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2009 Benchmark Assessment Review for Eastern Georges Bank Cod

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ABSTRACT

The assessment model formulation for the Eastern Georges Bank (EGB) cod management unit was last established in a benchmark review conducted in 2002. During the 2008 assessment, concerns were expressed about survey catchability and fishery partial recruitment (PR) patterns and the generation of appreciable “cryptic” biomass. A benchmark assessment to address these concerns was conducted in 2009. A further complication was the divergence of assessment approaches and results between the Canada/USA transboundary management unit, 5Zjm and the USA management unit, 5Z+6, of which the former is a part.

The background for the delineation of management units of cod on Georges Bank and the vicinity was reviewed. Stock structure, political and administrative boundaries and practical limitations of fishery monitoring and regulation all played a role. Various biological and tagging studies indicate that there is a resident spawning population that occupies eastern Georges Bank but exchanges with cod from the Great South Channel/Nantucket Shoals and stronger exchanges with Browns Bank cod occur. Maintaining the present management units is the least disruptive with respect to the existing agreement for consistent management by Canada and the USA but harmonization of the two assessments (Georges Bank and EGB) is required for this approach.

USA and Canadian catches (landings and discards) for 1978 to 2007 were updated and reviewed. Canadian landings were primarily from otter trawl and longline gear and discards from the groundfish fishery and scallop fishery were included. Almost all USA fisheries landings were taken by otter trawl. A change to the collecting and processing of USA fishery statistics occurred in 1994, going from a voluntary submission of catch quantities by processors and dealers and the use of personal interviews to obtain fishing effort and positional data, to mandatory submission of dealer reports and vessel trip reports (logbooks). Discards were primarily from the USA otter trawl fishery and were included for the years 1987 to 2007. Size and age composition of catches was obtained using port and at-sea sampling and the standard protocols employed by each country.

The DFO survey, conducted in February/March since 1986, the NMFS autumn, since 1963, and the NMFS spring, since 1968, along with the combined Canada/USA catch at age were used to determine stock status and size and maturity at age.

Investigations of fishery PR and survey trends in abundance and catchability at age from a basic Virtual Population Analysis (VPA) calibration, and total mortality and relative exploitation calculations from survey and fishery catch at age data determined that 1) there was no support for a change to steeply domed fishery PR, 2) there were indications of increased survey catchability for ages 3 or 4-6 in recent years, 3) total mortality declined some in the mid 1990s but remains high, 4) there were indications of higher natural mortality (M) for fish 6 years old and older and, 5) the relative exploitation rate had declined in recent years.

A number of VPA model formulations were explored, including splitting the surveys between 1993 and 1994 (“split”), letting the model estimate M and assigning various values for M starting from different ages. Three models were ultimately chosen for comparison of results and diagnostics: 1) no “split” with an M of 0.7 for ages 6+, 2) “split” with constant M of 0.2, and 3) “split” with M fixed at 0.5 for ages 6+. Diagnostics used to evaluate each model included: 1) survey catchability *q,* 2) population abundance, 3) estimated biomass trend compared with survey biomass trend, 4) population biomass, 5) age patterns in F, 6) time patterns in F with respect to catch, 7) residual patterns, 8) retrospective pattern, and 9) Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). All three models could be supported or criticized.

Model fit diagnostics did not provide convincing selection results among them and there were strong residual patterns no matter which model was used.

The Age Structured Assessment Program (ASAP) forward projection model was run as an exploratory alternative model to the VPA for both EGB and Georges Bank. This model allows for the inclusion of additional catch and survey indices without age composition data and provides more flexibility for weighting of input data and in examining partial recruitment by fleet. The models tested all exhibited retrospective patterns.

There was no strong biological information or knowledge to support large changes of survey *q* or M although some diagnostic evidence indicated that both survey *q* and M have changed. Several desirable features were displayed by the "split M 0.5" model. However, it was recommended during the benchmark review meeting that the results from the comparable model "split M 0.2" model also be considered. Until the fate of the 2003 year class has been documented (ages 6+) it will be necessary to use these two models to adequately account for uncertainty in the assessment. Doing so acknowledges that there is considerable uncertainty about selection of a single appropriate model.

It was decided that it may be premature to adjust F_{ref} because of the uncertainties about fish growth and natural mortality changes and the inability to characterize a stock-recruitment relationship.

Illustrative projections were conducted to evaluate how differences in stock status determination using the various models translated into differences for catch advice and biomass trajectory.

RÉSUMÉ

La formule actuelle du modèle d'évaluation de l'unité de gestion de la morue de l'Est du banc Georges (EBG) a été établie en 2002, lors d'un examen des points de référence. Au cours de l'évaluation de 2008 ont surgi des questions sur les profils de capturabilité dans le relevé et du recrutement partiel à la pêche ainsi que sur la constitution d'une biomasse cryptique appréciable. Un examen des points de référence a été effectué en 2009 pour tenter de régler ces problèmes. La divergence des approches d'évaluation et des résultats entre l'unité de gestion transfrontalière Canada–États-Unis 5Zjm et l'unité de gestion états-unienne 5Z+6, dont fait partie la première, vient encore compliquer la question.

Nous avons examiné le contexte de la délimitation des unités de gestion de la morue sur le banc Georges et aux alentours. La structure des stocks, les frontières politiques et administratives et les limites d'ordre pratique imposées par la surveillance et la réglementation des pêches avaient toutes une incidence. Diverses études biologiques et des travaux de marquage indiquent qu'une population reproductrice résidente occupe l'Est du banc Georges mais que des échanges ont lieu avec la morue du Grand Chenal Sud et des hauts-fonds de Nantucket et, de façon plus marquée, avec celle du banc de Browns. Le maintien des unités de gestion actuelles est l'approche la moins dérangeante au regard de l'entente existante sur la gestion rationnelle des stocks par le Canada et les États-Unis, mais une harmonisation des deux évaluations (banc Georges et EBG) s'impose alors.

Les prises canadiennes et états-uniennes (débarquements et rejets) de la période 1978-2007 ont été actualisées et revues. Les débarquements canadiens provenaient surtout des chalutiers et des palangriers, et on a inclus les rejets de la pêche des poissons de fond et des pétoncles. Presque tous les débarquements de la pêche états-unienne étaient le fait des chalutiers. En

1994, des changements au mode de collecte et de traitement des statistiques de pêche ont été apportés aux États-Unis; au lieu de déclarations volontaires des volumes de captures par les transformateurs et négociants et du recours à des entrevues en personne pour obtenir des données sur l'effort de pêche et la position, il est maintenant obligatoire de soumettre des rapports des négociants et des rapports sur les campagnes de pêche (journaux de bord). Les rejets, qui étaient surtout le fait des chalutiers aux États-Unis, ont été inclus pour la période 1987-2007. La composition des prises selon la taille et l'âge a été obtenue par des échantillonnages au port et en mer, selon les protocoles normalisés de chacun des pays.

Pour déterminer l'état des stocks et la taille et la maturité selon l'âge, on s'est appuyé sur le relevé mené en février-mars par le MPO depuis 1986, et sur les relevés du NMFS effectués à l'automne depuis 1963 et au printemps depuis 1968, ainsi que sur les données combinées Canada–États-Unis sur les captures selon l'âge.

Les examens du recrutement partiel (RP) à la pêche et des tendances de l'abondance et de la capturabilité selon l'âge d'après les relevés, après calibrage de l'analyse de la population virtuelle (APV) de base, ainsi que les calculs de la mortalité totale et de l'exploitation relative à partir des données sur les captures selon l'âge fournies par les relevés et par la pêche, ont permis de déterminer ce qui suit : 1) rien ne justifierait une modification de la courbe en dôme marqué du RP à la pêche; 2) on peut constater une hausse de la capturabilité des âges 3 ou 4-6 dans les relevés des dernières années; 3) la mortalité totale a légèrement baissé au milieu des années 1990 mais demeure élevée; 4) on note des signes de hausse de la mortalité naturelle (M) pour les poissons de 6 ans et plus; 5) le taux d'exploitation relative a baissé ces dernières années.

Diverses formules du modèle d'APV ont été explorées, notamment en fractionnant les relevés entre 1993 et 1994 (« fractionnement »), en laissant le modèle estimer M et en attribuant diverses valeurs à M en partant de différents âges. Trois modèles ont finalement été retenus pour la comparaison des résultats et les diagnostics : 1) pas de fractionnement avec une valeur M de 0,7 pour les âges 6+; 2) fractionnement avec M constante de 0,2; 3) fractionnement avec M fixée à 0,5 pour les âges 6+. Les diagnostics retenus pour évaluer chaque modèle étaient : 1) coefficient de capturabilité (*q*) des relevés; 2) abondance de la population; 3) tendance estimée de la biomasse comparée à la tendance de la biomasse d'après les relevés; 4) biomasse de la population, 5) profils des âges dans F; 6) profils chronologiques dans F en ce qui concerne les captures; 7) profils résiduels; 8) profils rétrospectifs; 9) critère d'information d'Akaike (AIC) et critère bayésien d'information (BIC). Chacun des trois modèles peut susciter autant l'adhésion que la critique. Les diagnostics d'ajustement des modèles n'ont pas fourni de résultats convaincants facilitant la sélection, et on notait de forts profils résiduels quel que soit le modèle employé.

On a essayé le modèle à projection prospective du programme d'évaluation à structure d'âge (ASAP) comme solution de rechange exploratoire à l'APV tant pour l'EBG que pour le banc Georges. Ce modèle permet d'inclure des indices supplémentaires des captures et des relevés sans que l'on ait besoin des données sur la composition par âge, et donne plus de souplesse pour pondérer les données d'entrée et pour examiner le recrutement partiel par flottille. Dans tous les cas, les modèles présentaient des profils rétrospectifs.

Aucun apport solide de données biologiques ou de connaissances ne justifierait des changements notables du *q* des relevés ni de M, même si certaines preuves diagnostiques pointent vers une modification dans ces deux paramètres. Plusieurs caractéristiques souhaitables ressortent du modèle fractionnement + M=0,5. Toutefois, pendant la réunion sur l'examen des points de référence, il a été recommandé de tenir aussi compte des résultats du modèle comparable fractionnement + M=0,2. Jusqu'au moment où l'on aura documenté le devenir de la classe 2003 (âges 6+), il sera nécessaire d'utiliser ces deux modèles pour rendre compte adéquatement de l'incertitude dans l'évaluation. Cette démarche prend acte de l'incertitude considérable qu'implique le choix d'un seul modèle approprié.

Il a été décidé qu'un ajustement de F_{ref} serait prématuré compte tenu des incertitudes relatives aux changements dans la croissance des poissons et la mortalité naturelle et de l'impossibilité de caractériser une relation stock-recrutement.

Des projections à caractère illustratif ont été effectuées pour évaluer en quoi les différences dans l'état des stocks obtenu par les divers modèles se traduisaient par des différences sur le plan des avis de gestion et des tendances de la biomasse.

INTRODUCTION

Following declaration of exclusive economic zones by coastal states in 1977, cod on Georges Bank have been exploited by only Canadian and USA fisheries. Cod are considered transboundary with respect to the Canada/USA maritime boundary that was established by the International Court of Justice in 1984. The Transboundary Resources Assessment Committee (TRAC) was established in 1998 to conduct joint Canada/USA peer review of assessments for transboundary resources in the Georges Bank/Gulf of Maine area and thus provide a common understanding of resource status. While stock assessment results are needed routinely to serve the management system, it is not practical to evaluate the assessment approach each time the assessment is conducted. The TRAC review process is two tiered, with annual assessment reviews undertaken between more intensive, periodic benchmark reviews. The assessment model formulation for Eastern Georges Bank cod was last established in benchmark review conducted in February 2002 (O'Boyle and Overholtz, 2002).

At the June 2008 assessment meeting, concerns were expressed about the model formulation established by the 2002 benchmark assessment. In recent years the model results exhibit domed catchability for older ages in surveys conducted by both Fisheries and Oceans Canada (DFO) and the USA National Marine Fisheries Service (NMFS), as well as a domed fishery partial recruitment (PR) for older ages, thereby generating 'cryptic' biomass that is not observed in the fishery or the surveys. This could potentially lead to an overestimation of fish at older ages and a benchmark review was recommended.

For the purpose of developing a sharing proposal, agreement was reached that the transboundary management unit for Atlantic cod would be limited to the eastern portion of Georges Bank (DFO Statistical Unit Areas 5Zj and 5Zm; USA Statistical Areas 551, 552, 561 and 562). For USA domestic management purposes, the multi-species management plan treats cod in NAFO Div. 5Z and Subarea 6 as an operational stock unit (Figure 1). At the 2008 USA Northeast Groundfish Assessment Review Meeting(GARM III) (NEFSC 2008), the assessment model for 5Z+6 cod was established using a model with split survey time series and natural mortality of 0.2 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.

This manuscript documents the supporting analyses that formed the basis of the consensus assessment model formulation reached during the benchmark review conducted in 2009.

MANAGEMENT UNIT

The previous benchmark assessment reviews of the two operational management units, 5Zjm cod and 5Z+6 cod, were conducted at the same TRAC meeting in 2002 where comparisons for harmony between the results from the two analyses were examined. The basis for the management units was not reviewed at that meeting. This section summarizes the background for the delineation of management units of cod on Georges Bank and the vicinity.

Management of Cod

A management unit is a geographic area defined for regulatory purposes. Stock is used to mean an identifiable population of a species. A stock complex is a group of stocks of a species. The designation of units for management entails a compromise between the biological realities of stock structure and the practical convenience of analysis and policy making (Gulland 1980).

The recent history of management units employed for cod on Georges Bank and the vicinity is briefly summarized here. From 1973 to 1981 the 'offshore stock' associated with Browns Bank was managed separately (Halliday 1974), but since 1982 all of 4X has been treated as a management unit due to difficulties in distinguishing catches from the components (Campana and Simon, 1985). Cod in 5Y have been managed separately from cod in 5Z since 1972 (Serchuk and Wigley, 1992). USA and Canada assumed separate responsibilities for management of cod in their respective waters following extension of jurisdiction in 1977. On the basis of demographic similarities (Serchuk and Wood, 1979), 5Z and Subarea 6 have been treated as an operational management unit for cod by the USA since 1977. Canada similarly considered 5Z and Subarea 6 as an operational management unit until a re-examination in 1989 resulted in designation of cod in DFO Statistical Unit Areas 5Zj and 5Zm as a separate management unit (Bowen 1987, Hunt 1989).

Delineation of Fishing Areas

The delineation of fishing areas for the purpose of collecting and reporting fisheries statistics pre-dates the designation of management units. Halliday and Pinhorn (1990) give a detailed description of the development of fishing area boundaries. Agreement on the first geographically defined areas in the northwest Atlantic was reached in the early 1930s. A finer scale statistical area grid was subsequently developed and has been in use by the USA and Canada since the 1940s. The statistical area grid was principally designed to reflect historically important fishing grounds and the distribution of fisheries.

The primary scientific input to fishing area delineation was information on stock structure. In addition, convenience with respect to political and administrative boundaries and practical limitations of fishery monitoring and regulation also played a role in the delineation of areas. For example, distributions of national fisheries interests in relation to the anticipated national member composition of Panels played a role in the designation of ICNAF Subarea boundaries. Due to the prominence of the haddock fishery at the time that fishing areas were being delineated, there are indications that the placement of statistical area boundaries was strongly influenced by knowledge about haddock fishing grounds and stock structure, particularly the line separating what is now Subarea 4 and Subarea 5 (Halliday and Pinhorn, 1990).

There has been general recognition that a fine scale grid system, which would permit aggregation of fishery information on varying scales, would be more flexible and capable of satisfying the diverse requirements than any fixed grid system. However, continuity is an important practical consideration that has curtailed radical changes in delineation of areas. Location of fishing activity is currently being collected and recorded by Canada and USA on a finer scale than statistical areas. While future consideration could be given to designation of management units that takes advantage of the resolution of the data, it is impractical at this time to consider management units on a scale finer than statistical areas.

Distribution and Movements of Cod

There is a fairly long history of studies pertaining to the stock structure of cod on Georges Bank and the vicinity. While these studies include investigations of morphometrics, meristics, parasite prevalence and other characteristics, analyses of tagging results play a prominent role. Loehrke and Cadrin (2007) provide a recent historical review of these studies. A brief summary of some key conclusions from these studies, largely extracted from Loehrke and Cadrin (2007), follows.

- Higgins (1929) tagging: existence of a Nantucket Shoals component with westward and eastward movements in summer, existence of coastal components from Massachusetts Bay to eastern Maine, and there is movement of cod between Georges and Browns Banks.
- Schroeder (1930) tagging and growth: Nantucket Shoals cod do not mix with the coastal components to the northeast. The Nantucket Shoals cod exhibit a pattern of seasonal migration west in the fall to wintering grounds and return in the spring; few cod from the north and east of Cape Cod are found on these wintering grounds.
- Higgins (1931) tagging: Browns Bank cod moved north and east with little movement to the south and west. Most of the cod tagged on Georges Bank stayed on Georges Bank with some movement to Browns Bank and less to Nantucket Shoals.
- Higgins (1933) tagging: Coastal cod stocks appeared to be local with little connection to the offshore banks.
- Wise (1958) tagging: reaffirmed the existence of the Nantucket Shoals component with seasonal winter migration southwest and spring return.
- Wise and Jensen (1960) tagging: eastern Georges Bank cod mix little with westerly and northerly groups but there was evidence of some movement to 4X. There was also evidence of another component in the South Channel which migrated inshore to the Nantucket Shoals; cod that wintered along the coast between Rhode Island and New Jersey joined the South Channel cod in the Nantucket Shoals. There were one or more components along the coast of the Gulf of Maine.
- Sherman and Wise (1961) parasite prevalence: separated Gulf of Maine, Georges Bank and Southern New England cod.
- Templeman (1962) synthesis: separated cod into coastal Nova Scotia, coastal Maine, Browns Bank, eastern Georges Bank and South Channel stocks.
- Wise (1963) synthesis: Gulf of Maine consists of many coastal components; Georges and Browns Bank cod are closely related; the South Channel cod are connected to cod in southern New England: the Georges Bank and South Channel cod are divided by the western shoals at about 68°W.
- Pentilla and Gifford (1976) growth rates (mean length at age): there were similarities between Georges Bank and South Channel/Southern New England cod but these differed from Gulf of Maine.
- Colton *et al*. (1979) spawning: spawning occurred on Georges Bank, Browns Bank and Nantucket Shoals with different peak spawning times.
- Bowen (1987) synthesis: 5Y is separate from 4X and Georges Bank with some north and south movement along the coast. There is evidence of exchange between the Bay of Fundy, Browns Bank and Georges Bank but enough segregation occurs to result in differences in demographic parameters.

- Hunt *et al*. (1999) tagging: the connection between eastern Georges Bank and Browns Bank is greater than with the South Channel; the strongest connection is between Browns Bank and the Bay of Fundy.
- Ruzzante *et al*. (1999) genetics: The Bay of Fundy, Browns Bank and Georges Bank are distinct.
- Begg *et al*. (1999) eggs, larvae and adult distributions, growth, maturity: there is continuity between 5Y and 5Z along Cape Cod, and separation between east and west Georges Bank. There are differences between the Gulf of Maine and Georges Bank as well as between east and west Georges Bank.
- Lage *et al*. (2004) genetics: there is more heterogeneity between Georges Bank and the Nantucket Shoals than between Georges Bank and Browns Bank (see also Wirgin et al 2007).
- O'Brien *et al*. (2005) synthesis: spawning occurs on eastern Georges Bank, western Georges Bank, Nantucket Shoals, Massachusetts Bay and Ipswich Bay and in distinct zones along the coast of Maine.
- Clark (2005) synthesis: there are structured coastal components with diffuse Bank groups in 4X.

The GARM review (NEFSC 2008) noted that there was a strong interaction between cod in 4X and 5Z. Loehrke and Cadrin, in their presentation highlights for the GARM report (NEFSC 2008) urged a re-evaluation of cod stock boundaries, particularly in the vicinity of the Great South Channel. Examination during this review meeting (O'Brien and Worcester 2009) of tag returns from the Northeast Regional Cod Tagging program suggested comparable exchange between eastern Georges Bank and both NAFO Division 4X and western Georges Bank.

Two important commonalities among the results from these historical studies are noteworthy in relation to management units for Georges Bank cod:

- Cod along the coasts of Nova Scotia, New Brunswick and Maine appear to belong to localized coastal stocks with limited connection to offshore banks.
- There appear to be components on Georges Bank (east of about 68°W), Great South Channel/Nantucket Shoals and Browns Bank with some exchange between Georges and Browns Banks and lesser exchange between Georges Bank and Great South Channel/Nantucket Shoals.

Summary of Stock Structure and Management Units

The population structure of cod in the broader Gulf of Maine area is characterized as offshore components on Georges Bank, Browns Bank and the Great South Channel/Nantucket Shoals, and localized coastal components that have limited connection to banks. The structure of cod on Georges Bank and the vicinity is complex involving seasonal migration patterns and seasonal mixing grounds with some exchange between putative stocks. Under these circumstances, precise delimitation of stocks is challenging. There are no general guidelines on how closely management unit boundaries should coincide with stock structure before the conservation objectives of the management measures are compromised. These matters typically have to be evaluated on a case by case basis.

It is often considered desirable to devise a management unit to encompass a unit stock. However, practical difficulties in separating catches into their constituent stocks when fisheries occur on seasonal mixing grounds may lead to management units that encompass stock complexes. There are many examples of this, e.g. Gulf of Maine/Georges Bank herring, cod in 4X and cod in 2J3KL. It may be necessary to introduce supplementary management measures to recognize and protect the components of the stock complex. For Georges Bank, it is possible to separate the catches from eastern Georges Bank. However, questions of the degree of exchange with adjacent areas remain. Arguments can be made to support either 5Z + Subarea 6 or statistical unit areas 5Zjm as management units.

Transboundary resources present additional challenges. Large transboundary management units carry greater bilateral transactional costs due to the greater number of fishermen involved. On the other hand, smaller management units may be ineffective if there is too great an exchange with adjacent areas.

If exchanges with adjacent areas are sufficiently low, treating eastern Georges Bank as the transboundary management unit satisfies the correspondence between stock and management unit and reduces bilateral transactional costs. The evidence suggests that there is a resident spawning population that occupies eastern Georges Bank. However, there are exchanges with cod on Browns Bank and the Great South Channel/Nantucket Shoals. The degree of exchange is not well quantified but is considered to be stronger with Browns Bank. Expanding the transboundary management unit to include either one or both of these adjacent areas introduces complications with respect to the existing agreement for consistent management by Canada and USA. There is no intrinsic reason why assessments of stocks and stock complexes could not be harmonized so that the sum of the parts approximates the total. It is not out of the question therefore for domestic USA management to continue using 5Z and Subarea 6 as a management unit while statistical unit areas 5Zjm is used as the transboundary management unit. This option, while the least disruptive in relation to the current agreement for consistent management, would benefit from establishment of adequate institutional arrangements to permit evaluation and comparison of the assessments so that their results can be harmonized.

The present agreement for consistent management of cod on Georges Bank between Canada and USA assumes that there is not appreciable net exchange of cod on eastern Georges Bank with adjacent areas. The USA has a requirement for management advice on cod west of eastern Georges Bank. 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. While other options could be followed, this option is possibly the least disruptive to the existing processes. However, this approach requires concurrent assessment reviews of 5Zjm and of 5Z+6 to harmonize results.

The remainder of this document deals with the assessment of cod on eastern Georges Bank.

FISHERY

Catch

Canada

Updated Canadian fisheries landings for 1978 to 2007 were extracted from the fisheries statistics database (MARFIS and ZIF) maintained by the Maritimes Region of Fisheries and Oceans Canada (DFO). Comparison with the data used in the 2008 assessment (Clark *et al*., 2008) revealed that there were no appreciable differences (Table 1, Figure 2). Canadian landings were taken primarily by longliners and otter trawlers during June to December on the northern edge of Georges Bank (Table 2, Figure 3 and 4). Catches in the fourth quarter have become more important in recent years. Dating back to the early 1970s, fishing has been restricted from March through May on spawning grounds. Between 1995 and 2004, fishing by the Canadian groundfish fishery on Georges Bank was not permitted during January and February.

Discards of cod from eastern Georges Bank have been attributed to Canadian groundfish and scallop fisheries. The estimated discards from the Canadian groundfish fisheries for 1997-1999, 2005 and 2006 (Van Eeckhaute and Gavaris, 2004; Gavaris *et al*., 2006, 2007a), and from scallop fishery for 1978-2007 (Van Eeckhaute *et al*., 2005; Gavaris, 2007b; Gavaris *et al*., 2008), were used for this benchmark assessment.

USA

Updated USA fisheries landings for 1978-2007 resulted in minor adjustments to the data used in the 2008 assessment. Almost all USA fisheries landings were taken by otter trawl, primarily during the second quarter (Figure 3).

The collecting and processing of the commercial fishery and landings data has been conducted using two methods during the time series. Prior to 1994, information of the catch quantity, by market category, was derived from reports of landings transactions submitted voluntarily by processors and dealers. More detailed data on fishing effort and location of fishing activity were obtained for a subset of trips from personal interviews of fishing captains conducted by port agents in the major ports of the Northeast. Information acquired from the interview was used to augment the total catch information obtained from the dealer.

In 1994, a mandatory reporting system was initiated requiring anyone fishing for or purchasing regulated groundfish in the Northeast to submit either vessel trip reports (logbooks) or dealer reports, respectively (Power *et al.* 1997). Information on fishing effort (number of hauls, average haul time) and catch location were now obtained from logbooks submitted to NMFS by vessel captains instead of personal interviews.

Estimates of total catch by species and market category are derived from mandatory dealer reports submitted on a trip basis to NMFS. A multi-tier trip-based allocation has been implemented to combine each mandatory reporting dealer trip with a vessel trip report (VTR) trip or a group of VTR trips of similar characteristics to obtain area fished and effort associated with the dealer trip (Wigley et al. 2007). Since 1994, annual cod landings from eastern Georges Bank have been summarized from all allocated trips fishing in statistical areas 551-552 and 561-562.

Discards of cod from eastern Georges Bank have been attributed to USA otter trawl and scallop fisheries. A ratio of discarded cod to total kept of all species (d:k) was estimated on a trip basis, semi-annually. Total discards (mt) were estimated from the product of d:k and total commercial landings (Wigley et al. 2008). The estimated discards (1989-2007) were used for this benchmark assessment. During 2005-2007, the magnitude of discards was similar to landings and discards were primarily from the otter trawl fisheries.

Compilation

Combined Canada/USA catches, which averaged 17,508 mt between 1978 and 1992, peaked at 26,463 mt in 1982, declined to 1,684 mt in 1995, fluctuated around 3,000 mt until 2003, and subsequently declined again. Catches in 2007 were 1,796 mt, including 472 mt of discards (Table 3, Figure 5). Since 1996, the proportion of the total catch accounted by discards ranged from 2% to 15% (Table 3).

Size and Age Composition

Canadian Fishery Landings

The size and age composition for the Canadian groundfish fisheries from 1978-2007 were derived for all principal gears and seasons using port and at-sea observer samples. Before 1990, because of the limited number of observer samples and the absence of a recorded landing date, only the port samples were used (Table 4 and Table 5).

For the derivation of size and age composition, a weight-length relationship was used to calculate numbers caught from weight caught. Figure 6 shows the comparison of the quarterly weight-length scatter plot for different years using Canadian at-sea observer samples. The relationships were similar for quarter 1-3 but differed for quarter 4. Because most of the samples since 2001, 502 out of 623, were from scallop discard observer samples, which have fewer large cod, these data were not used to derive weight-length parameters. Therefore, the weight-length parameters derived from 1995-2000 observer samples were applied in the catch at age calculations for all years. With round weight in kilograms and length in centimetres, these values were a=0.00001045 and b=2.983262 for quarter 1 and quarter 2, a=0.00001523 and b=2.906954 for quarter 3, a=0.00001205 and b=2.977549 for quarter 4.

The length samples from the three principal gears, otter trawlers, longliners and gillnetters, were grouped separately by month and then by quarter. Catch at length was obtained by prorating length frequency by the catch from the corresponding fishing gear within each quarter. The gear specific landings and sample numbers are shown in Table 2, 4 and 5. There were insufficient longline samples in the earlier years. A comparison of length frequency was conducted among longline samples from different quarters and otter trawl samples from the same quarter. This indicated that the longline length frequencies peak at a larger size than those of the trawlers' (Figure 7), therefore it was not considered appropriate to borrow samples from the otter trawl for the longline landings. Assuming that the longline length frequencies were similar in different quarters in these years, the longline length samples from other quarters were borrowed when there was no length sample available.

The age composition was estimated by quarter using the age length keys in the corresponding quarter. For the quarters when there were no age samples available in some early years, the age length keys from the USA commercial fishery in 5Zj and 5Zm were applied. The DFO spring survey age length keys were used to supplement first quarter age length keys after 1986. A summary of the number of length and age samples used to estimate Canadian commercial landings catch at age from 1978-2007 is listed in Table 6. The calculated landings at age are shown in Table 7.

Discards from Canadian Scallop Fisheries

Length frequency samples of cod discards from the scallop fishery are available from the routine at-sea observer trips since August 2004. The age length keys from these samples, supplemented with those from the commercial fishery and DFO survey samples, were used in calculating the discards at age quarterly for this time period.

Observer sampling of discards prior to 2004 was inadequate, therefore survey information was used. A comparison of the 2007 quarterly discards length frequency from the scallop fishery with the DFO and NMFS spring and fall surveys as well as commercial otter trawl samples (Figure 8) indicated that the selectivity from the scallop dredges was similar to the survey trawl. The scallop fishery was more likely to capture smaller cod than the commercial otter trawls. Therefore, for data prior to 2004, the age composition from the averaged DFO and NMFS spring survey for the first half year and from NMFS fall survey for the second half year were used to calculate the scallop discards at age. Then the sum of the first and second halves each year gave the annual scallop discards at age (Table 8).

The lengths and weights at age were assumed to be the same as the research survey samples when no at sea observer sample was available. Before 1986, NMFS spring and fall survey length at age data were used for first and second half year, respectively. After 1986, the averaged value of the DFO and NMFS spring survey data was applied for the first half year. For the weight at age, NMFS spring and fall survey data were only available after 1992 and so a weight-length function derived from the 1992-2000 data was applied to the pre-1992 length data. The number weighted average of length and weight at age of the first and second halves were calculated as the annual values.

Discards from Canadian Groundfish Fisheries

Cod discards from the Canadian groundfish fisheries were assumed to have the same size and age composition as the otter trawl landings samples. Therefore, the groundfish discards at age were derived by applying the age and length samples from the otter trawl landings to the discard.

USA Fishery Landings

The age composition of the USA landings was estimated, by market category, from length frequency and age samples pooled by calendar quarter. Landed mean weights were estimated by applying the weight-length equation:

$$\ln \text{Weight (kg,live)} = -11.7231 + 3.0521 \ln \text{Length (cm)},$$

to the quarterly length frequency samples, by market category. Numbers landed, by quarter, were estimated by dividing the mean weight into the quarterly landings, by market category, and prorating the total numbers by the corresponding market category sample length frequency. Quarterly age-length keys were then applied to the numbers-at-length to estimate numbers landed at age. Annual estimates of landings at age were obtained by summing values over market category and quarter. Landings were calculated by quarter, rather than by month, since there were months with less than two length frequency samples per market category (i.e., minimum desired for monthly catch estimates).

In some years samples were pooled semi-annually, or annually due to an insufficient number of samples within a quarter. The age composition of the USA landings from eastern Georges Bank was estimated by applying USA length frequencies and combined USA and Canadian age samples for 1978-2006. In 2007, however, Canadian age samples were not applied since there were sufficient USA samples.

Also, in a few years, primarily during the mid-1990s, combined eastern plus western length frequencies were applied due to the lack of sufficient length samples from eastern Georges Bank. The assumption was made that length frequencies from eastern and western Georges Bank would be similar, therefore, all length frequencies were combined to characterize the eastern component of landings. The resulting landings at age from the USA fishery are shown in Table 9.

Discards from USA Fisheries

Atlantic cod discarded in the eastern Georges Bank area by USA otter trawl and scallop fisheries were estimated using the NEFSC Observer data from 1989-2007. Annual discards at age were estimated by applying combined survey and commercial age-length keys to observer length frequency data (Table 10). No length frequency samples were available for 2001, so estimates of discards were derived based on the average of mean weights at age from 2000 and 2002.

Compilation

The combined Canada/USA fishery catch at age was obtained by pooling Canadian landings at age and discards at age from the groundfish and scallop fisheries with USA landings at age and discards at age (Table 11, Figure 9). The number of fish captured by the fishery for all ages has declined substantially since 1995. The proportion at age has tended to decrease for ages 2-3 and increase for ages 4-7. Both number and proportion caught at ages 9 and older are lower.

The average of weight at age from Canadian landings, Canadian groundfish and scallop fishery discards, and USA landings and discards, weighted by the respective numbers at age, was used as the Canada/USA fishery average weight at age (Table 12).

SURVEY INDICES

Surveys on Georges Bank have been conducted by DFO each year (February) since 1986 and by NMFS each autumn (October) since 1963 and each spring (April) since 1968. All surveys use a stratified random design (Figures 10 and 11). In the past assessment, the stratified mean catch in numbers per standard tow was used as the fish population abundance index. To make the meaning of the survey catchability coefficient q clearer, the stratified mean catch in numbers per tow was changed to total catch in numbers using swept area. The ratio of total numbers to stratified mean numbers per tow was calculated to allow comparability between years. The ratio only differs for years when there was no set in a stratum or when a large area of a stratum was not sampled, both an unusual occurrence.

Survey abundance indices at younger ages have declined substantially for all three surveys since the early 1990s (Tables 13-15, Figures 12-14). In contrast, the abundance indices for ages 4-6 fluctuate without trend since the early 1990s. Abundance indices for ages 9 and older are currently very low.

Population weight at age for beginning of year was derived from the DFO and NMFS spring survey results (1978-1985 DFO weight length relationship applied to NMFS spring average length at age; 1986-1992 DFO weight at age; 1992-2008 sample numbers weighted average of DFO weight at age and NMFS spring weight at age) (Table 16). Figure 15 shows the smoothed weight at age which displays a clearly declining trend since the early 1990s.

Length at maturity from the DFO survey data was analyzed for 2 time periods: 1987-1993 and 1994-2008. Results indicate that both male and female cod appear to be maturing at a smaller size in the recent time period, with length at 50% maturity decreasing from 42-45 cm to 36-39 cm for males and from 42 cm to 39 cm for females. No appreciable change was detected in the age at maturity except that 2-year old males showed a slight increase of proportion mature. Length and age at maturity were analyzed from the NMFS spring survey and estimated for the two time periods 1987-1993 and 1994-2008. Both males and females appear to be maturing at smaller sizes in the more recent period with 50% (median) maturity at length declining from 46 cm to 41 cm for males, and from 44 cm to 40 cm for females. Median maturity at age, however, did not decline: 50% maturity at age was about 2.3 for males and 2.1 for females for both time periods. At age 3, about 80% of females were mature in the earlier period and about 90% were mature in the latter period.

STOCK STATUS DETERMINATION

The adaptive framework, ADAPT, (Gavaris 1988) was used to calibrate the Virtual Population Analysis (VPA) with the research survey indices. The observed data used in the models were:

$C_{a,t}$ =catch at age for ages a = 1 to 10+ and time t = 1978 to 2007, where t represents the year during which the catch was taken

$I_{1,a,t}$ = DFO survey for ages a = 1 to 8 and time t = 1986.16, 1987.16… 2007.16, 2008.00

$I_{2,a,t}$ = NMFS spring survey (Yankee 41) for ages a = 1 to 8 and time t = 1978.29, 1979.29, 1980.29, 1981.29

$I_{3,a,t}$ = NMFS spring survey (Yankee 36), for ages a = 1 to 8 and time t = 1982.29, 1983.29… 2007.29, 2008.00

$I_{4,a,t}$ = NMFS autumn survey, ages a = 1 to 5 and time t = 1978.69, 1979.69… 2007.69.

For comparison with indices, the population numbers at the time of year the surveys occurred were derived by applying the fishing and natural mortality to the numbers at the beginning of the year. Since the fishing mortality rate for 2008 was not known, the DFO survey and the NMFS spring survey were designated as beginning of year for 2008 only. This deviation is not considered to have an appreciable impact as the catch prior to the surveys being conducted is small in recent years.

All model formulations assumed that observation errors for the catch at age data were negligible. Observation errors for the abundance indices at age were assumed to be independent and identically distributed after taking natural logarithms of the values. Zero observations for abundance indices were treated as missing data as the logarithm of zero is not defined. Numbers and fishing mortality for the 10+ age group were derived by aggregating the survivors for ages 9 and 10+ in the previous year.

Estimation was based on minimization of the objective function:

$\sum_{s,a,t}\left(lnI_{s,a,t}-\left(\hat{\kappa}_{s,a}+lnN_{a,t}\right)\right)^2$, where *s* indexes survey and *N* is population abundance.

Statistical properties of estimators were determined using conditional non-parametric bootstrapping of model residuals (Efron and Tibshirani 1993, Rivard and Gavaris 2003). Retrospective analyses were used to detect any patterns to consistently overestimate or underestimate fishing mortality, biomass and recruitment relative to the terminal year estimates.

Context

Basic VPA Calibration

For a basic VPA calibration, the annual natural mortality rate, M, was assumed constant and equal to 0.2 for all ages in all years. Fishing mortality on age 9 for 1978 to 2007 was assumed to be equal to the population number weighted average fishing mortality on ages 7 and 8. The estimated model parameters were:

$\nu_{a,t} = lnN_{a,t} = ln$ population abundance for a = 2 to 9 at time t = 2008
$\kappa_{1,a} = ln$ DFO survey catchability for a = 1 to 8
$\kappa_{2,a} = ln$ NMFS spring survey (Yankee 41) catchability for ages a = 1 to 8
$\kappa_{3,a} = ln$ NMFS spring survey (Yankee 36) catchability for ages a = 1 to 8
$\kappa_{4,a} = ln$ NMFS autumn survey catchability for ages a = 1 to 5.

The basic VPA calibration displayed notable age and time residual patterns (Figure 16). However, greatest concern was caused by the persistent retrospective patterns (Figures 18-19) which indicated that contemporary estimates of biomass were consistently lower than previously estimated.

2002 Benchmark Formulation

A benchmark assessment review was conducted in 2002 to address concerns about the residual patterns and the retrospective patterns from the assessment. For that consensus model formulation the age 10 catch was used rather than a 10+ age group. The benchmark formulation was otherwise similar to the basic formulation except that it also estimated population abundance at age 11 for 1999 onwards (referred to as corner). The estimated model parameters for the consensus formulation from that meeting applied to the currently available data were:

$\nu_{a,t} = lnN_{a,t} = ln$ population abundance for a = 2 to 11 at time t = 2008 and for a = 11 at time t = 1999 to 2007
$\kappa_{1,a} = ln$ DFO survey catchability for a = 1 to 8
$\kappa_{2,a} = ln$ NMFS spring survey (Yankee 41) catchability for ages a = 1 to 8
$\kappa_{3,a} = ln$ NMFS spring survey (Yankee 36) catchability for ages a = 1 to 8
$\kappa_{4,a} = ln$ NMFS autumn survey catchability for ages a = 1 to 5.

Note that the 2002 benchmark formulation excluded DFO survey abundance indices for ages 1 and 8. They are included here for comparative purposes, but do not have much influence on the fit.

The residuals from the 2002 benchmark formulation were somewhat improved compared to the basic formulation, but age and time patterns persisted (Figure 17). The retrospective pattern was greatly improved with contemporary estimates of biomass being either slightly lower or higher than previously estimated (Figures 18-19).

The benchmark formulation resulted in a somewhat domed fishery PR (Figure 20). In view of relatively flat survey catchability at older ages (Figure 21), this feature was not considered a concern at the time. Further, a domed shaped fishery PR was not inconsistent with the decline in catches during the first quarter, when larger cod were more prevalent (Figure 22). The resulting fishing mortality trend from the benchmark formulation also appeared to better reflect the trends in catches (Figure 23).

In recent assessments, the tendency for a dome shaped fishery PR with a more steeply descending limb (Figure 24), dome survey catchability at age (Figure 25) and high estimates of population at older ages (Figure 26) raised concerns. Preliminary exploration of alternative model formulations (Clark et al 2008) suggested that the benchmark formulation may be overestimating population biomass. A benchmark review was therefore recommended by the 2008 TRAC Assessment review (O'Brien and Worcester, 2008).

Data Features that Models Need to Fit or Explain

The rationale for a dome shaped fishery PR was revisited. While comparisons of length composition from Canadian fisheries between first quarter and second half confirmed that larger/older cod tended to be more prevalent in the first quarter, this was not always the case (Figures 27-30). More importantly, the proportion of the catch attributed to the first quarter only averaged 10% (Figure 31). As a consequence, the ratio of cod aged 4+ to 7+ was not appreciably affected by the absence of first quarter catches (Figure 32).

Another factor which might contribute to a dome shaped fishery PR is closed area II (Figure 10), which has been not accessible for the USA fishing fleets since 1994. The DFO spring survey data from 1987-2007 were used to examine fish size composition changes before and after the area closed. The survey catch data from strata 5Z3 and 5Z4 in 5Zjm were separated into two parts, east of 67.333 W and north of 41.0 N, and this area combined was considered to be an approximation of closed area II (Figure 10). Figure 33 and 34 are the age structure comparisons of inside and outside closed area II. There is no consistent pattern of difference both for pre- and post- 1994. Table 17 shows the comparison inside and outside closed area II for the 4+ age group proportion and weighted average age. Based on this information, no clear conclusion could be made about the impact of closed area II on the size distribution of fish.

Despite reduced catches of ages 4-6 since the mid-1990s, the catch of older fish has not increased appreciably (Figure 35).

Smoothed survey trends indicate a progressive decline for ages 2-3, a decline at ages 4-6 during the early 1990s followed by a moderate increase, and fluctuation without much trend at ages 7-8 (Figure 36). The 2002 benchmark formulation does a better job of fitting the ages 4-6 trend, but generates more fish at ages 7-8 than indicated by the surveys.

Time trends in survey catchability at age, extracted from the basic formulation, indicate that survey catchability has increased since the mid 1990s for ages 4-6 and perhaps age 3, but not necessarily for other ages (Figure 37). Indeed, the catchability appears to decline at ages 1 and 2.

Total mortality calculations suggest that there may have been a decline around the mid 1990s, but total mortality is currently as high or higher compared to pre-1995 (Figure 38). Notably, total mortality is appreciably higher for ages 6-8 compared to ages 4-5. Relative exploitation (fishery catch / survey catch), in contrast, suggests that fishing mortality decreased substantially in the mid 1990s (Figure 39).

Estimates of instantaneous total mortality (Z) were derived from both DFO and NMFS spring survey total catch indices and from fishery catch at age data. Z_{45} and Z_{678} were referred to as the approximation to total mortality of ages 4-5 and ages 6-8 in year i, respectively.

$$Z_{45}=\ln(\ (\Sigma \text{ age 4+ age 5 for years i })/\ (\Sigma \text{ age 5+age 6 for years i+1}))$$
$$Z_{678}=\ln(\ (\Sigma \text{ age 6+age 7+age8 for years i })/\ (\Sigma \text{ age 7+age8+age9 for years i+1}))$$

The LOESS smoothing method was fit to each of the total mortality time series data (Cleveland, 1979).

In summary, the following observations can be made:
– there is no support for a change to a steeply domed fishery PR,
– there are indications of increased survey catchability for ages 3 or 4-6 in recent years,
– total mortality declined somewhat in the mid 1990s but remains high,
– there are indications of higher M for fish 6 years old and older, and
– the relative exploitation rate has declined in recent years.

Model Options

No Split/Increase M

Both DFO and NMFS spring surveys show an increase in the number of fish of age 4-6 in recent years, but no increase for the older fish (Figure 12 and 13), despite a substantial decrease in the catch for ages 4-6 since 1994 (Figure 35). Further, the calculated total mortality rate, Z, from survey and catch data remains high after 1994 (Figure 38). This suggests that natural mortality might have increased in recent years. The starting year for an increase in natural mortality was selected as 1994, the date when new management measures were introduced and stock abundance was low.

ADAPT setup for this model:
- M=0.2 for ages 1-10+, years 1978-1993.
- M=0.2 for ages 1 to age A-1, from 1994-2007, then estimated as one block for ages A-10+.
- In 2008, N is estimated for ages 2-9.
- F for age 9 is calculated as the weighted average of F on age 7 and 8, for years 1978 - 2007.

