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A comparison of VPA, ASAP and Empirical Approach applications to Eastern Georges Bank Cod (*Gadus morhua)*

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ABSTRACT

The 2016 catch advice from the VPA “M 0.8” model provided at the 2015 TRAC assessment meeting differed significantly from the advice provided by the ASAP models (used as a consequence analysis for EGB cod by the TRAC and to assess cod for the entire Georges Bank by the USA). At the 2015 September meeting, the Transboundary Management Guidance Committee (TMGC) expressed concern about significant management impacts for both countries from the divergent catch advice and the potential risk that this posed for cooperative management. There was a request from the USA members to resolve the conflict between the international process and domestic process. The Terms of Reference for the 2016 TRAC cod assessment requested updating the 2013 benchmark VPA and ASAP models, the consequence analysis table, developing and applying an empirical approach and reporting on any factors and risks that should be considered in interpreting the catch advice provided. This working paper characterizes the uncertainties of this stock assessment, with the aim to promote a better understanding of the three approaches: VPA “M 0.8” model, ASAP “M 0.2” model and an empirical approach, and to facilitate discussion on the 2017 catch advice.

INTRODUCTION

For the purpose of a sharing agreement and consistent management by Canada and the USA, agreement was reached that the transboundary management unit for Atlantic cod would be limited to the eastern portion of Georges Bank (EGB, DFO Statistical Unit Areas 5Zej and 5Zem; USA Statistical Areas 551, 552, 561 and 562)) (DFO, 2002). The management area is shown in Figure 1. The USA has a requirement for management advice for the Georges Bank cod stock (5Z + SubArea 6). The status quo has been to use an assessment of cod in 5Zjm for transboundary management advice and an assessment of cod in 5Z+6 for USA domestic management advice. There is concern that development of fisheries management advice from potentially differing assessment approaches arrived at through independent reviews may make reconciliation of results difficult.

The TRAC employs a two-tiered review process: a benchmark assessment review and annual assessment review. The mandate of the annual assessment peer review is to appropriately apply the benchmark assessment framework to fishery, survey and biological data acquired since the last assessment in order to elucidate the current status of the stock (TRAC, Jun. 21, 2016, Retrieved from http://www.bio.gc.ca/info/intercol/trac-cert/index-en.php#trac-sigh). The most recent benchmark meeting for EGB cod was conducted in 2013. Although there was no consensus on the most appropriate model due to uncertainties on natural mortality, it was agreed that catch advice would be based on a VPA “M 0.8” model, and an ASAP “M 0.2” model would be used for consequence analysis.

The 2016 catch advice from the VPA “M 0.8” model provided at the 2015 TRAC assessment meeting differed significantly from the advice provided by the ASAP models (used as a consequence analysis for EGB cod by the TRAC and to assess cod for the entire Georges Bank by the USA). The Transboundary Management Guidance Committee (TMGC) expressed concern about significant management impacts for both countries from the divergent catch advice and the potential risk that this posed for cooperative management (TMGC, 2015). There was a request from the USA members to resolve the conflict between the international process and domestic process (SC meeting, Sep. 2015). The Terms of Reference for the 2016 TRAC cod assessment requested updating the 2013 benchmark VPA and ASAP models, the consequence analysis table, developing and applying an empirical approach and reporting on any factors and risks that should be considered in interpreting the catch advice provided. This working paper characterizes the uncertainties of this stock assessment, with the aim to promote a better understanding of the three approaches: VPA “M 0.8” model, ASAP “M 0.2” model (Wang *et al*., 2015) and an empirical approach (Brooks *et al.,* 2016), and to facilitate discussion on the 2017 catch advice.

TRAC PERFORMANCE

Canada and the USA have been jointly assessing cod on EGB since 1998. Since 2002, the TMGC has adopted a strategy to maintain a low to neutral risk of exceeding the current fishing

mortality limit reference (since 2013, Fref = 0.18 for ASAP “M 0.2” model, and Fishing reference point=0.11 for the VPA “M 0.8” model) and to further reduce fishing mortality rates when stock conditions are poor to promote rebuilding. The objective of TRAC and TMGC has been to reduce exploitation rate to sustainable levels (F<Fref), and improve stock status (stock recovery).

Relative fishing mortality (relF) is estimated as the ratio of fishery catch divided by a relative population abundance index from a research survey. If the survey catchability is constant, and the rate of catch reporting remains constant, this ratio will be proportional to the actual fishing mortality; trends in relF will reflect trends in F (Sinclair, 1997). In this paper, two methods of relF calculation were conducted: one uses the ratio of fishery catch at age to survey abundance index at age (Fig. 3), while the other uses the ratio of total fishery catch (in weight) to survey biomass index. For the second method, prior to the ratio calculation, the survey biomass indices and fishery catch were standardized using its mean over the period 1987-2015 where all three surveys had complete coverage (1978-2015 for the two NMFS surveys, 1987-2015 for the DFO survey). Both methods show similar temporal trends: relF was reduced to a low level in the mid-1990s and has stayed at lower levels since 2005, with the current relF being among the lowest since 1978 (Fig. 2 and 3).

