreasing age at maturity from the mid 1980s to the late 1990s would be consistent with increased natural mortality under Beverton-Holt's life history invariants. For southern gulf cod low growth rates since the mid-1980s would not indicate increased natural mortality based on the phylogenetic relationship between mortality and growth.

Intensive fishing pressure over the last 50 years has subjected a number of groundfish stocks off the east coast of Canada to strong size-selective mortality and there is evidence that this can cause genetic changes to growth in some stocks, particularly southern Gulf cod. Thus fishing could in part be responsible for the changes in natural mortality through selection pressure causing the fish to alter the trade-off between fecundity, survival and growth in order to attempt to retain some degree of optimality under high fishing mortality.

It is known that cod growth rate is affected by ambient temperature but the direction of the effect may depend on food supply. Water temperatures in the Gulf were high in the late 1970s and early 1980s, but decreased through the mid and late 1980s to reach a minimum by the early to mid 1990s. Subsequently temperatures have returned to normal. Length at age is correlated with temperature in northern Gulf cod but temperature has been found to only have a minor effect on growth of southern Gulf cod. Furthermore, trends in the ambient temperature of southern Gulf cod during the feeding season differed from the general environmental trends, with cod occupying warmer temperatures in the mid 1990s than in the early 1980s. Temperature effects could have played a role in the change in natural mortality in northern Gulf cod by affecting the trade-off between life history characteristics.

Condition has been found to have an effect on the survival of cod in the laboratory. Condition of northern Gulf cod in winter reached a minimum in the early 1990s and returned to average values in the early 2000s. Condition in southern Gulf cod decreased from the mid 1970s to the early 1980s and subsequently has fluctuated at an intermediate level without trend. Northern Gulf cod condition in the early 1990s reached levels that could have given rise to increased mortality.

Predation is undoubtedly a significant factor in both stocks, particularly with respect to the juvenile stages. Seal abundance in the Gulf has been increasing since the late 1970s. This corresponds with the increase in estimated *M* in both Gulf cod stocks. Consumption of large fish is greater by grey seals than by harp seals. Grey seals may be more abundant in areas south of the Laurentian Channel, where they are resident year round. Estimated increases in *M* for southern Gulf cod parallel increases in grey seal abundance. However, available diet information suggests that grey seals consume mainly juvenile cod, whereas evidence for an increase in *M* is for larger cod (ages 3 years and older). If grey seals often do not consume the heads of large fish, consumption of large cod will then be underestimated by the available diet data. Diet identification is based on hard parts such as otoliths. Although harp seal predation is undoubtedly contributing to mortality in northern Gulf cod, harp seals remain abundant there and hence most likely cannot account for the decline in *M* for this stock in recent years.

Methods for estimating changes in *M*

A number of potential methods exist for estimating natural mortality. These include empirical methods based on longevity, growth and maturation characteristics, analysis of survey data, analysis of tagging data and estimation using population models. Empirical methods based on longevity, growth and maturation characteristics, such as the Beverton-Holt life-history invariants, were considered to have most value with respect to species-level differences in natural mortality and with regard to general changes that could be expected under alternations in growth or maturation, but to be less useful in obtaining quantitative estimates for use in annual stock assessments.

Catch-curve analysis

Catch curve analysis of age-disaggregated research vessel survey data can provide estimates of total mortality (*Z*) for fully recruited age classes. Updated catch curve analyses for northern Gulf were carried out on August Needler research vessel survey (RV) data (1990-2006) and the sentinel trawl survey data (1995-2006). For the southern Gulf the analysis was applied to September RV data (1971-2006). *Z* estimates were significantly greater than the baseline value of 0.2 in the years immediately following the moratorium in both areas (Fig. 2). Estimates were also greater than 0.4 in both areas, although the differences were not always statistically significant. Given that fishing was greatly reduced during the moratorium, previous analyses

indicating an *M* of 0.4 over this period were confirmed. The catch curve analysis suggests that *Z* is increasing in the southern Gulf and provides no evidence that *M* has returned to the traditional value of 0.2 since the moratorium. *Z* estimates increased initially in the post moratorium period in the northern Gulf, declined in the early 2000s to below 0.4, then increased in the most recent time period. The decline in *Z* in northern Gulf in the early 2000s may suggest a decline in *M*.