In order to decide on a suitable age A at which the higher M begins, a few trial VPAs were done starting at different ages from 4 to 7, respectively. The time and age patterns in F, age patterns in survey catchability *q*, sum of square residuals (SSQ) and Akaike's Information Crieteria (AIC) were used to diagnose the fits (Figures 40-42). The model with the M change starting at age 6 has the lowest SSQ, with a flat topped fishery PR and survey catchability, and estimates M as 0.7. The AIC comparison shows that the model starting at age 6 has the highest Akaike weight (0.95) of the four models (Table 18). Estimation of M can be erratic due to the correlation of survey *q* and M. Therefore comparisons were made with M fixed at different values from 0.2 to 0.7 starting at age 6 (Figures 43-45). The F for post-1994 remained as high as the F during the 1980s when M= 0.2, 0.3 and 0.4. The trial with M =0.7 has flat shaped survey catchablity *q*, the lowest SSQ with an Akaike weight of 0.83 (Table 19). The retrospective runs are used to confirm the consistency of M estimation with time changes (Figure 46). The estimated M was around 0.7 for all the terminal years from 2000-2008. Based on the above analysis, the model with fixed M at 0.7 starting at age 6 from 1994 (referred to as "no split M 0.7") was examined further.

Tables 20-21 show the assessment result using "no split M 0.7" model formulation. This model produces a 3+ biomass of about 17,500 mt in 2008. The averaged fishing mortalities (F) in the 3 time blocks (1978-1993,1994-2000,2001-2007) are around 0.5, 0.25 and 0.18, all with flat shaped fishery PR patterns (Figure 47). The survey catchability *q* of the DFO spring survey is 0.8 at fully recruited age 5 (Figure 48). Comparisons between the estimated *q* and the *q* calculated as the ratio of the survey abundance index to estimated population numbers shows a clear increasing trend of calculated *q* for ages 4 to 6, which occurred around the mid 1990s (Figure 49) . For ages 4 and 5, most of the calculated *q* points are below the estimated *q* for the early years and above that for the recent years. This suggests that the survey catchability *q* has changed.

<u>Split/Constant M</u>

At the GARM III meeting, the *q* changed model was accepted as the assessment model of 5Z+6 cod (NEFSC 2008). In that model, the survey abundance indices were split at 1993-1994, and constant M=0.2 assumed for all the years. This model was also explored the 2009 benchmark meeting for Atlantic cod on eastern Georges Bank. It is referred to as the "split M 0.2" model.

The estimated beginning year population abundance and annual fishing mortality are presented in Tables 22-23. The model produces almost the same level of fishing mortality at 0.6 for the 3 time blocks, despite the restrictive management measures that have been in place in the recent time period (Figure 50). The 3+ biomass in 2008 is estimated at around 9,000mt. Survey catchability *q* of the DFO spring survey reaches 3.0 at fully recruited age 6, which seems incredibly high and represents a marked change from pre-1994 (Figure 51). There is a clear increasing trend in both model estimated and calculated *q* for ages 3 to 8; however, in a few ages, most of the calculated *q* points are still below the estimated q, greatly affected by the survey year effects from high catches (Figure 52). Our ability to estimate *q* well may be compromised by the short time series for data since 1994 and the high variability in survey catches, both confounded with potential changes in M

Split/ M Change

Due to the problems with the above 2 models, a model with both *q* and M changes was explored. This model has the same setup as the "split M 0.2" model, except that M was estimated for ages A-10+ for the years 1994-2007.

The results for the trial VPA where M was estimated for various starting ages from 4-8 are presented in Figures 53-55. The fishery PR and survey catchablity increased with ages when the starting age was 4 or 5, but became dome shaped when the starting age was 7 or 8. From the fit statistics, a starting age of 6 for an increase in M had the smallest SSQ value and the Akaike weight was relatively low at 28% (Table 24). A starting age of 5 or 7 had 21% of the selection probability, which means that there was some uncertainty about the best starting age. The high variability in survey data and the correlation of survey *q* and estimated M are suspected to contribute to the difficulty in clearly identifying a preferred starting age. A few VPA trials were done fixing M at different values from 0.2 to 0.7 with a starting age of 6 (Figure 56-58). For runs with M=0.2, 0.3 and 0.4, the estimated F in 1994-2000 remained as high as the F during the 1980s. An M=0.5 had the smallest SSQ value, and flat survey *q* at older ages. AIC also selected the M=0.5 model with an Akaike weight of 0.35, while M=0.6 had the weight of 0.31 and M=0.4 had the weight of 0.18 (Table 25). M between 0.4-0.6 accounted for about 80% of the probability in the fit statistics. The retrospective runs had the same estimated M values for all the terminal years except for 2003 and 2004 which had lower M values with higher CVs (Figure 59). Therefore, a model with M fixed at 0.5 and with a starting age of 6, referred to as "split M 0.5" model, was examined further.

This "split M 0.5" model estimated Ages 3+ biomass at about 11,500 mt in 2007 (Table 26). Estimates of average fishing mortality were 0.6 from 1978 to 1993, 0.45 from 1995 to 2000 and 0.35 from 2001 to 2007 (Table 27, Figure 60). Survey catchability *q* for the DFO spring survey was 1.5 at fully recruited age 5 (Figure 61). The estimated *q* of younger fish at ages 1 and 2 decreased for the recent time period, slightly increased for age 3, and a clear increasing trend was seen for older fish (Figure 62). Year effects from high catches persisted. For a few ages, most of the calculated *q* points were still below the estimated *q*.

Comparisons

The following diagnostics were used to compare the above three models.
– Survey catchability *q* (Figures 48, 51 and 61)
– Population abundance (Figure 63)
– Estimated biomass trend compared with survey biomass trend (Figure 64)
– Population biomass (Figure 65)
– Age patterns in F (Figures 47, 50 and 60)

– Time patterns in F with respect to catch (Figure 66)
– Residual patterns (Figure 67)
– Retrospective pattern (Figure 68-69)
– AIC and Bayesian Information Criteria (BIC, which penalizes models with more parameters) selection (Table 28)

All three models can be supported or criticized. Model fit diagnostics hardly provide convincing selection results among them. There was no strong biological information or knowledge to support large changes of survey *q* or M. Some evidence indicated that both survey *q* (time trends of survey catchability *q*) and M (both AIC and BIC selected the model with high M) have changed. The "split M 0.5" model displays the following desirable features:
– Flatter survey catchablility at older ages
– Calculated time trends of *q* from VPA support *q* changes, and smaller changes in survey catchability at all ages after 1994
– Flatter fishery PR
– Time trends of F are more consistent with catch in the past
– Better retrospective patterns of 3+ biomass
– The Z from survey and catch support a high Z of older fish
– Fit statistics favour "split M 0.5" model over the other 2 models

However, there are strong residual patterns no matter which model is used (Fig 67). A residual autocorrelation analysis was conducted by calculating the lag 1 autocorrelation coefficient using the Yule-Walker function and a comparison was made between the "split M 0.2" model and "basic VPA calibration" model. There was no significant difference in the autocorrelations between these two "split" and "no split" models (Figure 70). Most of the residual patterns were associated with year effects in the survey data. A sensitivity analysis was done by dropping some years of survey data (Table 29) from the calibration indices based on low or high survey coefficients of variation (CV). The "split M change" model was used to compare these results. There was no significant difference for 3+ biomass and 2008 fish population numbers (Figure 71). Furthermore, the selection criterion for dropping survey years was quite arbitrary, and no standard method has been documented. Because of the noisy survey abundance indices, and the high correlation of *q* and M, there are uncertainties about the scale and time of M and *q* changes.

Other model explorations

Fratio in VPA

A further exploration was done using the Fratio method in VPA. In this method, the F on age 10+ group was calculated as a ratio of F on age 9. M was set up as 0.2 for all the ages and years. In 2008, N was estimated for ages 2-10+. This model formulation resulted in a dome shaped fishery PR and survey catchablility *q* (Figure 72), which was similar to the 2002 benchmark formulation. It was suspected that the amount of older fish was overestimated (Figure 73).

q power in VPA

Under the assumption that survey catchablility depends on population abundance, a VPA model formulation in which a power function was used for the relationship between survey and population abundance was explored. This method had a similar pattern in population abundance and fishery PR to the basic formulation (Figure 74). A strong retrospective pattern was expected from this model formulation.

ASAP

The Age Structured Assessment Program (ASAP) forward projection model was run as an exploratory alternative model to the VPA. The ability of this model to include additional catch and survey indices when no age composition data is available can provide additional information on stock productivity. ASAP model runs were conducted for both Eastern Georges Bank (EGB, 5Zjm) and Georges Bank (GB, 5Z + subarea 6) cod. There was no term of reference to present assessment results for GB cod at this benchmark meeting; however, applying the same model formulations to both management units provided a useful comparison.

Three model formulations were run for both EGB and GB cod. The base formulation allowed the PR to be freely estimated, the 'flat PR' formulation imposed a flat topped PR pattern, and the 'dome PR' formulation imposed a dome shaped PR pattern. The PR for each fleet was estimated by age, with two selectivity blocks within each fleet based on changes in management measures (quotas, mesh regulations, area closures) during those years. The selectivity blocks were between 1998 and 1999 for the US western GB fleet, between 1994 and 1995 for US eastern GB fleet, and between 1992 and 1993 for the Canadian eastern GB fleet.

The input data for all three models were the same, with only the PR formulation varying. For the GB cod, the GB cod landings were disaggregated into 3 fleets: US western GB, US eastern GB, and Canadian EGB. For the EGB, the EGB cod landings were disaggregated into two fleets: US EGB and Canadian EGB. The times series of landings (1978-2007) and survey abundance indices as area-swept estimates (NEFSC spring 36 and 41 Yankee ages 1-8, DFO ages 1-8, and NEFSC autumn ages 1-5 for GB and ages 1-5 for EGB) were same as those used in the assessment VPA. Landings and survey biomass estimates from 1964-1977, without age composition data, were also input to the model. The survey time series was not split.

ASAP diagnostics provided similar partial recruitment and retrospective patterns to those of the VPA. However, the model provides the capability for data input of disaggregated catch at age by fleet and historical catch without age composition. These options allow for more flexibility for weighting of input data and in examining partial recruitment by fleet.

EGB Model Results

The base and 'dome PR' formulations had a similar pattern in the survey catchability (*q*) at age. The NEFSC 36 (Yankee trawl) and the DFO surveys exhibited a domed PR at age 5, whereas the NEFSC 41 (Yankee trawl) exhibited relatively flat-topped PR patterns. The 'flat PR' formulation exhibited flat-topped *q* after age 6 for NEFSC 41 and DFO, and after age 3 for NEFSC autumn, and the NEFSC 36 tended toward a dome PR after age 5.

The fishery selectivity of the base run was generally flat topped for the early selectivity block, but exhibited a strong dome for the latter selectivity block. Trends in F and SSB (Figure 75) estimates were similar for all three runs, with the 'dome' run estimating the lowest Fs and the 'flat' runs the highest. The opposite was observed in SSB, with the 'dome' run indicating the highest SSB and the 'flat' runs the lowest. All three runs exhibited a retrospective pattern in F (Figure 76), SSB (Figure 77) and age 1 recruits (Figure 78); however, the lowest magnitude occurred in the 'dome' run.

A sensitivity analysis was also conducted to examine the effect of an increase in the variability of the survey indices from a coefficient of variability (CV) of 0.4 to 0.8. The higher CV resulted in higher F, lower SSB and an increase in the retrospective pattern relative to the CV=0.4 run. The higher variability in the survey allowed the catch at age to have more influence in the estimation.

GB Results

The base formulation showed a relatively flat catchability by age 6 for all 4 surveys with some slight decline by age 8. The 'flat PR' formulation showed increasing *q* with age for the NEFSC 36 and DFO survey, and relatively flat *q* at age after age 4 for NEFSC 41 and NEFSC autumn. The 'dome PR' showed a strong decline in *q* after age 6 for the DFO survey, and less of a dome at age 6 for NEFSC 36 for the other 3 surveys. The base run fishery selectivity was generally flat topped for both the US western and Canadian fleets, but tended to a dome for both selectivity blocks for the US eastern fleet. Trends in F and SSB estimates (Figure 79) were similar for all three runs, with the 'dome' run estimating the lowest Fs and the 'flat' runs the highest. The opposite was observed in SSB, with the 'dome' run indicating the highest SSB and the 'flat' runs the lowest. All three runs exhibited a retrospective pattern in F (Figure 80), SSB (Figure 81) and age 1 recruits (Figure 82); however, the lowest magnitude occurred in the 'dome' run.

Model Consensus

"Split M 0.5" model is indicated by fit diagnostics as the basis for management advice. However, it is recommended during the benchmark review meeting that the results from the comparable model "split M 0.2" model also be considered. Until the fate of the 2003 year class has been documented (ages 6+) it will be necessary to use these two models to adequately account for uncertainty in the assessment. Doing so acknowledges that there is considerable uncertainty about selection of a single appropriate model. It is also notable that domestic USA management of NAFO Divisions 5Z+6 is based on a model with split survey time series and natural mortality of 0.2 (O'Brien and Worcester, 2009).

REFERENCE POINTS

The Transboundary Management Guidance Committee has adopted a strategy to maintain a low to neutral risk of exceeding the fishing mortality limit reference, F_{ref} = 0.18. Changes in M and changes in weight at age would invoke an update of F_{ref}. Results from dynamic pool models would indicate a higher F_{ref}. However, incorporating a Beverton-Holt stock recruitment relationship into the dynamic pool models would cause a reduction in F_{ref} (Figure 83). Inability to characterize a stock-recruitment relationship and uncertainty about the magnitude and persistence of any change in M suggest that it may be imprudent to increase the F_{ref} on the basis of results from dynamic-pool models (Figure 84). There do not appear to be any time trends in recruits per spawner that might be associated with compensatory processes in response to either higher M or reduced biomass (Figure 85). Further, there are indications that weight at age has increased in recent years, particularly at younger ages (Figure 15, includes preliminary weight at age from 2009 survey). It may be premature to adjust F_{ref} for changes in growth that may not be persistent.

PROCEDURE FOR PROJECTION

The outlook is provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2009. Uncertainty about standing stock generates uncertainty in forecast results, which is expressed here as the risk of exceeding F_{ref} =0.18 or the risk that biomass will not increase by a given percentage. The risk calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. However, they are dependent on the data and model assumptions and do not include uncertainty due to variations in weight at age, partial recruitment to the fishery, natural mortality, systematic errors in data reporting or the possibility that the model may not reflect stock dynamics closely enough.

For projections, the 2005-2007 average values for the fishery weight at age and the 2003-2007 average values for partial recruitment pattern were assumed for 2008-2009 and the 2006-2008 average values were assumed for beginning of year population weight at age in 2009-2010. In general, 5 year averages were used when trends are not apparent and shorter time periods were used to account for appreciable trends.

Projection and Risk Analyses

Illustrative projections were conducted to evaluate how differences in stock status determination using the various models translated into differences for catch advice and biomass trajectory. The “no split M 0.7” model generated a fairly high catch at F=0.18 but resulted in an almost certain biomass decline (Table 30, Figure 86). In contrast, the “split M 0.2” model generated a relatively low catch at F=0.18 but provided the greatest prospects for biomass increase. The results from the “split M 0.5” model were intermediate.

SUMMARY

The TRAC consensus was to accept two models to determine stock status for the annual assessment. These were the “split M 0.2” and “split M 0.5” models. The F reference point was not updated, however, given uncertainties in growth, M, and the stock-recruit relationship.

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Table 1. Landings (mt) comparison from eastern Georges Bank for 1978-2007.

	Canada			USA			Total	
Year	Benchmark	2008 assessment	Difference	Benchmark	2008 assessment	Difference	Benchmark	2008 assessment
1978	8,777	8,778	-1	5,502	5,502	0	14,279	14,280
1979	5,979	5,978	1	6,408	6,408	0	12,387	12,386
1980	8,066	8,063	3	6,418	6,418	0	14,484	14,481
1981	8,508	8,499	9	8,092	8,094	-2	16,600	16,593
1982	17,827	1,7824	3	8,565	8,565	0	26,392	26,389
1983	12,131	12,130	1	8,572	8,572	0	20,704	20,702
1984	5,761	5,763	-2	10,550	10,551	-1	16,311	16,314
1985	10,442	10,443	-1	6,641	6,641	0	17,083	17,084
1986	8,504	8,504	0	5,696	5,696	0	14,200	14,200
1987	11,844	11,844	0	4,793	4,792	1	16,637	16,636
1988	12,741	12,741	0	7,645	7,645	0	20,387	20,386
1989	7,895	7,895	0	6,182	6,182	0	14,077	14,077
1990	14,364	14,364	0	6,414	6,378	36	20,779	20,742
1991	13,467	13,462	6	6,353	6,777	-424	19,820	20,239
1992	11,667	11,673	-6	5,080	5,080	0	16,747	16,753
1993	8,526	8,524	2	4,019	4,019	0	12,545	12,543
1994	5,277	5,278	-1	998	1,228	-230	6,275	6,506
1995	1,102	1,100	1	544	665	-121	1,645	1,765
1996	1,924	1,926	-2	676	773	-97	2,600	2,699
1997	2,919	2,919	0	549	557	-8	3,468	3,476
1998	1,907	1,907	0	679	795	-116	2,587	2,702
1999	1,818	1,818	0	1,195	1,150	45	3,013	2,968
2000	1,572	1,572	0	772	661	111	2,344	2,233
2001	2,143	2,143	0	1,487	1,361	126	3,630	3,504
2002	1,278	1,279	-1	1,680	1,379	301	2,958	2,658
2003	1,328	1,325	2	1,854	1,813	41	3,181	3,138
2004	1,112	1,111	1	1,007	980	27	2,119	2,091
2005	630	630	0	174	124	50	804	754
2006	1,096	1,096	1	134	79	55	1,230	1,174
2007	1,108	1,108	0	216	216	0	1,324	1,324

Table 2. Gear specific Canadian landings (mt) from Eastern Georges Bank

Year	OTB	Longline	Gillnet	Others	Total landing
1978	8,043	729		5	8,777
1979	4,637	1,338		4	5,979
1980	5,423	2,635		8	8,066
1981	3,981	4,526		1	8,508
1982	12,337	5,489			17,827
1983	6,903	5,201	21	7	12,131
1984	736	4,979	36	9	5,761
1985	7,555	2,812	26	49	10,442
1986	6,109	2,124	229	42	8,504
1987	7,607	3,444	705	88	11,844
1988	7,467	4,585	616	73	12,741
1989	2,022	4,653	1,114	106	7,895
1990	7,921	5,458	909	76	14,364
1991	6,659	4,986	1,741	81	13,467
1992	5,585	4,751	1,217	114	11,667
1993	4,891	2,397	1,174	64	8,526
1994	1,893	2,289	1,031	63	5,277
1995	395	546	126	35	1,102
1996	657	1,023	245		1,924
1997	1,033	1,416	470		2,919
1998	645	963	300		1,907
1999	619	929	270		1,818
2000	535	799	238		1,572
2001	722	1,137	284		2,143
2002	445	693	140		1,278
2003	474	742	112		1,328
2004	371	689	52		1,112
2005	283	311	36		630
2006	458	595	43		1,096
2007	393	657	58		1,108

Table 3. Catches (mt) from Canadian and USA fisheries on eastern Georges Bank.

	Canada				USA			Canada+USA		
Year	Landings	Discards Scallop	Discards Grndfish	Total	Landings	Discards	Total	Landings	Discards	Total
1978	8,777	98		8,875	5,502		5,502	14,279	98	14,377
1979	5,979	103		6,082	6,408		6,408	12,387	103	12,490
1980	8,066	83		8,149	6,418		6,418	14,484	83	14,567
1981	8,508	98		8,606	8,092		8,092	16,600	98	16,698
1982	17,827	71		17,898	8,565		8,565	26,392	71	26,463
1983	12,131	65		12,196	8,572		8,572	20,704	65	20,769
1984	5,761	68		5,829	10,550		10,550	16,311	68	16,379
1985	10,442	103		10,545	6,641		6,641	17,083	103	17,186
1986	8,504	51		8,555	5,696		5,696	14,200	51	14,251
1987	11,844	76		11,920	4,793		4,793	16,637	76	16,713
1988	12,741	83		12,824	7,645		7,645	20,387	83	20,470
1989	7,895	76		7,971	6,182	104	6,286	14,077	180	14,257
1990	14,364	70		14,434	6,414	98	6,512	20,779	168	20,946
1991	13,467	65		13,532	6,353	150	6,502	19,820	215	20,035
1992	11,667	71		11,738	5,080	204	5,284	16,747	275	17,022
1993	8,526	63		8,589	4,019	69	4,089	12,545	132	12,677
1994	5,277	63		5,340	998	6	1,004	6,275	69	6,344
1995	1,102	38		1,140	544	0	544	1,645	38	1,684
1996	1,924	56		1,980	676	2	678	2,600	58	2,658
1997	2,919	58	428	3,405	549	6	555	3,468	492	3,960
1998	1,907	92	273	2,272	679	8	687	2,587	373	2,960
1999	1,818	85	253	2,156	1,195	14	1,209	3,013	352	3,365
2000	1,572	69		1,641	772	33	805	2,344	102	2,446
2001	2,143	143		2,286	1,487	367	1,855	3,630	510	4,140
2002	1,278	94		1,372	1,680	11	1,690	2,958	105	3,063
2003	1,328	200		1,528	1,854	117	1,970	3,181	317	3,498
2004	1,112	145		1,257	1,007	66	1,073	2,119	211	2,330
2005	630	110	144	884	174	260	434	804	514	1,318
2006	1,096	118	237	1,451	134	129	263	1,230	484	1,714
2007	1,108	124		1,232	216	348	564	1,324	472	1,796
Minimum	630	38	144	884	134	0	263	804	38	1,318
Maximum	17,827	200	428	17,898	10,550	367	10,550	26,392	514	26,463
Average	6,390	88	267	6,523	3,963	105	4,030	10,354	199	10,553

Table 4. The number of port samples and number of fish measured for length from Canadian cod fisheries on eastern Georges Bank.

	Trip numbers				Fish numbers			
Year	OTB	Longline	Gillnet	Total	OTB	Longline	Gillnet	Total
1978	28			29	7,684			7,684
1979	11			12	3,363			3,363
1980	10			10	2,784			2,784
1981	14	2		16	3,518	388		3,906
1982	15	2		17	4,437	511		4,948
1983	14	1		15	3,647	175		3,822
1984		7		7		1,889		1,889
1985	9	7		18	6,115	1,529		7,644
1986	17	4	1	22	4,675	937	278	5,890
1987	20	9	2	32	6,164	2,770	543	9,477
1988	20	16	4	41	5,867	4,584	1,228	11,679
1989	11	11	10	32	3,178	2,940	2,608	8,726
1990	23	12	4	40	5,681	3,690	1,112	10,483
1991	17	18	6	41	4,158	5,026	1,689	10,873
1992	29	10	6	45	6,530	2,835	1,517	10,882
1993	32	10	7	49	7,691	2,542	1,925	12,158
1994	17	8	4	29	4,094	2,211	1,095	7,400
1995	12	2	3	17	2,945	608	559	4,112
1996	15	7	3	26	3,913	1,987	730	6,630
1997	27	9	2	38	6,127	1,913	552	8,592
1998	22	16	9	47	5,400	4,082	2,018	11,500
1999	19	11	4	34	4,375	2,702	1,049	8,126
2000	25	13	6	45	5,355	3,126	1,465	9,946
2001	22	21	9	52	4,705	5,052	2,072	11,829
2002	27	18	9	54	6,193	4,299	1,927	12,419
2003	24	22	3	49	5,336	5,291	693	11,320
2004	19	19	4	42	3,897	3,577	1,034	8,508
2005	18	8	4	30	3,412	1,356	731	5,499
2006	17	11	1	29	3,725	2,860	217	6,802
2007	16	19	4	39	3,951	4,372	669	8,992

Table 5. The number of at sea observer samples and number of fish measured for length from Canadian cod fisheries on eastern Georges Bank.

	Trip numbers				Fish numbers			
year	**OTB**	**Longline**	**Gillnet**	**Total**	**OTB**	**Longline**	**Gillnet**	**Total**
1978	8			8	2,344			2,344
1980	2			2	226			226
1981	6			6	746			746
1982	20			20	2,362			2,362
1983	9			9	1,740			1,740
1984				0				
1985	3	7		10	460	4,778		5,238
1986	1			1	50			50
1987	15			15	2,027			2,027
1988	7			7	1,490			1,490
1989	10	1		11	1,126	348		1,474
1990	69	1		70	13,378	80		13,458
1991	51	6		57	8,514	3,058		11,572
1992	27	11	6	44	6,696	3,994	2,658	13,348
1993	38	2	10	50	7,342	672	5,718	13,732
1994	66	15	1	82	13,178	5,952	538	19,668
1995	11	5		19	1,388	1,362		2,750
1996	56	38	6	100	5,856	9,236	2,768	17,860
1997	32	30	3	65	4,226	13,138	2,450	19,814
1998	60	7	1	68	8,322	2,216	822	11,360
1999	37	12	2	51	4,760	7,472	932	13,164
2000	38	11	3	52	3,896	5,872	1,052	10,820
2001	33	12	1	54	2,870	5,988	288	9,146
2002	16	9	1	29	1,142	3,028	1,200	5,370
2003	25	18	2	45	1,796	7,116	556	9,468
2004	57	26	2	90	4,560	6,520	984	12,064
2005	83	22	1	117	12,894	9,864	120	22,878
2006	242	26		279	35,207	9,312		44,519
2007	470	11		495	111,458	5,320		116,778

Table 6. Length and age samples for landings at age calculation from Canadian fisheries on eastern Georges Bank. At-sea observer samples are included since 1990. The first quarter age samples are supplemented with USA age samples from 5Zjm for 1978-1986 and DFO survey age samples for 1987-2007, the numbers are shown in brackets.

Year	Samples	Lengths	Ages
1978	28	7,684	1,364
1979	11 + 8 US ALK	3,103	796(205)
1980	10 + 6 US ALK	2,784	728(192)
1981	16	3,906	842
1982	16 + 7 US ALK	4,948	1,054(268)
1983	15 + 4 US ALK	3,822	754(150)
1984	7+32 US ALK	1,889	1,241(858)
1985	16+12 US ALK	7,031	1,309(351)
1986	22+ 4 US ALK	5,890	987(103)
1987	31+DFO Survey	9,133	1,429(193)
1988	40+DFO survey	11,350	1,892(510)
1989	32	8,726	1,499
1990	99+DFO survey	31,951	2,825(1153)
1991	92	27,739	1,782
1992	83+DFO survey	28,825	2,215(359)
1993	92	31,473	2,146
1994	95	27,659	1,268
1995	30	6,633	548
1996	101	25,818	828
1997	85	31,420	1,216
1998	95	25,743	1,643
1999	77+DFO survey	25,871	1,290(410)
2000	77	20,127	1,374
2001	85	18,627	1,505
2002	70	15,616	1,252
2003	80	19,185	1,070
2004	124+DFO survey	17,856	1,370
2005	136+DFO survey	21,942	1,483(697)
2006	258+DFO survey	43,259	1,455(648)
2007	494+DFO survey	139,816	1,672(456)

Table 7. Estimated landings at age numbers (thousands) of cod from Canadian fisheries on eastern Georges Bank.

year/age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1978	1	71	2341	720	216	76	57	12	11	3	1	1	0	0	0	0	3511
1979	4	553	532	794	267	57	15	12	2	1	1	0	0	0	0	0	2240
1980	1	705	1078	201	499	135	31	14	26	13	3	1	0	0	0	0	2707
1981	3	267	875	633	182	287	97	43	27	8	1	0	0	0	0	0	2423
1982	7	2200	1455	901	689	154	234	105	30	8	17	3	0	3	1	0	5807
1983	15	411	1430	863	290	219	90	127	70	11	11	2	0	0	0	0	3539
1984	0	25	133	380	258	156	95	18	35	15	7	3	0	2	0	0	1129
1985	3	2203	976	404	548	152	45	49	13	8	1	1	1	0	0	0	4358
1986	10	244	1359	396	157	240	38	22	12	2	1	0	0	0	0	0	2480
1987	20	3057	605	764	99	82	116	25	15	4	2	1	0	0	0	0	4789
1988	18	229	2726	345	411	63	72	129	43	15	10	3	0	0	0	0	4064
1989	1	390	340	928	136	200	35	26	41	12	6	4	0	0	0	0	2121
1990	8	429	2108	702	834	88	93	7	9	20	2	2	1	0	0	0	4305
1991	35	688	654	1301	582	481	67	49	15	9	7	3	2	0	1	0	3896
1992	44	1747	918	293	550	204	216	38	28	3	4	2	1	0	0	0	4048
1993	5	269	1159	624	193	247	97	73	19	15	2	0	0	0	0	0	2704
1994	3	149	358	640	229	38	50	25	17	1	1	0	0	0	0	0	1510
1995	1	41	163	62	57	12	5	3	2	0	0	0	0	0	0	0	345
1996	1	28	170	283	55	38	11	3	2	0	0	0	0	0	0	0	590
1997	3	105	148	273	245	61	26	10	3	1	0	0	0	0	0	0	874
1998	0	58	210	102	95	80	16	9	3	1	0	1	0	0	0	0	573
1999	4	41	263	177	48	28	26	7	1	0	0	0	0	0	0	0	597
2000	0	30	59	238	95	23	14	8	2	0	0	0	0	0	0	0	471
2001	0	9	185	114	213	61	18	9	3	0	0	0	0	0	0	0	612
2002	0	3	35	145	42	76	14	5	2	1	0	0	0	0	0	0	323
2003	0	5	56	73	143	29	40	9	2	1	0	0	0	0	0	0	357
2004	0	3	60	64	54	73	18	19	4	1	0	0	0	0	0	0	296
2005	0	6	12	83	24	18	21	8	4	1	0	0	0	0	0	0	178
2006	0	3	112	44	124	32	14	14	2	1	0	0	0	0	0	0	345
2007	0	17	29	236	19	56	10	6	6	0	0	0	0	0	0	0	380

Table 8. Estimated catch at age numbers (thousands) of cod discards from Canadian scallop fisheries on eastern Georges Bank.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+
1978	1	7	0	19	3	2	1	2	0	0	0	0	0	0	0	0	0
1979	1	8	13	1	13	3	1	0	1	0	0	0	0	0	0	0	0
1980	2	6	8	10	1	6	1	0	0	0	0	0	0	0	0	0	0
1981	3	23	13	13	6	0	2	1	0	0	0	0	0	0	0	0	0
1982	0	8	12	5	4	3	0	1	0	0	0	0	0	0	0	0	0
1983	10	2	7	14	2	1	1	0	0	0	0	0	0	0	0	0	0
1984	0	9	1	6	9	1	2	1	0	1	0	0	0	0	0	0	0
1985	33	6	30	5	3	3	1	0	0	0	0	0	0	0	0	0	0
1986	1	30	4	6	1	1	1	0	0	0	0	0	0	0	0	0	0
1987	2	2	21	4	5	0	1	1	0	0	0	0	0	0	0	0	0
1988	1	4	2	20	2	3	0	0	1	0	0	0	0	0	0	0	0
1989	1	4	13	3	10	1	2	0	0	0	0	0	0	0	0	0	0
1990	1	2	3	9	3	4	1	1	0	0	0	0	0	0	0	0	0
1991	0	12	6	6	4	3	2	0	0	0	0	0	0	0	0	0	0
1992	0	4	18	6	1	2	1	1	0	0	0	0	0	0	0	0	0
1993	0	3	6	12	2	1	2	0	0	0	0	0	0	0	0	0	0
1994	1	2	7	6	7	2	1	1	0	0	0	0	0	0	0	0	0
1995	3	0	2	7	3	2	1	0	0	0	0	0	0	0	0	0	0
1996	0	4	2	7	9	2	1	0	0	0	0	0	0	0	0	0	0
1997	1	3	7	4	4	5	1	1	0	0	0	0	0	0	0	0	0
1998	0	3	15	15	4	5	2	0	1	0	0	0	0	0	0	0	0
1999	0	0	2	14	10	4	2	1	0	0	0	0	0	0	0	0	0
2000	1	2	8	5	10	4	1	0	0	0	0	0	0	0	0	0	0
2001	1	3	5	25	4	11	4	1	1	1	0	0	0	0	0	0	0
2002	1	0	3	6	18	3	4	1	0	0	0	0	0	0	0	0	0
2003	13	0	5	21	23	19	3	3	1	0	0	0	0	0	0	0	0
2004	0	19	4	23	13	10	7	1	1	0	0	0	0	0	0	0	0
2005	0	1	20	11	32	4	1	1	0	0	0	0	0	0	0	0	0
2006	0	5	13	41	9	12	2	0	0	0	0	0	0	0	0	0	0
2007	0	0	15	14	49	4	4	0	0	0	0	0	0	0	0	0	0

Table 9. Estimated landings at age numbers (thousands) of cod from USA fisheries on eastern Georges Bank.

Year/Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1978	0	37	1283	444	175	86	68	10	12	2	1	0	0	0	0	0	2120
1979	2	323	201	713	273	124	58	48	9	2	1	1	0	0	0	0	1755
1980	0	259	562	100	463	217	65	12	20	3	1	0	0	0	0	0	1703
1981	10	575	964	694	95	194	87	54	31	11	2	1	0	0	0	0	2719
1982	0	1303	511	364	395	42	164	50	19	6	5	3	3	1	0	0	2866
1983	5	365	1067	432	271	178	28	55	32	14	16	10	1	3	1	0	2478
1984	7	204	666	965	287	219	183	20	54	23	10	4	2	1	0	0	2646
1985	1	668	443	255	430	115	64	60	8	18	2	3	1	1	0	0	2069
1986	2	202	901	192	185	215	30	26	17	2	6	1	0	0	0	0	1778
1987	0	1038	237	379	64	50	58	15	8	4	1	0	0	0	0	0	1854
1988	0	57	1443	333	441	67	45	52	9	6	3	0	0	0	0	0	2458
1989	0	215	463	1039	91	171	21	13	17	2	1	0	0	0	0	0	2034
1990	0	257	972	330	534	56	59	5	3	4	0	0	0	0	0	0	2221
1991	5	208	344	609	319	264	38	20	5	2	0	1	0	0	0	0	1814
1992	1	645	450	162	336	108	98	7	6	0	1	0	0	0	0	0	1814
1993	0	181	708	282	105	111	35	23	6	2	0	0	0	0	0	0	1454
1994	0	22	118	141	40	6	10	5	3	0	0	0	0	0	0	0	346
1995	0	14	67	29	46	6	2	1	2	0	0	0	0	0	0	0	167
1996	0	10	57	106	22	21	2	1	1	0	0	0	0	0	0	0	220
1997	0	10	22	35	69	14	8	3	1	0	0	0	0	0	0	0	162
1998	0	10	42	36	44	43	6	3	1	0	0	0	0	0	0	0	186
1999	0	18	143	123	50	28	28	6	1	0	0	0	0	0	0	0	396
2000	0	16	41	130	52	13	8	4	1	0	0	0	0	0	0	0	265
2001	0	8	229	92	174	40	12	8	3	0	0	0	0	0	0	0	567
2002	0	3	81	280	63	75	15	4	3	1	0	0	0	0	0	0	526
2003	0	1	58	139	239	49	46	9	2	1	0	0	0	0	0	0	544
2004	0	2	34	70	81	58	17	10	2	0	0	0	0	0	0	0	274
2005	0	0	1	15	13	5	10	1	1	0	0	0	0	0	0	0	48
2006	0	0	6	6	17	8	2	1	0	0	0	0	0	0	0	0	41
2007	0	0	3	51	3	13	1	1	0	0	0	0	0	0	0	0	72

Table 10. Estimated catch at age numbers (thousands) of cod discards from USA fisheries on eastern Georges Bank

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1989		30.11	64.83	5.88	3.63	0.07	0.05	0.02			
1990		9.50	45.58	27.82	3.02	2.21	0.22	0.10	0.03		
1991		12.84	120.99	5.68	9.93	0.00	0.13				
1992		17.96	164.27	4.55	3.27	1.92	0.41	0.75		0.04	
1993		1.93	43.31	19.15	0.13	0.03	0.25	0.15	0.18	0.03	
1994		0.87	5.38	0.39	0.00						
1995		0.33	0.24	0.02							
1996		2.93	1.08	0.30							
1997		0.06	1.41	0.97	0.36	0.15					
1998		0.51	4.56	1.91	0.23	0.04	0.04				
1999		0.62	4.48	8.46							
2000		8.05	24.34	9.00	0.30						
2001		94.10	202.01	94.60	10.91	5.48	0.07	0.07			
2002		0.58	2.73	3.78	0.90	0.33	0.00	0.00			
2003		0.00	25.23	30.63	8.80	3.94	1.06	0.28	0.01		
2004		2.39	3.62	27.07	3.64	1.72	0.95	0.19	0.03	0.01	
2005		0.96	63.72	26.58	38.35	10.40	2.87	3.82			
2006		1.14	2.79	51.14	5.99	7.94	1.00	0.25	0.07		
2007	0.09	1.94	44.38	38.02	69.49	4.36	12.54	0.26	0.47	0.25	0.02

Table 11. Catch at age numbers (thousands) from Canadian and USA fisheries on eastern Georges Bank.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1978	1	8	108	3643	1167	394	163	127	22	23	6	2	1	0	0	0	0	5667
1979	1	15	890	734	1520	543	182	74	61	11	3	2	1	0	1	0	0	4037
1980	2	6	973	1650	301	968	354	97	26	46	16	4	1	0	0	0	0	4445
1981	3	35	855	1853	1333	276	484	185	97	58	20	3	1	0	0	0	0	5202
1982	0	15	3516	1971	1269	1087	195	399	155	49	14	22	6	3	4	1	0	8707
1983	10	22	783	2510	1297	562	398	118	182	102	25	28	12	1	3	1	0	6055
1984	0	17	230	805	1353	546	376	279	39	90	38	17	7	2	3	0	1	3804
1985	33	9	2861	1409	661	987	271	110	110	21	27	3	4	1	1	0	0	6509
1986	1	41	451	2266	588	343	456	68	48	29	4	8	1	0	0	0	0	4303
1987	2	22	4116	846	1148	163	132	174	41	24	8	3	1	0	0	0	0	6680
1988	1	23	289	4190	680	855	130	116	182	52	21	13	4	1	0	0	0	6556
1989	1	35	683	812	1980	228	373	56	40	59	15	7	5	0	0	0	0	4294
1990	1	20	735	3117	1038	1374	145	153	12	12	24	3	2	1	0	0	0	6639
1991	0	65	1023	1010	1924	904	746	105	69	21	11	8	4	2	0	1	0	5893
1992	0	67	2575	1378	459	890	314	316	45	34	3	5	2	1	0	0	0	6090
1993	0	10	499	1898	909	299	359	133	97	25	17	2	0	0	0	0	0	4249
1994	1	5	184	483	788	270	45	61	30	21	2	1	0	0	0	0	0	1890
1995	3	1	57	237	94	105	18	7	4	4	0	0	0	0	0	0	0	531
1996	0	8	40	234	397	79	60	13	4	3	0	0	0	0	0	0	0	840
1997	1	7	145	206	358	358	83	37	13	4	1	1	0	0	0	0	0	1213
1998	0	4	100	315	161	158	134	23	13	4	1	0	1	0	0	0	0	914
1999	0	7	77	486	337	109	61	57	14	2	1	0	0	0	0	0	0	1152
2000	1	10	79	114	379	151	37	22	12	3	0	0	0	0	0	0	0	809
2001	1	97	224	533	221	404	105	32	17	7	1	0	0	0	0	0	0	1643
2002	1	1	12	126	444	108	155	30	9	6	2	1	0	0	0	0	0	894
2003	13	0	37	166	243	405	81	90	19	4	1	0	0	0	0	0	0	1059
2004	0	21	12	145	151	147	139	35	30	7	1	1	0	0	0	0	0	689
2005	0	2	92	59	200	57	32	40	11	5	1	0	0	0	0	0	0	499
2006	0	6	20	250	78	188	48	18	17	2	1	0	0	0	0	0	0	629
2007	0	2	77	84	405	30	86	11	7	7	0	0	0	0	0	0	0	709

Table 12. Average weight at age (kg) from Canadian and USA fisheries on eastern Georges Bank.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+
1978	0.0	0.4	1.3	2.1	2.7	3.7	5.4	5.6	8.3	7.5	11.3	15.0	15.4	13.6	12.2	17.4	19.7
1979	0.0	0.7	1.4	1.5	3.3	4.5	6.6	9.4	9.6	9.9	14.2	12.0	15.5	20.6	19.6		
1980	0.0	0.4	1.2	2.2	3.1	5.0	6.3	7.2	11.5	10.4	12.5	16.3	17.8				
1981	0.0	0.5	1.3	2.0	3.1	4.6	6.5	8.0	9.2	11.5	14.5	19.7	20.5				
1982	0.0	0.6	1.3	2.1	3.6	5.0	6.8	8.5	9.9	11.9	14.0	15.8	18.3	19.0	18.3	19.9	
1983	0.0	0.9	1.5	2.2	3.1	4.6	6.1	7.8	10.2	11.5	13.2	15.0	15.9	22.4	20.2	27.5	16.2
1984	0.0	0.7	1.6	2.3	3.4	4.8	6.1	8.3	9.4	11.2	12.0	13.9	16.1	18.6	21.2		20.2
1985	0.0	0.5	1.3	1.8	3.2	4.6	5.9	7.9	9.6	10.8	12.5	15.9	16.6	20.4	18.9	23.8	
1986	0.0	0.5	1.4	2.4	3.3	4.8	6.7	8.1	9.2	11.4	11.5	11.8	17.3				
1987	0.0	0.6	1.5	2.4	3.9	5.4	7.2	8.8	9.5	11.3	12.0	16.7	18.4	17.6			
1988	0.0	0.6	1.2	2.2	3.1	4.9	6.1	8.3	9.9	11.1	12.5	14.5	16.8	19.2	27.5	14.2	
1989	0.0	0.7	1.3	2.0	3.3	4.9	6.0	6.8	9.8	10.7	12.8	15.3	14.6	18.6	18.2		
1990	0.0	0.7	1.5	2.4	3.2	4.6	6.0	7.8	9.8	11.2	12.8	15.6	14.8	17.7		18.7	
1991		0.7	1.5	2.4	3.1	4.2	5.5	7.5	9.5	9.2	13.3	13.9	12.7	17.5	22.5	11.0	
1992		0.9	1.4	2.3	3.3	4.2	5.7	6.8	8.7	11.2	14.9	13.8	17.5	16.8			
1993		0.6	1.4	2.1	2.8	4.3	5.4	6.8	8.3	9.1	11.1	16.4	26.4	22.5			
1994	0.0	0.6	1.3	2.1	3.4	4.4	6.4	7.2	8.2	8.0	11.4	13.1		22.2	27.7		
1995	0.0	0.3	1.3	2.1	3.4	4.9	6.4	10.1	10.0	10.4	15.6	20.5	19.3				
1996	0.1	0.5	1.4	2.2	3.0	4.7	5.8	6.4	9.0	10.4	10.3	11.9			21.7		
1997	0.0	0.7	1.4	2.1	2.9	3.9	5.4	7.3	8.3	11.5	9.9	13.2	18.9				
1998	0.0	0.8	1.4	2.1	3.0	4.0	5.3	6.6	7.8	10.2	12.8	15.7	14.1	17.6			
1999	0.0	0.6	1.3	2.0	3.1	3.9	5.5	6.3	7.5	9.4	13.6	15.9		24.3			
2000	0.0	0.7	1.2	1.9	2.9	4.0	4.7	5.7	6.8	8.4	14.1	11.2	18.5		17.3		
2001	0.0	0.5	0.9	1.8	2.7	3.5	4.9	5.2	7.3	8.6	11.0	10.4	9.4				
2002	0.0	0.3	1.2	2.0	2.8	4.0	4.9	6.4	8.2	8.0	10.1	13.7	12.4		22.1		
2003	0.0		1.2	2.1	2.7	3.5	4.3	5.5	6.8	7.6	8.1	11.9					
2004		0.2	1.2	1.8	2.8	3.5	4.6	5.2	7.2	8.5	8.6	10.6	14.9		19.4	19.9	24.3
2005		0.2	0.9	1.5	2.4	3.5	4.5	4.9	6.8	8.0	8.7	15.4	14.5	9.6			
2006		0.2	0.7	1.7	2.4	3.4	4.3	6.1	5.8	6.8	7.3	8.7	7.1				
2007	0.0	0.5	1.1	1.6	2.4	3.1	4.0	6.3	6.8	6.9	9.3	10.8					