The trend of survey abundance indices at age standardized by scaling each series to its mean over the period of post-1994 was used to derive information on stock status changes (Fig. 4-6). Also looking at the trend of different age groups in research surveys can characterize patterns of total mortality between age groups.”. Generally the population numbers at younger ages (1-3) have been low due to poor recruitment since the mid-1990s (Fig. 4); the recent period of low recruitments were suspected to be caused by low spawning stock biomass, truncated age structure and possible environmental effects (Wang *et al.*, 2015). The population numbers at age for ages 4 through 6 have stayed at similar or even higher levels compared to the pre-1995 (Fig. 5); this was consistent with what was expected following a sharp decrease in fishing mortality. However, the population numbers at older ages (7-8) showed a declining trend despite the low fishing mortality (Fig. 6); it is possible that some factors other than the fishery (e.g., higher natural mortality (M)) have contributed to the lack of rebuilding of older fish.

Overall, the above analysis indicates that TRAC and TMGC have been effective in controlling fishing mortality, however factors other than fishing (poor recruitment, high M on older fish and low growth (Wang *et al.,* 2015)) have also played an important role in the lack of recovery of this stock.

COMPARISON OF VPA “M 0.8”, ASAP “M 0.2” AND EMPIRICAL APPROACH

A model is defined as a “simplified description, especially a mathematical one, of a system or process, to assist calculations and predictions” (oxforddictionaries.com, 2016). Thus all three approaches being considered (VPA “M 0.8”, ASAP “M 0.2” and an empirical approach) are models, but differ in terms of the assumptions and the data used. The three models were

compared in terms of model assumptions, model fit and interpretation on stock population dynamics.

Model assumptions: A comparison of model assumptions, model input data and the methodologies used for catch advice are summarized in Table 1. Factors considered include assumptions on natural mortality, survey catchability, seasonal changes, errors in fishery catch, cohort tracking, as well as input data and catch advice.

Model fit: The model fit was evaluated by comparing model estimated biomass and recruitment with survey biomass indices and abundance indices. Considering there were frequent zero observations for abundance indices at age 1 in DFO and NMFS spring surveys, recruitment at age 2 was used for comparison. The comparison was for years where all three surveys had complete coverage (1987-2015) and was scaled to its mean over this period.

Figure 7 shows the CV weighted average of survey biomass indices and biomass from the VPA "M 0.8" model and ASAP "M 0.2" model.

- *VPA "M 0.8" model:* Generally, the model estimated biomass tracked the survey biomass, except for the years 2001-2012 when the model underestimated the biomass. The low model estimate in this time period was due to the difficulty in estimating the 2003 year class in the 2013 assessment when it had passed into the older (age 9) age group (Wang and O'Brien, 2013). The fit was much improved when the bias of the 2003yc estimate was fixed by the "est 2003yc" run (Fig. 8).
- *ASAP "M 0.2" model:* Figure 7 suggests that the model has underestimated biomass since the mid-1990s.

Figure 9 shows the average of survey abundance indices at age 2 and the population abundance at age 2 from the VPA "M 0.8" model and ASAP "M 0.2" model.

- *VPA "M 0.8" model:* Generally, the model estimated recruitment at age 2 tracked the survey abundance indices at age 2 very well, except for the stronger 1998 and 2003 year classes, which were underestimated by the model. This is consistent with what was reported in the 2013 assessment (Wang and O'Brien, 2013).
- *ASAP "M 0.2" model:* The model underestimated almost all of the cohorts since the mid-1990s.

Interpretation of stock population dynamics:

- *VPA "M 0.8" model:* Based on the 2015 assessment (Wang *et al*., 2015), recent biomass has been low and comparison with the combined survey biomass indicates that the model may be underestimating biomass in recent years (Fig. 7). Fishing mortality has been decreasing and F<Fref in recent years, which is consistent with relative F and fishery management effort. High M, poor recruitment and low growth are contributing to the lack of rebuilding.
- *ASAP "M 0.2" model:* Based on the 2015 assessment (Wang *et al*., 2015), biomass has been at very low levels in recent decades. A comparison with the combined survey

index indicates that the model may be underestimating biomass since the mid-1990s. Fishing mortality has been high (F>>Fref) and peaked in 2009-2012 (F>1). The high fishing mortality is hard to reconcile with relative F and the fishery management approach of reducing quotas. High F, poor recruitment and low growth contribute to the lack of rebuilding.