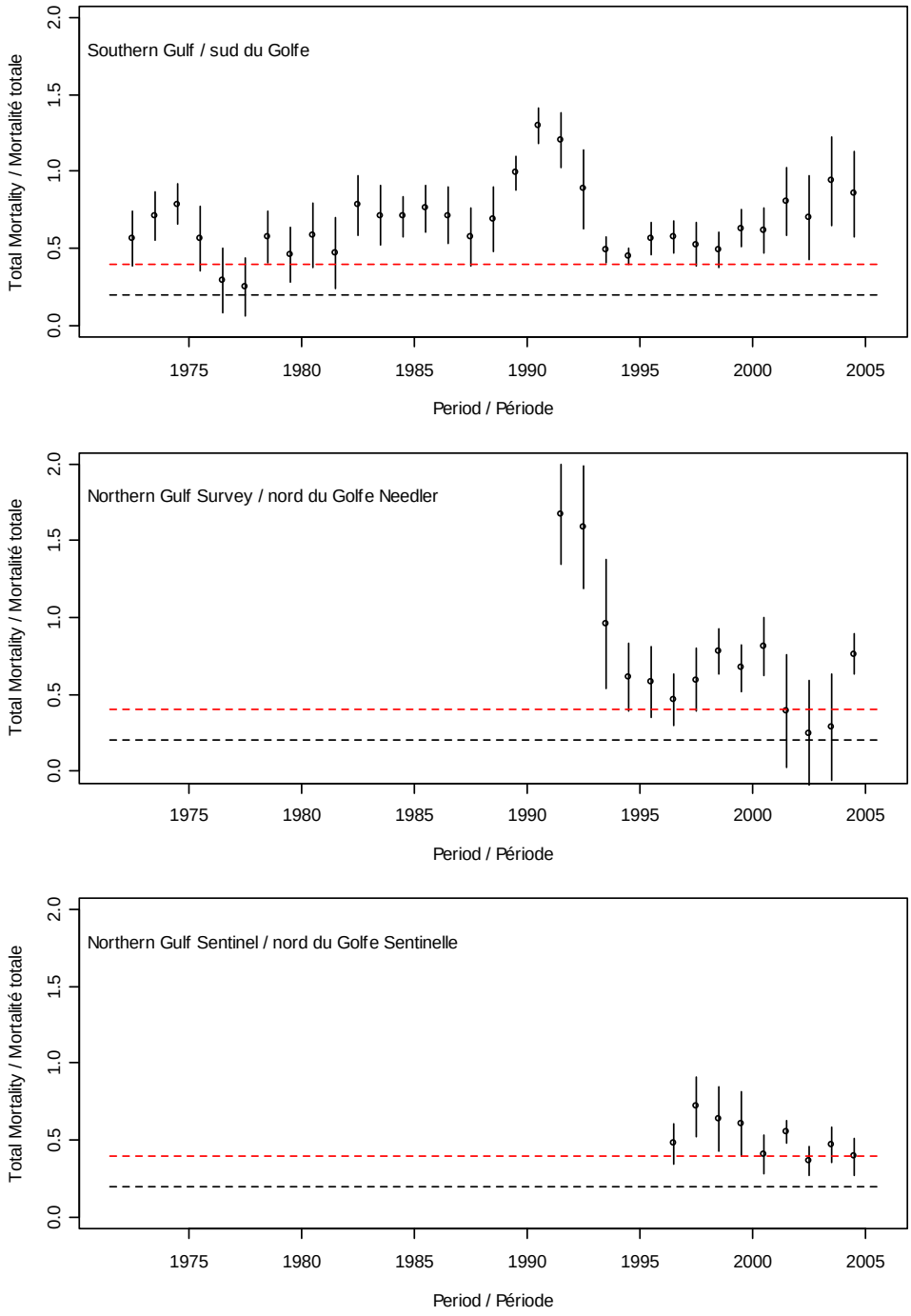


Figure 2 Modified catch curve analysis of northern and southern Gulf cod data indicate levels of total mortality significantly higher than the baseline natural mortality level of 0.2 (lower broken line), in the vicinity of 0.4 (upper broken line). Error bars represent plus and minus two standard errors.