Table 13. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the DFO survey.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1986		770	3538	3204	331	692	445	219	35	66	0	10	0	0	0	0	0	9311
1987		48	1791	642	753	162	89	181	89	13	13	0	13	16	0	0	0	3812
1988		148	450	5337	565	838	95	79	179	18	12	4	0	16	0	0	0	7741
1989		350	2169	764	1706	258	332	42	85	112	5	32	8	5	0	0	0	5868
1990	20	106	795	3471	1953	4402	535	1094	144	157	289	65	52	37	0	0	5	13125
1991		1198	1019	1408	1639	882	1195	148	249	38	45	30	12	5	8	0	0	7876
1992		48	2049	1221	409	643	451	300	93	38	0	3	3	18	0	0	0	5276
1993		31	355	1723	622	370	754	274	268	51	31	0	20	6	0	0	0	4504
1994		13	629	691	1289	477	182	363	84	119	12	0	0	0	8	5	0	3871
1995		32	187	1240	757	520	186	44	67	28	18	8	6	0	0	0	0	3093
1996		90	203	1744	4337	1432	1034	445	107	149	39	4	0	0	5	0	0	9590
1997		30	376	568	1325	1262	216	50	35	23	17	0	3	0	0	0	0	3905
1998		6	582	831	322	317	238	56	29	7	8	3	4	0	0	0	0	2402
1999		3	156	1298	1090	449	317	190	10	28	5	9	0	3	0	0	0	3561
2000		0	423	1294	4967	2157	1031	510	317	20	23	12	0	0	0	0	0	10754
2001		3	37	802	519	1391	645	334	224	225	36	24	7	0	0	0	0	4248
2002		0	118	477	2097	694	1283	458	188	63	76	7	0	0	0	0	0	5462
2003		0	8	200	510	867	194	219	69	12	0	0	0	0	0	0	0	2078
2004		427	40	246	381	422	353	59	108	25	5	0	3	0	0	0	0	2069
2005		25	1025	1398	7149	1766	816	743	60	87	8	4	0	0	0	0	0	13082
2006		0	41	1500	673	1779	757	217	216	83	34	10	15	0	0	0	0	5325
2007		18	130	549	2606	379	653	119	81	53	0	4	0	0	0	0	0	4591
2008		12	147	1027	755	2978	194	392	41	4	20	0	0	0	0	0	0	5569

Table 14. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS spring survey. Conversion factors to account for vessel and trawl door changes have been applied. During 1973-1981 a Yankee 41 net was used rather than the standard Yankee 36 net.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1970	0	354	1115	302	610	73	263	48	0	71	24	0	48	0	0	0	0	2907
1971	0	185	716	503	119	326	124	257	227	40	40	79	0	0	0	0	0	2615
1972	56	1578	1856	2480	393	114	136	60	88	73	18	14	0	0	14	0	0	6879
1973	0	665	37880	5474	6109	567	467	413	0	163	231	0	0	0	95	0	0	52064
1974	0	461	5877	4030	759	2001	360	91	267	45	48	54	0	0	0	0	0	13991
1975	0	0	467	3061	4348	446	960	79	0	122	0	0	0	0	0	0	0	9483
1976	84	1733	1111	620	444	759	0	167	35	0	0	0	0	48	0	0	0	5001
1977	0	0	2358	736	354	307	334	22	35	0	0	0	0	0	0	0	0	4145
1978	373	187	0	2825	615	916	153	787	62	43	40	0	0	0	0	0	0	6001
1979	71	339	1332	122	1430	543	176	91	130	0	0	0	0	0	0	0	0	4234
1980	0	11	2251	2168	169	1984	410	78	48	31	0	47	0	0	0	0	0	7197
1981	283	1956	1311	2006	1093	43	453	197	59	0	0	0	0	0	0	0	0	7399
1982	44	455	6642	13614	12667	9406	0	3088	992	120	0	0	0	0	0	0	0	47027
1983	0	389	2017	3781	779	608	315	106	98	0	70	0	0	0	0	0	35	8197
1984	0	103	117	344	483	92	182	74	18	105	0	0	0	0	0	0	0	1518
1985	58	36	2032	633	1061	1518	328	217	213	83	116	34	23	0	0	0	0	6352
1986	97	619	339	1132	298	427	536	20	109	142	0	0	0	0	0	0	0	3719
1987	0	0	1194	247	568	0	152	148	30	54	0	0	0	0	0	0	0	2394
1988	138	320	243	2795	274	461	51	5	67	0	0	10	0	0	0	0	0	4364
1989	0	174	1238	338	1685	234	396	99	12	36	48	24	0	0	0	0	0	4284
1990	24	45	360	1687	586	634	152	164	19	0	0	24	0	0	0	0	0	3696
1991	217	725	620	514	903	460	382	44	17	0	24	53	0	0	0	0	0	3957
1992	0	81	666	349	103	261	152	159	27	52	0	0	0	0	0	0	0	1850
1993	0	0	462	1284	262	46	182	46	43	46	12	0	0	0	0	0	0	2382
1994	38	54	194	152	185	44	11	33	0	8	0	0	0	0	0	0	0	720
1995	384	70	294	927	495	932	191	253	0	68	0	0	0	0	0	0	0	3614
1996	0	139	300	990	1343	121	94	28	0	0	0	0	0	0	0	0	0	3016
1997	271	54	218	48	402	519	53	126	57	0	0	0	0	0	0	0	0	1747
1998	54	0	1040	1985	995	983	609	30	31	0	0	0	0	0	0	0	0	5729
1999	22	22	145	673	624	370	172	107	34	8	0	0	0	0	0	0	0	2176
2000	36	0	304	643	1348	492	138	52	20	0	0	0	0	0	0	0	0	3032
2001	0	0	64	889	96	350	109	0	12	10	0	0	0	0	0	0	0	1530
2002	36	0	121	470	1081	175	214	61	0	0	0	0	0	0	0	0	0	2158
2003	0	0	125	287	812	1154	135	78	9	0	0	0	0	0	0	0	0	2599
2004	0	549	10	838	2091	2105	1351	239	382	29	0	0	0	0	0	0	0	7595
2005	36	15	345	70	747	287	190	131	34	0	0	0	0	0	0	0	0	1855
2006	0	37	73	952	411	1007	340	151	79	0	0	0	0	0	0	0	0	3050
2007	0	0	369	308	2258	239	291	47	28	0	0	0	0	0	0	0	0	3540
2008	43	37	112	675	372	1385	51	66	0	0	0	0	0	0	0	0	0	2741

Table 15. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS fall survey. Conversion factors to account for vessel and trawl door changes have been applied.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1970	348	1416	836	208	412	11	0	0	5	25	0	0	0	0	0	0	0	3261
1971	203	1148	900	181	232	130	142	14	0	0	0	0	0	0	0	0	0	2951
1972	1110	3299	614	667	24	40	0	0	0	0	0	0	0	0	0	0	0	5753
1973	46	2435	2947	997	979	93	0	25	63	0	0	0	0	0	0	0	0	7584
1974	77	196	399	622	54	31	15	0	0	0	0	0	0	0	0	0	0	1394
1975	414	660	177	414	764	27	46	0	0	0	0	0	0	0	0	0	0	2501
1976	0	8260	362	144	0	91	0	48	0	0	0	0	0	0	0	0	0	8904
1977	51	0	3475	714	184	156	178	3	0	0	0	0	0	0	0	0	0	4760
1978	113	1519	58	3027	417	58	63	77	0	0	0	0	0	0	0	0	0	5330
1979	182	1704	1695	116	1522	243	48	20	11	18	0	0	0	0	0	0	0	5557
1980	315	782	409	649	22	184	14	17	20	0	0	0	0	0	0	0	0	2412
1981	360	2352	1208	933	269	15	29	0	0	0	53	0	0	0	0	0	0	5220
1982	0	549	718	54	59	0	0	27	0	0	0	0	0	0	0	0	0	1406
1983	948	73	267	567	24	8	8	0	23	0	0	0	0	0	0	0	0	1917
1984	29	1805	120	690	1025	23	32	0	0	9	0	0	0	0	0	0	0	3734
1985	1245	209	993	161	18	5	9	0	0	0	4	0	0	0	0	0	0	2645
1986	119	3018	56	198	0	0	6	0	0	0	0	0	0	0	0	0	0	3396
1987	156	129	845	121	100	0	0	0	0	0	0	0	7	0	0	0	0	1357
1988	95	561	177	1182	163	206	0	30	41	10	0	0	0	0	0	0	0	2464
1989	318	570	1335	222	607	78	24	0	0	0	0	0	0	0	0	0	0	3154
1990	198	403	442	831	120	204	20	0	15	0	0	0	0	0	0	0	0	2232
1991	0	158	60	71	10	24	0	0	0	0	0	0	0	0	0	0	0	322
1992	0	205	726	154	0	37	12	0	0	0	0	0	0	0	0	0	0	1134
1993	0	81	104	158	19	0	0	0	0	0	0	0	0	0	0	0	0	362
1994	10	78	282	220	143	13	26	0	0	0	0	0	0	0	0	0	0	771
1995	223	28	122	304	66	29	7	0	0	0	0	0	0	0	0	0	0	779
1996	10	291	76	293	211	53	28	0	0	0	0	0	0	0	0	0	0	961
1997	0	161	394	181	58	84	29	0	0	0	0	0	0	0	0	0	0	907
1998	0	171	684	480	65	109	0	0	29	0	0	0	0	0	0	0	0	1538
1999	0	15	14	249	124	32	0	0	0	0	0	0	0	0	0	0	0	434
2000	30	55	204	68	89	46	0	0	0	0	0	0	0	0	0	0	0	493
2001	25	74	106	257	38	75	12	12	0	0	0	0	0	0	0	0	0	598
2002	122	110	635	712	2499	170	211	17	0	0	0	0	0	0	0	0	0	4476
2003	76	0	24	100	70	17	0	6	0	0	0	0	0	0	0	0	0	293
2004	108	422	68	840	385	545	436	103	30	0	30	0	0	0	0	0	0	2969
2005	21	29	508	114	251	43	0	10	0	0	0	0	0	0	0	0	0	976
2006	0	146	123	530	37	263	16	16	16	16	0	0	0	0	0	0	0	1162
2007	60	22	136	7	69	0	7	0	0	0	0	0	0	0	0	0	0	302

Table 16. Beginning of year population weight at age derived from DFO and NMFS spring surveys. The weight for age group 10+ was derived from catch number weighted fishery weight at age.

Year/Age	1	2	3	4	5	6	7	8	9	10+
1970	0.093	0.838	1.735	2.597	4.797	5.644	8.153	7.990	11.427	14.635
1971	0.116	0.811	1.798	2.347	4.372	5.377	6.450	7.990	7.384	14.635
1972	0.085	0.866	1.979	2.959	3.482	5.212	5.608	6.539	13.806	14.635
1973	0.085	0.802	1.890	2.958	3.247	3.434	7.722	7.129	9.998	14.635
1974	0.149	0.606	1.705	2.641	4.173	5.806	7.452	7.754	8.153	14.635
1975	0.109	1.132	2.354	2.745	3.734	5.184	7.714	7.567	9.150	14.635
1976	0.138	0.946	2.156	2.999	3.753	5.342	8.011	7.384	9.150	14.635
1977	0.124	0.905	2.130	3.365	6.182	5.503	6.667	5.664	9.150	14.635
1978	0.112	0.886	1.624	3.564	5.414	6.247	8.626	8.973	10.226	14.635
1979	0.112	0.868	1.740	2.995	4.565	5.188	9.629	10.885	10.976	14.635
1980	0.276	0.706	1.892	2.786	5.244	6.281	5.919	8.973	11.762	14.635
1981	0.095	0.852	1.826	3.342	4.971	6.862	8.184	12.712	11.262	14.635
1982	0.092	0.869	2.219	3.050	4.114	6.427	8.061	8.828	10.776	14.635
1983	0.224	1.131	1.871	2.263	3.132	6.011	8.153	8.653	10.525	14.635
1984	0.050	0.582	1.954	2.443	2.699	4.121	5.890	8.973	10.279	14.635
1985	0.087	0.646	1.926	3.205	3.781	5.834	8.771	9.866	14.114	14.635
1986	0.131	0.770	1.742	3.217	4.920	5.698	7.439	8.988	10.684	14.635
1987	0.150	0.845	1.701	2.686	5.672	7.487	7.480	6.659	10.100	14.635
1988	0.152	0.931	1.785	3.020	4.169	6.268	8.438	8.724	12.330	14.635
1989	0.142	0.832	1.705	2.759	4.306	6.432	7.615	7.813	11.320	14.635
1990	0.215	0.787	1.843	2.899	4.362	6.003	8.589	9.518	13.493	14.635
1991	0.088	0.897	1.952	3.167	4.243	4.895	7.544	10.059	9.973	14.635
1992	0.127	0.846	2.045	2.793	4.163	6.127	6.979	8.555	9.906	14.635
1993	0.070	0.955	1.845	2.907	4.513	5.889	6.999	7.383	9.279	14.635
1994	0.143	0.657	1.433	2.629	3.954	7.458	7.330	8.661	8.871	14.635
1995	0.183	0.794	1.587	2.245	3.474	4.697	6.692	7.920	11.886	14.635
1996	0.088	0.838	1.553	2.597	3.908	6.112	5.458	12.028	11.920	14.635
1997	0.190	0.717	1.694	2.176	3.218	6.200	6.204	9.796	10.174	14.635
1998	0.078	0.650	1.382	2.258	3.034	4.516	5.831	7.787	8.211	14.635
1999	0.111	1.001	1.350	2.237	2.973	4.635	6.513	8.250	8.448	14.635
2000	0.060	0.896	1.587	2.326	3.234	4.461	6.501	8.211	11.523	14.635
2001	0.010	0.771	1.418	2.584	3.602	5.089	6.909	7.552	10.254	10.687
2002	0.016	0.495	1.214	2.269	3.538	4.385	5.856	8.436	10.001	10.687
2003	0.016	0.441	1.141	1.882	3.046	3.361	5.120	6.702	7.661	10.687
2004	0.022	0.288	1.454	2.447	3.449	4.086	4.312	6.320	10.535	10.687
2005	0.058	0.589	1.167	1.770	2.972	3.297	3.936	7.655	6.448	10.687
2006	0.031	0.307	1.151	1.574	2.621	3.182	4.615	4.684	5.729	10.687
2007	0.054	0.625	1.073	1.764	2.622	4.098	5.789	6.810	7.981	10.687
2008	0.046	0.577	1.450	2.041	2.504	3.465	4.165	7.931	10.050	10.687
Average	0.106	0.768	1.694	2.628	3.901	5.290	6.854	8.265	10.126	13.825
Minimum	0.010	0.288	1.073	1.574	2.504	3.182	3.936	4.684	5.729	10.687
Maximum	0.276	1.132	2.354	3.564	6.182	7.487	9.629	12.712	14.114	14.635

Table 17. Eastern Georges Bank(5Zjm) cod age composition comparison between inside (Closed) and outside (Nclosed) closed area II in strata 5Z3 and 5Z4. The analyzed data are from the DFO spring survey.

Year	4^+ proportion		Weighted average age	
	Nclosed area	Closed area	Nclosed area	Closed area
1987	0.68	0.34	4.3	3.2
1988	0.46	0.22	3.7	3.1
1989	0.35	0.20	2.7	2.4
1990	0.53	0.52	3.9	3.7
1991	0.37	0.29	3.2	2.5
1992	0.82	0.63	5.1	4.4
1993	0.16	0.44	3.1	3.9
1994	no fish caught			
1995	0.41	0.38	3.6	3.5
1996	0.95	0.75	5.0	4.1
1997	0.53	0.75	2.9	4.1
1998	0.68	0.34	4.3	3.2
1999	0.30	0.34	3.2	3.4
2000	0.83	0.88	4.1	4.4
2001	0.61	0.71	4.1	4.5
2002	0.98	0.84	4.5	4.2
2003	0.89	0.80	5.1	4.8
2004	0.26	0.24	2.5	2.3
2005	0.74	0.83	4.4	4.1
2006	0.90	0.63	4.8	4.2
2007	0.47	0.61	3.6	3.7
2008	0.76	0.83	4.1	4.4

Table 18. The AIC comparison results when M changes starting at different ages using "no split M change" model.

Age	AIC	ΔAIC	exp((-Δ/2)	Akaike weight w_i
6	-29.72	0	1	0.95
5	-22.98	6.74	0.03	0.03
7	-22.19	7.53	0.02	0.02
4	-4.35	25.37	0.00	0.00

Table 19. The AIC comparison results when M is fixed at different values from age 6 using "no split M change" model.

M	AIC	ΔAIC	exp((-Δ/2)	Akaike weight w_i
0.7	-29.7	0	1	0.83
0.8	-26.4	3.26	0.20	0.16
0.6	-18.1	11.59	0.003	0.00
0.5	0.2	29.83	0.00	0.00
0.9	3.8	33.43	0.00	0.00
0.4	20.7	50.37	0.00	0.00
0.3	42.1	71.76	0.00	0.00
0.2	62.0	91.71	0.00	0.00

Table 20. Beginning of year population abundance(numbers in 000s) for eastern Georges Bank cod using the "no split M 0.7" model formulation.

Year/Age	1	2	3	4	5	6	7	8	9	10+	3+ biomass
1978	12307	3352	10864	4026	1324	709	622	105	111	100	52495
1979	10111	10069	2646	5628	2248	731	434	395	66	144	46821
1980	9952	8265	7441	1507	3243	1352	434	289	268	156	54394
1981	17462	8142	5890	4609	963	1786	789	268	213	287	59683
1982	5687	14265	5954	3332	2639	534	986	467	128	333	55983
1983	5090	4643	8520	3108	1592	1188	262	450	243	288	47913
1984	14229	4148	3096	4723	1384	799	616	109	206	281	35452
1985	5207	11634	3188	1812	2652	645	318	255	55	256	35567
1986	23891	4255	6955	1351	891	1287	286	162	110	203	35908
1987	7986	19523	3077	3662	580	423	645	173	90	220	31624
1988	13822	6519	12282	1760	1968	328	227	372	105	221	47206
1989	4909	11296	5077	6300	832	847	153	82	142	187	41214
1990	7037	3988	8632	3425	3382	477	360	74	32	192	50499
1991	9389	5743	2603	4275	1873	1539	260	158	50	146	40282
1992	3250	7629	3781	1227	1781	727	595	119	68	117	30584
1993	4301	2600	3938	1862	593	665	314	206	57	110	25132
1994	3277	3512	1680	1530	713	219	224	139	82	97	15875
1995	2010	2678	2709	942	550	342	79	70	49	73	12664
1996	3655	1645	2141	2005	687	356	157	34	32	58	15887
1997	6075	2985	1310	1542	1284	491	136	69	15	42	15031
1998	2641	4968	2313	887	940	729	187	42	25	25	13334
1999	6892	2159	3977	1610	581	628	271	77	12	21	16415
2000	3130	5636	1697	2818	1015	377	270	96	29	14	17300
2001	2282	2554	4543	1287	1966	696	162	119	39	19	23008
2002	3571	1780	1889	3239	855	1246	274	59	47	24	20951
2003	1117	2923	1447	1433	2252	602	513	116	23	29	17121
2004	9132	914	2360	1035	954	1480	244	194	44	22	18280
2005	1138	7457	737	1802	712	649	640	97	76	27	12342
2006	2976	930	6022	551	1295	531	301	290	41	46	16358
2007	1144	2431	744	4705	381	891	231	137	132	40	17503
2008	2500	935	1921	533	3487	284	384	107	63	81	17536

Table 21. Annual fishing mortality rate for eastern Georges Bank cod using the "no split M 0.7" model formulation.

Year/Age	1	2	3	4	5	6	7	8	9	10+
1978	0.00	0.04	0.46	0.38	0.39	0.29	0.26	0.26	0.26	0.11
1979	0.00	0.10	0.36	0.35	0.31	0.32	0.21	0.18	0.20	0.05
1980	0.00	0.14	0.28	0.25	0.40	0.34	0.28	0.10	0.21	0.16
1981	0.00	0.11	0.37	0.36	0.39	0.39	0.33	0.54	0.38	0.10
1982	0.00	0.32	0.45	0.54	0.60	0.51	0.58	0.45	0.54	0.18
1983	0.00	0.21	0.39	0.61	0.49	0.46	0.68	0.58	0.62	0.31
1984	0.00	0.06	0.34	0.38	0.56	0.72	0.68	0.49	0.65	0.31
1985	0.00	0.31	0.66	0.51	0.52	0.61	0.48	0.64	0.55	0.17
1986	0.00	0.12	0.44	0.65	0.55	0.49	0.30	0.39	0.33	0.07
1987	0.00	0.26	0.36	0.42	0.37	0.42	0.35	0.30	0.34	0.06
1988	0.00	0.05	0.47	0.55	0.64	0.57	0.82	0.76	0.78	0.21
1989	0.01	0.07	0.19	0.42	0.36	0.66	0.52	0.75	0.60	0.17
1990	0.00	0.23	0.50	0.40	0.59	0.41	0.62	0.20	0.55	0.19
1991	0.01	0.22	0.55	0.68	0.75	0.75	0.58	0.65	0.61	0.23
1992	0.02	0.46	0.51	0.53	0.79	0.64	0.86	0.54	0.81	0.11
1993	0.00	0.24	0.75	0.76	0.80	0.89	0.62	0.72	0.66	0.21
1994	0.00	0.06	0.38	0.82	0.53	0.33	0.46	0.35	0.42	0.04
1995	0.00	0.02	0.10	0.12	0.24	0.08	0.13	0.08	0.11	0.01
1996	0.00	0.03	0.13	0.25	0.14	0.26	0.13	0.16	0.13	0.01
1997	0.00	0.05	0.19	0.29	0.37	0.27	0.47	0.30	0.41	0.06
1998	0.00	0.02	0.16	0.22	0.20	0.29	0.18	0.55	0.25	0.12
1999	0.00	0.04	0.14	0.26	0.23	0.14	0.34	0.29	0.33	0.05
2000	0.00	0.02	0.08	0.16	0.18	0.15	0.12	0.19	0.14	0.06
2001	0.05	0.10	0.14	0.21	0.26	0.23	0.31	0.22	0.28	0.08
2002	0.00	0.01	0.08	0.16	0.15	0.19	0.16	0.23	0.17	0.21
2003	0.00	0.01	0.13	0.21	0.22	0.21	0.27	0.25	0.27	0.09
2004	0.00	0.02	0.07	0.17	0.19	0.14	0.22	0.24	0.23	0.15
2005	0.00	0.01	0.09	0.13	0.09	0.07	0.09	0.17	0.10	0.08
2006	0.00	0.02	0.05	0.17	0.17	0.13	0.09	0.08	0.09	0.06
2007	0.00	0.04	0.13	0.10	0.09	0.14	0.07	0.08	0.07	0.02

Table 22. Beginning of year population abundance (numbers in 000s) for eastern Georges Bank cod using the “split M 0.2” model formulation.

Year/Age	1	2	3	4	5	6	7	8	9	10+	3+ biomass
1978	12302	3351	10862	4025	1324	709	622	105	111	100	52484
1979	10106	10065	2645	5627	2247	731	434	394	66	144	46806
1980	9944	8260	7438	1506	3242	1352	434	289	268	156	54372
1981	17434	8136	5886	4606	962	1785	789	268	213	287	59649
1982	5680	14243	5949	3329	2637	533	985	466	128	332	55936
1983	5065	4637	8501	3103	1589	1187	262	449	243	288	47835
1984	14178	4127	3091	4707	1381	797	615	109	205	280	35364
1985	5109	11593	3171	1808	2639	642	317	254	54	255	35416
1986	23619	4174	6921	1337	888	1277	284	160	110	202	35679
1987	7603	19300	3011	3635	569	420	637	171	89	218	31247
1988	13338	6205	12100	1706	1946	319	225	365	104	219	46439
1989	4505	10899	4820	6151	788	829	145	81	137	184	39883
1990	6285	3656	8308	3215	3260	441	345	68	30	186	48241
1991	8795	5127	2332	4010	1701	1441	231	146	45	139	37213
1992	2338	7143	3278	1007	1567	588	515	95	58	107	26192
1993	3030	1854	3541	1451	414	491	202	141	38	95	19700
1994	1967	2472	1069	1209	382	75	85	47	30	69	9087
1995	1282	1606	1858	444	292	74	22	16	12	60	6608
1996	2323	1048	1263	1308	279	145	44	12	9	56	8644
1997	3676	1894	822	823	714	158	64	24	6	50	7898
1998	1474	3004	1421	488	354	265	55	20	8	42	6484
1999	3720	1203	2369	880	255	149	97	25	4	35	8003
2000	1760	3039	915	1502	419	111	68	29	8	29	7995
2001	1212	1432	2417	647	890	208	57	35	13	27	10447
2002	1797	905	970	1499	331	368	77	18	13	26	8379
2003	569	1470	730	681	829	174	162	36	7	24	6614
2004	4978	466	1171	449	339	318	70	53	12	21	6262
2005	722	4056	370	828	233	147	136	26	17	19	4124
2006	2132	590	3238	250	498	139	92	76	12	23	6964
2007	1040	1740	465	2425	135	240	71	59	47	25	7563
2008	2500	850	1356	305	1621	83	120	48	42	52	8791

Table 23. Annual fishing mortality rate for eastern Georges Bank cod using the "split M 0.2" model formulation.

Year/Age	1	2	3	4	5	6	7	8	9	10+
1978	0.00	0.04	0.46	0.38	0.39	0.29	0.26	0.26	0.26	0.11
1979	0.00	0.10	0.36	0.35	0.31	0.32	0.21	0.18	0.20	0.05
1980	0.00	0.14	0.28	0.25	0.40	0.34	0.28	0.10	0.21	0.16
1981	0.00	0.11	0.37	0.36	0.39	0.39	0.33	0.54	0.38	0.10
1982	0.00	0.32	0.45	0.54	0.60	0.51	0.59	0.45	0.54	0.18
1983	0.00	0.21	0.39	0.61	0.49	0.46	0.68	0.58	0.62	0.31
1984	0.00	0.06	0.34	0.38	0.57	0.72	0.68	0.49	0.65	0.31
1985	0.00	0.32	0.66	0.51	0.53	0.62	0.48	0.64	0.55	0.17
1986	0.00	0.13	0.44	0.65	0.55	0.50	0.31	0.39	0.34	0.07
1987	0.00	0.27	0.37	0.42	0.38	0.42	0.36	0.30	0.34	0.06
1988	0.00	0.05	0.48	0.57	0.65	0.59	0.83	0.78	0.80	0.21
1989	0.01	0.07	0.20	0.43	0.38	0.68	0.55	0.78	0.63	0.18
1990	0.00	0.25	0.53	0.44	0.62	0.45	0.66	0.22	0.59	0.20
1991	0.01	0.25	0.64	0.74	0.86	0.83	0.69	0.73	0.70	0.24
1992	0.03	0.50	0.61	0.69	0.96	0.87	1.09	0.73	1.04	0.12
1993	0.00	0.35	0.87	1.13	1.51	1.55	1.25	1.35	1.29	0.25
1994	0.00	0.09	0.68	1.22	1.44	1.03	1.48	1.14	1.36	0.04
1995	0.00	0.04	0.15	0.26	0.50	0.32	0.43	0.32	0.39	0.01
1996	0.00	0.04	0.23	0.41	0.37	0.61	0.40	0.41	0.41	0.01
1997	0.00	0.09	0.32	0.64	0.79	0.86	0.99	0.90	0.97	0.04
1998	0.00	0.04	0.28	0.45	0.67	0.80	0.60	1.33	0.79	0.05
1999	0.00	0.07	0.26	0.54	0.63	0.59	1.00	0.97	0.99	0.03
2000	0.01	0.03	0.15	0.32	0.50	0.46	0.45	0.61	0.50	0.02
2001	0.09	0.19	0.28	0.47	0.68	0.80	0.93	0.76	0.87	0.04
2002	0.00	0.01	0.15	0.39	0.44	0.62	0.56	0.73	0.59	0.15
2003	0.00	0.03	0.29	0.50	0.76	0.71	0.92	0.86	0.91	0.08
2004	0.00	0.03	0.15	0.46	0.64	0.65	0.79	0.96	0.86	0.12
2005	0.00	0.03	0.19	0.31	0.31	0.27	0.39	0.61	0.42	0.09
2006	0.00	0.04	0.09	0.42	0.53	0.48	0.24	0.28	0.26	0.09
2007	0.00	0.05	0.22	0.20	0.28	0.50	0.19	0.15	0.17	0.03

Table 24. The AIC comparison results when M changes, starting at different ages using the "split M change" model.

Age	AIC	ΔAIC	exp((-Δ/2)	Akaike weight w_i
6	-41.70	0	1	0.28
5	-41.18	0.52	0.77	0.21
7	-41.14	0.57	0.75	0.21
4	-40.95	0.75	0.69	0.19
8	-39.88	1.82	0.40	0.11

Table 25. The AIC comparison results when M is fixed at different values from age 6 using the "split M change" model.

M	AIC	ΔAIC	exp((-Δ/2)	Akaike weight w_i
0.5	-42.71	0	1	0.35
0.6	-42.44	0.27	0.88	0.31
0.4	-41.38	1.32	0.52	0.18
0.7	-39.40	3.31	0.19	0.07
0.3	-39.34	3.37	0.19	0.07
0.2	-36.71	6.00	0.05	0.02

Table 26. Beginning of year population abundance (numbers in 000s) for eastern Georges Bank cod using the “split M 0.5” model formulation.

Year/Age	1	2	3	4	5	6	7	8	9	10+	3+ biomass
1978	12304	3351	10863	4025	1324	709	622	105	111	100	52488
1979	10108	10066	2646	5627	2248	731	434	394	66	144	46811
1980	9947	8262	7439	1507	3242	1352	434	289	268	156	54379
1981	17443	8138	5888	4607	963	1785	789	268	213	287	59660
1982	5682	14250	5950	3330	2638	533	985	466	128	332	55951
1983	5074	4639	8507	3105	1590	1187	262	449	243	288	47860
1984	14195	4134	3093	4712	1382	798	615	109	205	281	35392
1985	5140	11606	3177	1809	2643	643	317	255	54	256	35465
1986	23706	4200	6932	1342	889	1280	284	161	110	202	35753
1987	7728	19372	3033	3643	573	421	640	172	89	219	31369
1988	13492	6307	12158	1724	1953	322	226	367	104	220	46686
1989	4642	11026	4903	6199	802	835	148	81	138	185	40313
1990	6517	3769	8411	3283	3299	453	350	70	31	188	48969
1991	9025	5317	2424	4094	1757	1472	240	150	47	141	38211
1992	2621	7331	3433	1082	1635	633	540	103	61	111	27603
1993	3453	2085	3695	1578	475	546	238	162	44	100	21491
1994	2344	2818	1259	1333	484	124	129	77	46	78	11303
1995	1512	1914	2141	598	391	156	41	33	24	58	8504
1996	2719	1237	1516	1540	405	226	80	20	17	47	10878
1997	4383	2219	976	1030	904	261	91	38	9	36	9983
1998	1810	3583	1686	614	522	419	95	27	13	23	8415
1999	4557	1479	2843	1097	358	286	153	41	7	18	10327
2000	2124	3724	1141	1890	596	195	127	50	14	12	10584
2001	1521	1730	2978	831	1207	353	90	60	21	13	13943
2002	2308	1157	1214	1958	482	626	135	30	23	15	11802
2003	720	1889	937	881	1204	298	262	59	12	17	9396
2004	6361	589	1513	618	502	623	119	91	21	13	9443
2005	886	5188	471	1109	371	280	272	45	33	14	6317
2006	2601	724	4165	333	728	252	146	135	19	23	9686
2007	1267	2124	575	3184	203	427	116	74	69	22	10482
2008	2500	1035	1670	395	2242	139	194	62	40	50	11552

Table 27. Annual fishing mortality rate for eastern Georges Bank cod using the "split M 0.5" model formulation.

Year/Age	1	2	3	4	5	6	7	8	9	10+
1978	0.00	0.04	0.46	0.38	0.39	0.29	0.26	0.26	0.26	0.11
1979	0.00	0.10	0.36	0.35	0.31	0.32	0.21	0.18	0.20	0.05
1980	0.00	0.14	0.28	0.25	0.40	0.34	0.28	0.10	0.21	0.16
1981	0.00	0.11	0.37	0.36	0.39	0.39	0.33	0.54	0.38	0.10
1982	0.00	0.32	0.45	0.54	0.60	0.51	0.58	0.45	0.54	0.18
1983	0.00	0.21	0.39	0.61	0.49	0.46	0.68	0.58	0.62	0.31
1984	0.00	0.06	0.34	0.38	0.57	0.72	0.68	0.49	0.65	0.31
1985	0.00	0.32	0.66	0.51	0.53	0.62	0.48	0.64	0.55	0.17
1986	0.00	0.13	0.44	0.65	0.55	0.49	0.30	0.39	0.34	0.07
1987	0.00	0.27	0.36	0.42	0.38	0.42	0.35	0.30	0.34	0.06
1988	0.00	0.05	0.47	0.56	0.65	0.58	0.82	0.78	0.79	0.21
1989	0.01	0.07	0.20	0.43	0.37	0.67	0.54	0.77	0.62	0.18
1990	0.00	0.24	0.52	0.43	0.61	0.43	0.65	0.21	0.57	0.19
1991	0.01	0.24	0.61	0.72	0.82	0.80	0.65	0.70	0.67	0.24
1992	0.03	0.49	0.58	0.62	0.90	0.78	1.01	0.65	0.95	0.12
1993	0.00	0.30	0.82	0.98	1.15	1.24	0.93	1.05	0.98	0.24
1994	0.00	0.07	0.54	1.03	0.93	0.59	0.87	0.65	0.79	0.04
1995	0.00	0.03	0.13	0.19	0.35	0.16	0.24	0.17	0.21	0.01
1996	0.00	0.04	0.19	0.33	0.24	0.41	0.24	0.26	0.24	0.01
1997	0.00	0.07	0.26	0.48	0.57	0.51	0.71	0.56	0.66	0.06
1998	0.00	0.03	0.23	0.34	0.40	0.51	0.35	0.91	0.48	0.11
1999	0.00	0.06	0.21	0.41	0.41	0.31	0.62	0.57	0.61	0.06
2000	0.01	0.02	0.12	0.25	0.32	0.27	0.25	0.37	0.28	0.06
2001	0.07	0.15	0.22	0.34	0.46	0.46	0.58	0.45	0.53	0.11
2002	0.00	0.01	0.12	0.29	0.28	0.37	0.33	0.44	0.35	0.32
2003	0.00	0.02	0.22	0.36	0.46	0.42	0.55	0.51	0.55	0.14
2004	0.00	0.02	0.11	0.31	0.39	0.33	0.46	0.53	0.49	0.24
2005	0.00	0.02	0.15	0.22	0.19	0.15	0.21	0.36	0.23	0.15
2006	0.00	0.03	0.07	0.30	0.33	0.27	0.17	0.17	0.17	0.10
2007	0.00	0.04	0.18	0.15	0.18	0.29	0.13	0.13	0.13	0.03

Table 28. AIC and BIC selection result for the four models. Red numbers are the minimum AIC or BIC values.

Model	AIC	BIC
split M 0.5	**-42.71**	216.2
split 0.2	-36.71	222.2
no split M 0.7	-29.67	**134.3**
basic	62.04	229.2

Table 29. The dropped survey data. Red numbers are the small catch years.

Survey	Year
DFO	2005
	2000
	1996
	2003
NMFS spring	**2004**
	1998
	2004
	1994
NMFS fall	**2005**
	2002
	2004
	2007
	2003

Table 30. Projection results for eastern Georges Bank cod using three models.

a. Projected population biomass

no split M 0.7	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
2008	125	542	2785	1088	8717	987	1596	849	632	864	18186	18061	17519	14734
2009	100	1022	920	2550	978	8872	596	1072	366	684	17159	17059	16037	15117
2010	100	1022	2005	975	2513	928	4995	330	543	510	13921	13821	12799	10794
split 0.2	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
2008	125	493	1966	622	4053	290	497	381	418	556	9401	9276	8784	6818
2009	100	1020	822	1688	481	3432	240	458	225	690	9155	9055	8035	7213
2010	100	1022	2001	902	1694	456	3186	219	383	752	10715	10615	9594	7592
split M 0.5	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
2008	125	601	2422	806	5606	481	806	492	397	532	12267	12142	11541	9120
2009	100	1021	1010	2178	677	5204	324	603	236	490	11842	11742	10721	9711
2010	100	1022	2003	1109	2186	642	3579	219	373	433	11666	11566	10544	8541

b. Projected catch biomass

no split M 0.7	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
2008	1	11	265	153	1383	115	211	66	44	51	2300	2299	2289	2024
2009	1	29	131	510	188	1258	85	128	40	51	2420	2419	2389	2259
split M 0.2	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
2008	2	22	298	169	1359	90	174	79	76	32	2300	2298	2276	1978
2009	1	29	85	306	92	609	43	68	31	22	1287	1285	1256	1171
split M 0.5	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
2008	1	19	269	163	1406	97	185	66	47	46	2300	2299	2279	2010
2009	1	29	104	395	130	805	50	79	28	33	1655	1654	1624	1520

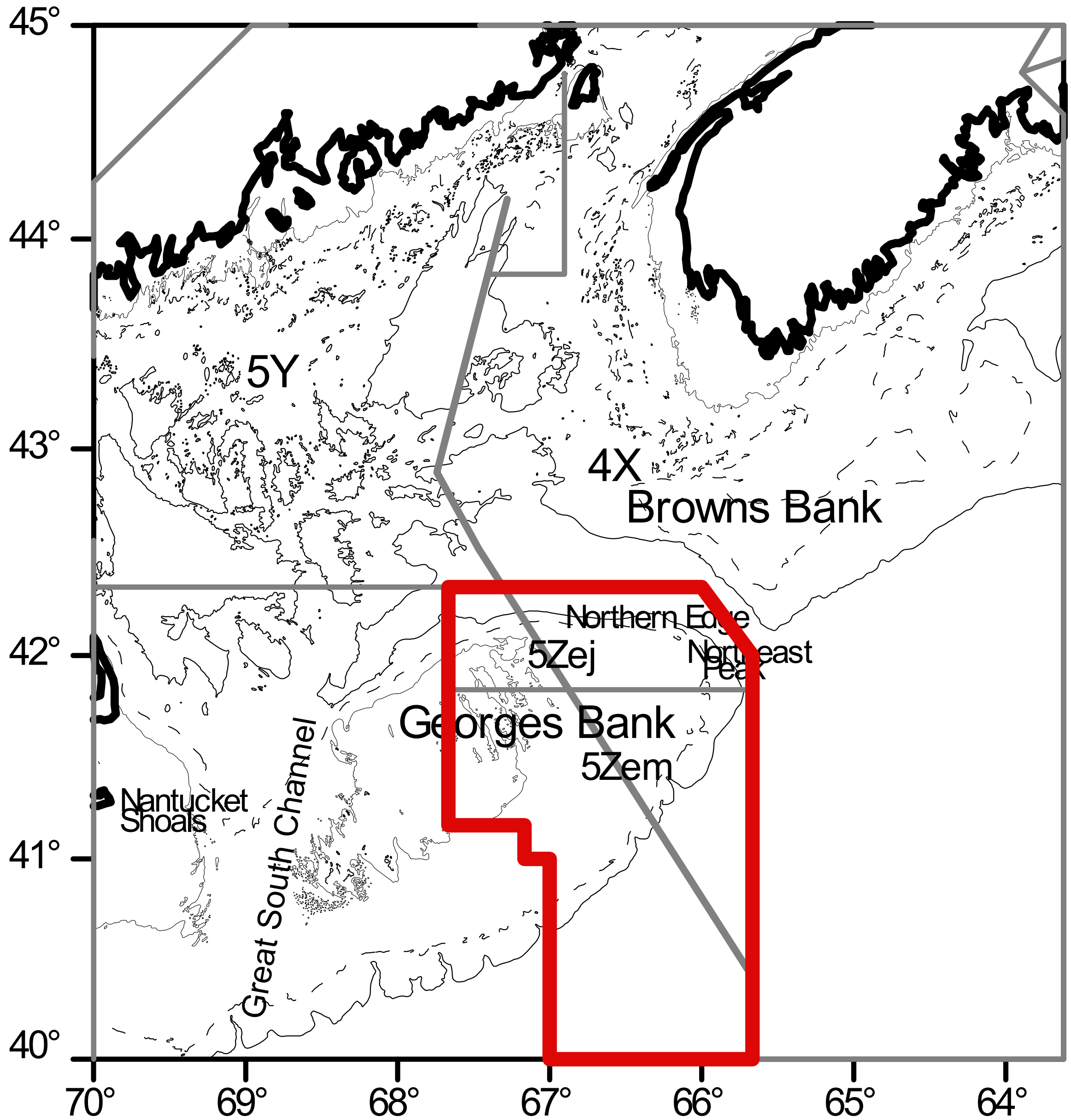


Figure 1. Fishery Management units area for cod on Georges Bank and the vicinity. The eastern Georges Bank management unit is outlined by a heavy red line.

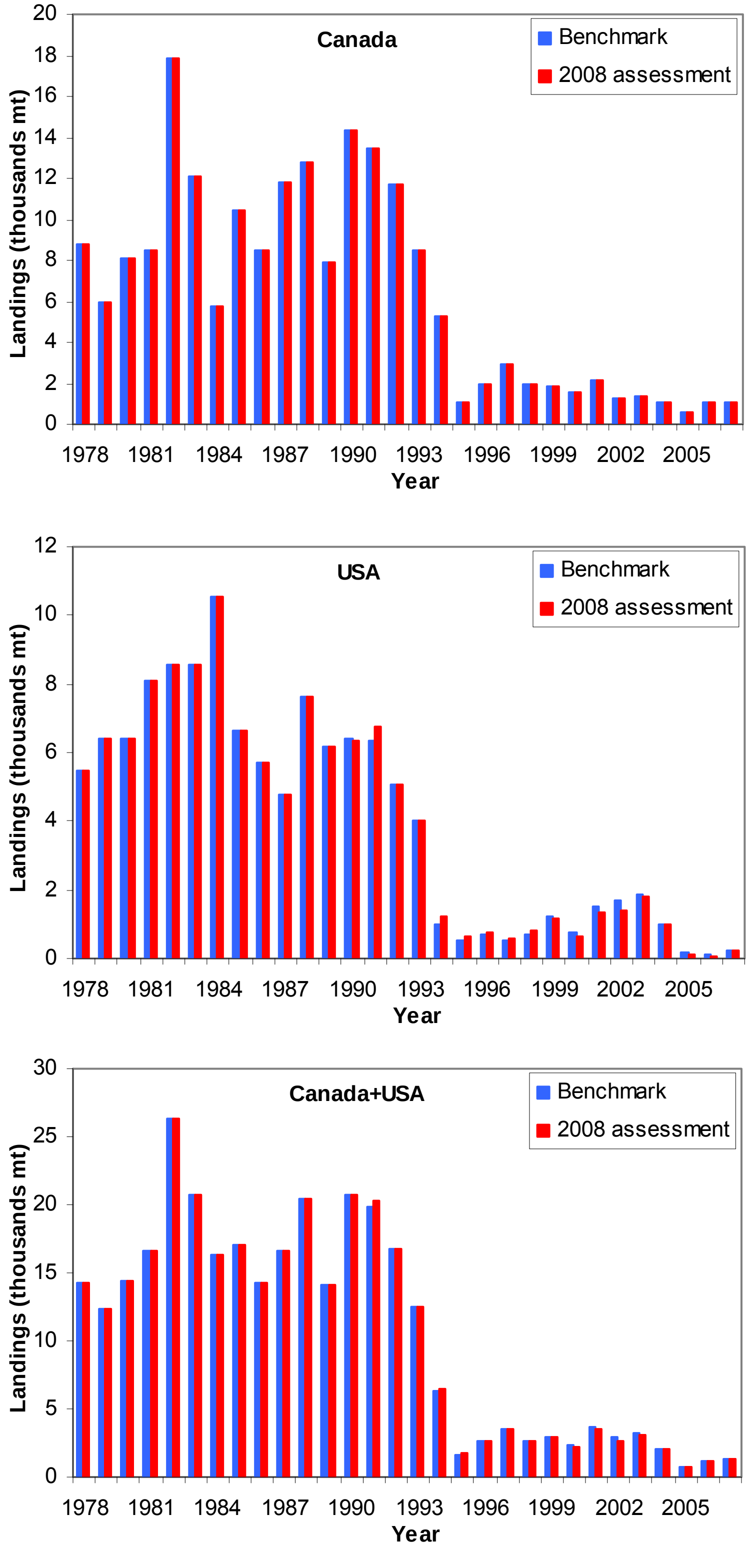
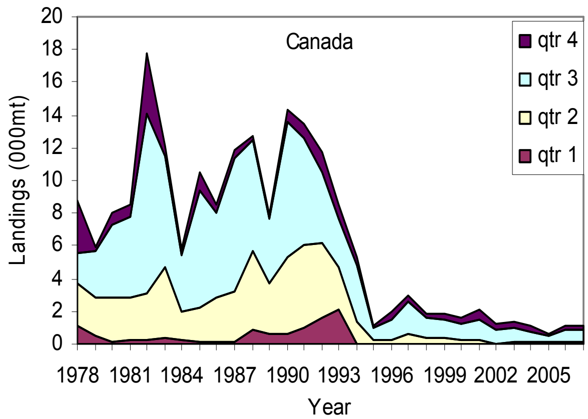


Figure 2. Comparison of cod landings (1978-2007) from eastern Georges Bank between benchmark and 2008 assessment.