- *Empirical approach:* Only a relative biomass estimate from surveys is available. Current biomass is low, and recent catches have not allowed recovery. If signals from the surveys show that biomass has been decreasing in recent years, catch should be further reduced in the future to promote rebuilding.

SUMMARY

High total mortality (Z), poor recruitment and low growth contribute to the low abundance and lack of rebuilding of EGB cod.

- *VPA "M 0.8" model:* Indicates that the main issue for the low stock abundance of cod and its failure to recover is elevated M (aliasing some other factors) on older fish. If neither fishery nor survey can see those older fish, then for the purposes of fishery management, using high M to alias the disappearance of older fish is more practical, although the exact cause of the elevated M has not been identified.
- *ASAP "M 0.2" model:* Overfishing is the principal reason for the severe depletion of the cod stock. This is difficult to reconcile with the low fishing effort.
- *Empirical approach:* The decline and lack of rebuilding is due to high Z, regardless of whether the fishery has been the major contributor to stock decline or if the decline is caused by something else. If survey biomass has decreased, this approach further reduces fishing, with the aim of the conservation of the cod stock and stock rebuilding. If the fishery is not the main cause of the decline in biomass, then further reducing catch may not result in stock increase.

The three approaches presented at the 2016 TRAC reflect the uncertainties with the EGB cod stock assessment. The role of TRAC is to provide the scientific basis for catch levels corresponding to risk and to provide guidance to fisheries management. The difference among these three approaches should be kept in mind when discussing catch advice, to ensure that advice is based on "best available science".

Groundfish fisheries on Georges bank are interconnected, especially cod and haddock fisheries. Also this cod stock is connected with other fisheries because of by-catch, like the offshore scallop fishery. We manage fisheries, the human activity, not the single fish stock. Decisions should consider other fish stocks, economics and social impacts.

Future research with some simulations would help quantify the risks of the uncertainty about M and the implications of managing under the assumption of the wrong M. It might even lead to TMGC choosing a model to manage by, even if there is uncertainty about the M assumption.

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Table 1. Summarized comparison of model assumptions and catch advice of VPA "M 0.8" model, ASAP "M 0.2" model and an empirical approach for cod on Eastern Georges Bank.

	VPA "M 0.8"	ASAP "M 0.2"	Empirical approach
Model Assumptions	M=0.8 for ages 6+ since 1994	Age and time invariant M=0.2	No assumption on M
	Age-dependent and time-invariant catchability of survey abundance indices	Age-dependent and time-invariant catchability of survey abundance indices	Age-aggregated and time-invariant catchability of survey biomass indices
	Seasonal changes	Seasonal changes	Seasonal changes are accounted by simple average of different survey biomass indices
	No error on fishery catch	Random error on fishery catch with small CV of 0.05; Multinomial distribution on fishery catch at age.	NA, fishery catch data is not used to evaluate stock status
	Age structured; Tracking cohorts using exponential decay function	Age structured; Tracking cohorts using exponential decay function	No age structure; Not tracking cohorts; Biomass changes by $B_{i+1}=B_i*\exp(\omega)$, ω is used to adjust catch advice; No real projection, and time lag when there is strong cohort going through
Model Input Data	Using 2-pieces of information (Survey and fishery data) to get stock status	Using 2-pieces of information (Survey and fishery data) to get stock status	Survey data and most recent 3-year TAC
Catch Advice	Risk analysis: Fref based catch advice; and Biomass changes under different catch scenarios.	Risk analysis: Fref based catch advice; and Biomass changes under different catch scenarios.	No real risk analysis; No Fref, using recent TAC as a starting point; Based on recent catch has not allowed rebuilding, adjusting fishing is the only way to promote rebuilding, regardless whether fishery is the driving factor of population dynamics