Population model estimates of *M*

Although traditionally stock assessment population models of cod off the east coast of Canada applied an assumed estimate of *M* of 0.2 consistent with life history characteristics in the 1960s, this assumption appeared to become more tenuous in the last 20 years based on analysis of survey data over the moratorium period and changes in life history characteristics. Models such as ADAPT, commonly used in Atlantic Canadian groundfish stock assessments, can treat *M* as a parameter to be estimated for various combinations of ages and years, the number of additional *M* parameters depending on the degrees of freedom. The extent to which such estimation is advisable also depends on the observation error, process error and model error, including the various assumptions and constraints applied within the estimation procedure. Observation error will typically be large for most survey data series and process error in survey catchability can also be substantial. In ADAPT the commercial catch (landings plus discards and other forms of unreported fishing mortality) is assumed to be known exactly, while in reality the reliability of catch reporting varies over time and between stocks. Survey observation error, changes in survey catchability and changes in the relationship between reported catch and actual deaths due to fishing can all confound attempts to estimate *M* within the ADAPT framework. *M* estimation sensitivity analysis with respect to assumptions and constraints in the estimation procedure also needs to be carried out. Despite these limitations, *M*-estimation approaches are thought to have progressed from a useful diagnostic tool into a statistical method for obtaining more accurate estimates of population numbers at age and fishing mortality in stock assessments. When *M* is formally treated as a parameter to be estimated within the assessment framework, uncertainty in the estimate can be computed and carried forward in stochastic projections to determine risk associated with alternative TAC options. In addition to ADAPT-based estimation of *M*, alternative population models can be applied. For example, preliminary estimates of *M* from a random-walk model applied to southern Gulf cod were reviewed. Results tended to confirm ADAPT-based estimates.

Estimates of *M* from tagging data

A group of tagged fish monitored over successive years can provide a population from which inferences about annual natural mortality can be made. Tagged survivors from the initial population of tagged fish in each year are those fish that have not been caught in the fishery nor have died due to initial tagging mortality, natural mortality (annual mortality resulting from natural causes) nor have lost their tag. Tag reporting-rates are also important to quantify. The initial tagging mortality rate can be inferred from cage experiments on tagged and non-tagged fish. Tag loss rate can be inferred from double-tagged fish. A good approach to estimate reporting rates is to utilize tag-return rewards, with some rewards high enough to insure all the high-reward tags are returned. In this case it is also possible to estimate the reporting rates of other lower-reward tags. When annual time-series of tag-releases and recaptures are available, then it is also possible to estimate *M*. Several software packages for analyzing tagging data do this. Another approach is to adjust assumptions about *M* to fit model predicted tag-returns to those observed. The primary information about *M* comes from differences in the fraction of tags returned from older tagging experiments, where sufficient time-at-liberty has elapsed for *M* to have an effect, and those from recent experiments in which natural morality has not had much time to affect the survivors and the fraction returned are primarily determined by harvest and reporting rates. This approach has been applied to northern cod and St. Pierre Bank cod stocks for which extensive tagging data exist. The general approach could also be applied to northern Gulf cod tagging data. An alternative approach using similar inputs but based on the Baranov catch equation can also be considered. Preliminary results for northern Gulf cod suggest M>0.3 for the 1999-2006 period using this latter method.

Comparative ADAPT analyses on northern and southern Gulf cod

In the 2006 assessments of northern and southern Gulf cod, *M* was assumed to vary with time according to a prescribed pattern (Fig. 3) suggested by prior ADAPT runs in which *M* was estimated for various time blocks. For northern Gulf cod *M* was assumed to be 0.2 from 1975 to 1985, 0.4 from 1986 to 1996, 0.3 from 1997 to 2000 and 0.2 from 2001 to 2005. For southern Gulf cod, *M* was assumed to be 0.2 from 1971 to 1985 and 0.4 from 1986 to 2005.