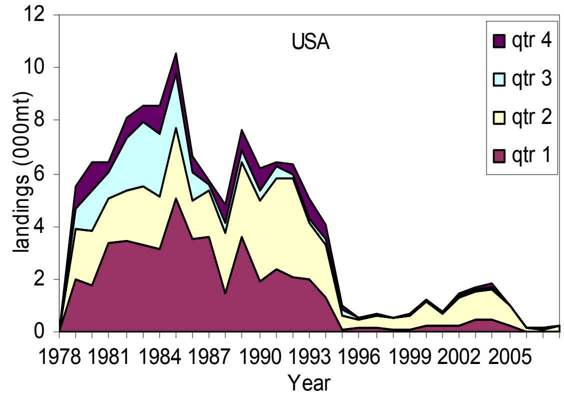


Figure 3. Quarterly Canadian and USA landings (1978-2007) of cod from eastern Georges Bank.

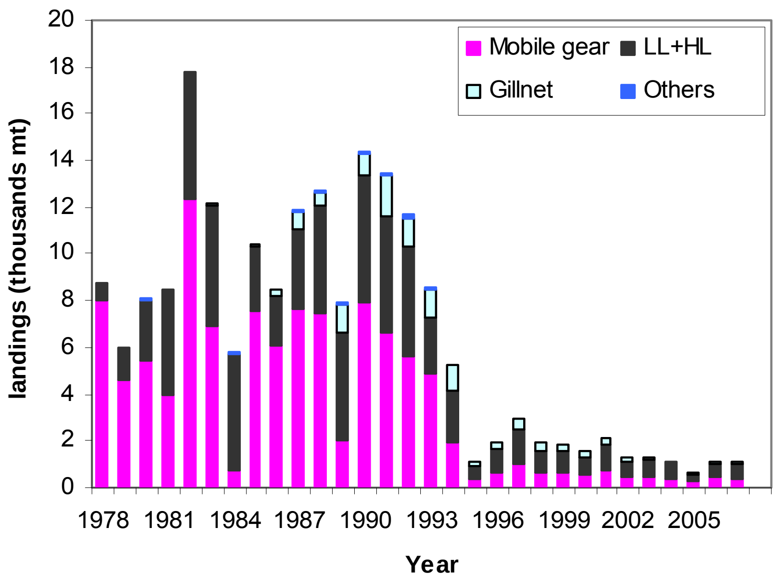


Figure 4. Gear specific Canadian landings (1978-2007) for eastern Georges Bank cod.

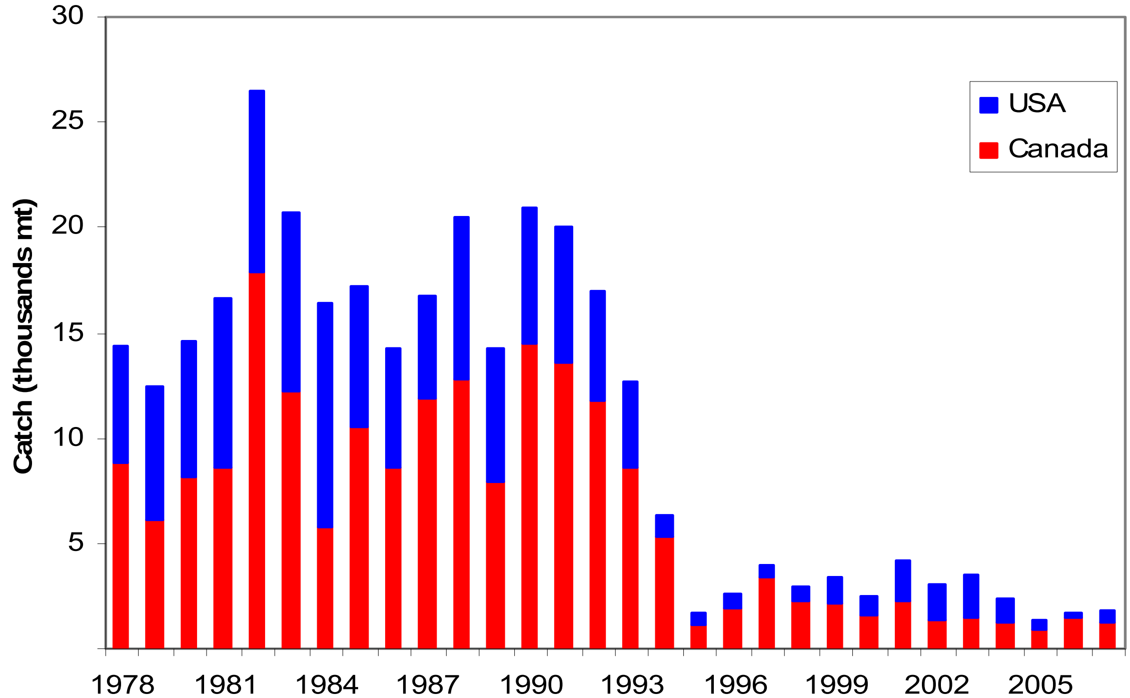


Figure 5. Fishery catches (landings + discards, 1978-2007) of eastern Georges Bank cod.

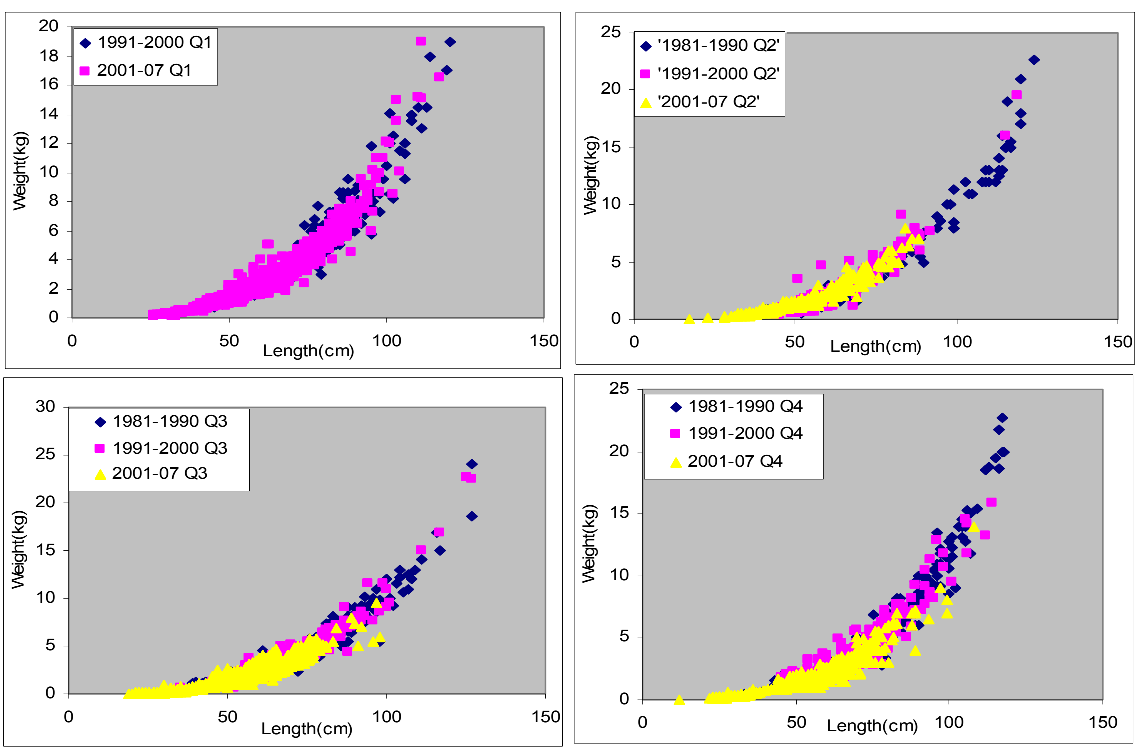


Figure 6. Length-weight scatter plot of cod on eastern Georges Bank from Canadian at-sea observer samples.

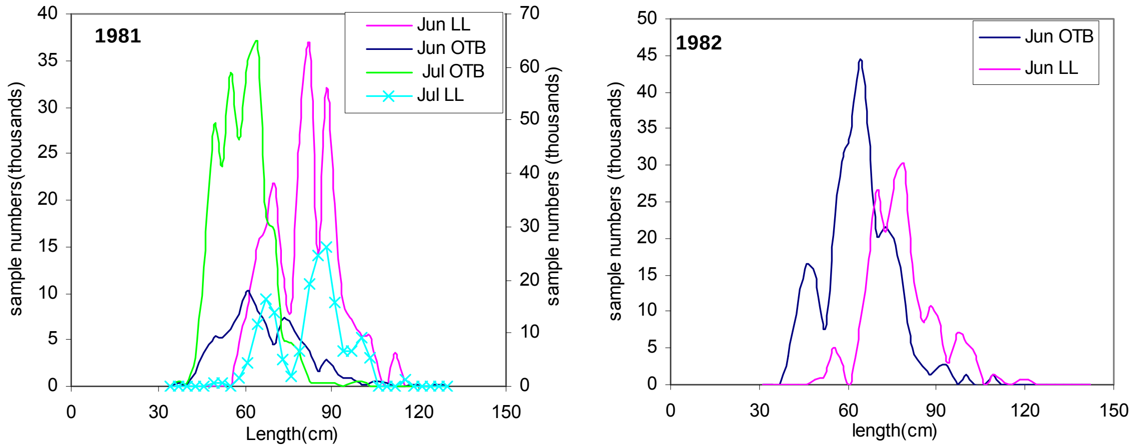


Figure 7. Examples of comparison of cod length composition for Canadian Longliners and OTB catches on eastern Georges Bank.

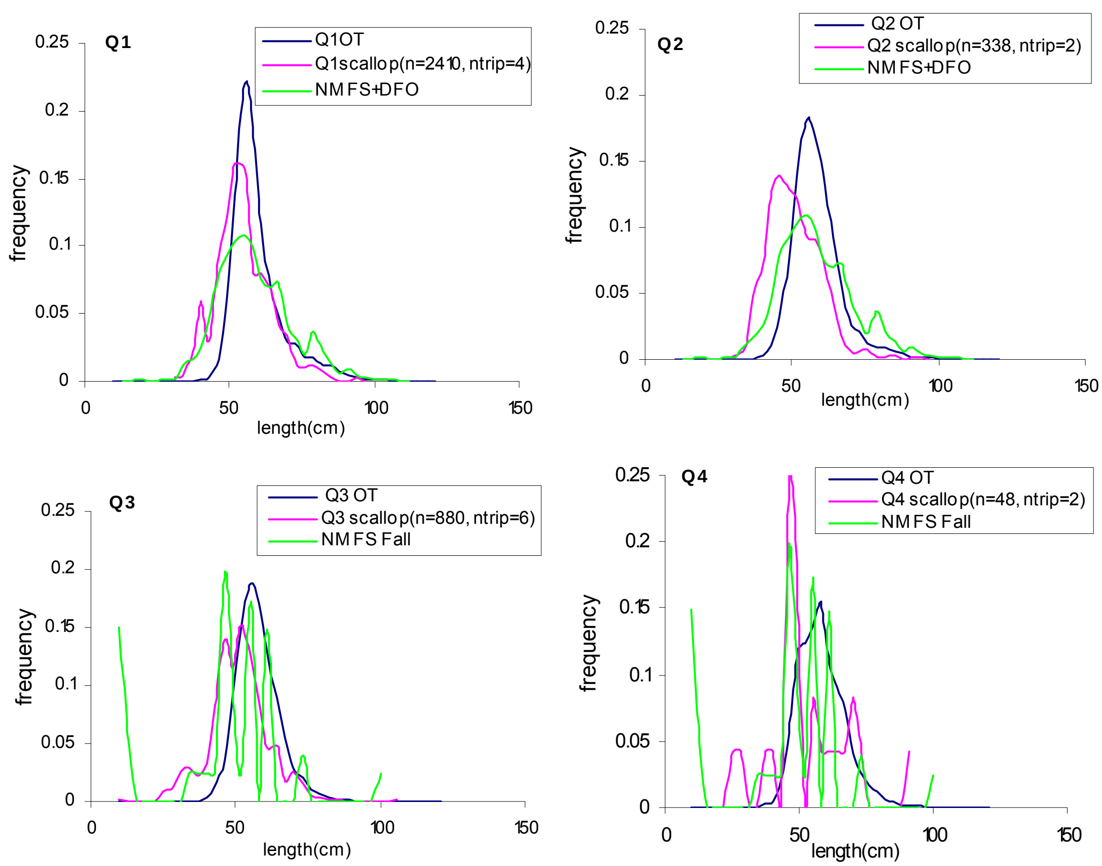
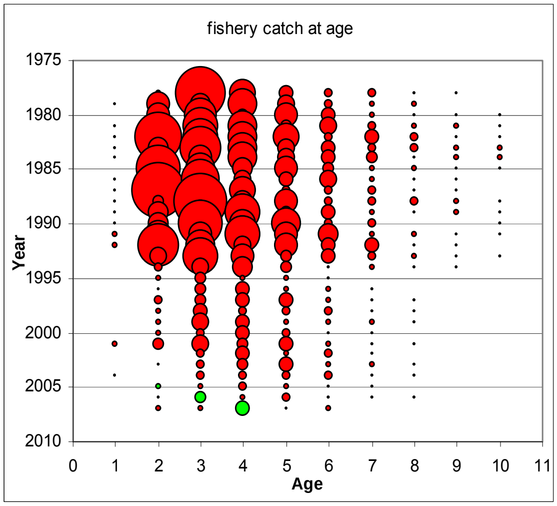


Figure 8. Quarterly cod length frequency comparisons among Canadian otter trawl catch samples, survey samples and discards samples from Canadian scallop fishery on eastern Georges Bank during 2007.



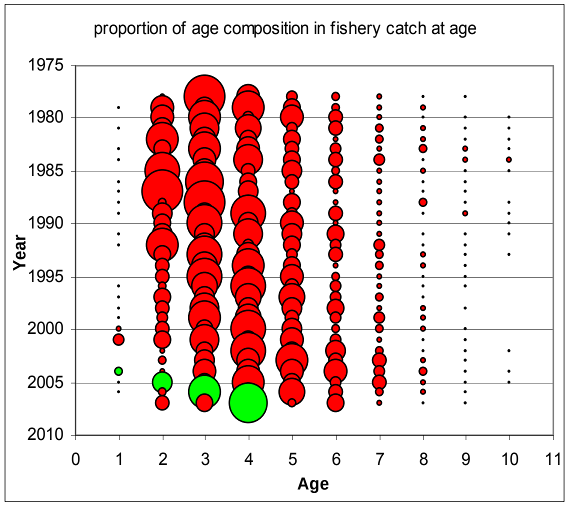


Figure 9. Fishery catch at age of eastern Georges Bank cod during 1978-2007. The 2003 year class is identified with green bubbles.

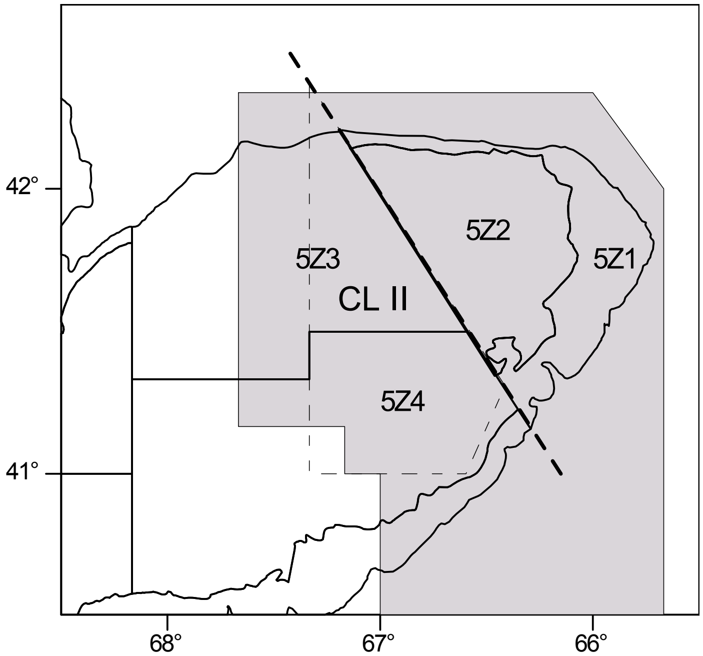


Figure 10. Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading. CL II is the closed area II.

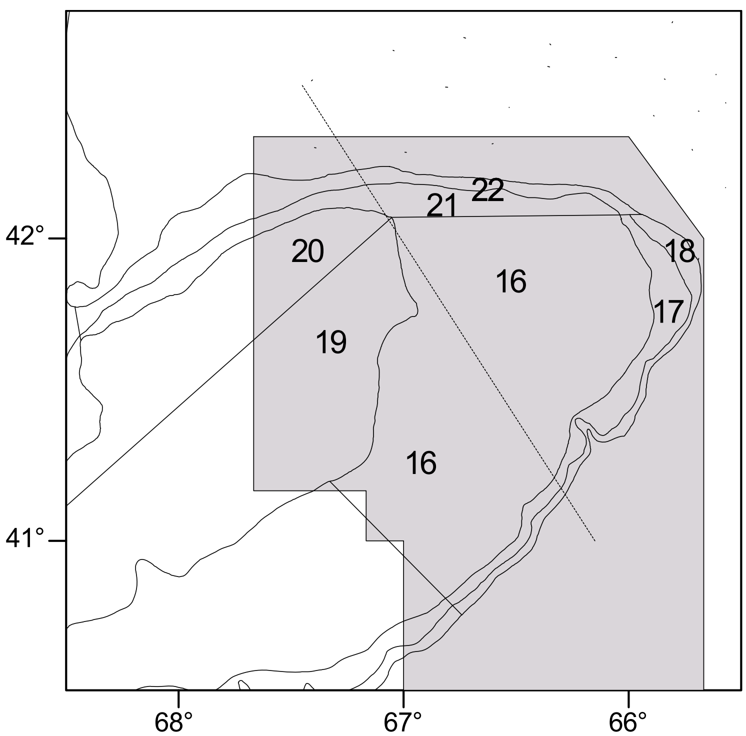


Figure 11. Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.

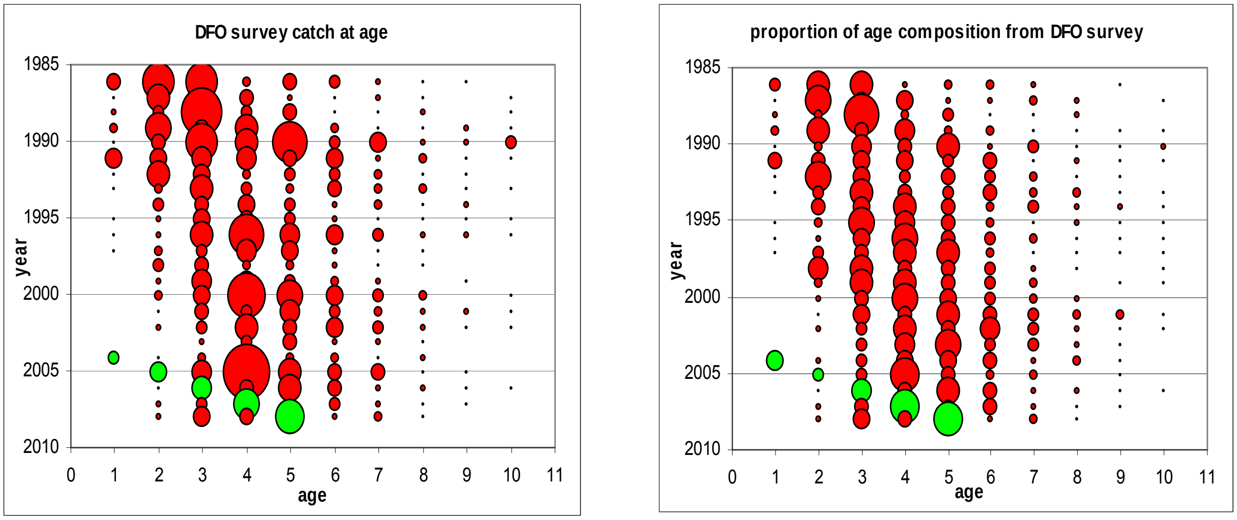


Figure 12. DFO survey abundance at age (numbers) and proportion at age (1996-2009) of eastern Georges Bank cod. The bubble area is proportional to the magnitude. The 2003 year class is identified with green bubbles.

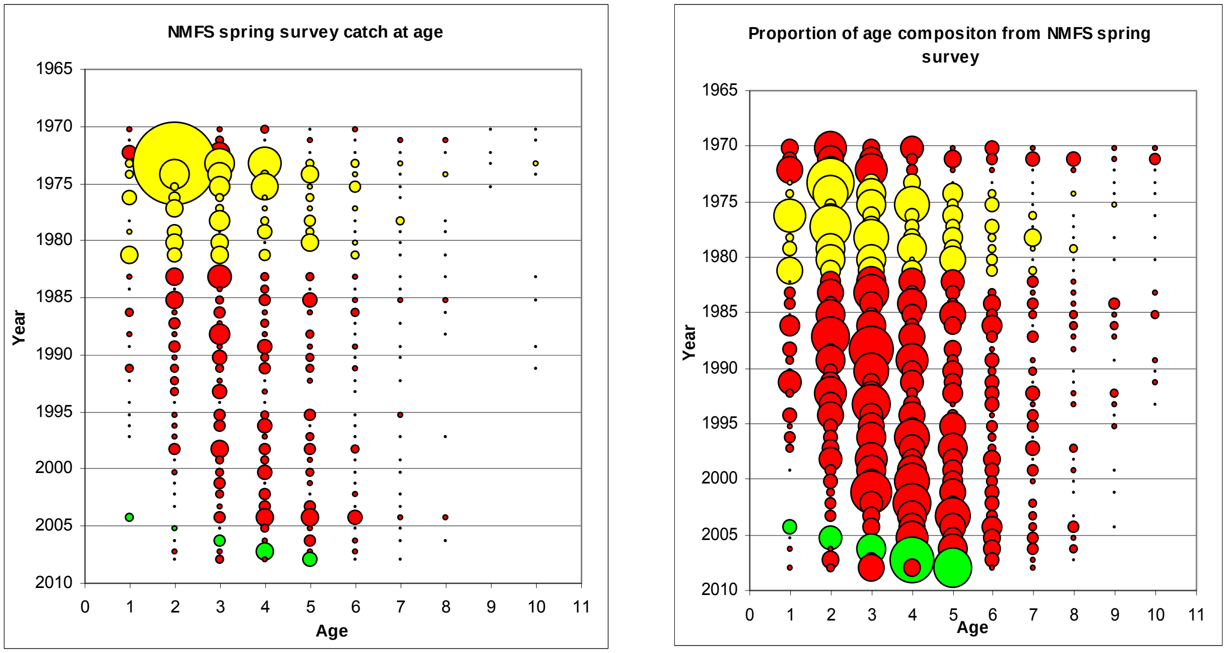


Figure 13. NMFS spring survey abundance at age (numbers) and proportion at age (1970-2008) of eastern Georges Bank cod. The bubble area is proportional to the magnitude. The NMFS spring survey was conducted using a modified Yankee 41 during 1978to 1981(yellow bubbles). Conversion factors to account for changes in door type and survey vessel were applied to the NMFS spring survey. The 2003 year class is identified with green bubbles.

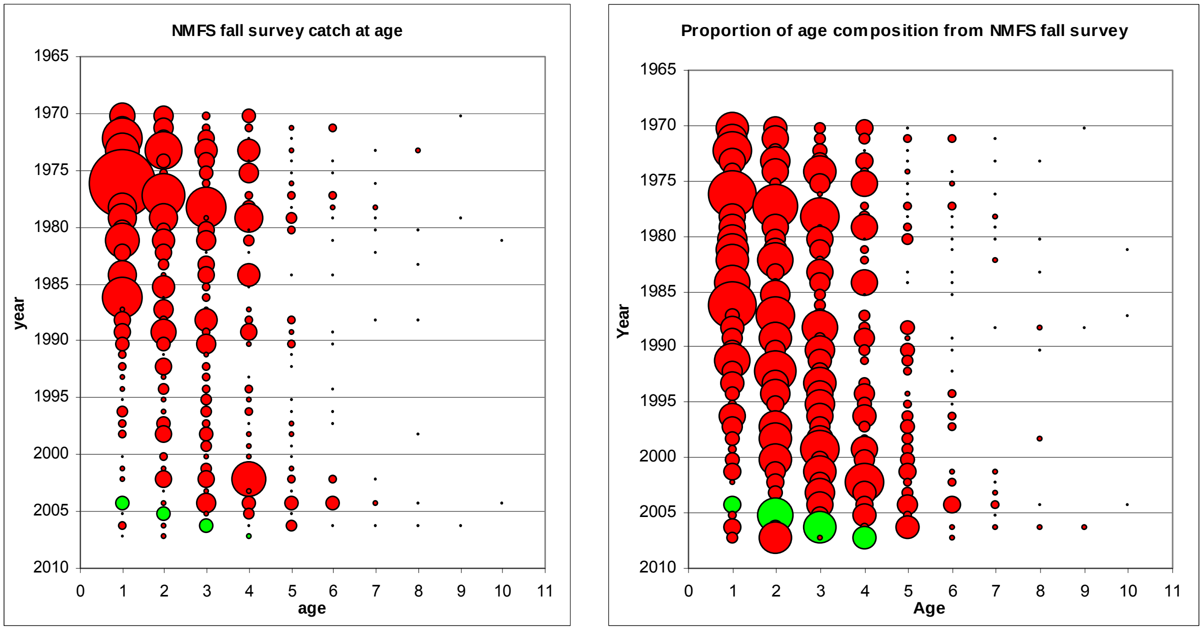


Figure 14. NMFS fall survey abundance at age (numbers) and proportion at age (1968-2008) of eastern Georges Bank cod. The bubble area is proportional to the magnitude. The NMFS spring survey was conducted using a modified Yankee 41 during 1978to 1981(yellow bubbles). Conversion factors to account for changes in door type and survey vessel were applied to the NMFS spring survey. The 2003 year class is identified with green bubbles.

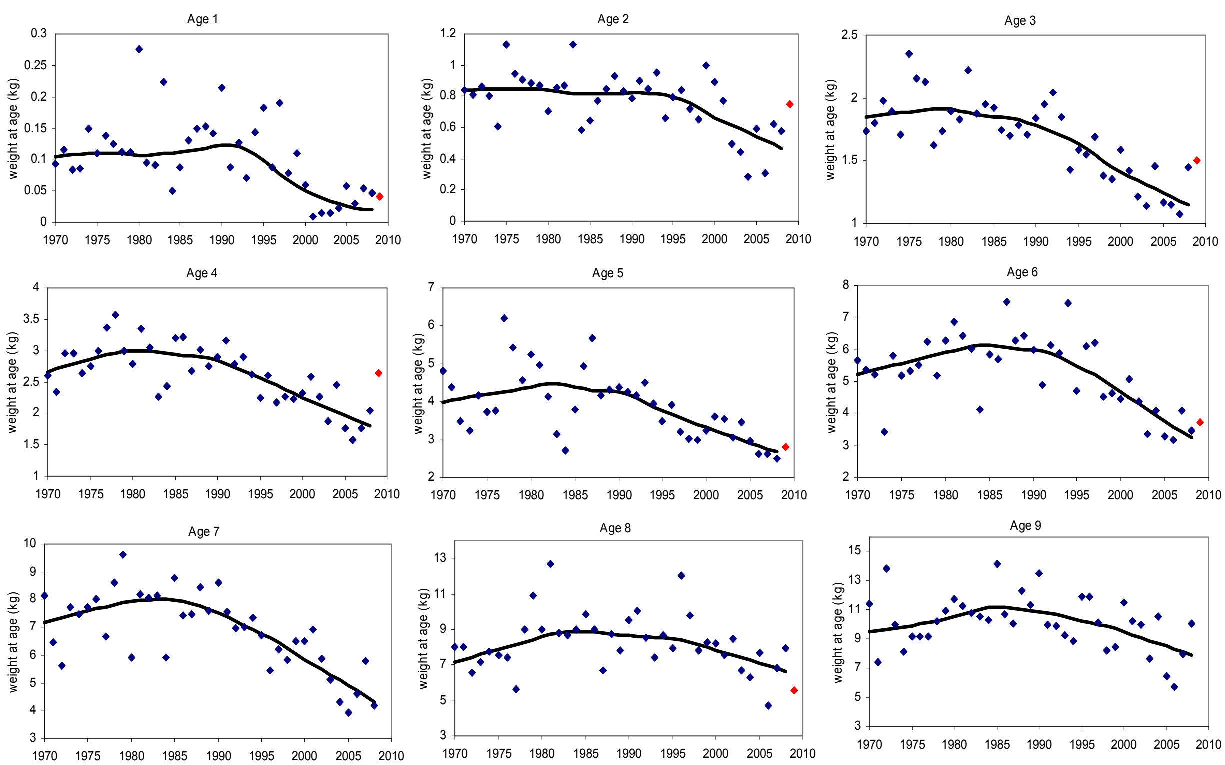


Figure 15. Beginning of year weight at age derived from DFO and NMFS spring surveys of eastern Georges Bank cod. The red points are from 2009 DFO survey.

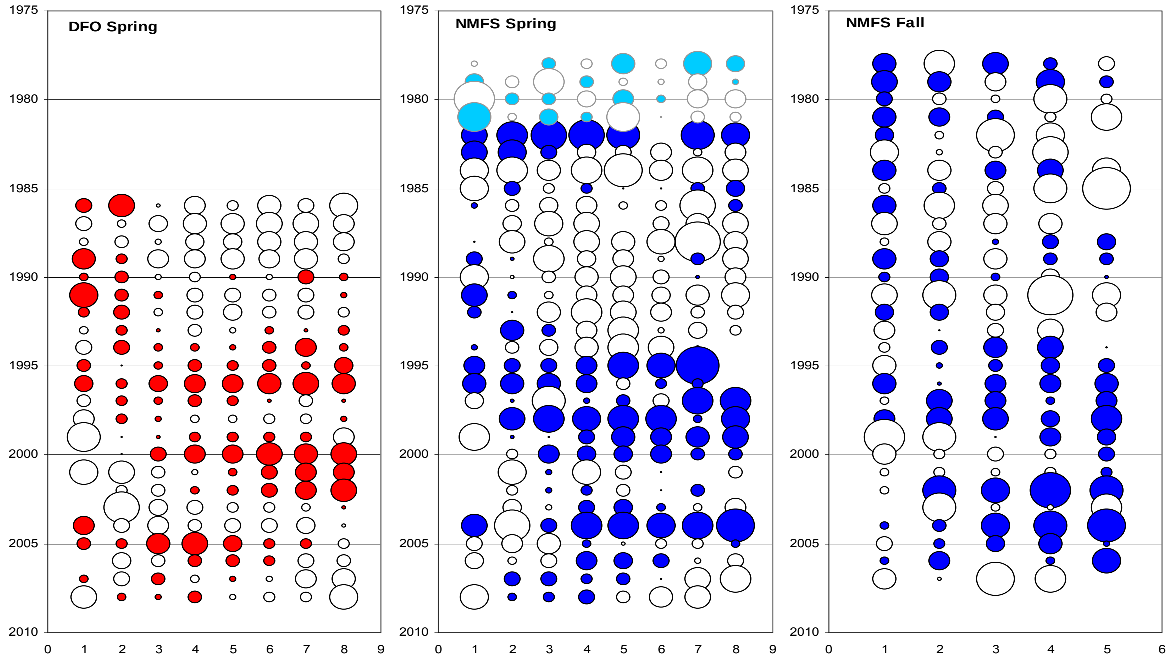


Figure 16. Residuals from basic VPA calibration by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 during 1978 to 1981(pale blue bubbles).

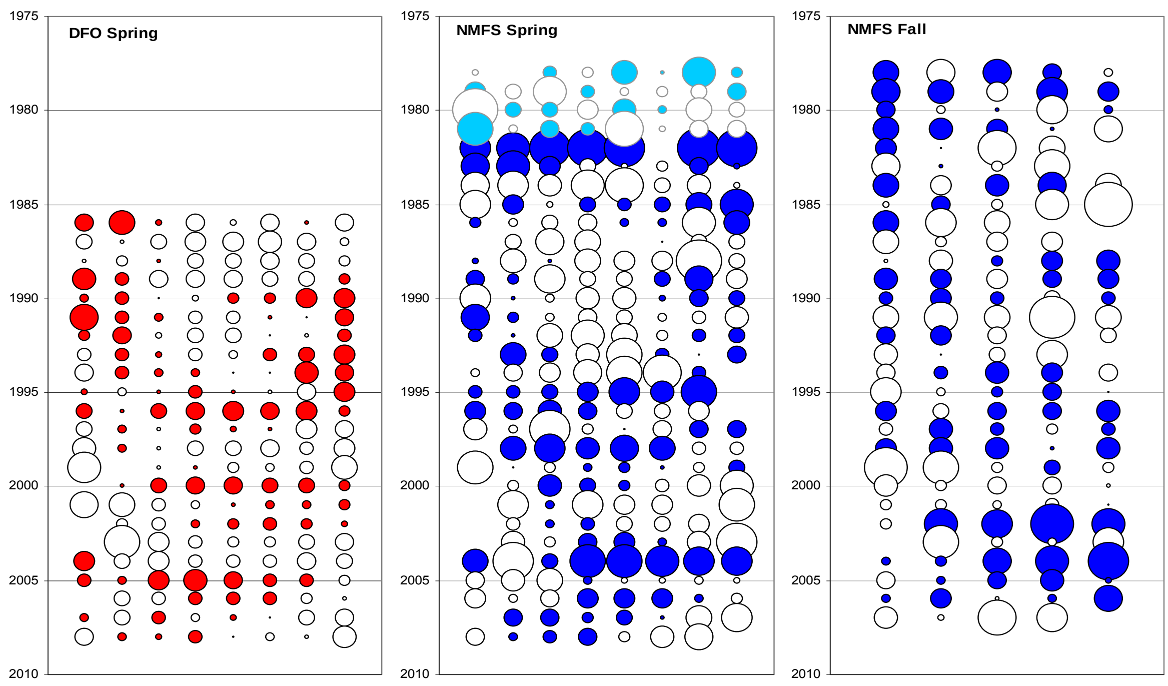


Figure 17. Residuals from 2002 benchmark formulation (corner) by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 during 1978 to 1981(pale blue bubbles).

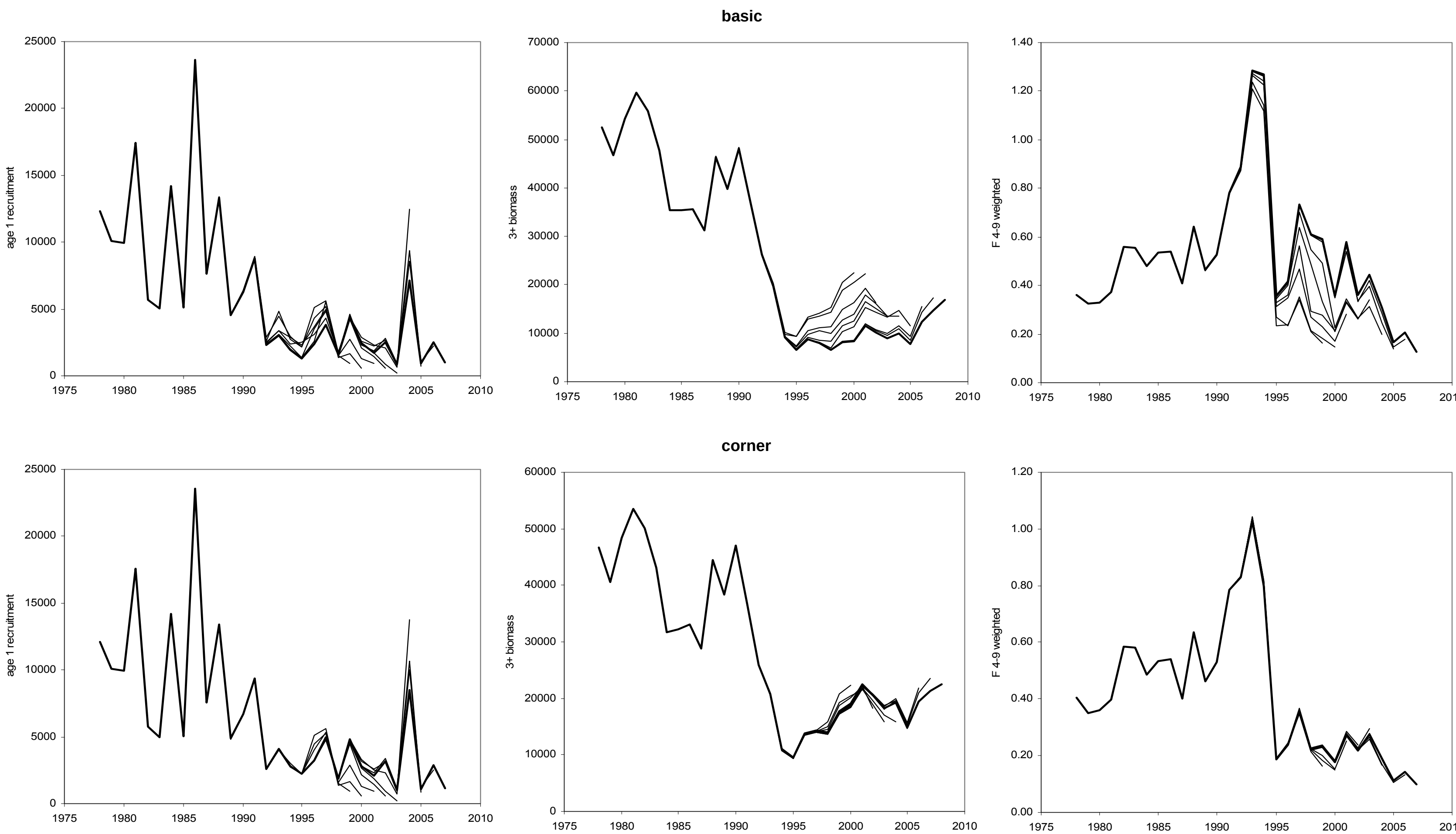


Figure 18. Comparison of retrospective from basic VPA calibration and 2002 benchmark(corner) formulation for eastern Georges Bank cod.

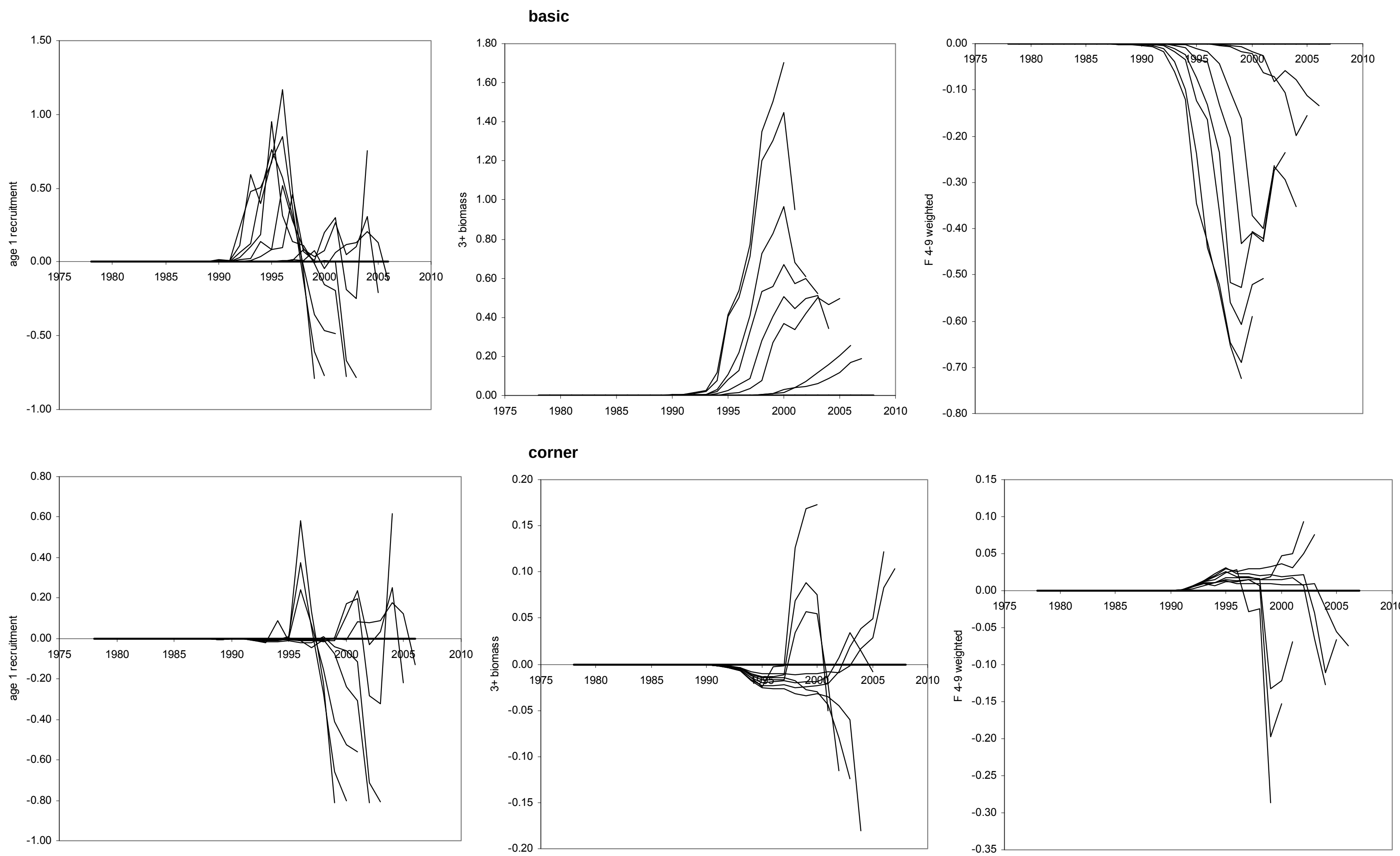


Figure 19. Comparison of relative retrospective from basic VPA calibration and 2002 benchmark (corner) formulation (note difference in scale) for eastern Georges Bank cod.