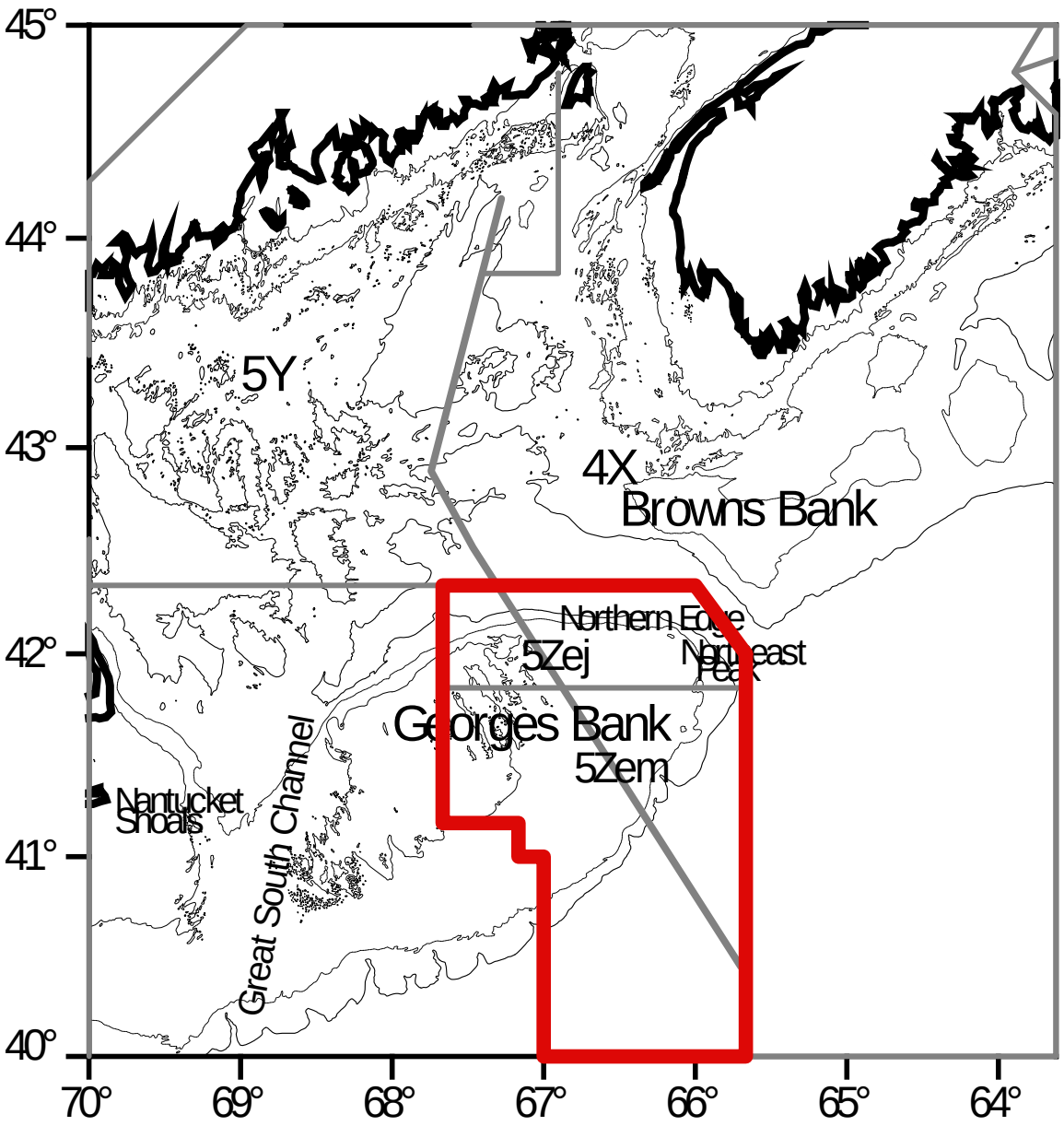

Figure 1. Transbounday management unit area of cod on Eastern Georges Bank shown in red.