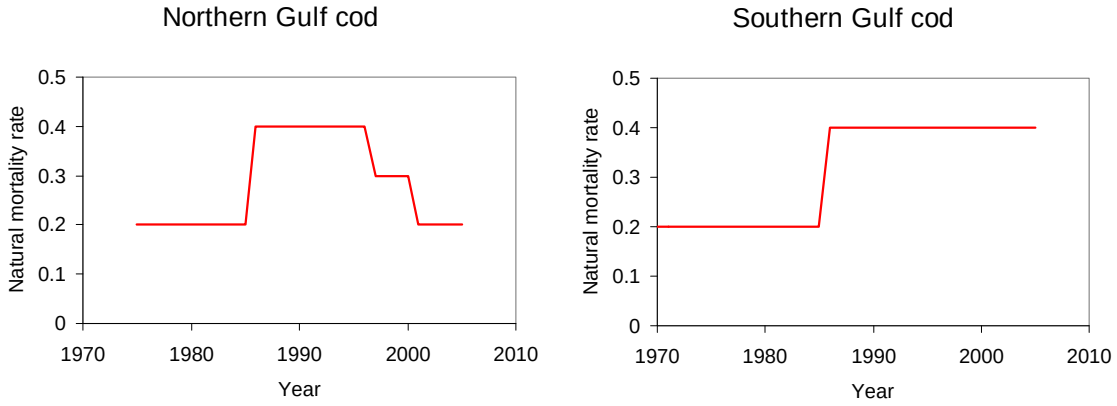


Figure 3 Sequence of M values assumed in the 2006 northern and southern Gulf cod assessments.

In order to further investigate the basis for the different assumptions in the 2006 assessments, identical exploratory runs were carried out on both stocks as part of the *M*-Review. For these runs (Fig. 4) *M* was fixed at 0.2 to 1985, estimated for the period 1986 to 1992, fixed at 0.4 for the period 1993 to 1997, estimated for the period 1998 to 2001 and then estimated separately for the period 2002 to 2005/2006. The only difference was that for northern Gulf cod the analysis included 2006 data (i.e. the data to be used in the 2007 assessment, whereas the southern Gulf cod analysis only included data up to 2005 (i.e. the data used in the 2006 assessment).

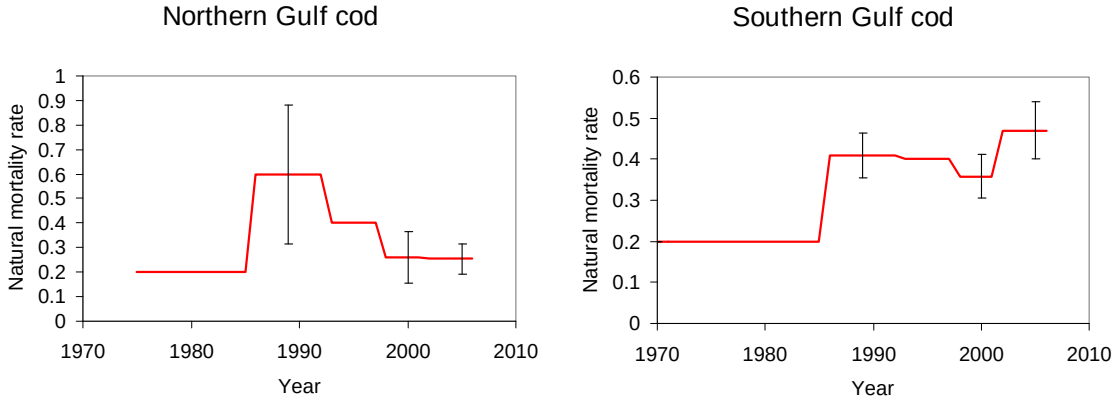


Figure 4 Comparative M-estimation exploratory runs included fixed values and estimated values, plus and minus two standard errors.