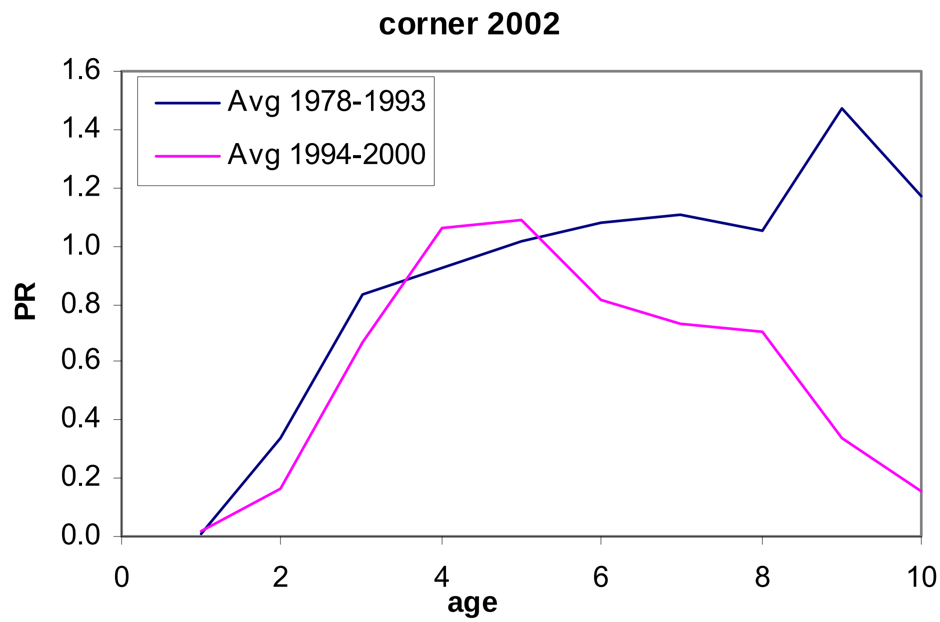


Figure 20. Fishery partial recruitment from the 2002 benchmark formulation when using data up to 2002 only for eastern Georges Bank cod.

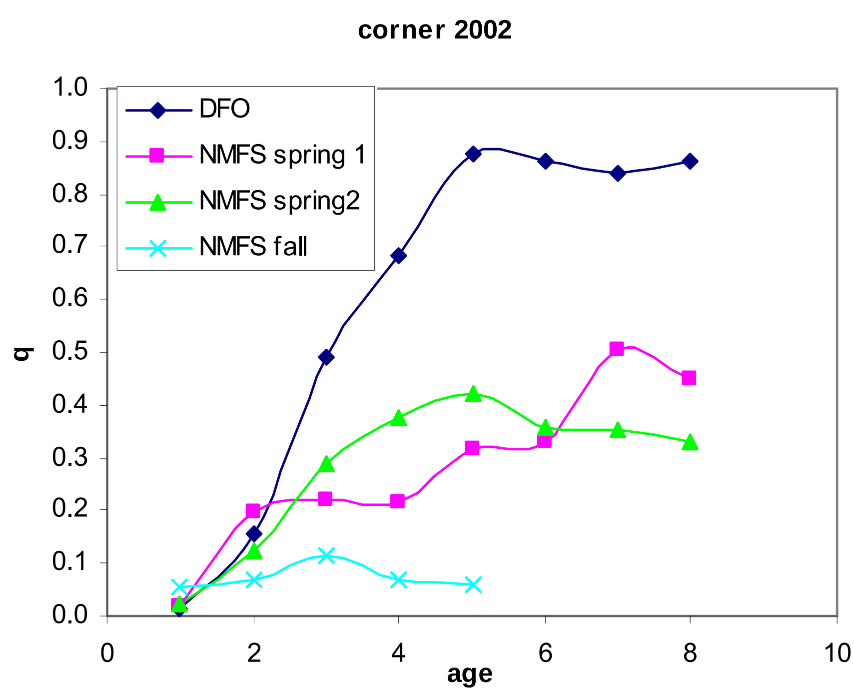


Figure 21. Survey catchability at age from the 2002 benchmark formulation when using data up to 2002 only for eastern Georges Bank cod.

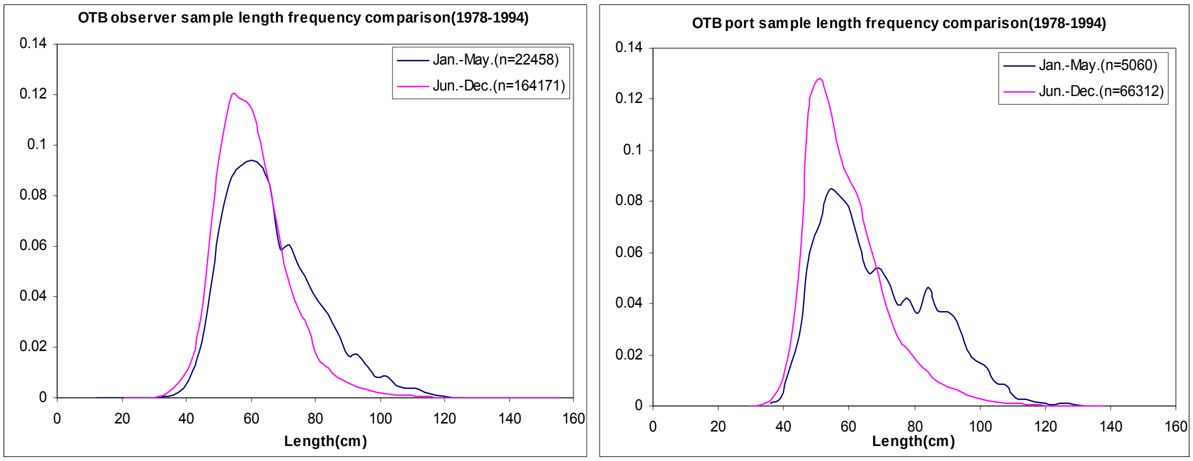


Figure 22. Comparison of length composition between the first quarter and last half of year from the Canadian otter trawl cod fishery on Georges Bank.

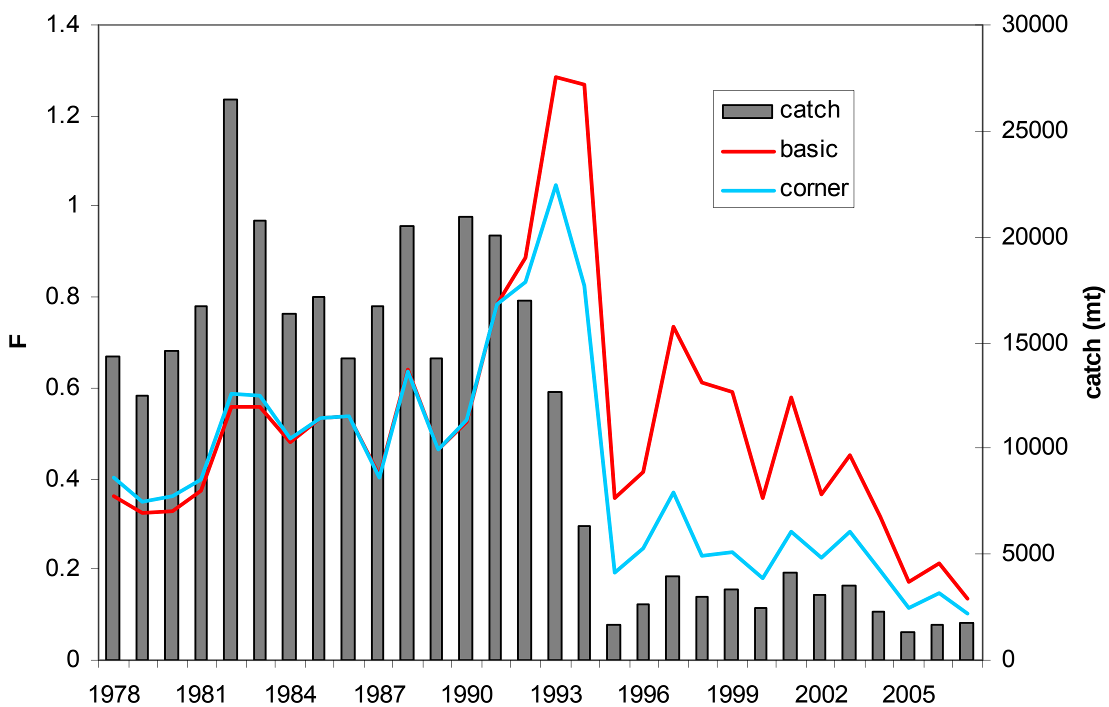


Figure 23. Comparison of F trends from basic and 2002 benchmark (corner) formulations for eastern Georges Bank cod.

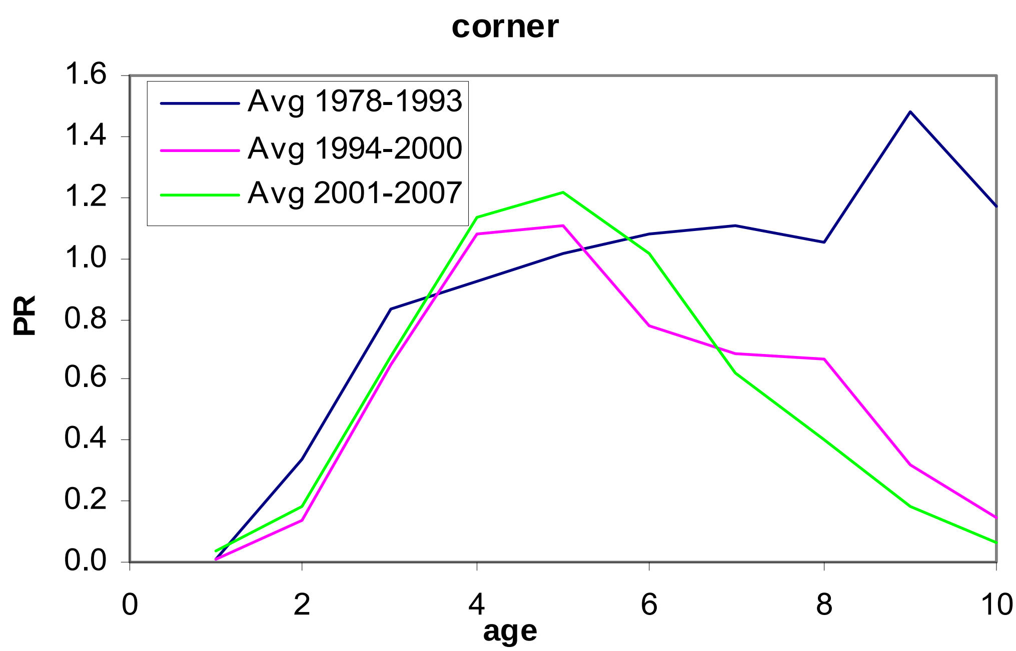


Figure 24. Fishery partial recruitment from the 2002 benchmark formulation when using data up to 2008 for eastern Georges Bank cod.

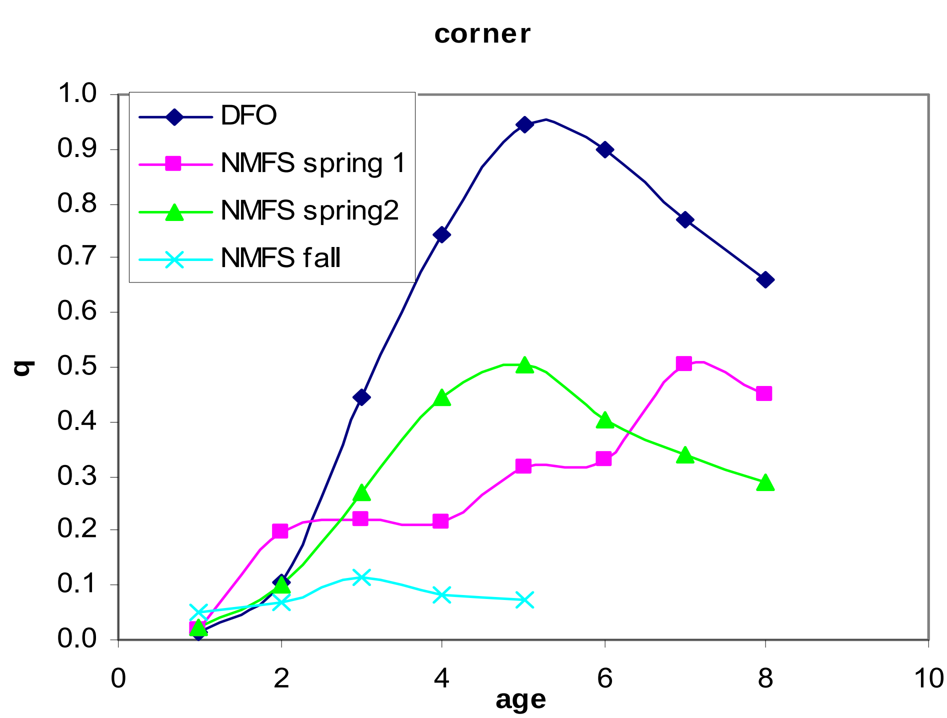


Figure 25. Survey catchability at age from the 2002 benchmark formulation when using data up to 2008 for eastern Georges Bank cod.

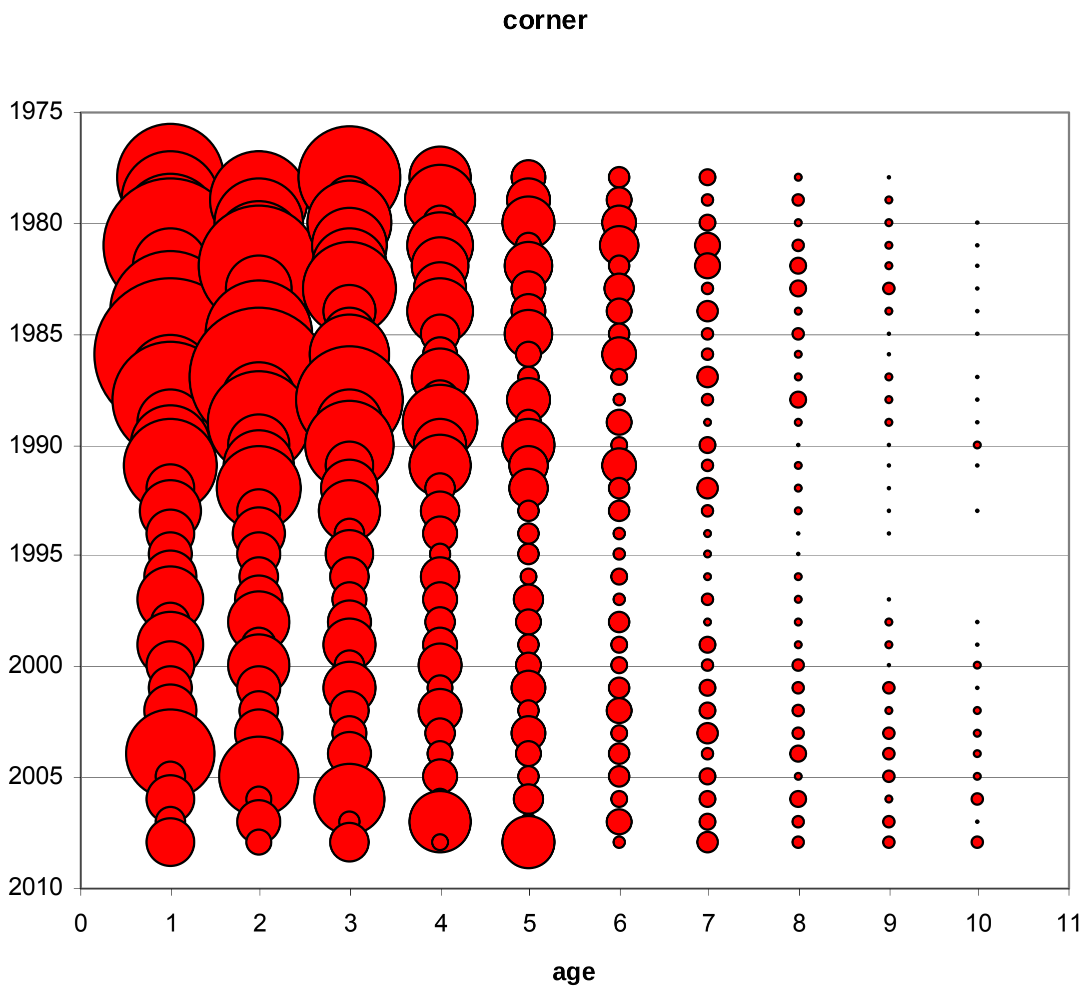


Figure 26. Population abundance from the 2002 benchmark formulation for eastern Georges Bank cod.

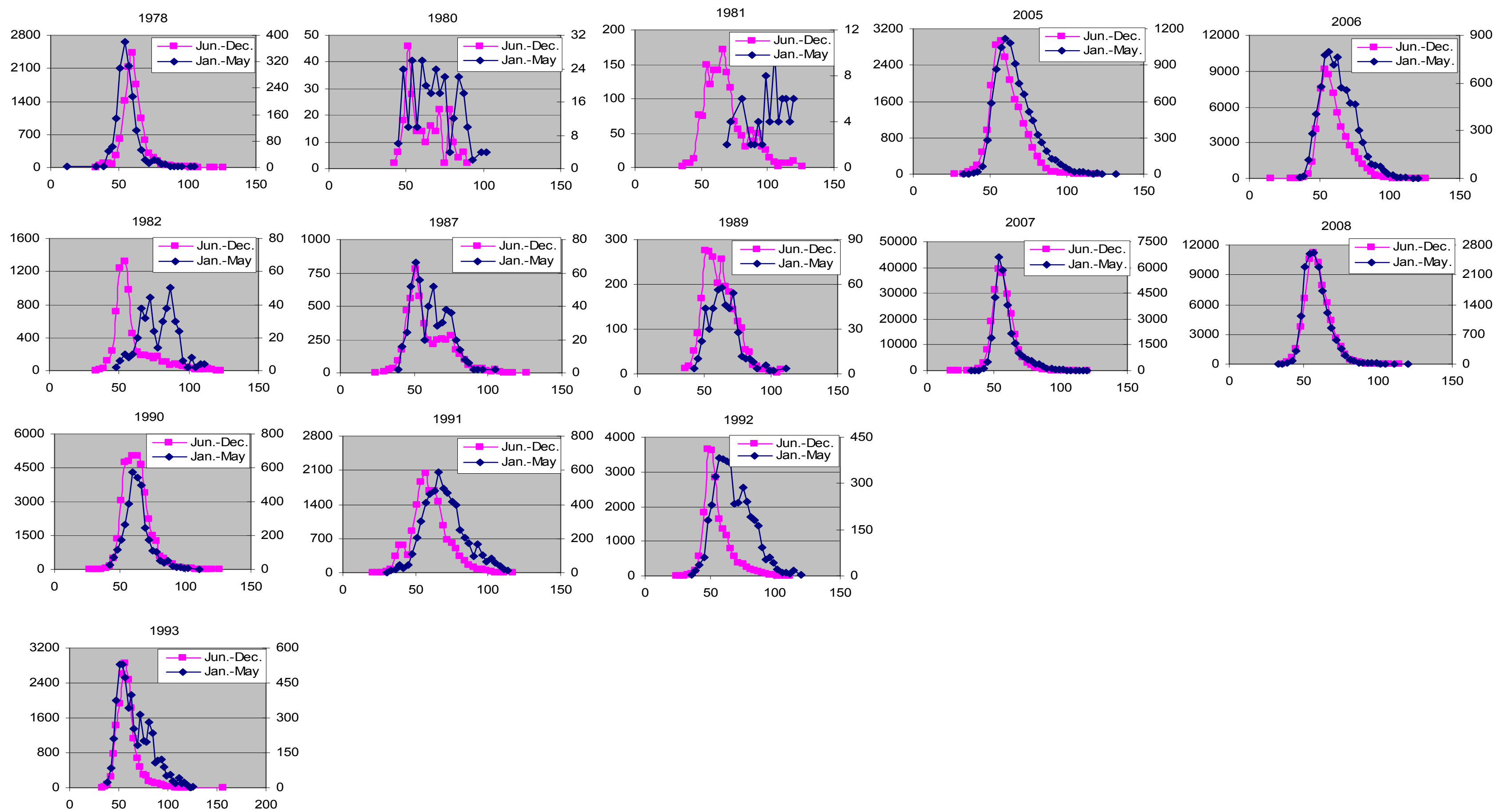


Figure 27. Yearly comparison of catch at length between two time periods (Jan.-May. and Jun.-Dec.) from observer samples of the Canadian otter trawl cod fishery on eastern Georges Bank. The X-axes are fish length (cm), and Y-axes are sample numbers at length.

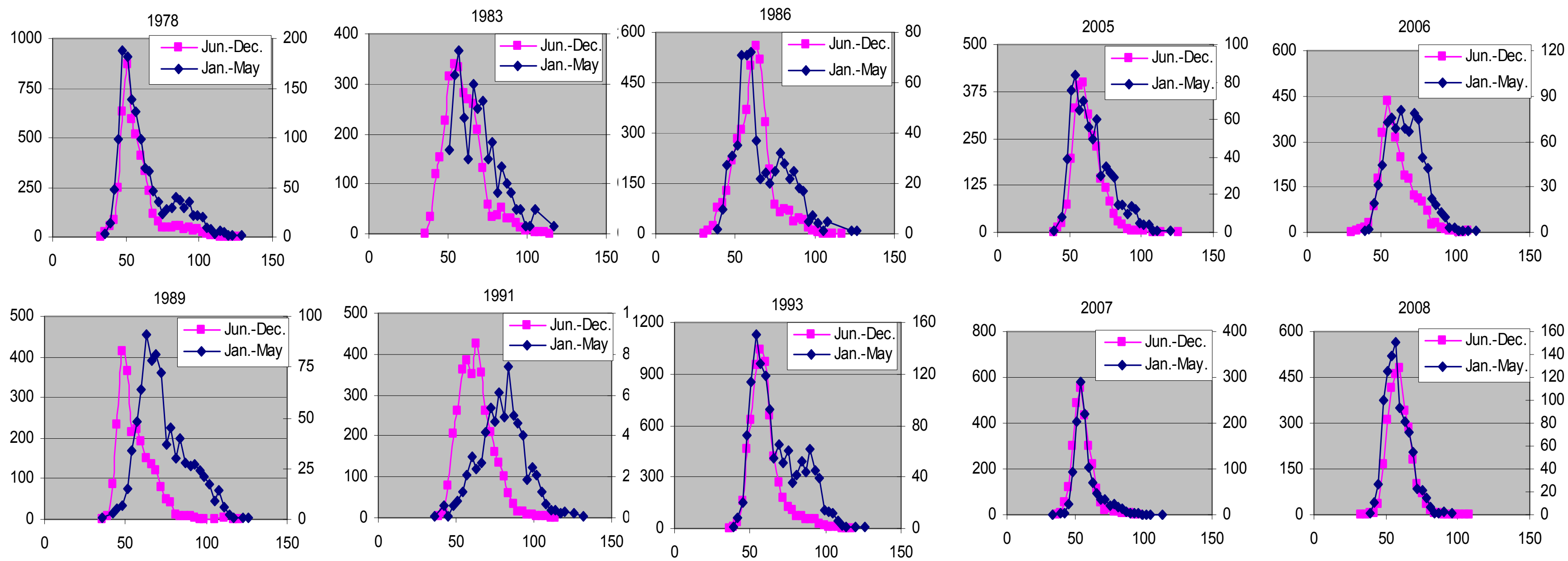


Figure 28. Yearly comparison of catch at length between two time periods (Jan.-May. and Jun.-Dec.) from port samples from the Canadian otter trawl cod fishery on eastern Georges Bank. The X-axes are fish length (cm), and Y-axes are sample numbers at length.

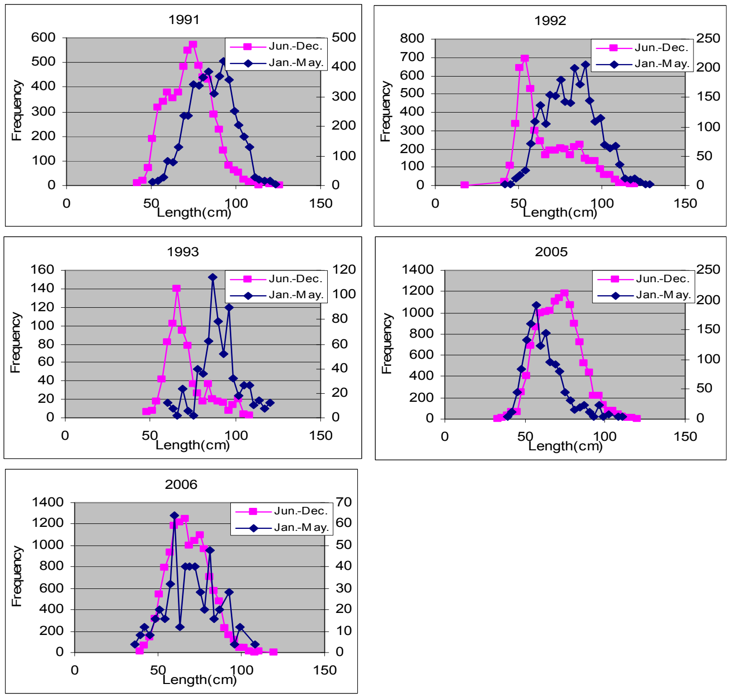


Figure 29. Yearly comparison of catch at length between two time periods (Jan.-May. and Jun.-Dec.) from observer samples from the Canadian longline cod fishery on eastern Georges Bank.

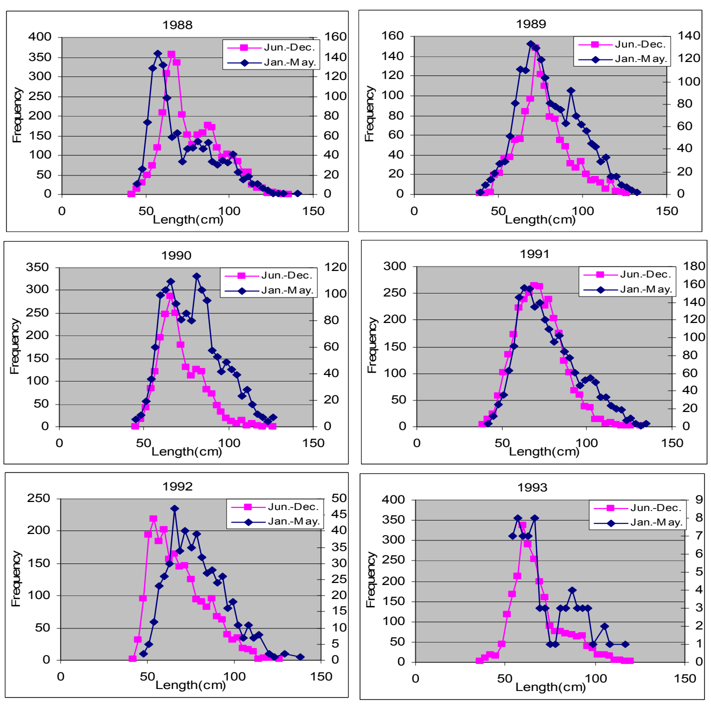


Figure 30. Yearly comparison of catch at length between two time periods (Jan.-May. and Jun.-Dec.) from port samples from the Canadian longline cod fishery on eastern Georges Bank.

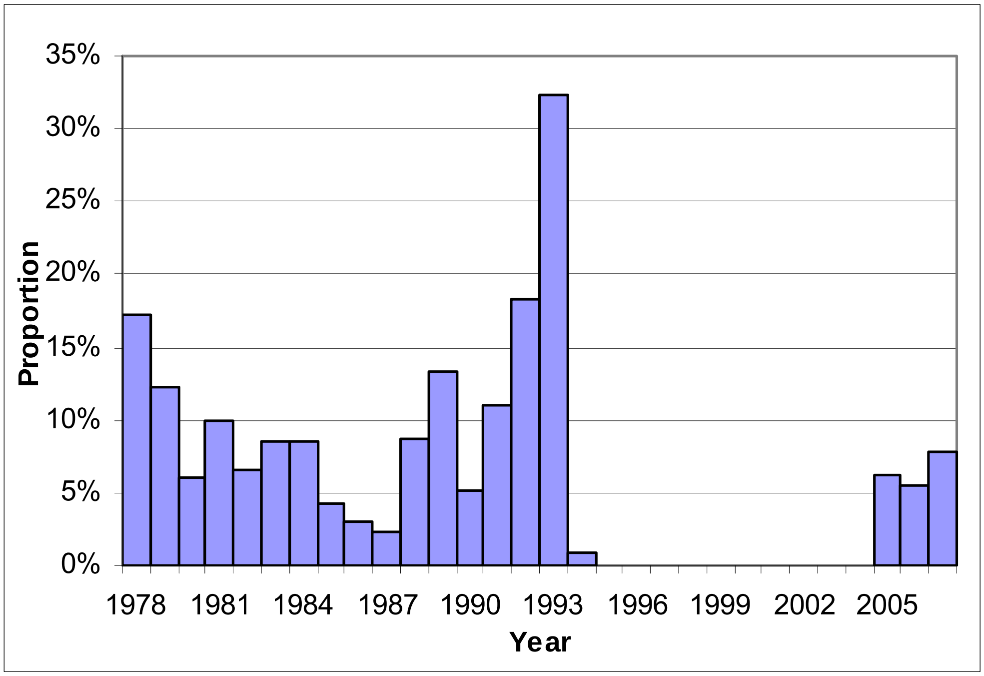


Figure 31. The proportion of the Canadian catch of cod on eastern Georges Bank (1978-2007) that is comprised of fish from the first quarter of the year.

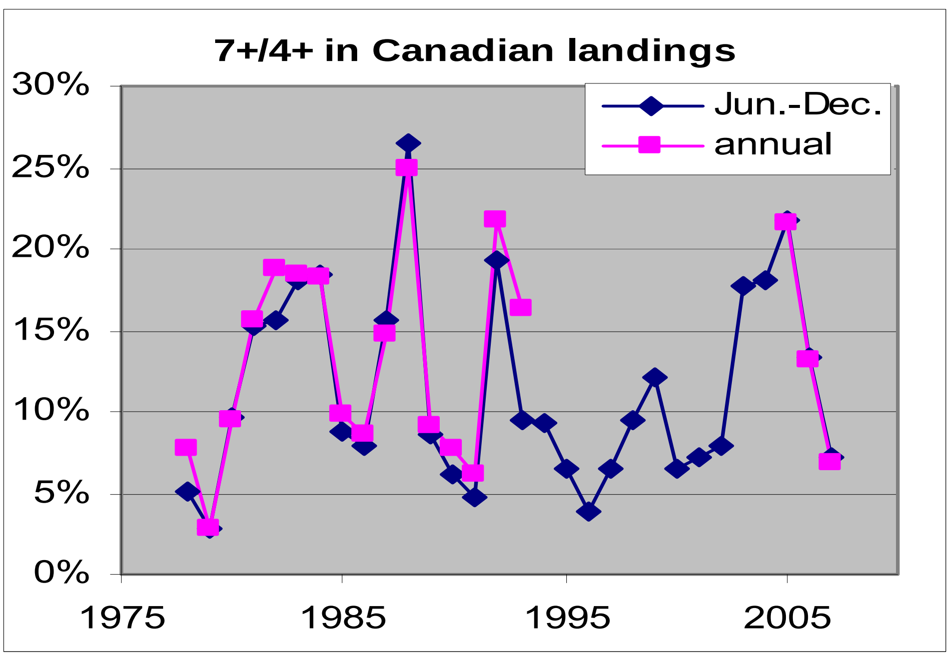


Figure 32. Comparison of the ratio of the eastern Georges Bank Canadian catch in numbers of cod aged 4+ to 7+ with or without the first quarter catch (1978-2007).

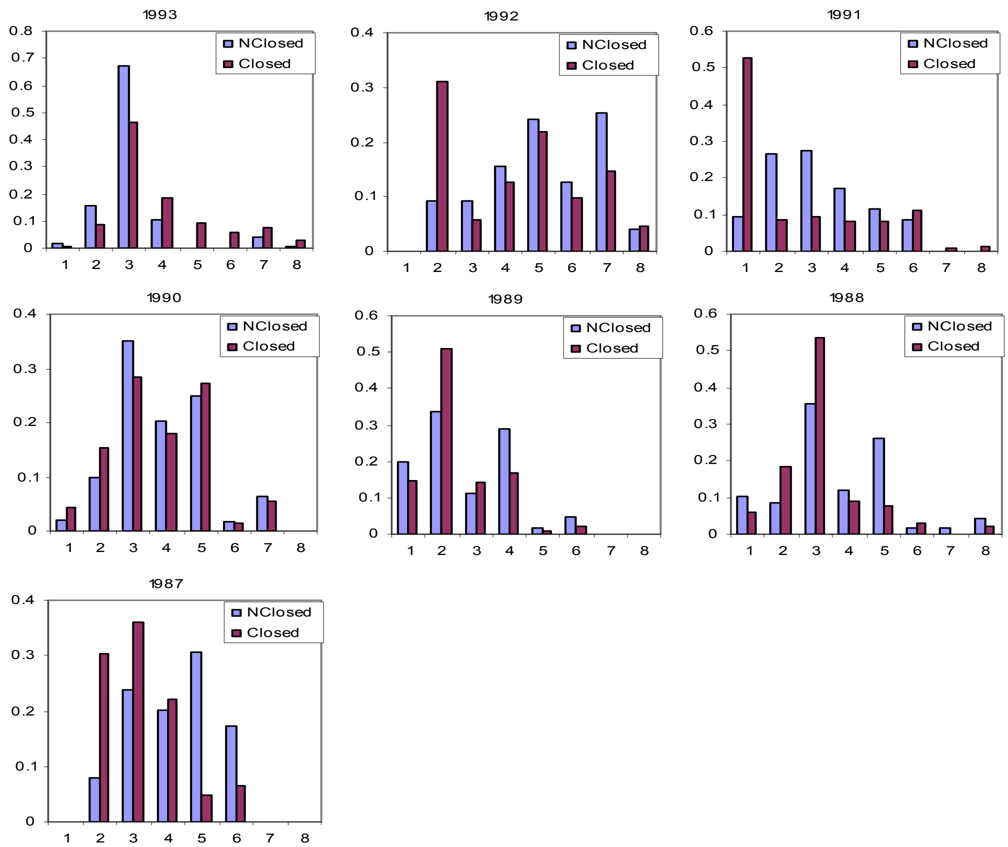


Figure 33. Eastern Georges Bank(5Zjm) cod age composition comparison between inside (closed) and outside (Nclosed) the closed area in strata 5Z3 and 5Z4. The analyzed data are from the 1987-1993 DFO spring surveys. The X-axes are ages and the Y-axes are proportions at age.

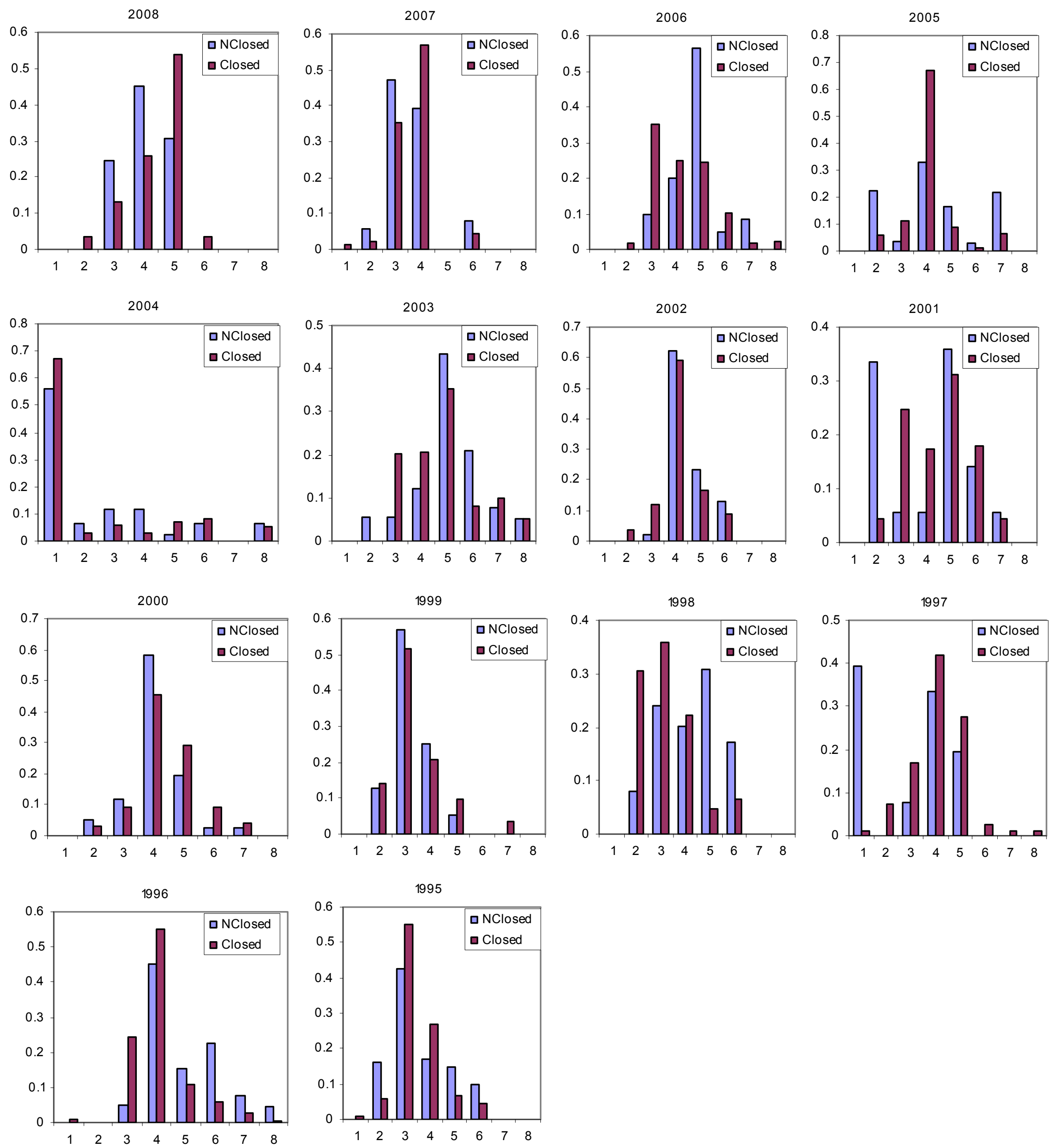


Figure 34. Eastern Georges Bank(5Zjm) cod age composition comparison between inside and outside the closed area in strata 5Z3 and 5Z4. The analyzed data are from the 1995-2008 DFO spring surveys. The X-axes are ages and the Y-axes are proportions at age.

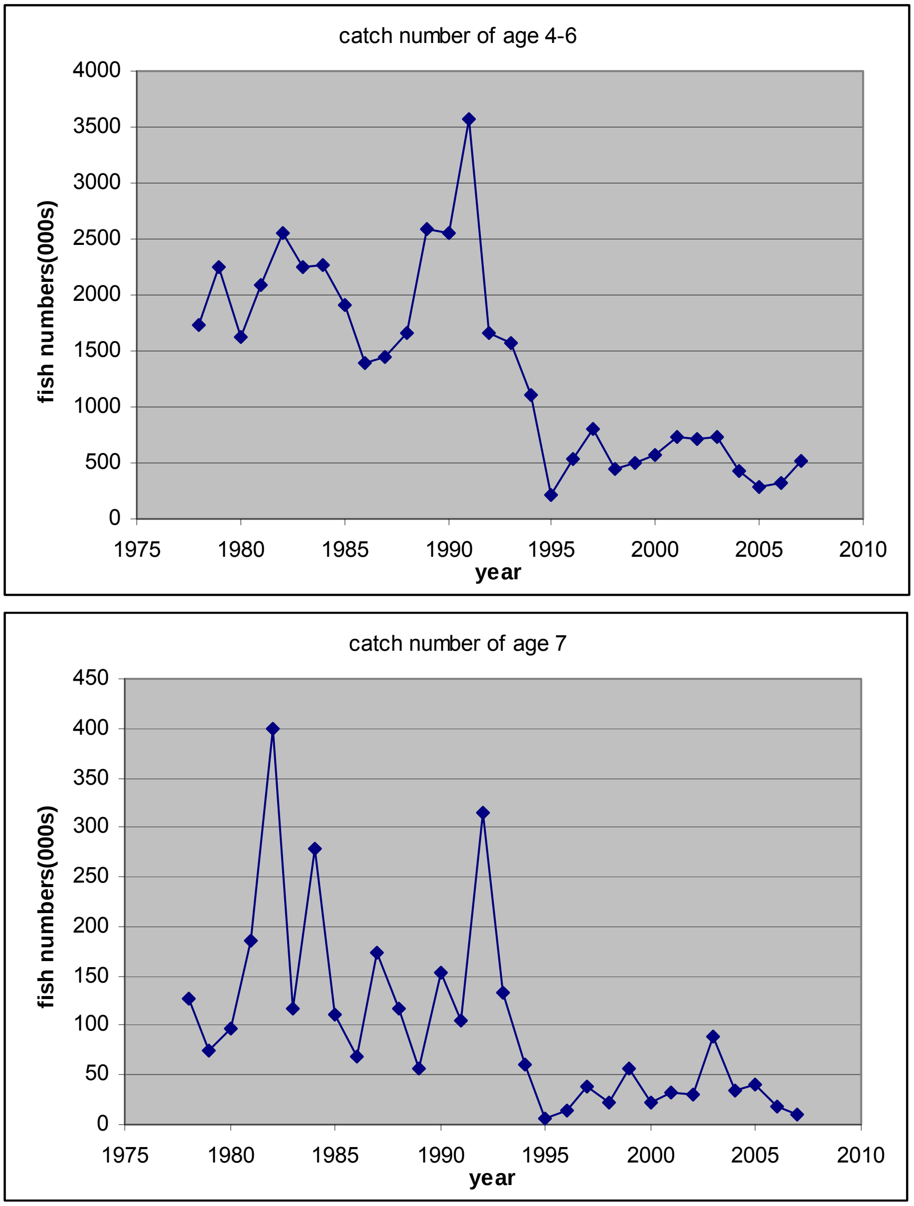
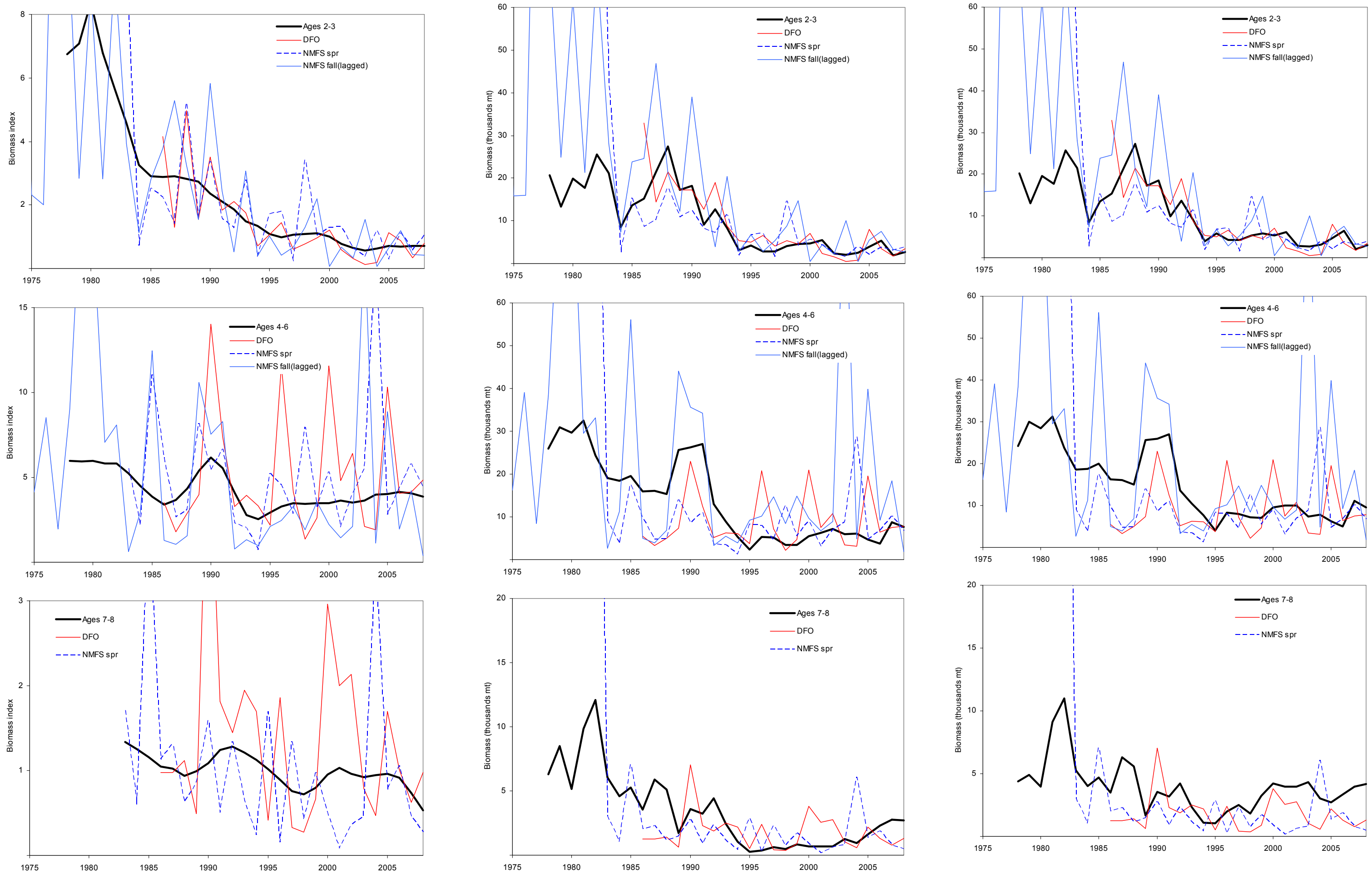


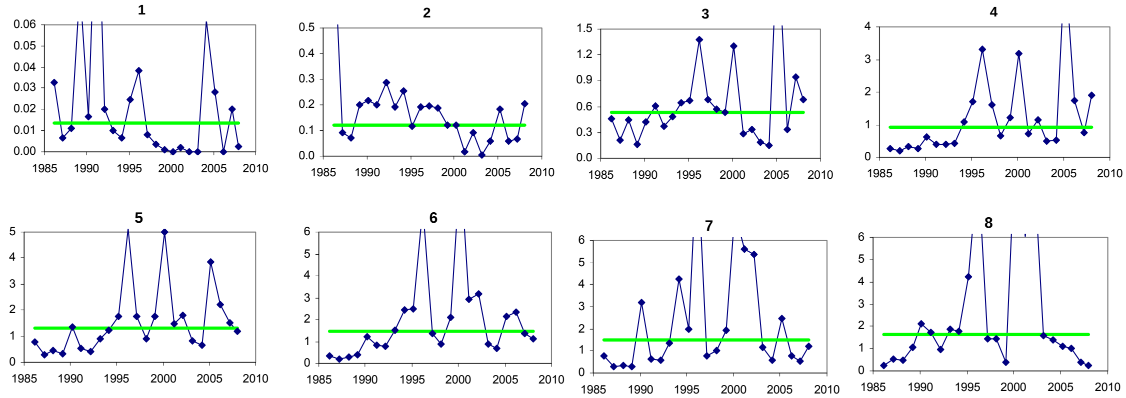
Figure 35. Fishery catch numbers at ages 4-6 and at age 7 of cod on eastern Georges Bank (1978-2007).