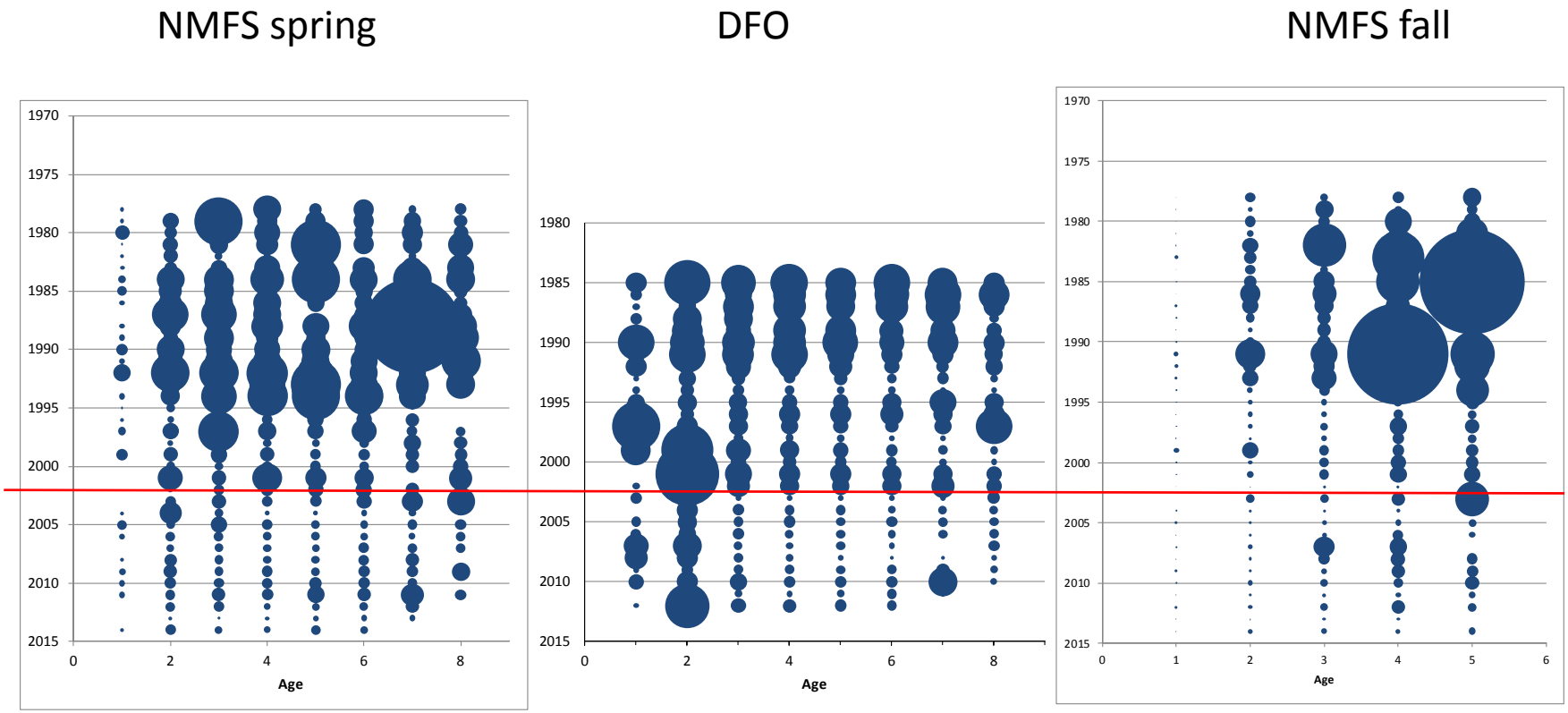

Figure 2. Relative fishing mortality(relF) by age of cod on Eastern Georges Bank, TRAC started in 2002 as shown by the red line.

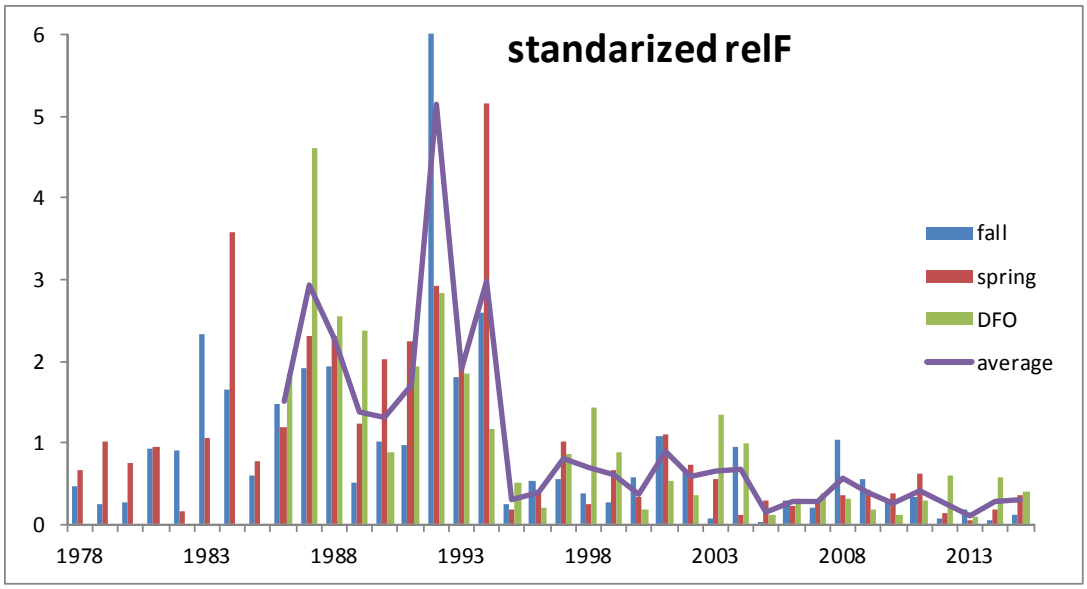

Figure 3. Relative fishing mortality(relF) using standarized fishery catch (in weight) and survey biomass data of cod on Eastern Georges Bank.