The results from the experiment generally supported the values used in the 2006 assessment of each stock. For northern Gulf cod the estimate for the 1986 to 1992 period was about 0.6, substantially higher than the value assumed in the 2006 assessment, but not significantly so given the large standard error (SE). For southern Gulf cod the estimate for this period was almost exactly 0.4 with a small SE. For the period 1998 to 2001 the estimate for northern Gulf

cod was 0.26, similar to 0.3 assumed for the 1997-2000 period in the 2005 assessment. For southern Gulf cod the estimate for this period was 0.36, not significantly different from the value of 0.4 applied in the 1986 to 2005 period in the 2006 assessment. For the period 2002 to 2006 the estimate for northern Gulf cod was 0.25, similar to the value of 0.2 assumed in the 2005 assessment for that period. The estimate for the 2002 to 2005 period for southern Gulf cod was 0.47, marginally significantly different from 0.4.

Proposed treatment of *M* in the 2007 assessments

The Review concluded that there was empirical evidence that *M* had decreased in the recent period in northern Gulf cod but remains high in southern Gulf cod. The Review also recommended that near-consistent ADAPT formulations should be used for the two cod stocks in the 2007 assessments. For both stocks *M* should be fixed for a period prior to 1985 at 0.2 to be consistent with earlier studies that show *M* to be at this value or lower. For both stocks *M* should be fixed at 0.4 for the years comprising the moratorium - northern Gulf cod 1994-1996, southern Gulf cod 1994-1997. Periods of fixed *M* are necessary to anchor the ADAPT estimation. For the period from 1980 to 1993 *M* can be estimated in the southern Gulf. For northern Gulf *M* should be fixed at 0.2 up to 1985 and at 0.4 from 1986 to 1996. For the period from 1997/8 to 2006 *M* should be estimated in two blocks for both stocks unless there is statistical justification for three blocks.

CONCLUSIONS AND ADVICE

There is good empirical evidence that natural mortality in northern and southern Gulf cod has varied over the last 20 years. These changes can have a big impact on stock assessment estimates of population size and productivity. Attempts to incorporate these changes in recent assessments of these two stocks by estimating *M* in blocks of years in ADAPT is considered to be a step in the right direction, but there are a number of caveats. Estimation of *M* can be confounded by changes in survey catchability and fishery catch reporting, and may be sensitive to assumptions and constraints applied in the ADAPT estimation procedure. Assessments in which *M* is estimated in ADAPT, or in any other assessment model, may require additional evaluation and peer review. This peer review may best be provided by framework meetings or zonal reviews which have critical mass with respect to expertise in quantitative methods. The *M*-Review provides a first step in this regard. The consensus advice is that changes in *M* should be incorporated in the 2007 assessments for northern and southern Gulf cod stocks, but that the estimation should be restricted to a limited number of year blocks interspersed with periods at the beginning and in the middle of the time period in which *M* is fixed, so as to anchor the estimation. The Review could see no reason why the approach adopted in the two assessments should not be essentially similar, although there will be slight differences in the fixed and estimated year blocks. Detailed recommendations are provided in this regard. The Review advises that uncertainty in estimation of *M* for the recent period should be carried forward in stochastic projections used to compute risk profiles associated with alternative TAC options. This was not done in the 2006 assessments for these two stocks. Further work on methods for estimating *M* within ADAPT and other assessment model approaches is encouraged.

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FOR MORE INFORMATION

Contact: Dr. Martin Castonguay
Maurice Lamontagne Institute
850, route de la Mer
P.O. Box 1000
Mont-Joli, Quebec
G5H 3Z4

Tel: (418) 775-0634
Fax: (418) 775-0740
E-Mail: CastonguayM@dfo-mpo.gc.ca

This report is available from the:

Center for Science Advice (CSA)
Quebec Region
Fisheries and Oceans Canada
Maurice Lamontagne Institute
P.O. Box 1000, Mont-Joli
Quebec (Canada)
G5H 3Z4

Telephone: (418) 775-0825
Fax: (418) 775-0679
E-Mail: Bras@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas

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