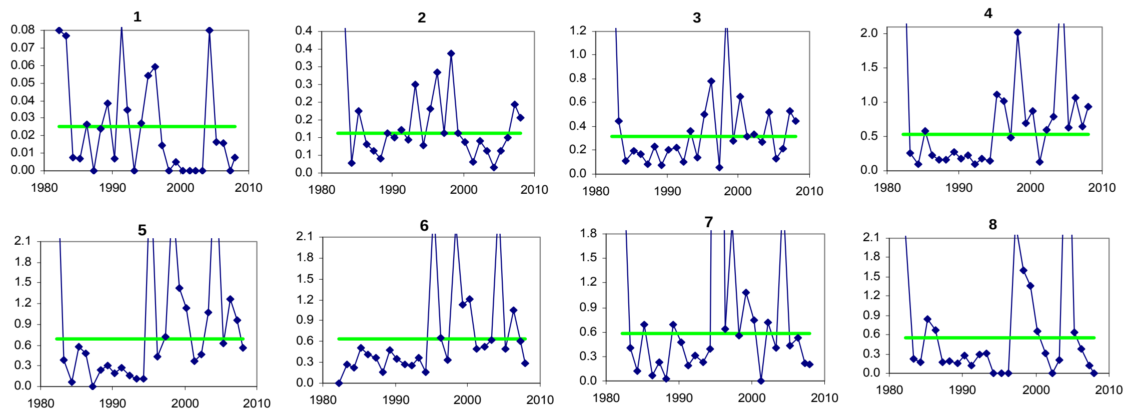
surveys **basic VPA** **2002 benchmark**

Figure 36. Biomass trends from surveys compared to basic VPA calibration and 2002 benchmark formulations for cod on eastern Georges Bank.

a) DFO



b) NMFS Spring



c) NMFS Fall

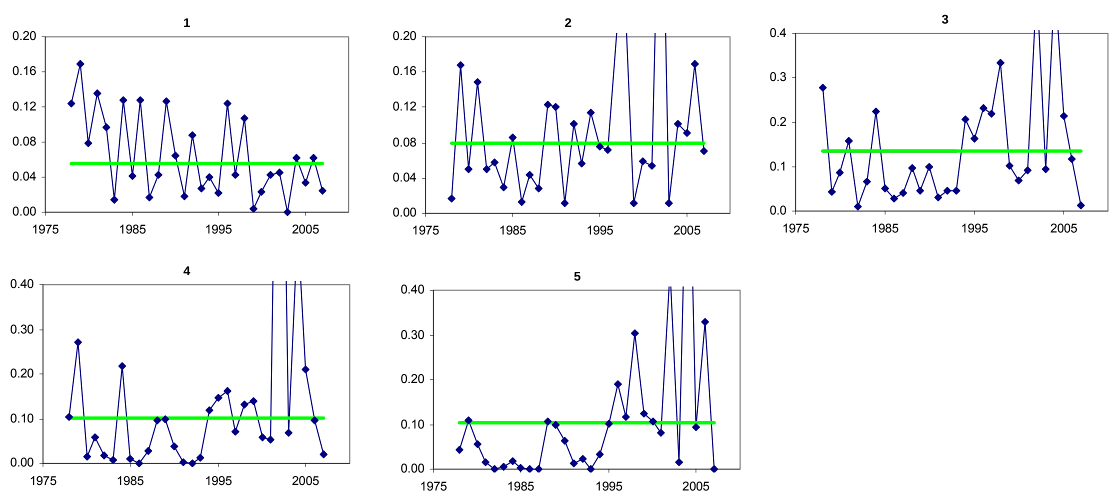


Figure 37. Time trends in survey catchability at age of cod on eastern Georges Bank, estimated (horizontal line) and calculated (diamonds) from the basic formulation. a): from DFO survey, b): from NMFS spring survey, c): from NMFS fall survey.

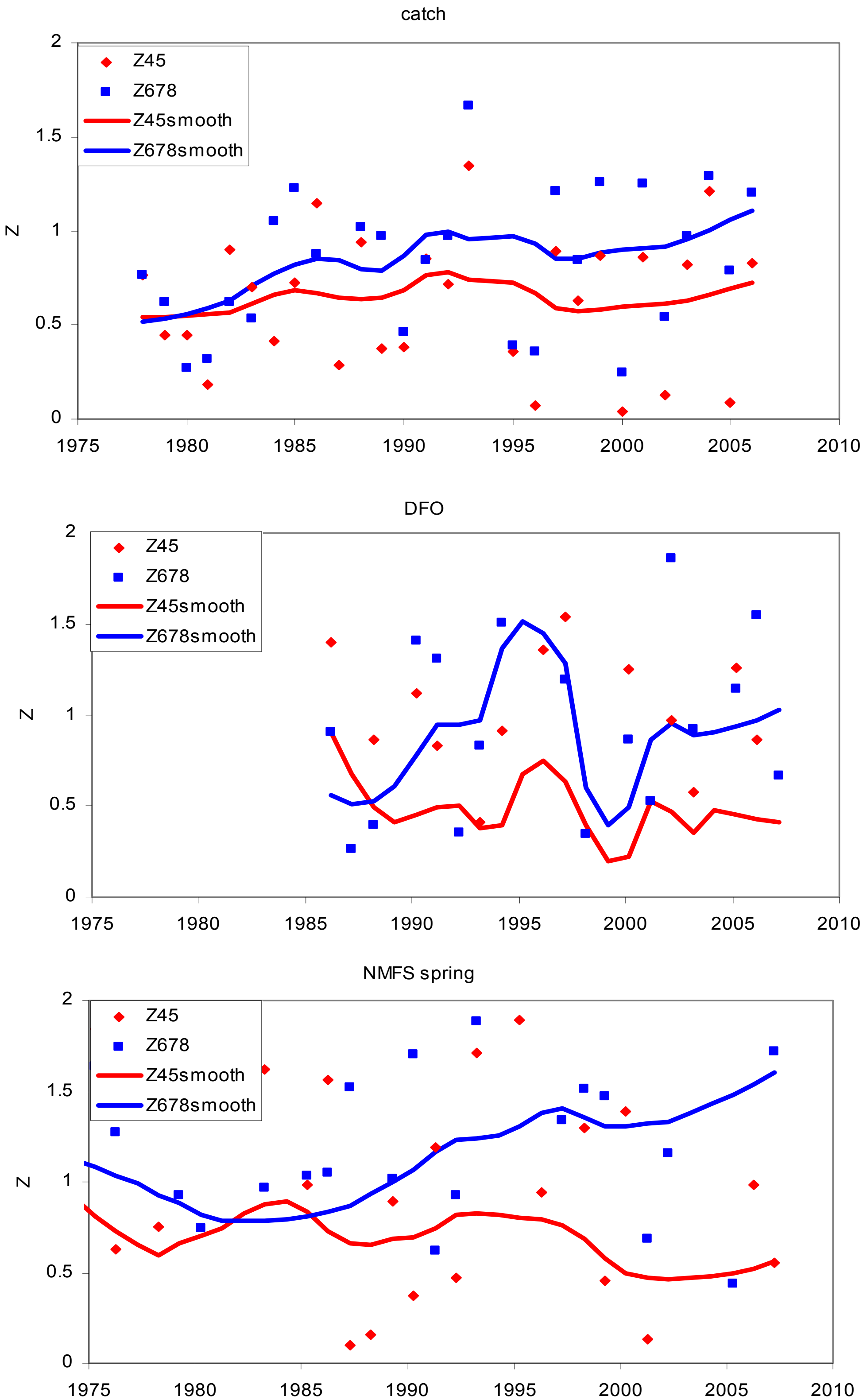


Figure 38. Total mortality calculations from the catch, DFO survey and NMFS spring survey for cod on eastern Georges Bank.

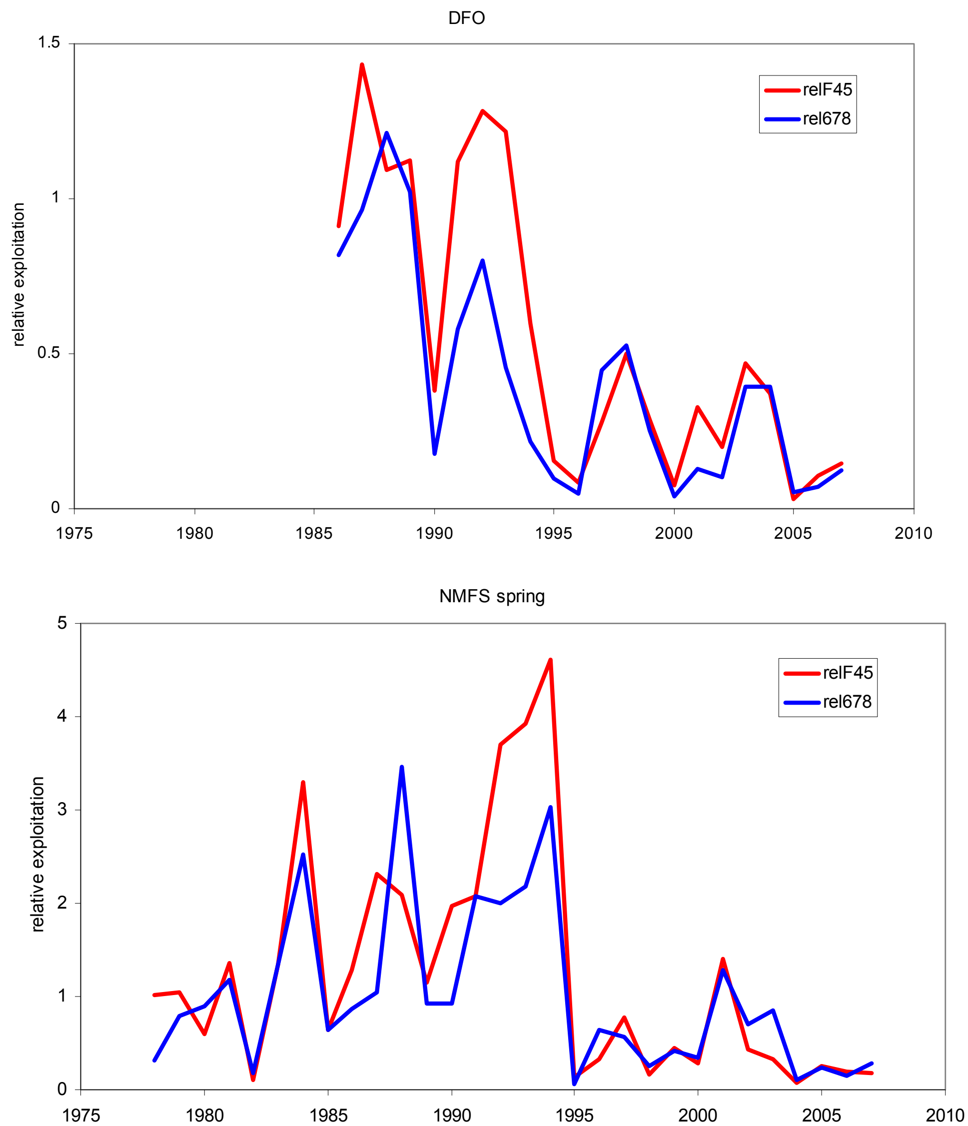


Figure 39. Relative exploitation of cod on eastern Georges Bank using catch with the DFO survey and NMFS spring survey.

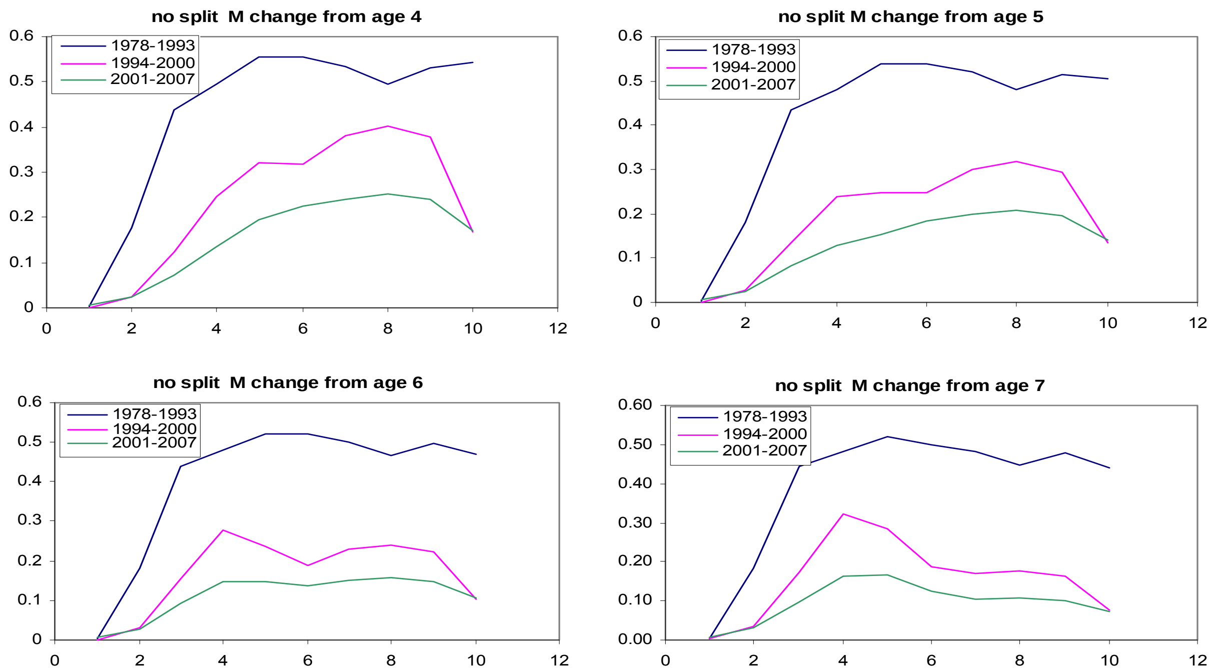


Figure 40. Comparison of average fishing mortality of cod on eastern Georges Bank by age from the “no split M change” model. The age at which M starts to change is 4, 5, 6 and 7. X-axes are ages and Y-axes are fishing mortality.

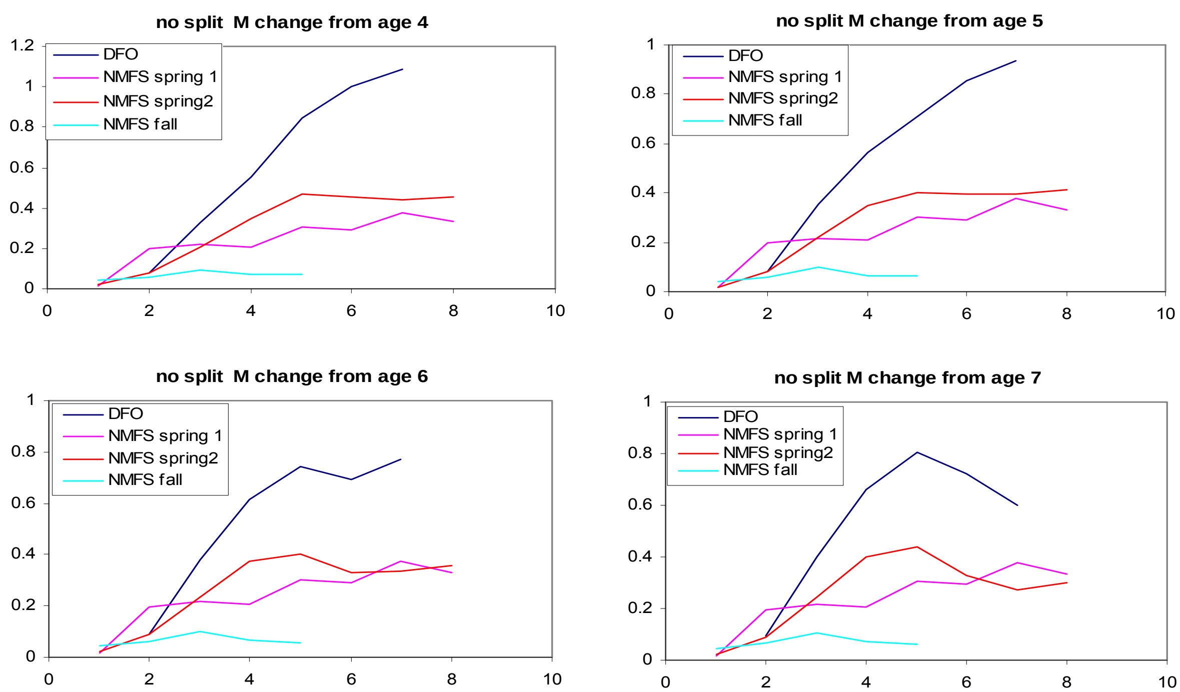


Figure 41. Comparison of survey catchabilities (*q*) of cod on eastern Georges Bank by age from the “no split M change” model. The age at which M starts to change is 4, 5, 6 and 7. X-axes are ages and Y-axes are *q*.

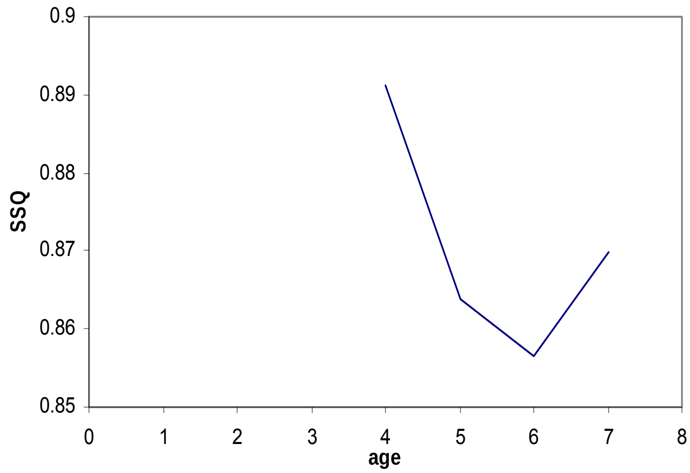


Figure 42. Comparison of sum squares of residuals (SSQ) from the “no split M change” model for cod on eastern Georges Bank. The age at which M starts to change is 4, 5, 6 and 7.

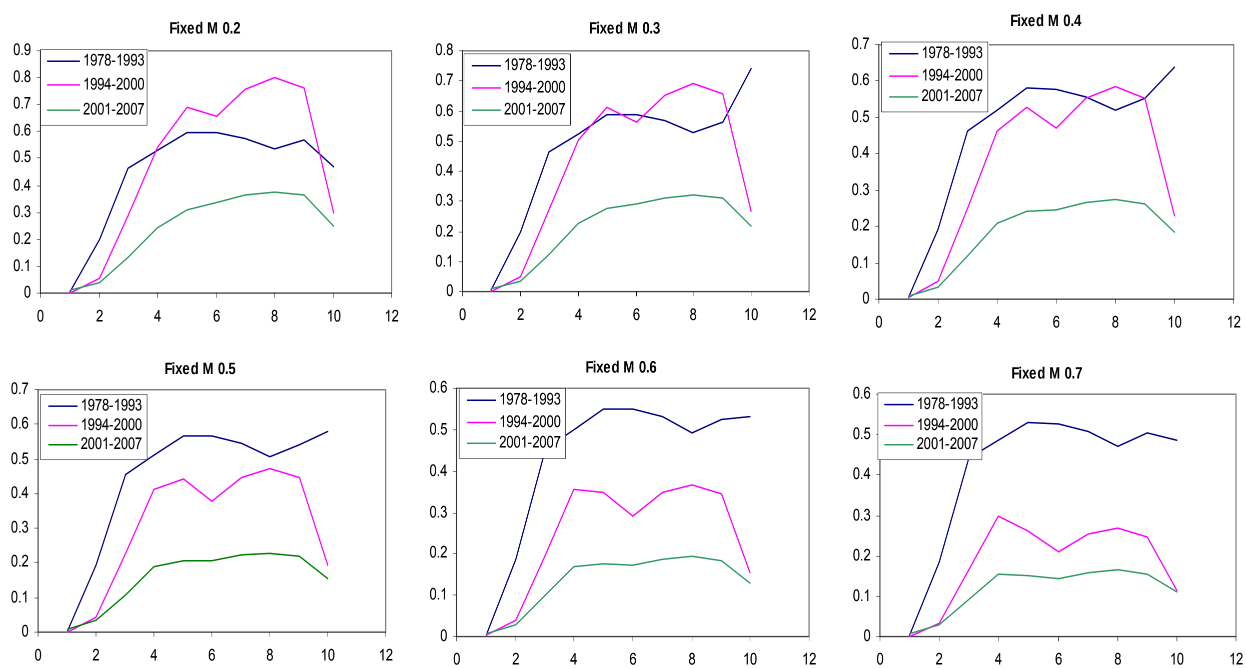


Figure 43. Comparison of average fishing mortality from the “no split M change” model for cod on eastern Georges Bank. The M is fixed at different values from 0.2 to 0.7 with a starting age of 6. X-axes are ages and Y-axes are fishing mortality.

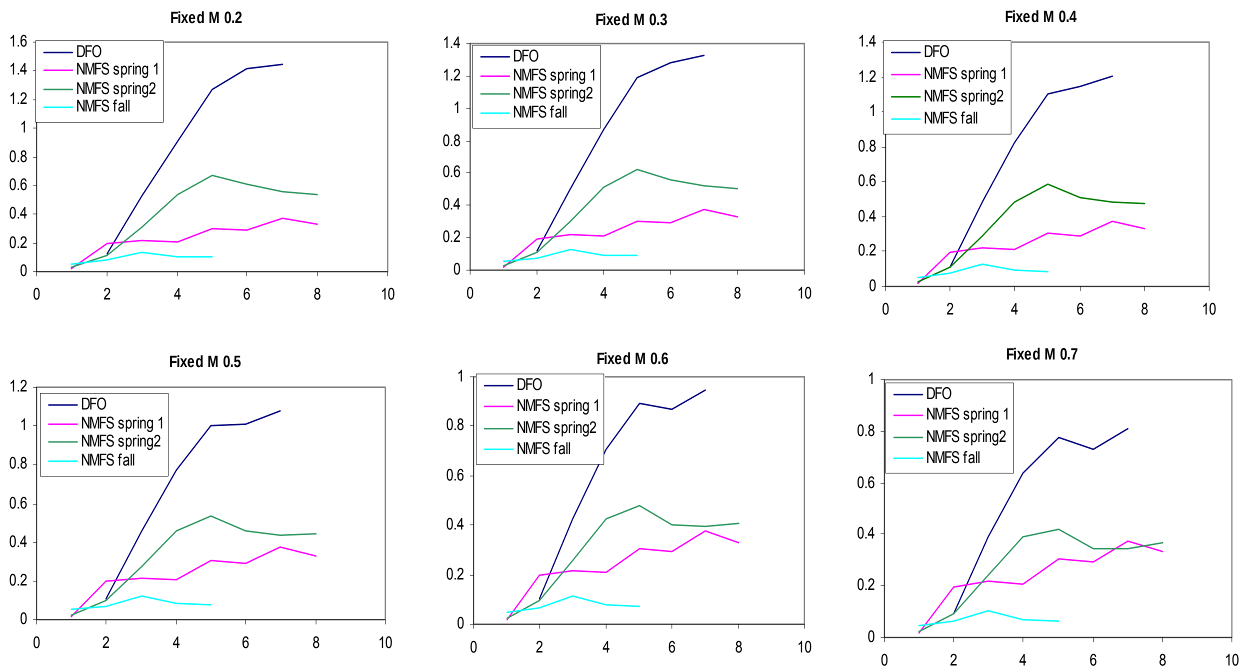


Figure 44. Comparison of survey catchabilities (*q*) by age from the "no split M change" model for cod on eastern Georges Bank. The fixed M value starting at age 6 are from 0.2 to 0.7. X-axes are ages and Y-axes are survey *q*.

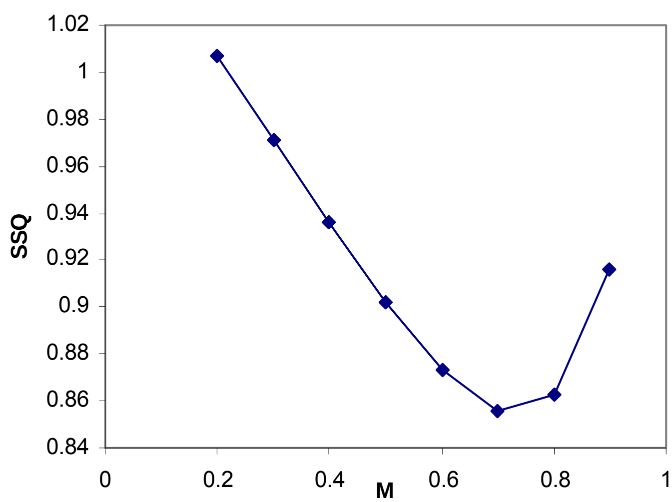


Figure 45 . Comparison of sum squares of residuals (SSQ) by age from the "no split M change" model for cod on eastern Georges Bank. The fixed M value starting at age 6 are from 0.2 to 0.7.

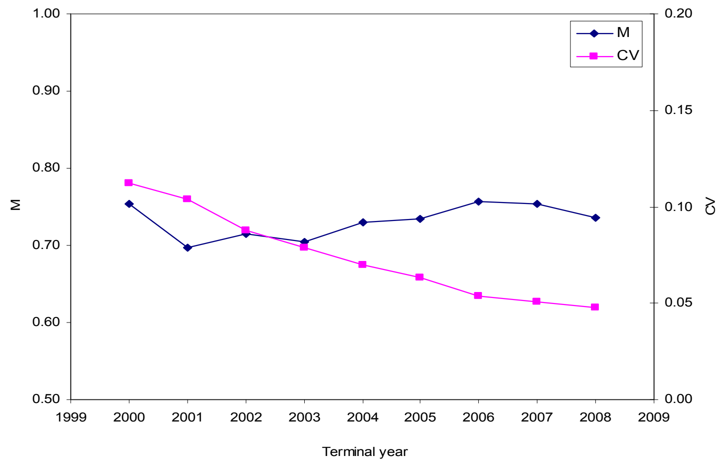


Figure 46. Comparison of estimated M and CV from retrospective runs of the “no split M change” model for cod on eastern Georges Bank.

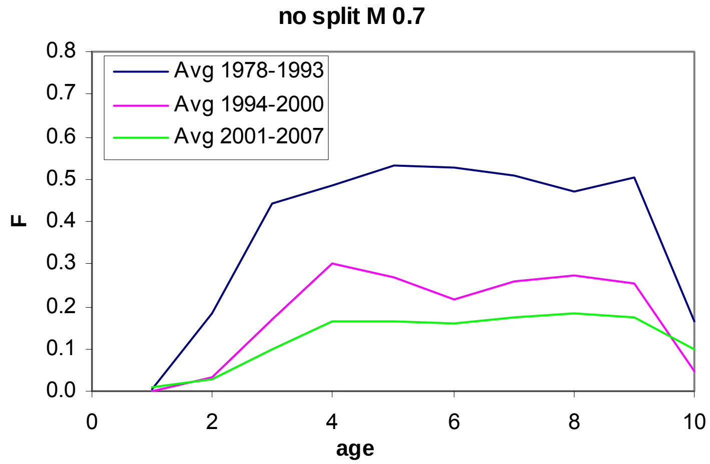


Figure 47. Fishing mortality from the “no split M 0.7” model formulation for cod on eastern Georges Bank.

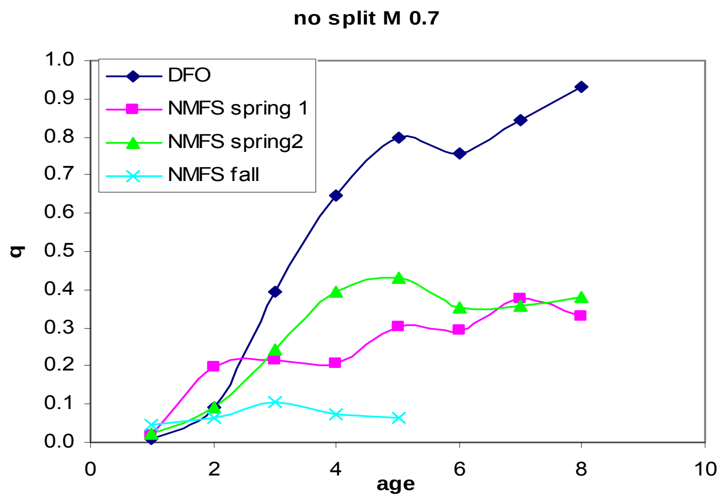
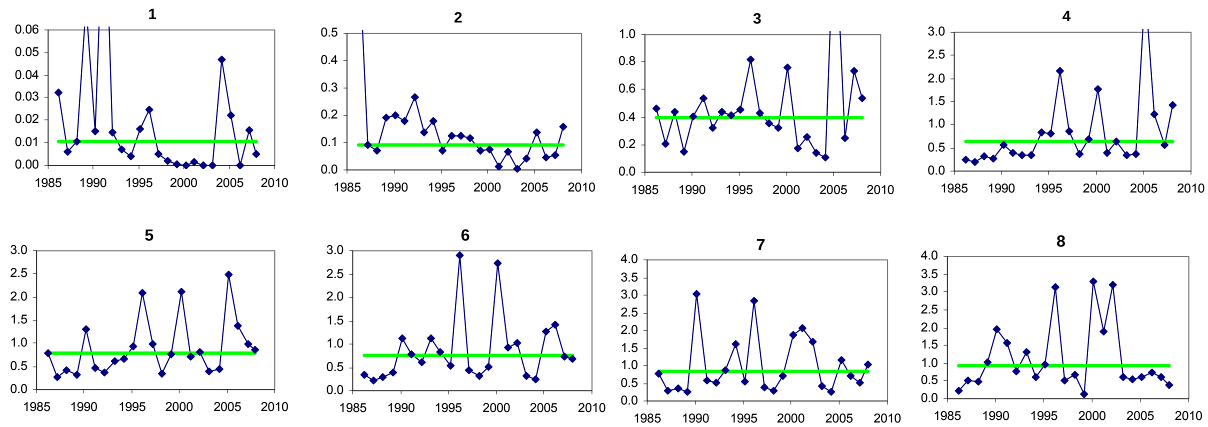
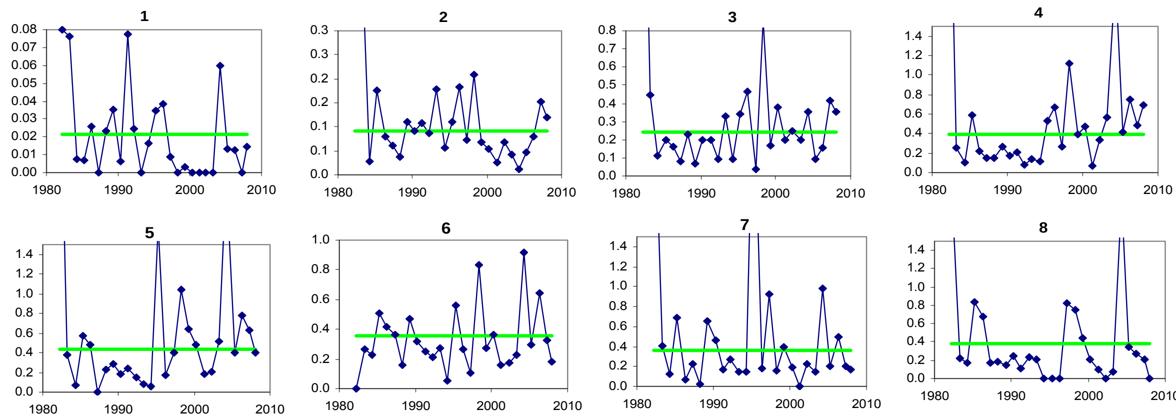


Figure 48. Survey catchabilities(q) from the “no split M 0.7” model formulation for cod on eastern Georges Bank.

a) DFO



b) NMFS Spring



c) NMFS Fall

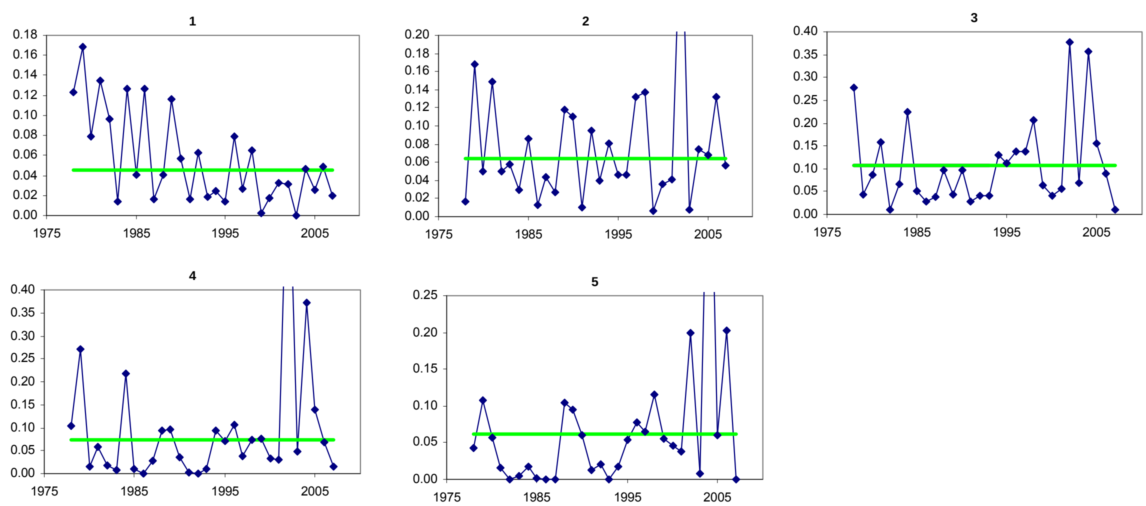


Figure 49. . Time trends in survey catchability at age of cod on eastern Georges Bank, estimated (horizontal line) and calculated (diamonds) from the “no split M 0.7” model formulation. a): from DFO survey, b): from NMFS spring survey, c): from NMFS fall survey.

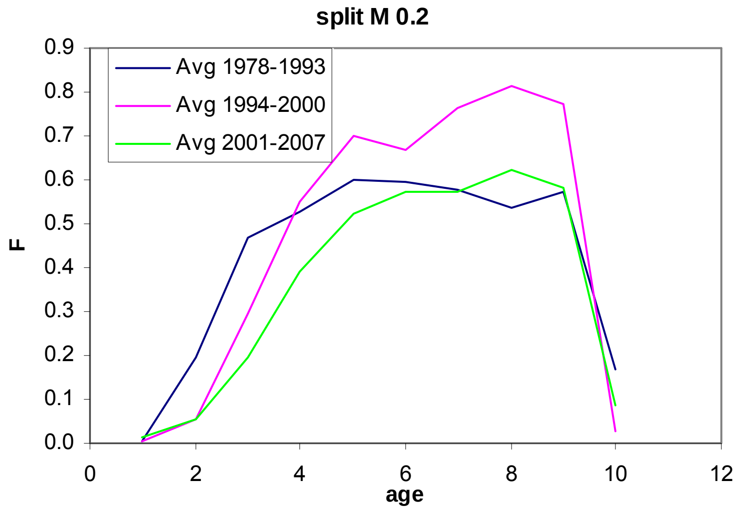


Figure 50. Fishing mortality from the “split M 0.2” model formulation for cod on eastern Georges Bank.

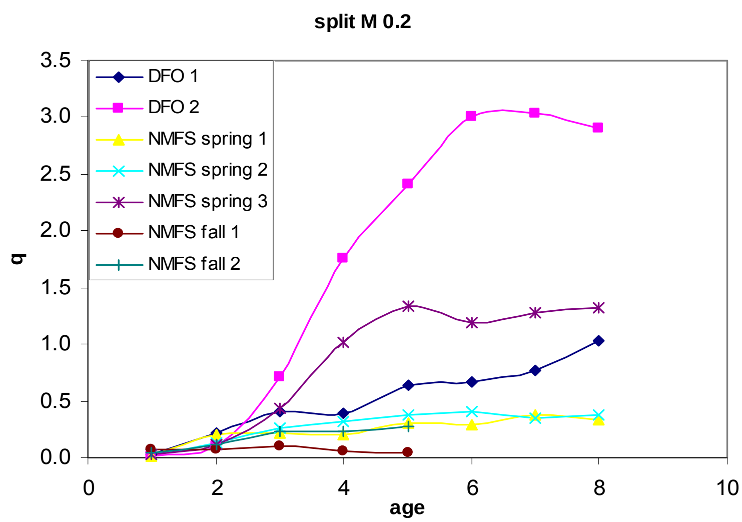


Figure 51. Survey catchabilities (q) from the “split M 0.2” model formulation for cod on eastern Georges Bank.

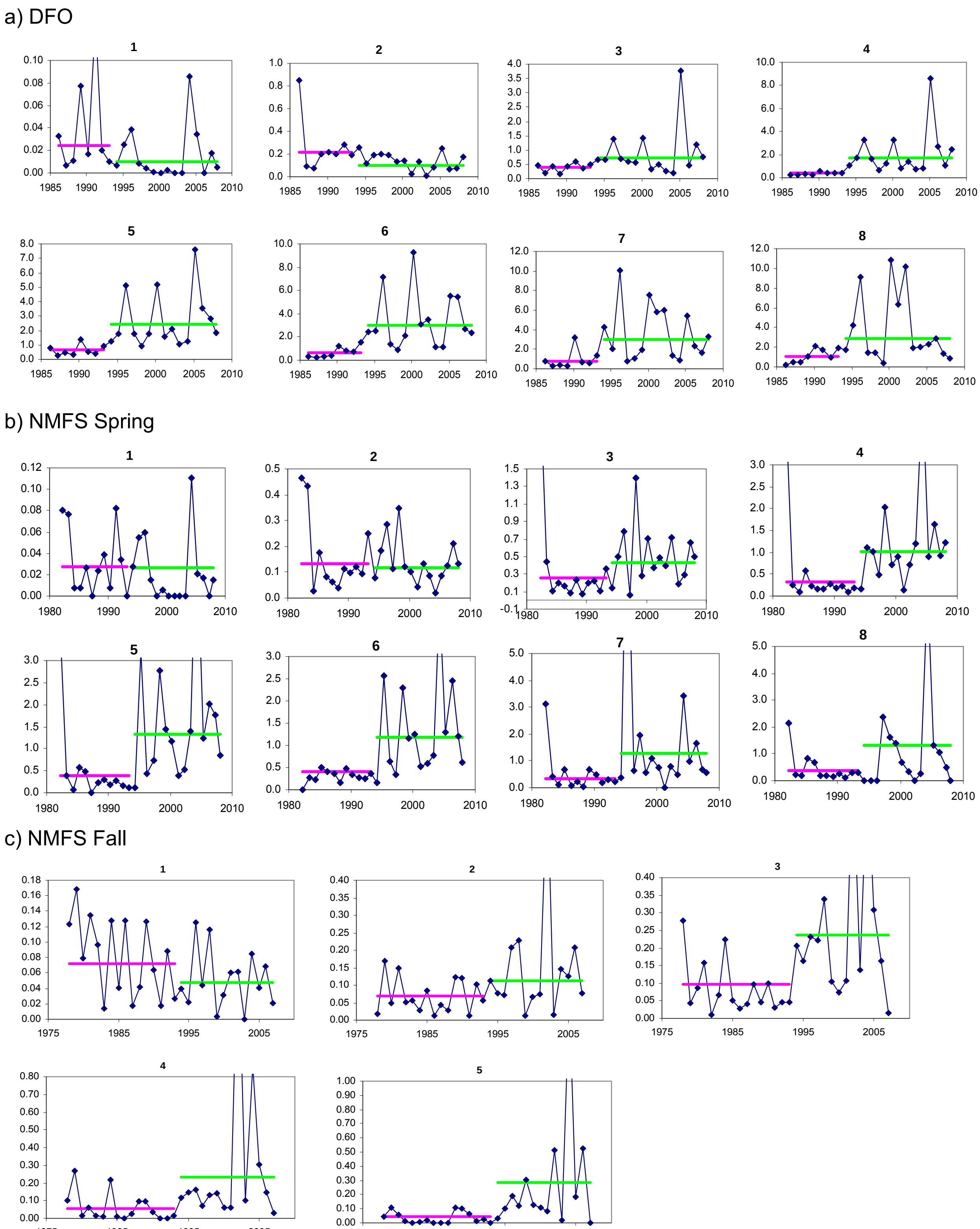


Figure 52. Time trends in survey catchability at age of cod on eastern Georges Bank, estimated (horizontal line) and calculated (diamonds) from the “split M 0.2” model formulation. a): from DFO survey, b): from NMFS spring survey, c): from NMFS fall survey.