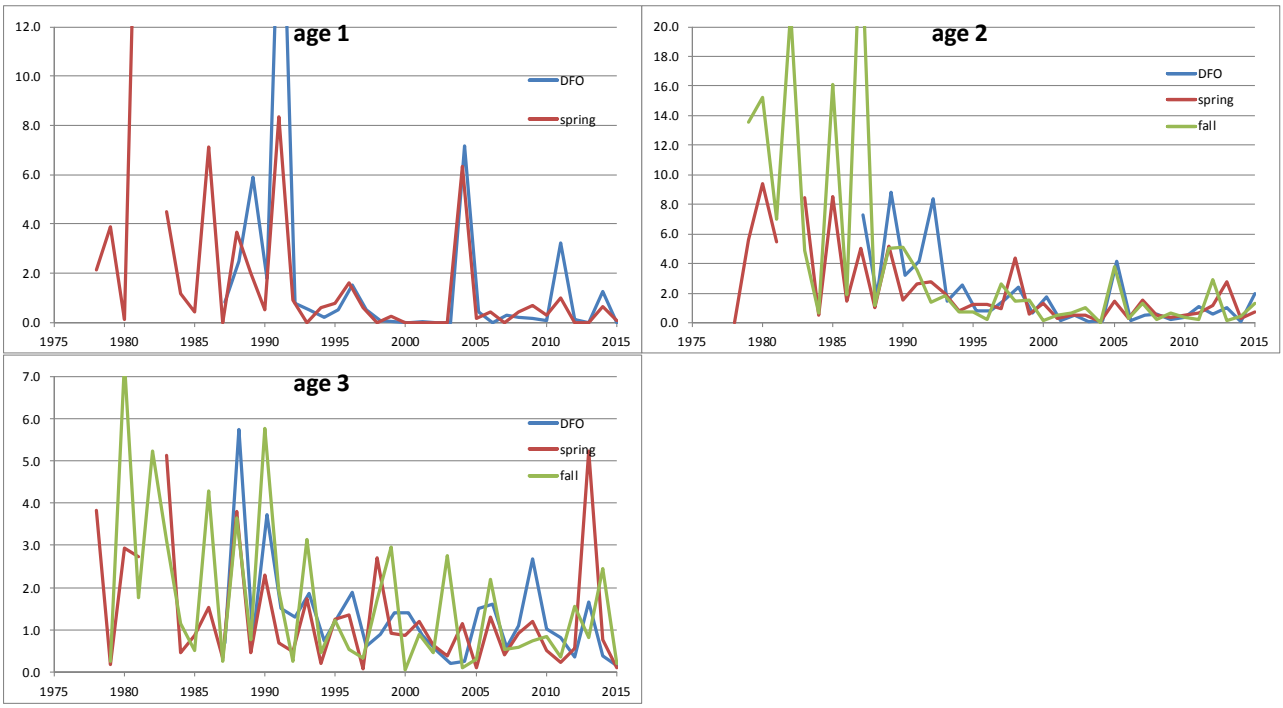

Figure 4. Survey abundance indices at ages 1-3 of cod on Eastern Georges Bank, standardized by scaling each series to its mean over the period of post-1994.