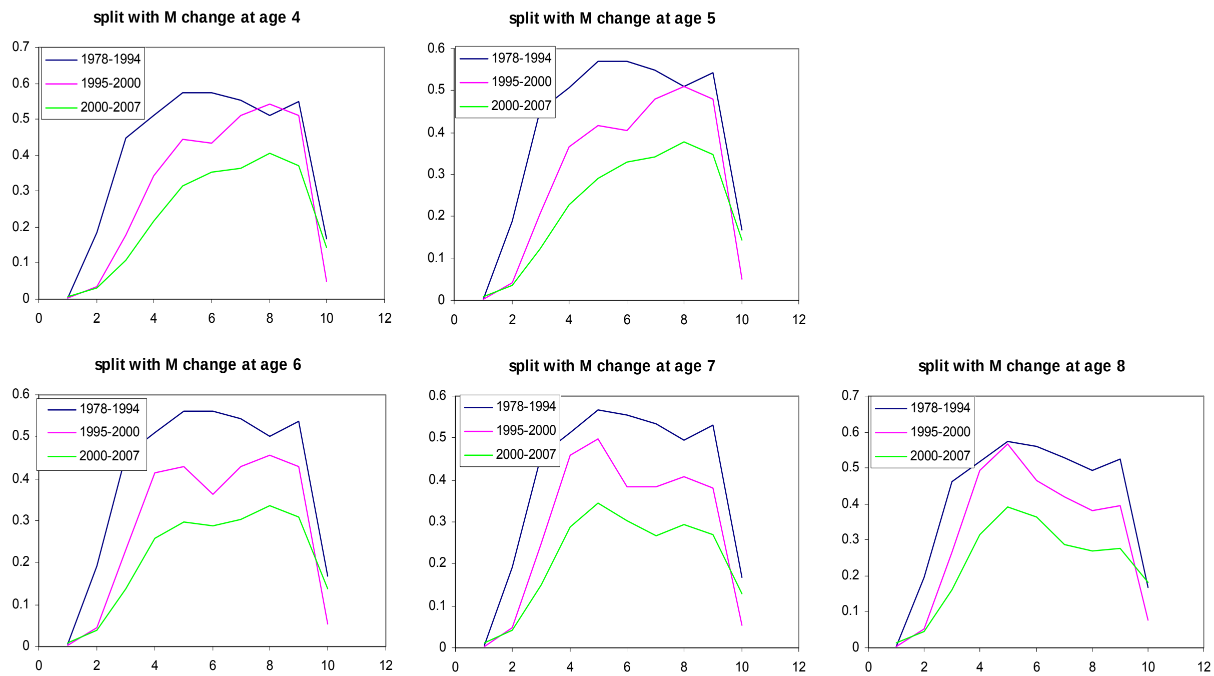


Figure 53. Comparison of average fishing mortality by age from the "split M change" model for cod on eastern Georges Bank. The age at which M starts to change is 4, 5, 6, 7 and 8. X-axes are ages and Y-axes are fishing mortality.

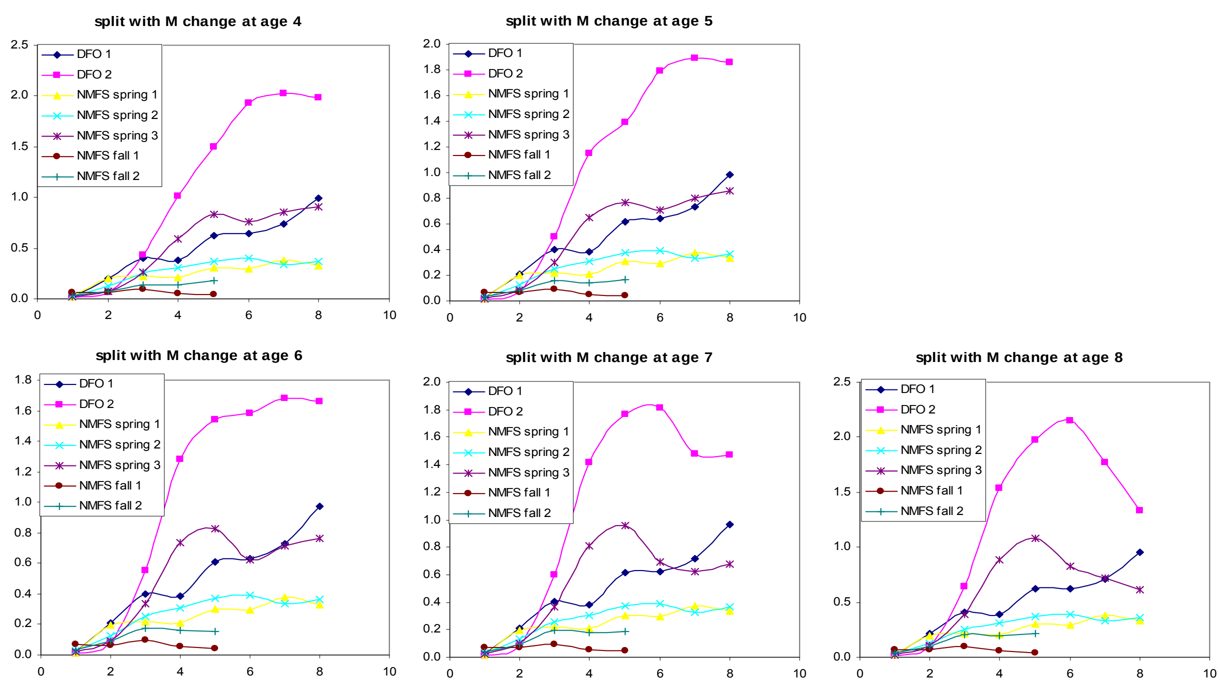


Figure 54. Comparison of survey catchabilities (*q*) by age from the "split M change" model for cod on eastern Georges Bank. The age at which M starts to change is 4, 5, 6, 7 and 8. X-axes are ages and Y-axes are survey *q*.

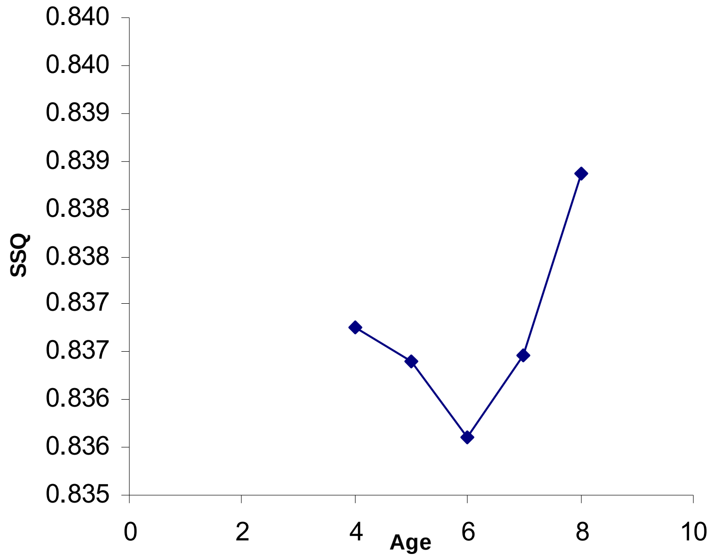


Figure 55. Comparison of sum squares of residuals (SSQ) by age from the “split M change” model for cod on eastern Georges Bank. The age at which M starts to change is 4, 5, 6, 7 and 8.

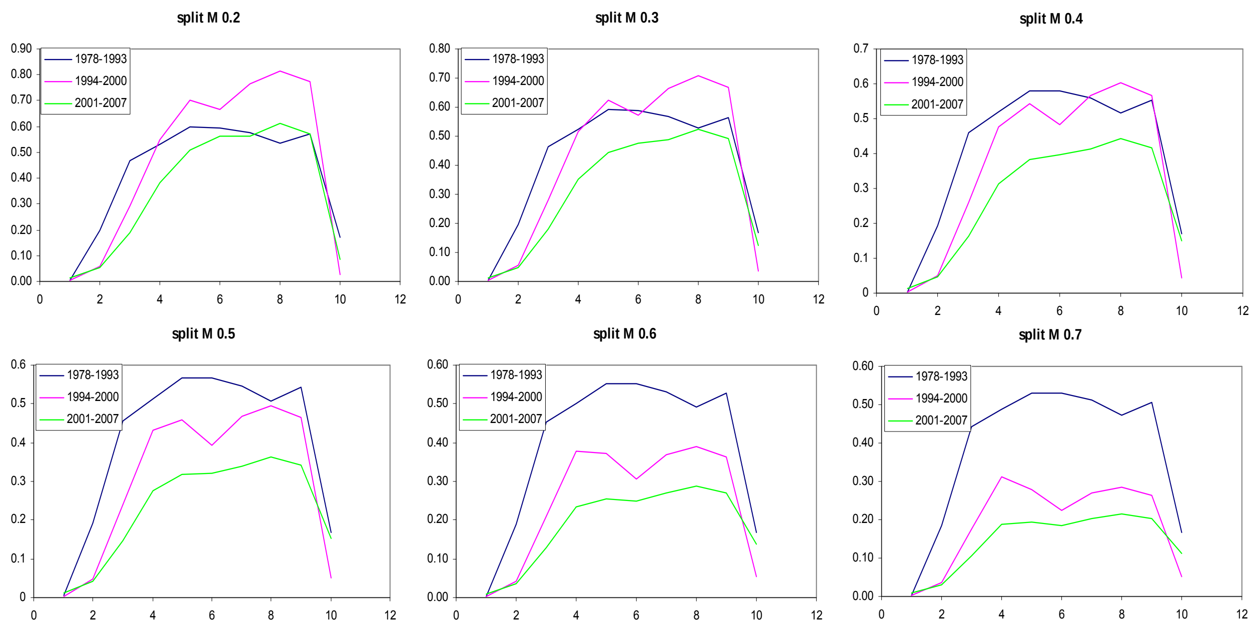


Figure 56. Comparison of average fishing mortality from the “split M change” model for cod on eastern Georges Bank. The fixed M values starting at age 6 are from 0.2 to 0.7. X-axes are ages and Y-axes are fishing mortality.

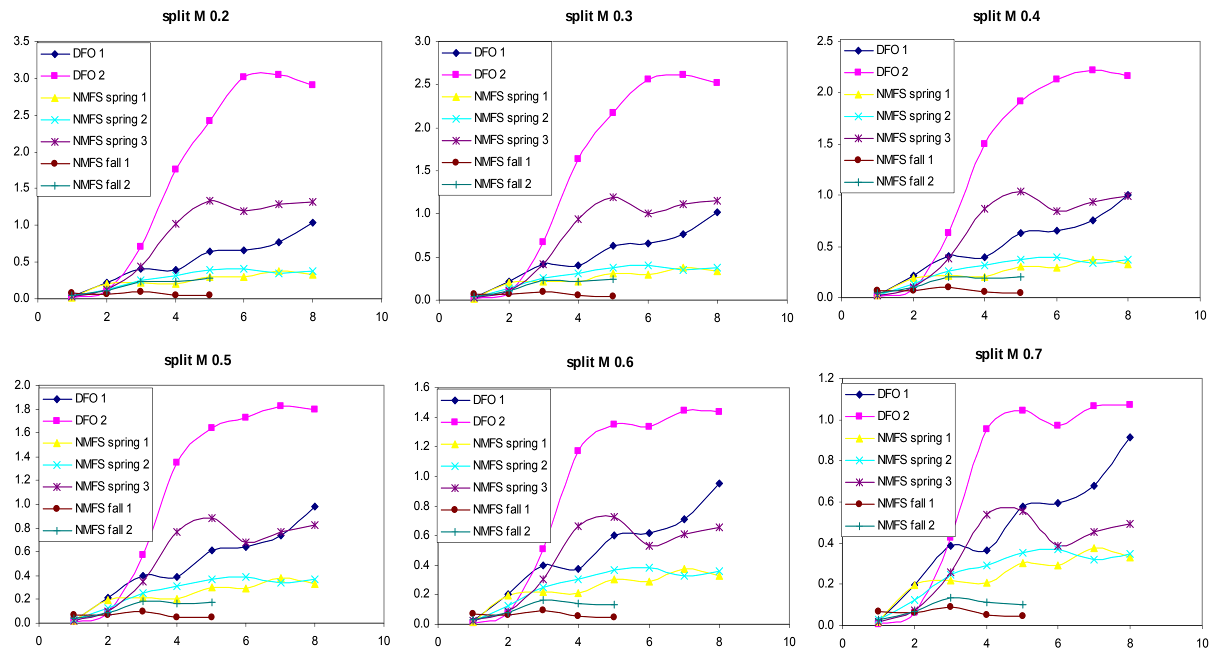


Figure 57. Comparison of survey catchabilities(*q*) from the "split M change" model for cod on eastern Georges Bank. The fixed M values starting at age 6 are from 0.2 to 0.7. X-axes are ages and Y-axes are survey *q*.

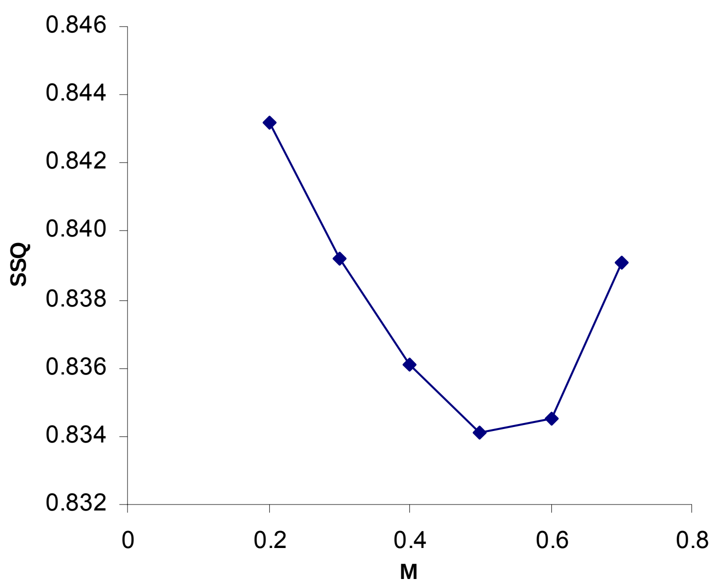


Figure 58. Comparison of sum squares of residuals (SSQ) from the "split M change" model for cod on eastern Georges Bank. The fixed M value starting at age 6 ranges from 0.2 to 0.7.

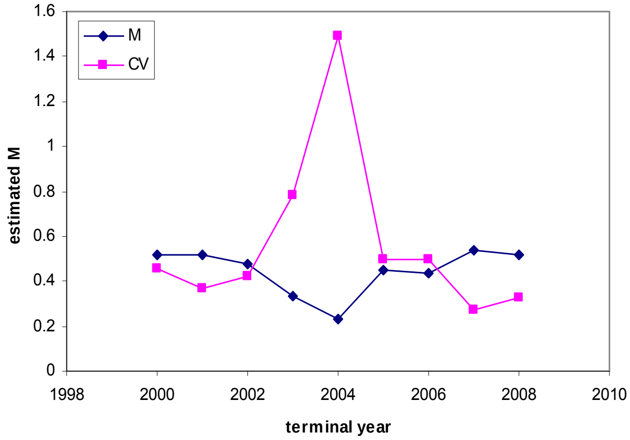


Figure 59. Comparison of estimated M and CV from retrospective runs of the "split M change" model for cod on eastern Georges Bank.

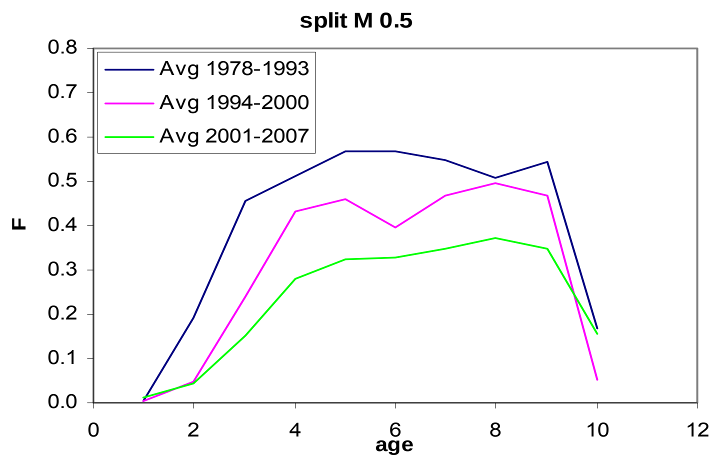


Figure 60. Fishing mortality from the "split M 0.5" model formulation for cod on eastern Georges Bank.

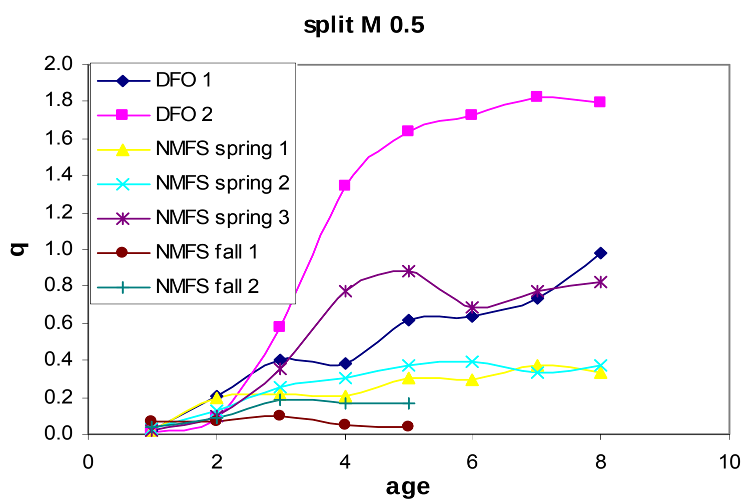
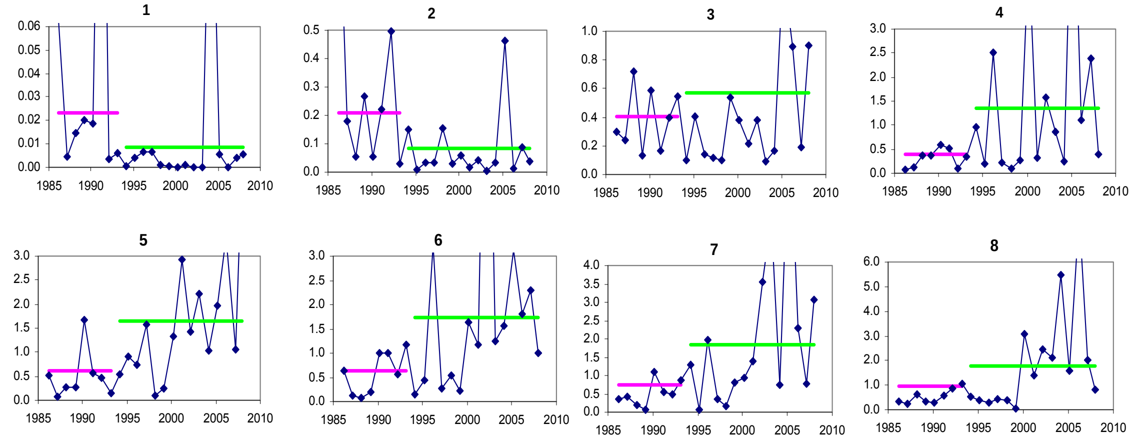
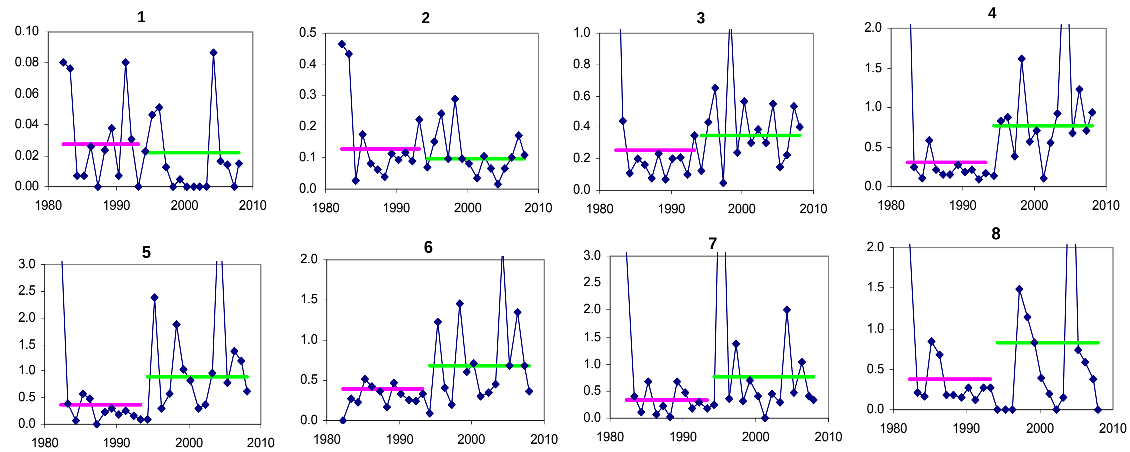


Figure 61. Survey catchabilities (*q*) from the "split M 0.5" model formulation**.**

a) DFO



b) NMFS Spring



c) NMFS Fall

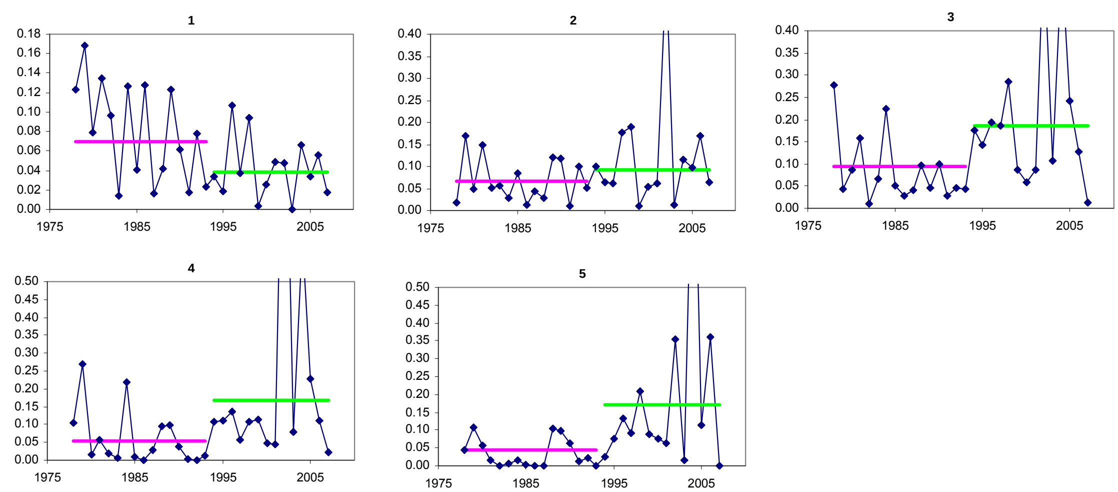


Figure 62. Time trends in survey catchability at age of cod on eastern Georges Bank, estimated (horizontal line) and calculated (diamonds) from the "split M 0.5" model formulation. a): from DFO survey, b): from NMFS spring survey, c): from NMFS fall survey.

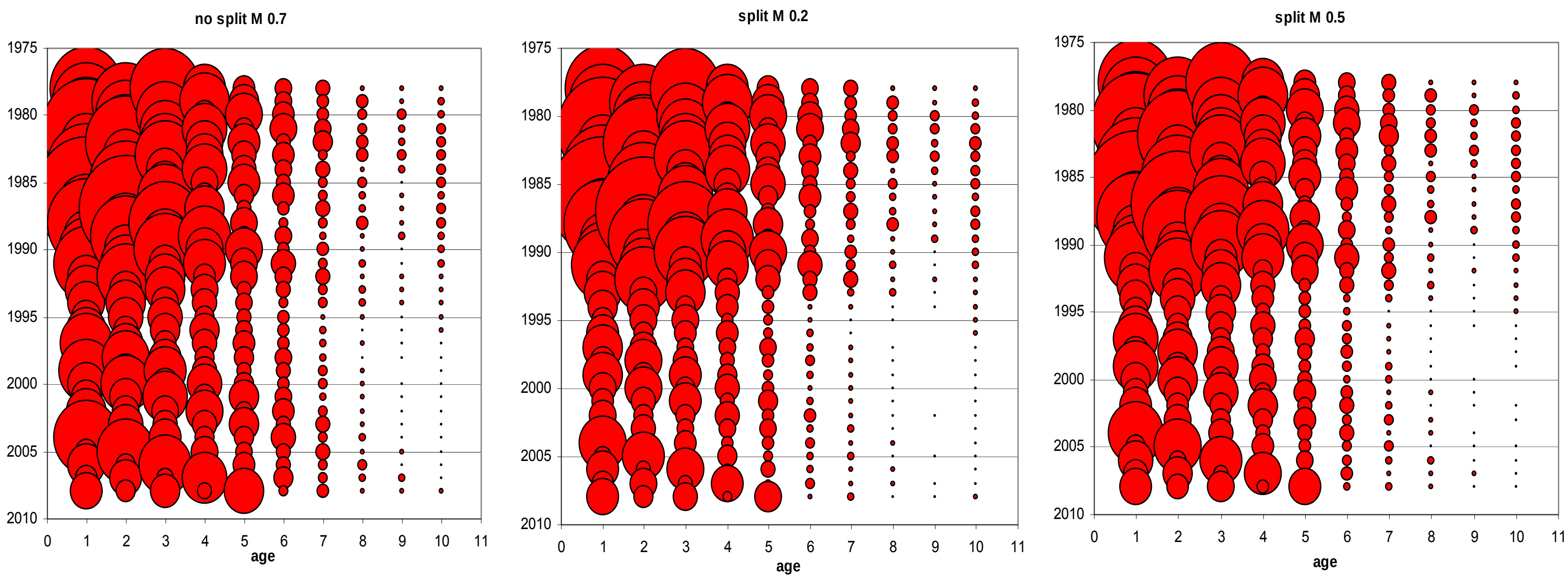


Figure 63. Comparison of VPA estimated population numbers at age from the three models for cod on eastern Georges Bank.

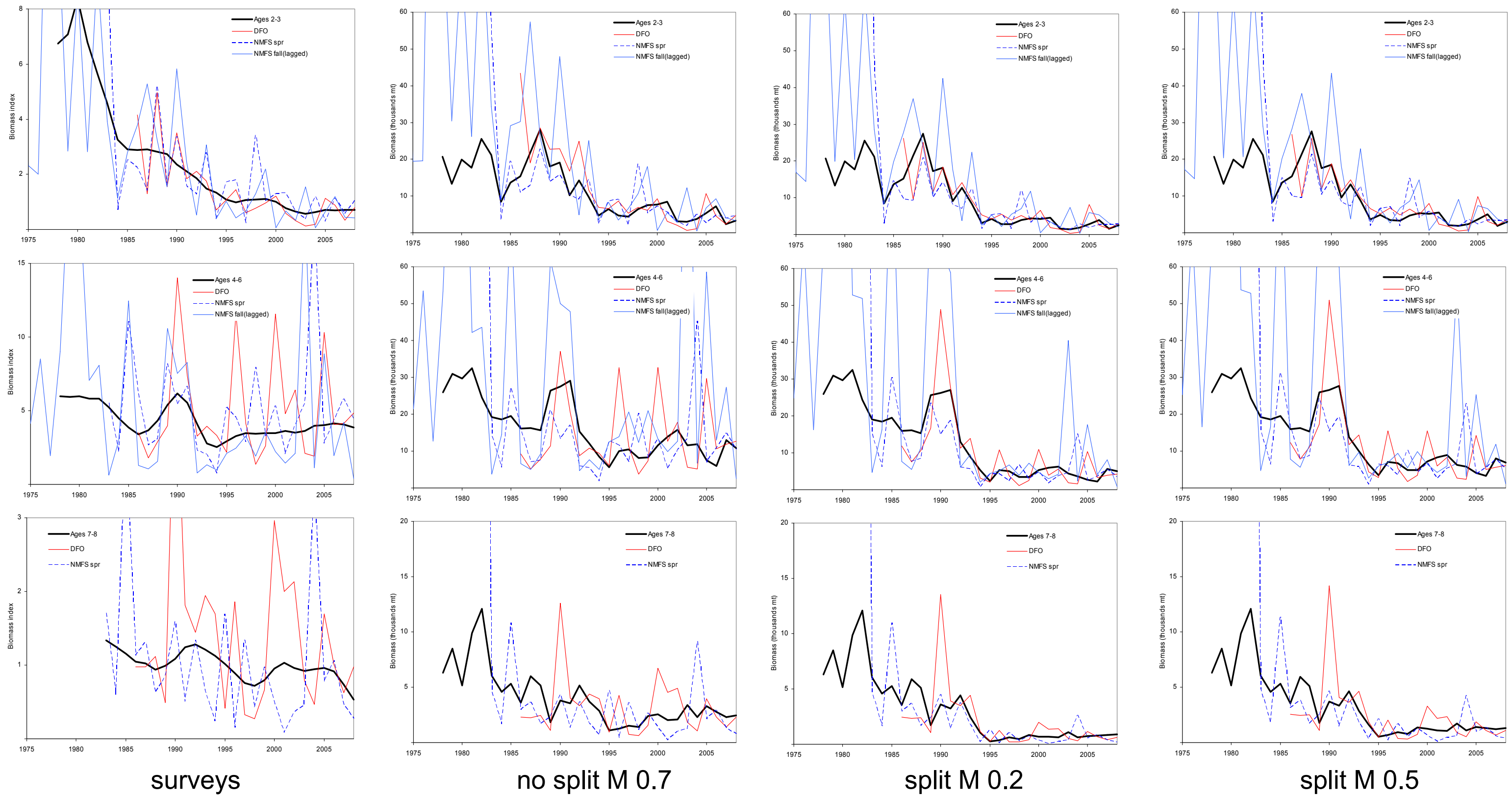


Figure 64. Biomass trends from surveys compared to the three model formulations for cod on eastern Georges Bank.

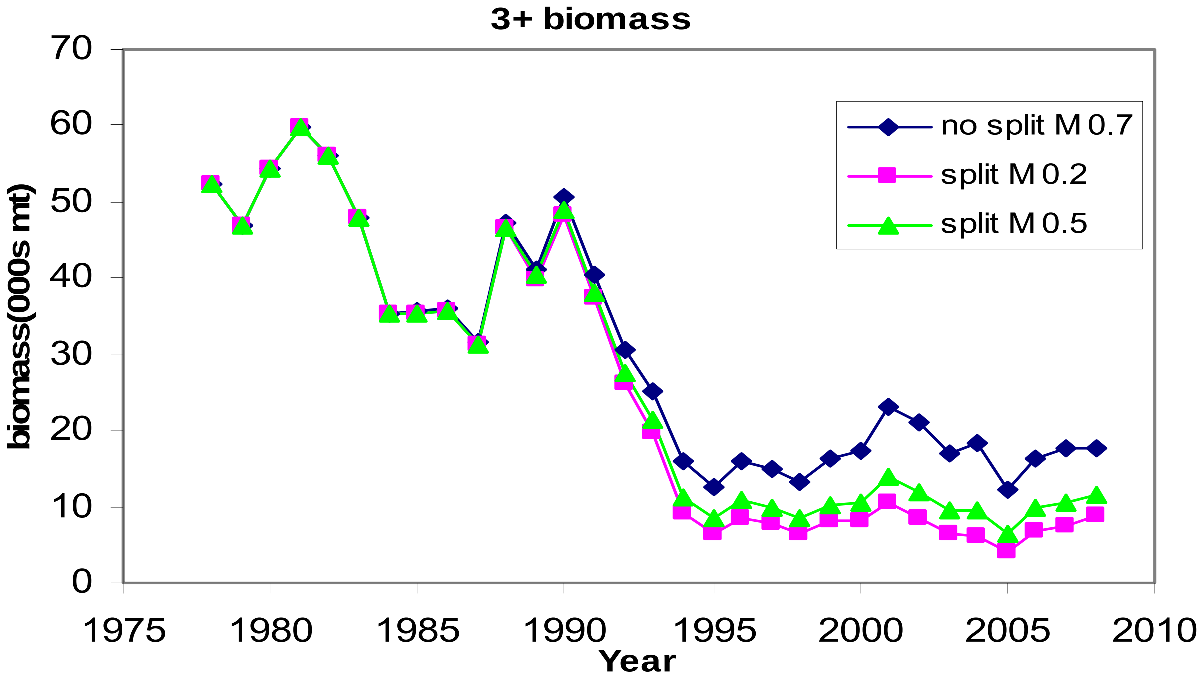


Figure 65. Comparison of 3+ biomass from the three models for cod on eastern Georges Bank.

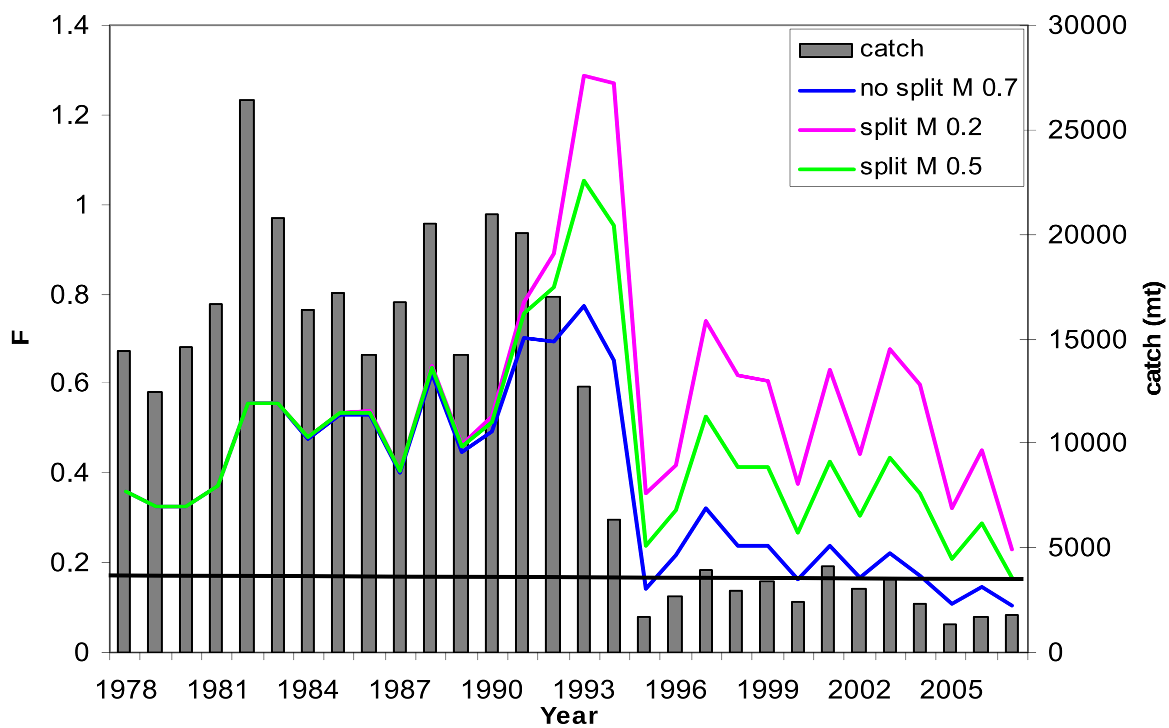


Figure 66. Comparison of fishing mortality from the three models with fishery catch for cod on eastern Georges Bank.

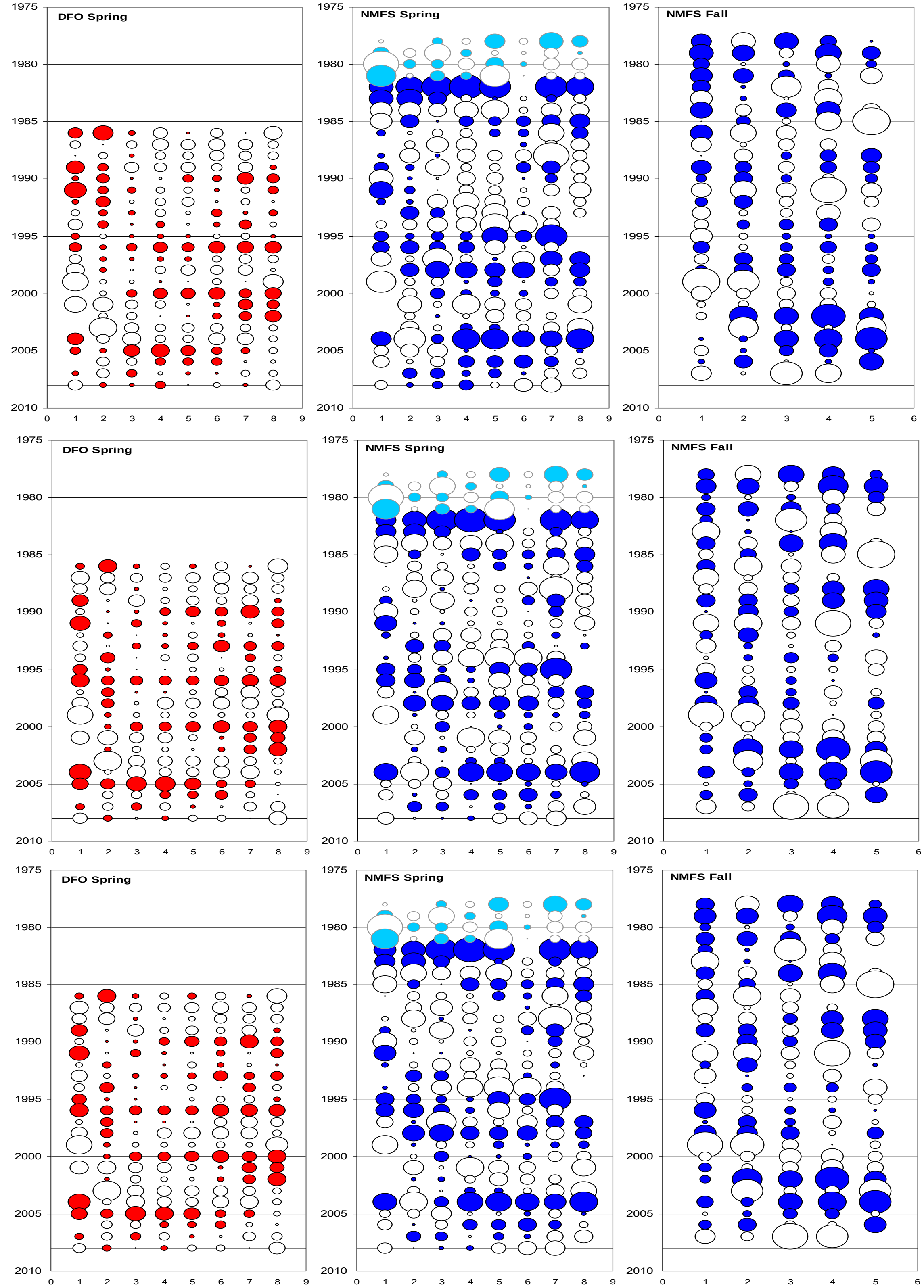


Figure 67. Comparison of residuals from "no split M 0.7" model (top panel), "split M 0.2" model (middle), and "split M 0.5" model (bottom) for cod on eastern Georges Bank.

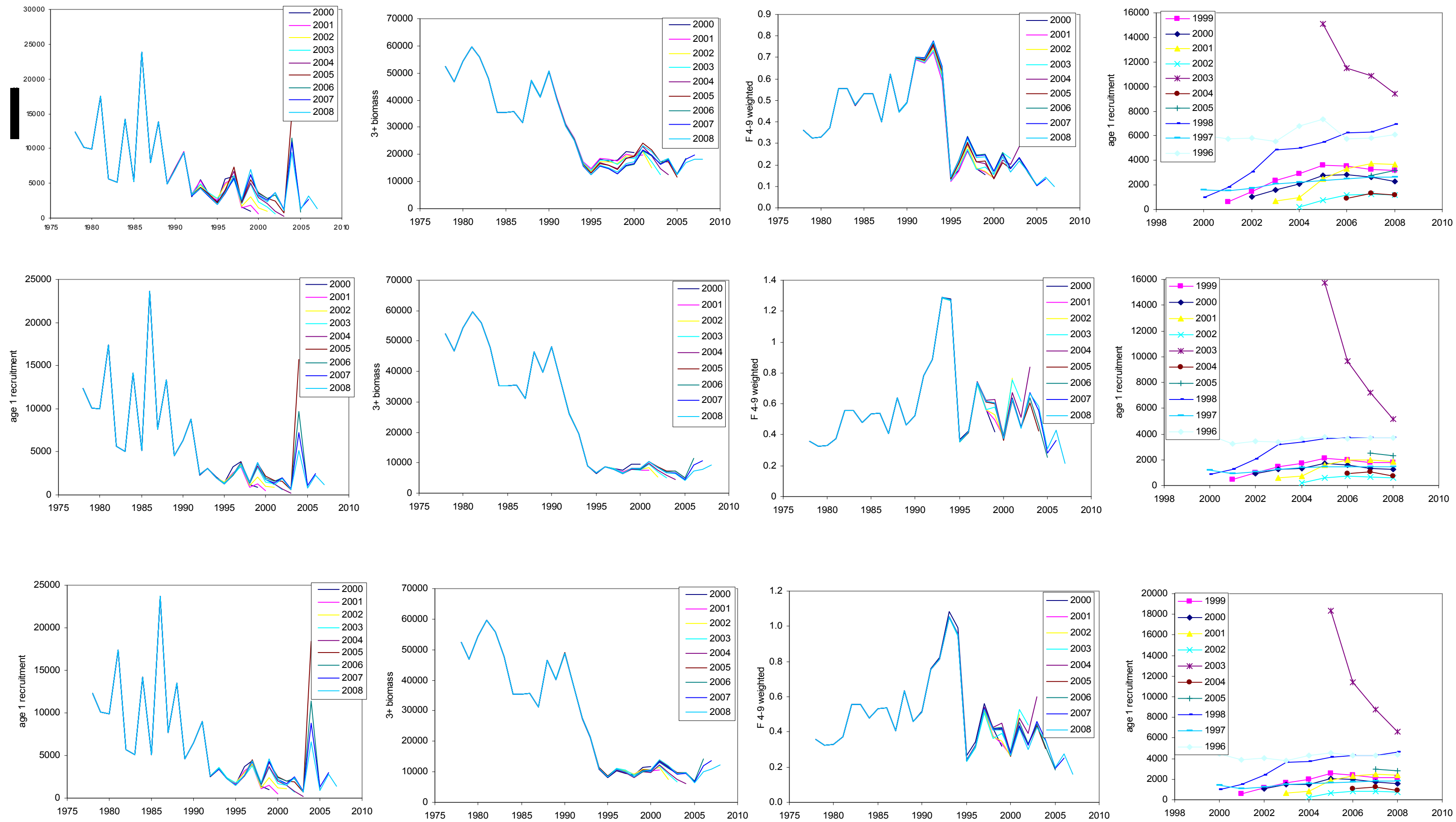


Figure 68. Comparison of retrospective patterns for “no split M 0.7” model (top panel), “split M 0.2” model (middle), and “split M 0.5” model (bottom) for cod on eastern Georges Bank.

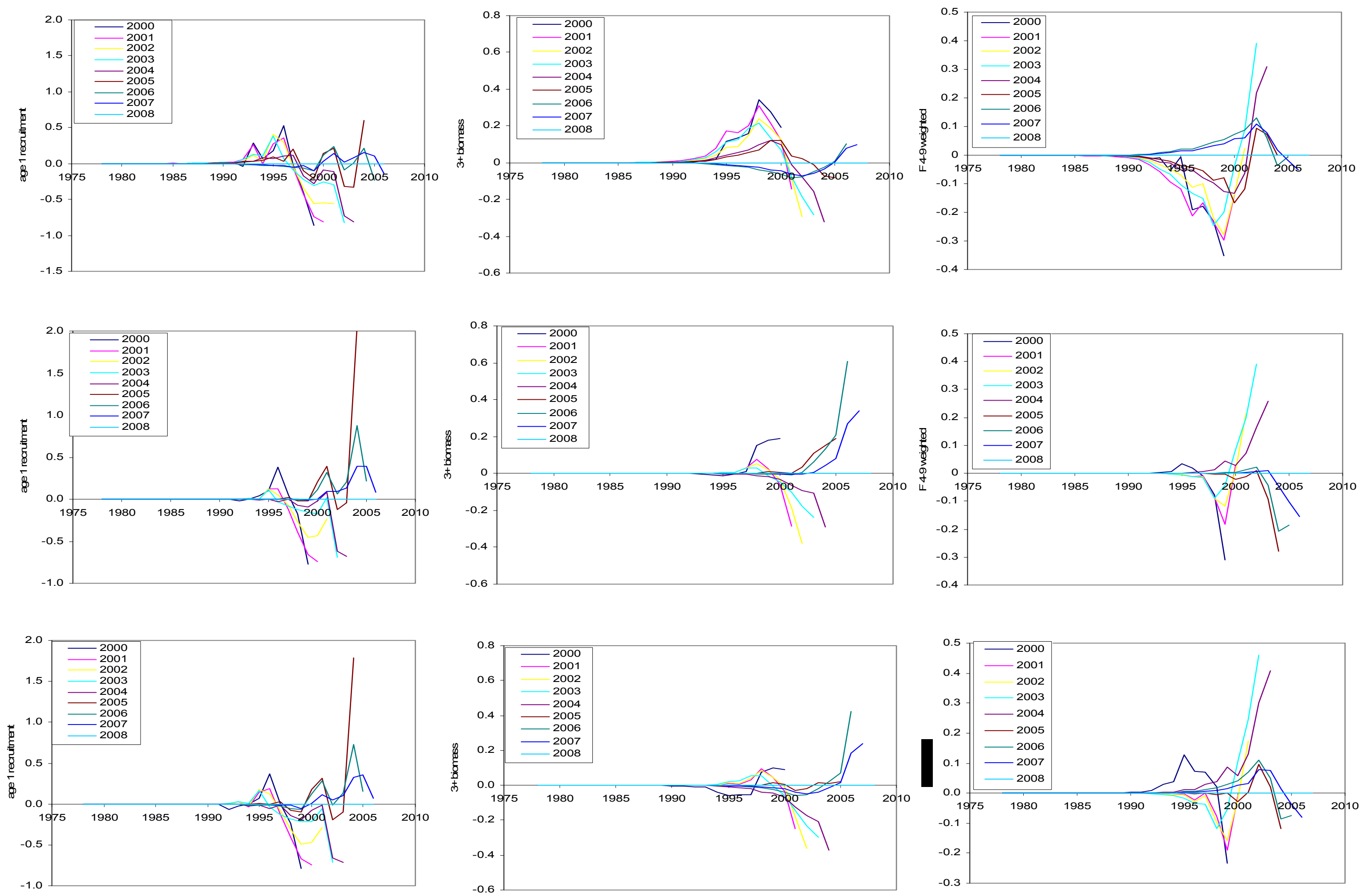


Figure 69. Comparison of relative retrospective patterns for "no split M 0.7" model (top panel), "split M 0.2" model (middle), and "split M 0.5" model (bottom) for cod on eastern Georges Bank.