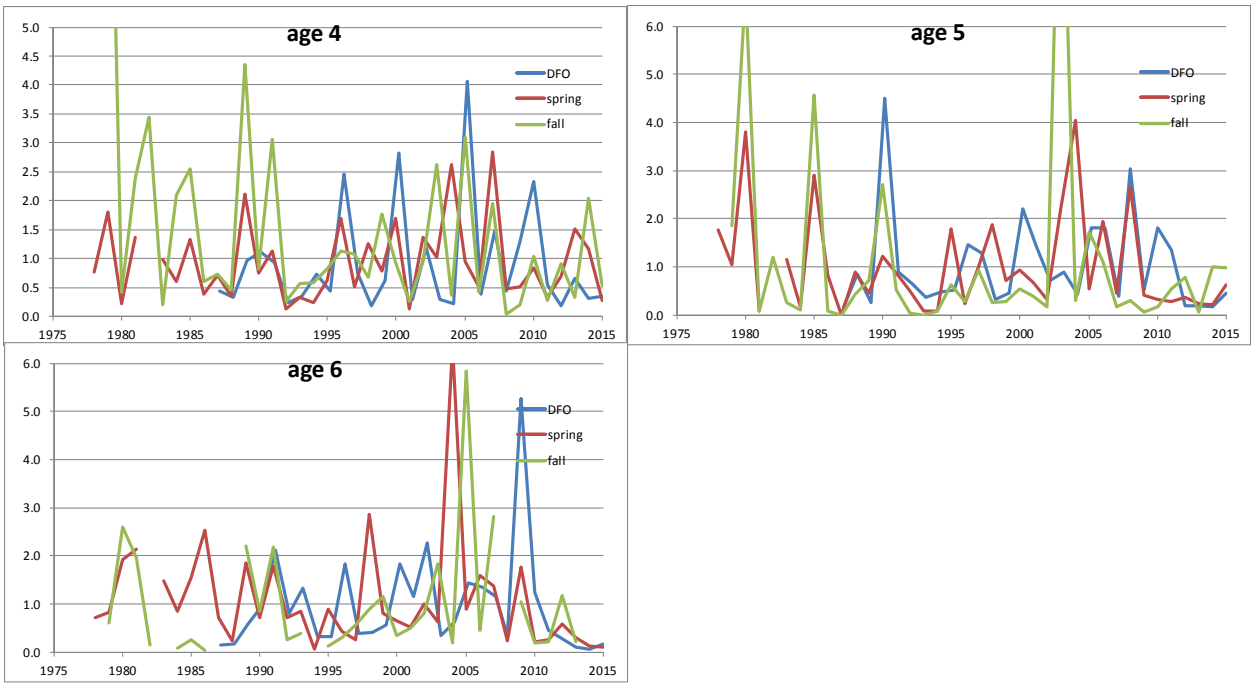

Figure 5. Survey abundance indices at ages 4-6 of cod on Eastern Georges Bank, standardized by scaling each series to its mean over the period of post-1994.

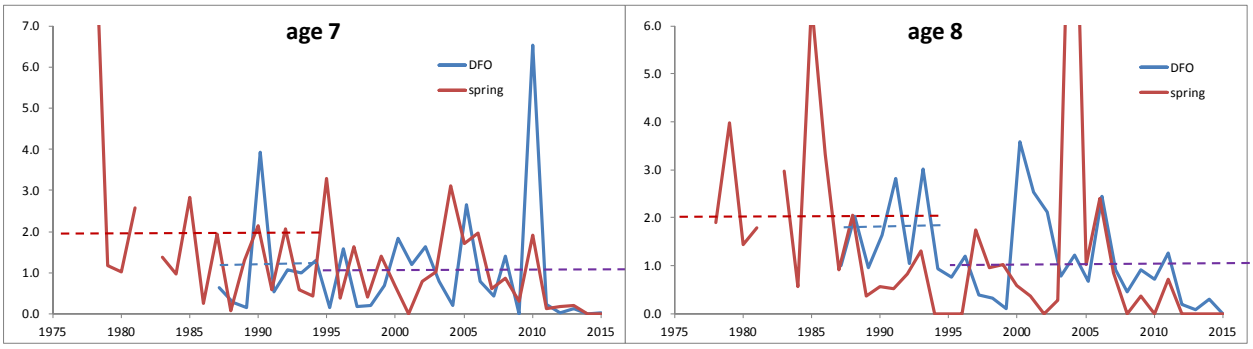

Figure 6. Survey abundance indices at ages 7-8 of cod on Eastern Georges Bank, standardized by scaling each series to its mean of post-1994; the dotted lines show the mean over the period of pre-1994 and post-1994.

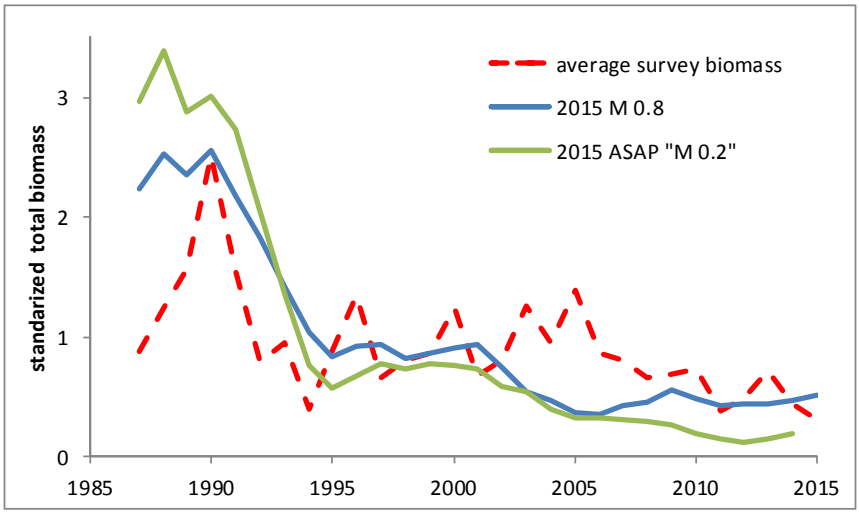

Figure 7. Comparison of standardized survey biomass index, population biomass from VPA "M 0.8" model and ASAP "M 0.2" model of cod on Eastern Georges Bank. The data used were from the 2015 assessment.

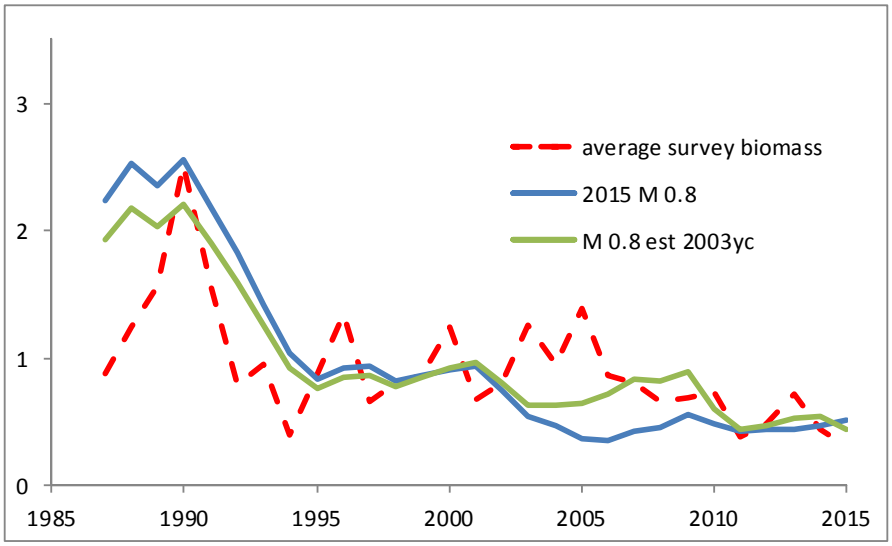

Figure 8. Comparison of standardized survey biomass index, population biomass from VPA "M 0.8" model and the "M 0.8 est 2003yc" model of cod on Eastern Georges Bank. The data used were from the 2015 assessment.

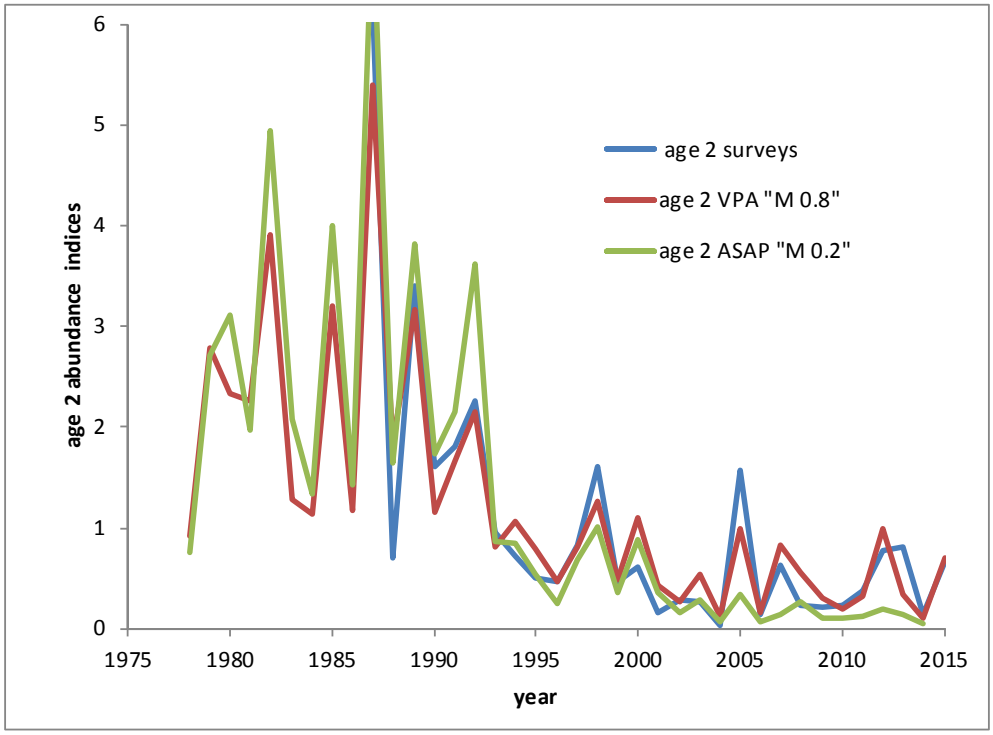

Figure 9. Comparison of standardized survey abundance indices at age 2, model estimated population abundance at age 2 from the VPA “M 0.8” model and ASAP “M 0.2” model of cod on Eastern Georges Bank. The data used were from the 2015 assessment.