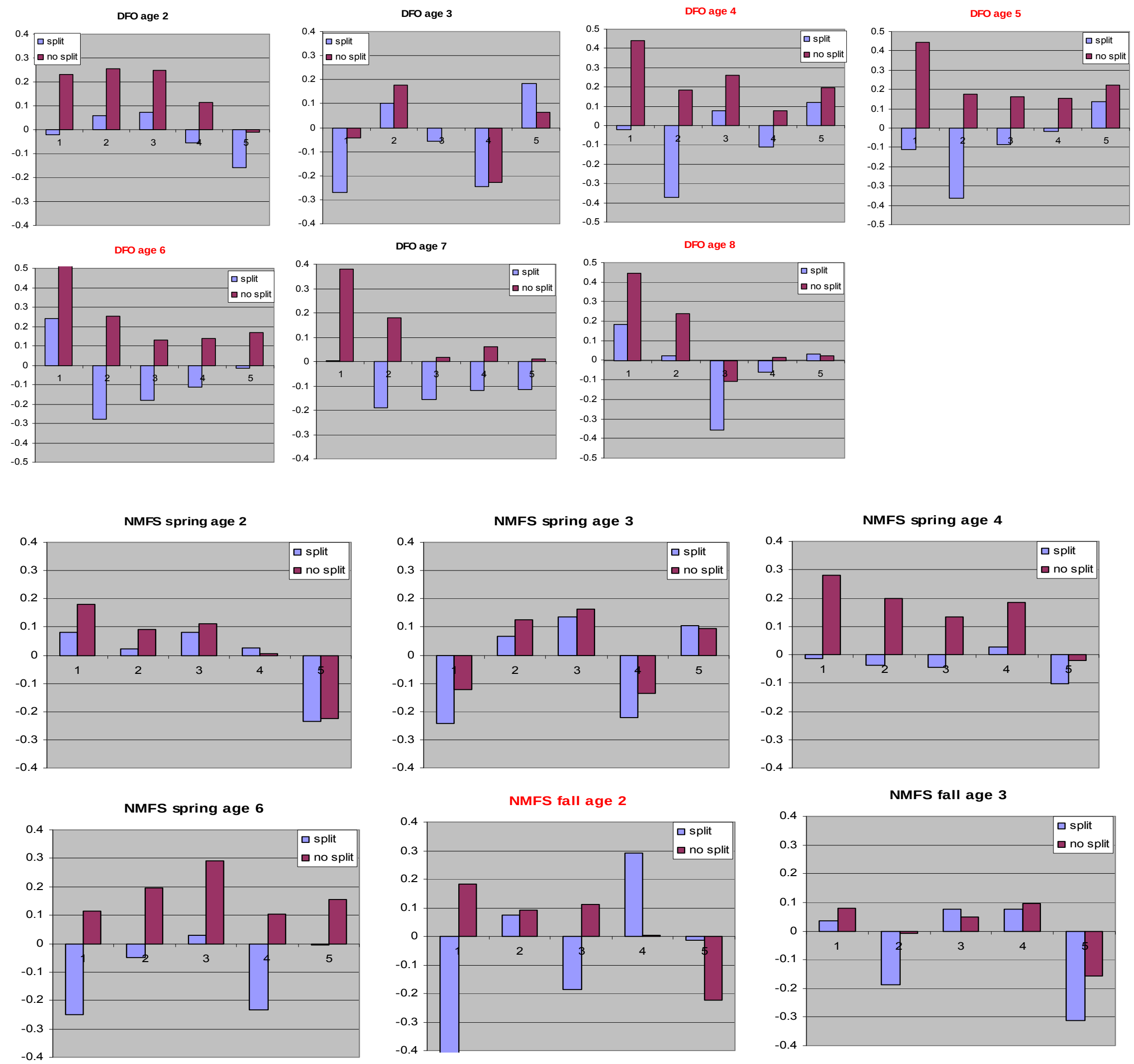
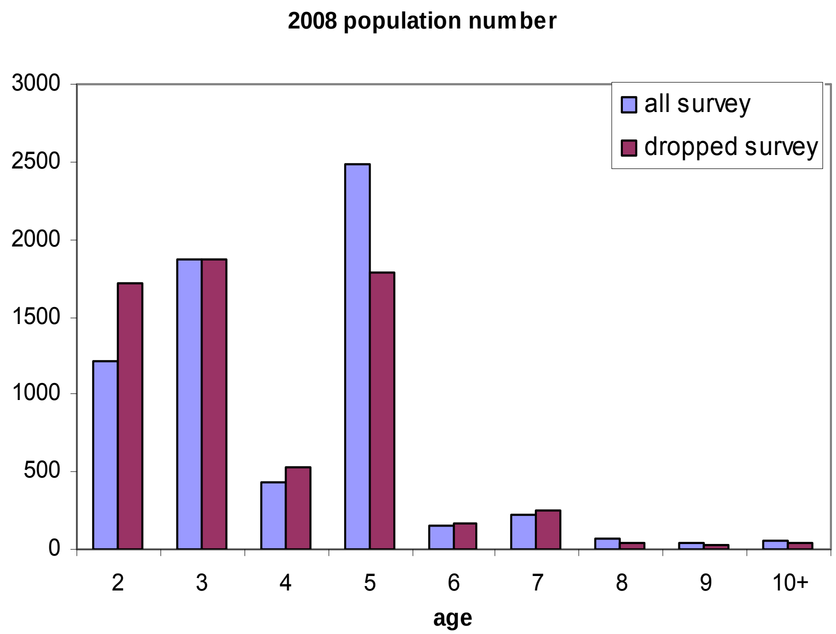


Figure 70. Comparison of autocorrelation coefficients of residuals between the “split M 0.2” and no split “basic VPA calibration” model. The X-axes are time lag (years), and the Y-axes are autocorrelation coefficients.



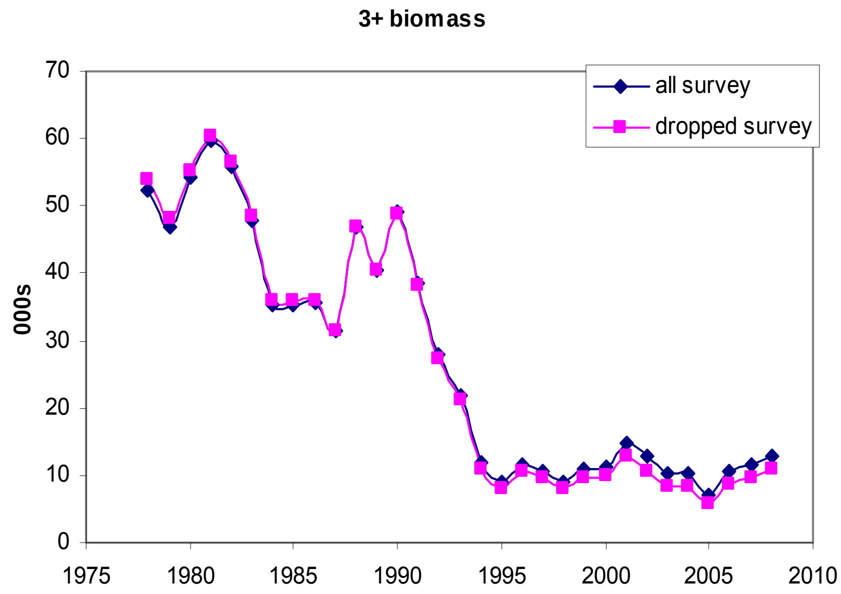


Figure 71. Comparison of the assessment results of “split M change” model for eastern Georges Bank cod when using all the survey data or just the survey data with years with low and high coefficients of variation removed (“dropped survey”).

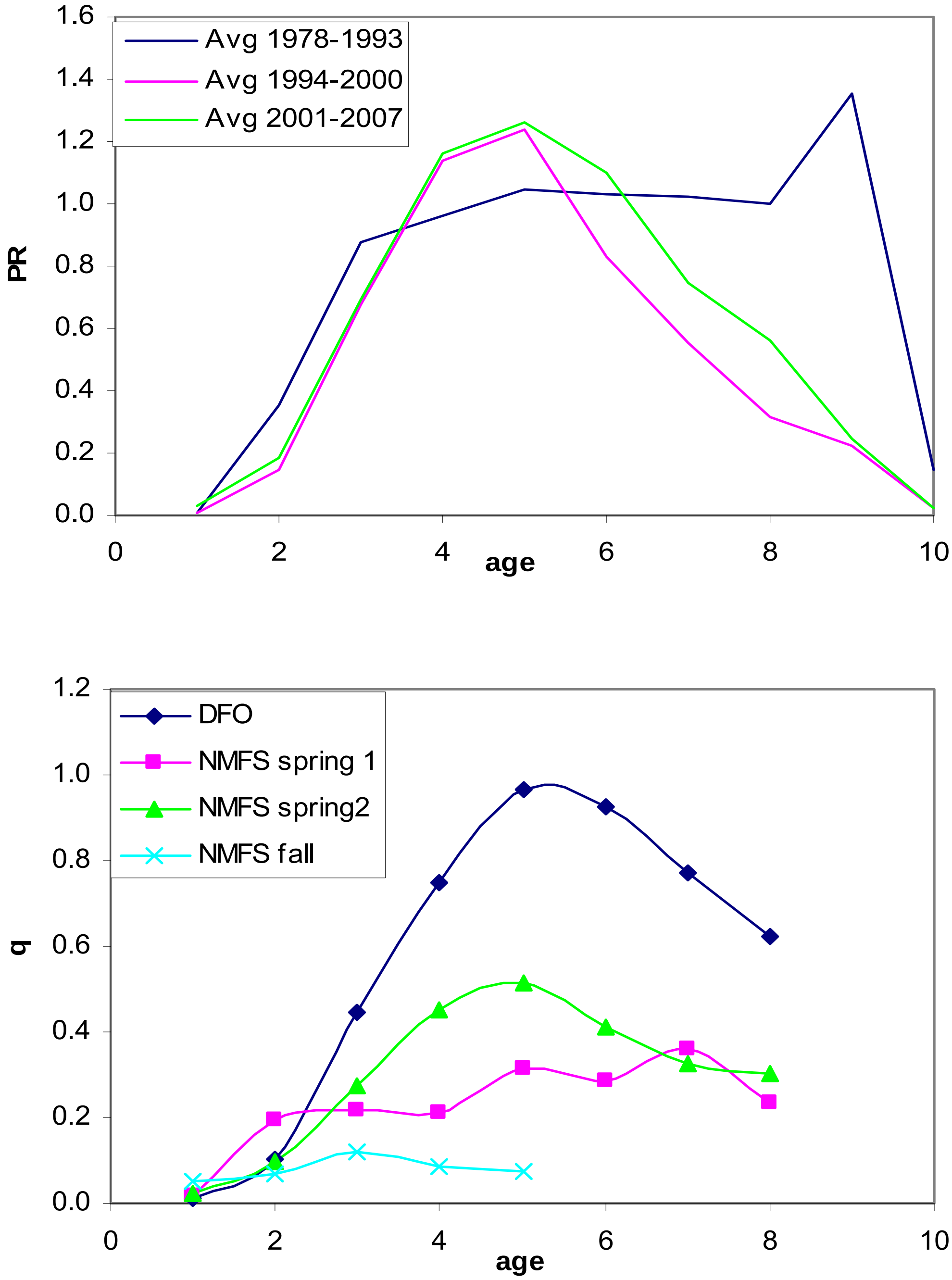


Figure 72. Fishery partial recruitment (PR) (top) and survey catchability *q* from the "F ratio" model formulation for cod on eastern Georges Bank.

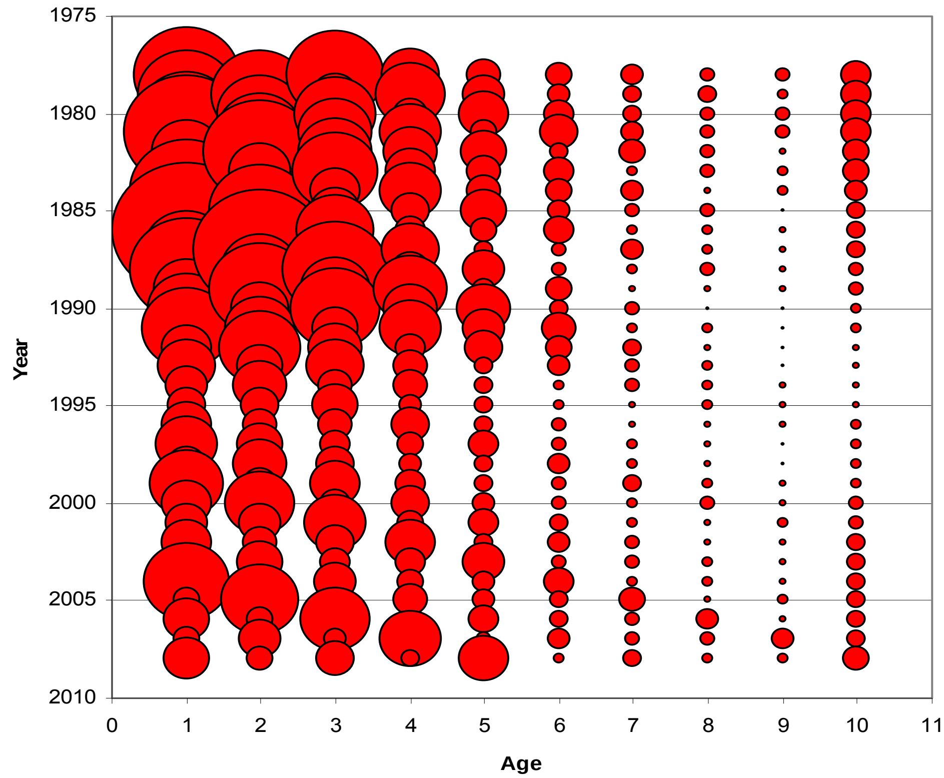
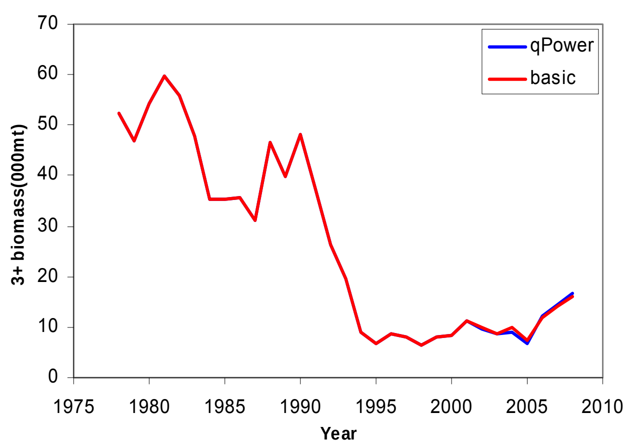


Figure 73. Fish population abundance from the "F ratio" model formulation for cod on eastern Georges Bank.



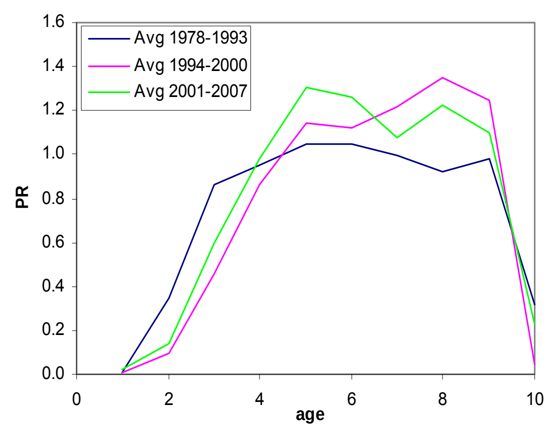


Figure 74. Population biomass (ages 3+) and fishery partial recruitment (PR) from the "q power" model formulation for cod on eastern Georges Bank.

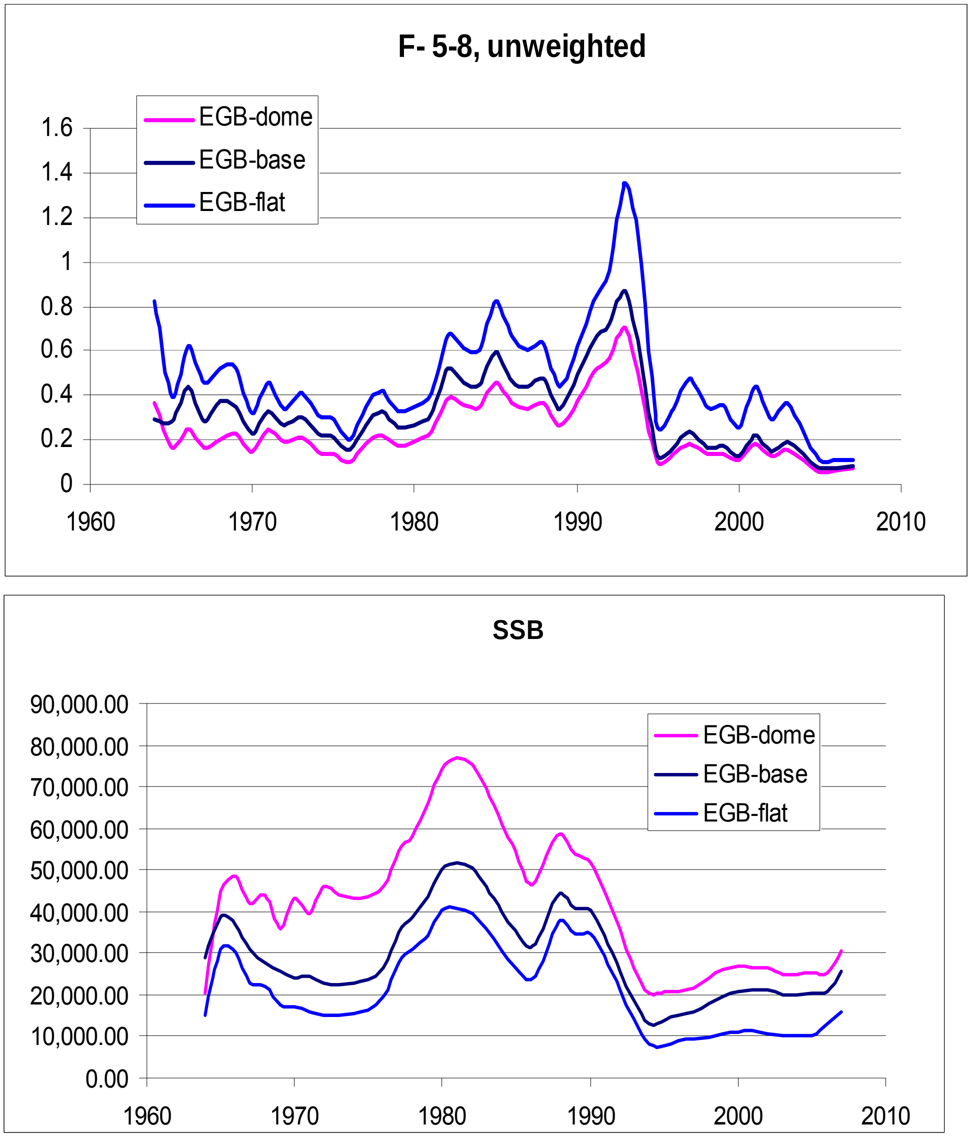


Figure 75. Fishing mortality (top panel) and spawning stock biomass (mt) (lower panel) from ASAP runs with different partial recruitment (base, flat, dome) for cod on eastern Georges Bank (5Zjm).

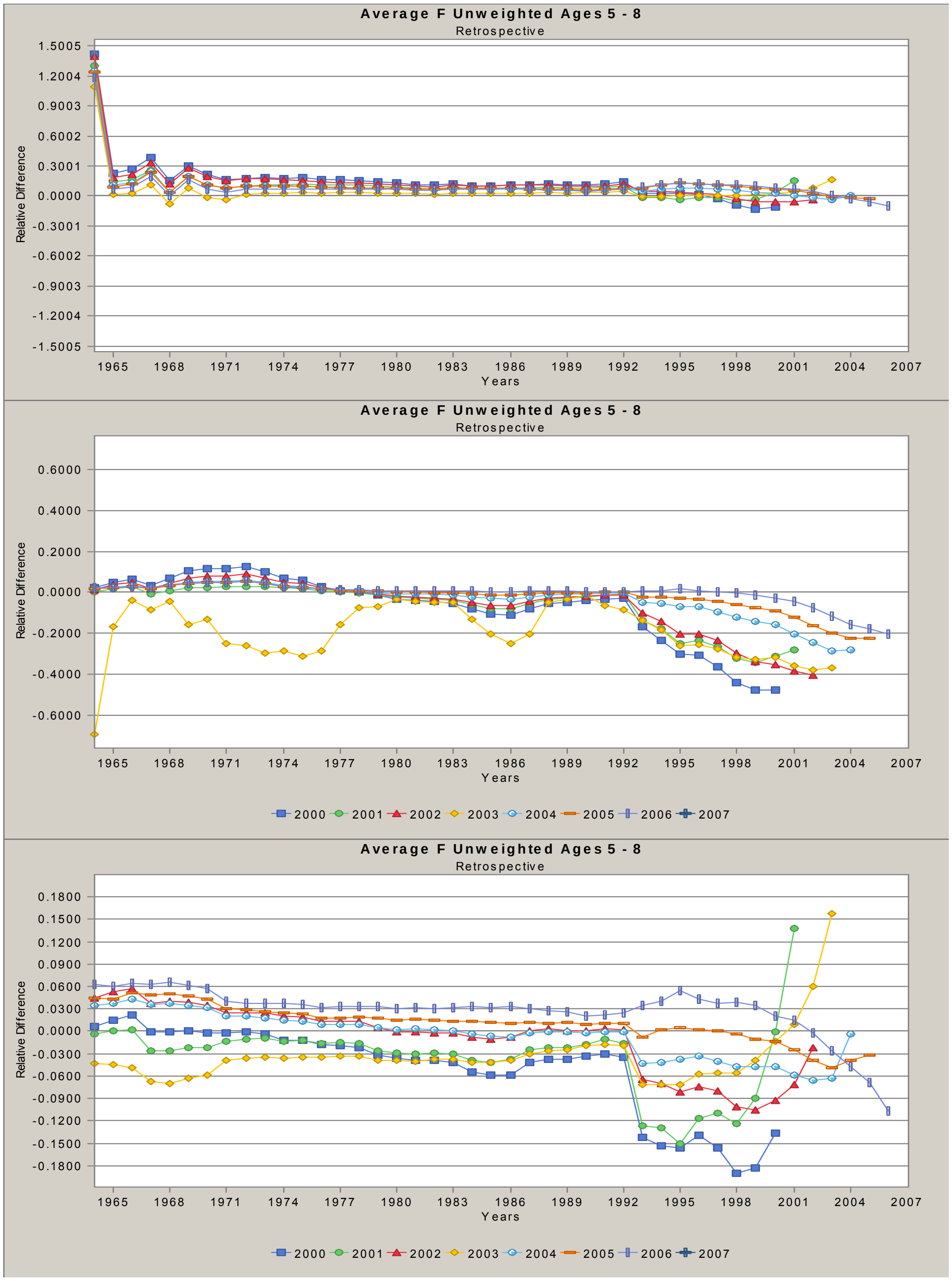


Figure 76. Retrospective pattern for fishing mortality from ASAP runs with different partial recruitment: base (top panel), flat (middle panel), and dome (bottom panel) for cod on eastern Georges Bank (5Zjm).

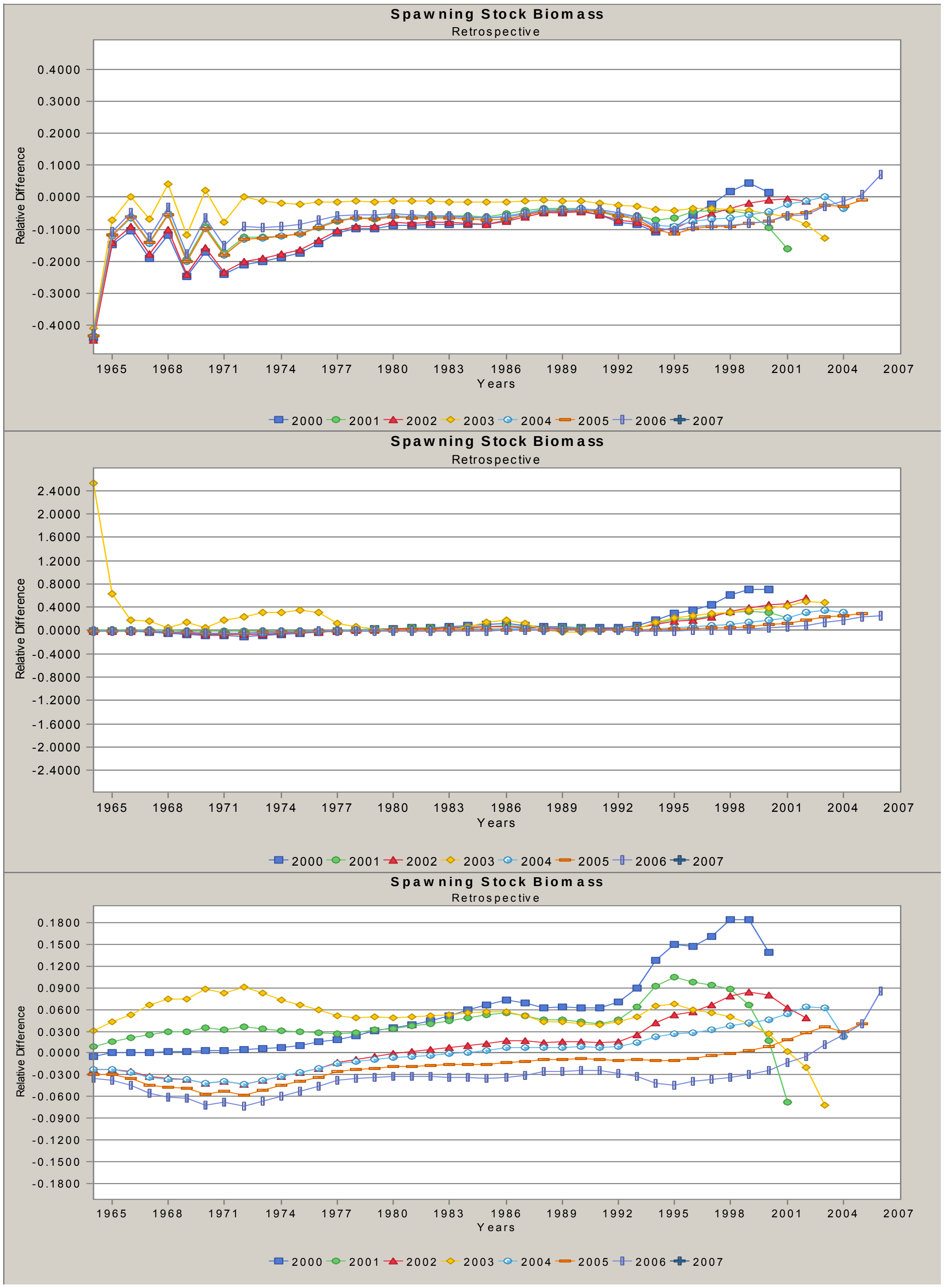


Figure 77. Retrospective pattern for spawning stock biomass from ASAP runs with different partial recruitment: base (top panel), flat (middle panel), and dome (bottom panel) for cod on eastern Georges Bank (5Zjm).

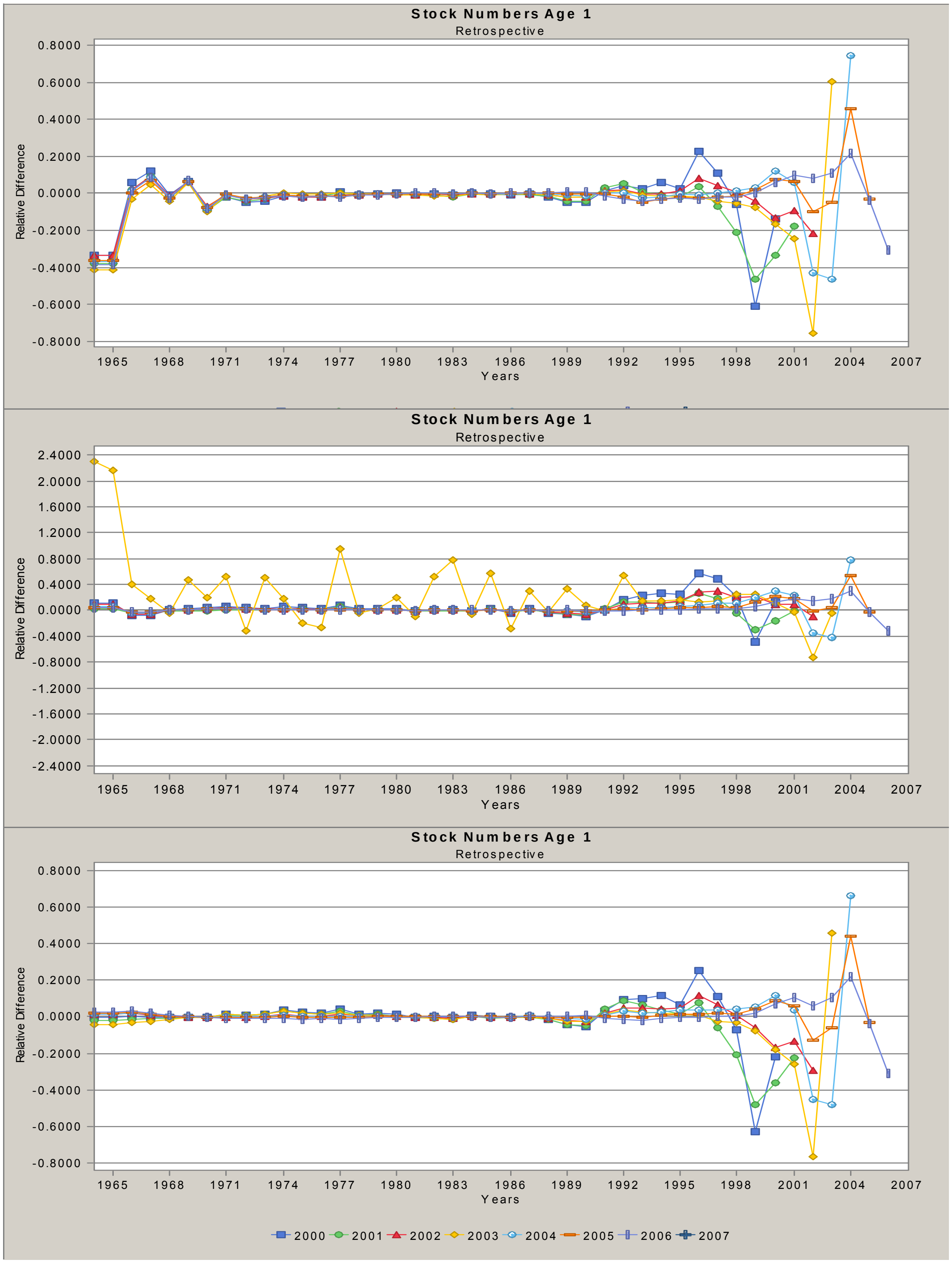


Figure 78. Retrospective pattern for age 1 recruits from ASAP runs with different partial recruitment: base (top panel), flat (middle panel), and dome (bottom panel) for cod on eastern Georges Bank (5Zjm).

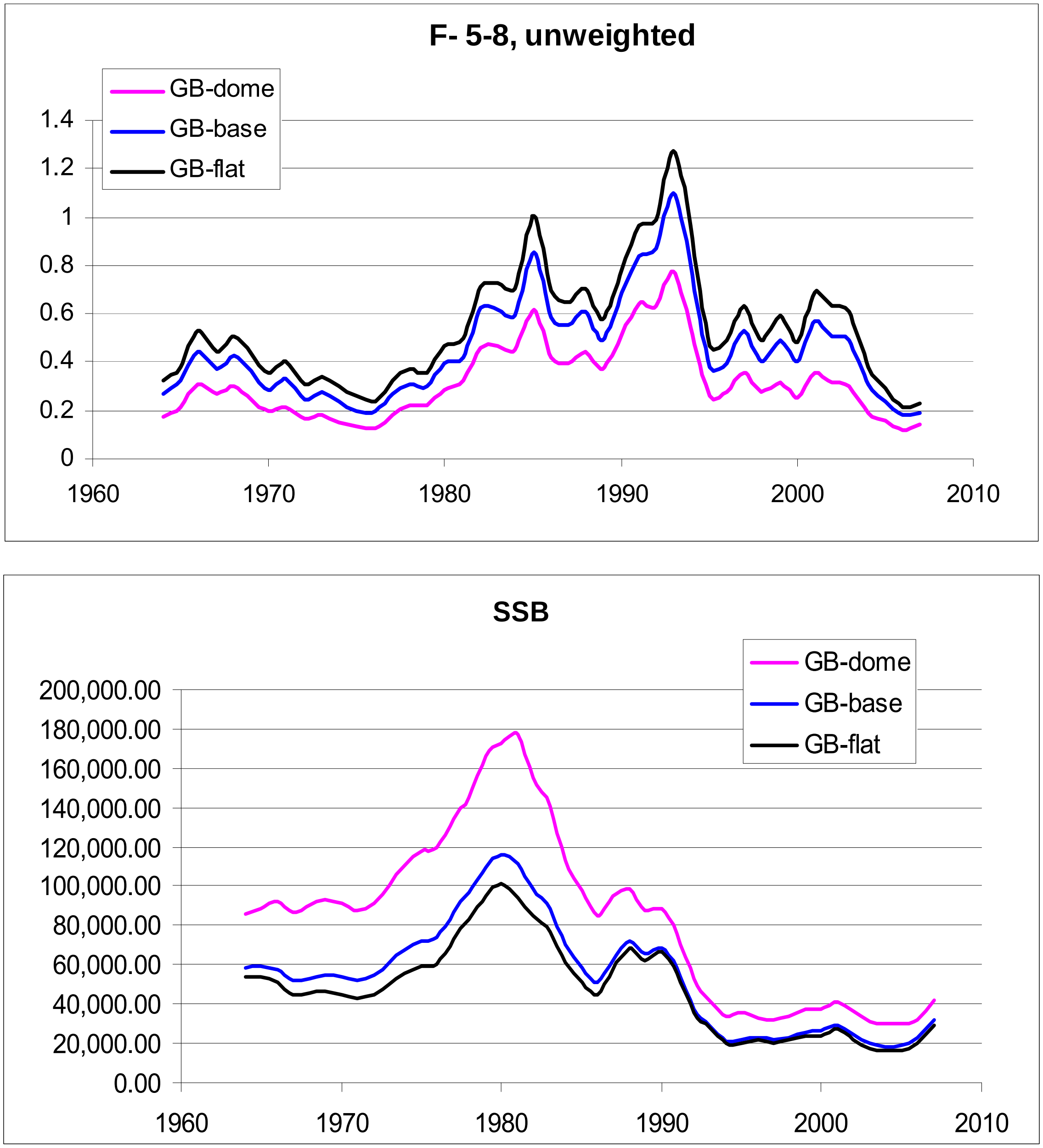


Figure 79. Fishing mortality (top panel) and spawning stock biomass (mt) (lower panel) from ASAP runs with different partial recruitment (base, flat, dome) for cod on Georges Bank (5Z).

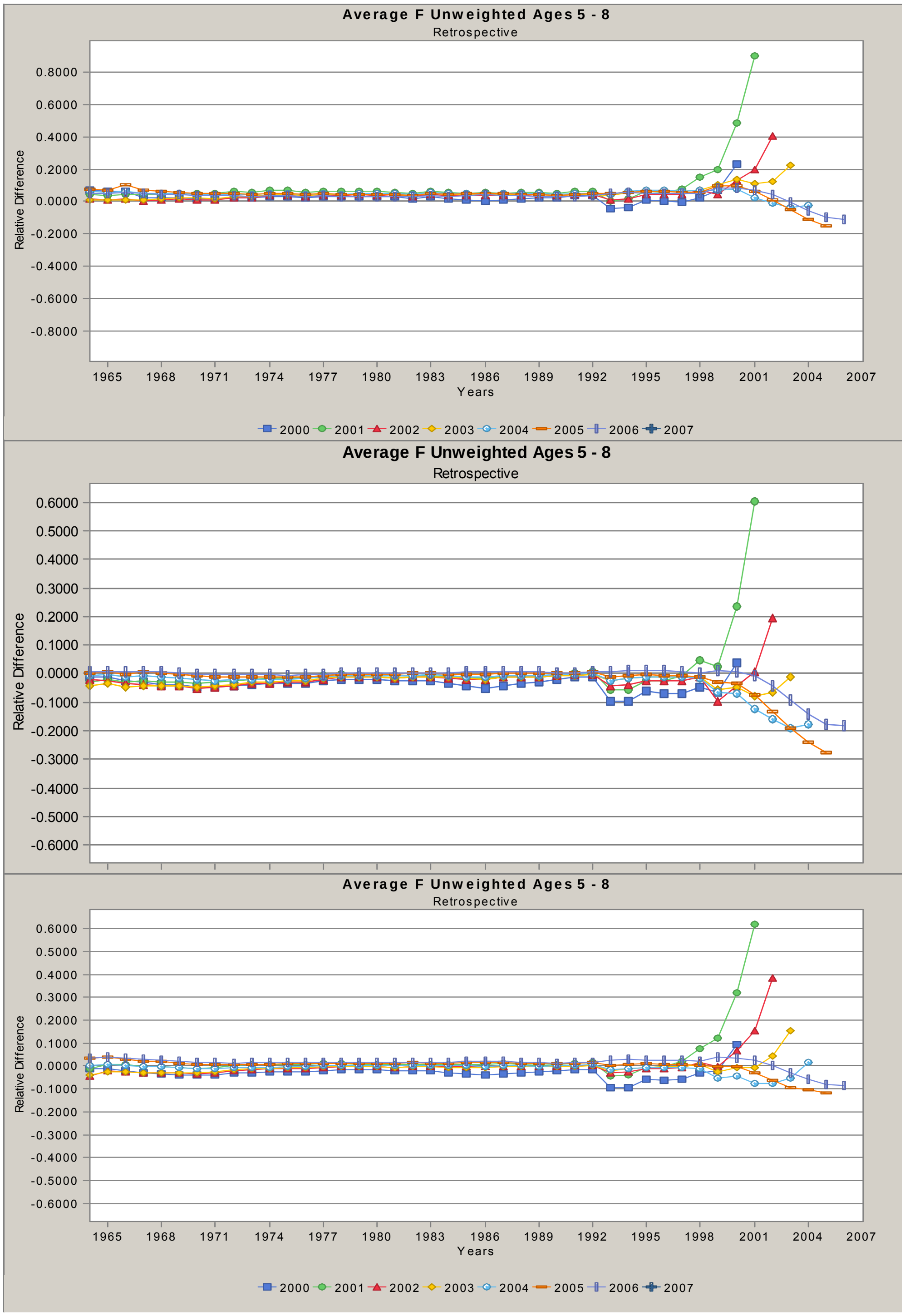


Figure 80. Retrospective pattern for fishing mortality from ASAP runs with different partial recruitment: base (top panel), flat (middle panel), and dome (lower panel) for cod on Georges Bank (5Z).

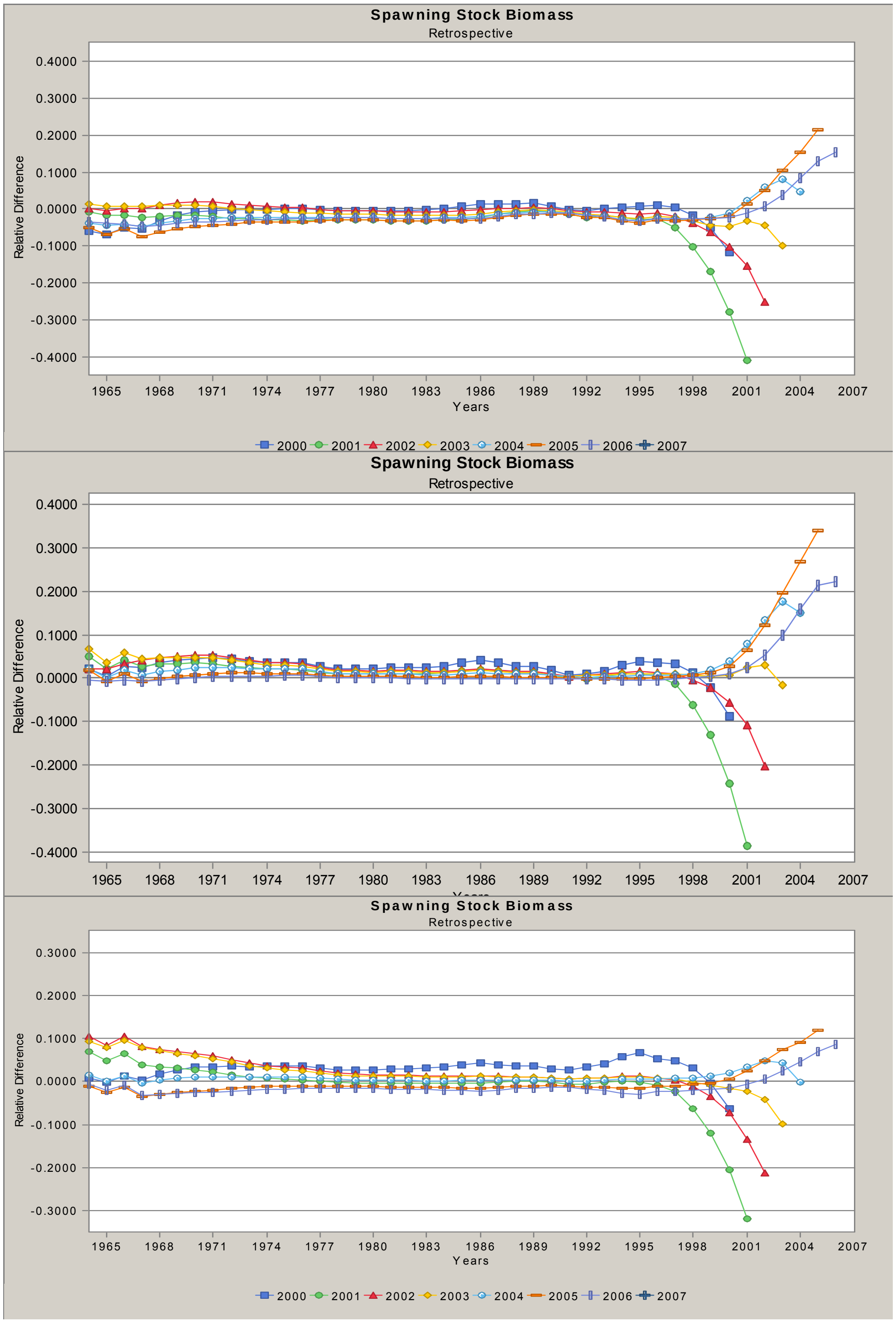


Figure 81. Retrospective pattern for spawning stock biomass from ASAP runs with different partial recruitment: base (top panel), flat (middle panel), and dome (lower panel) for cod on Georges Bank (5Z).

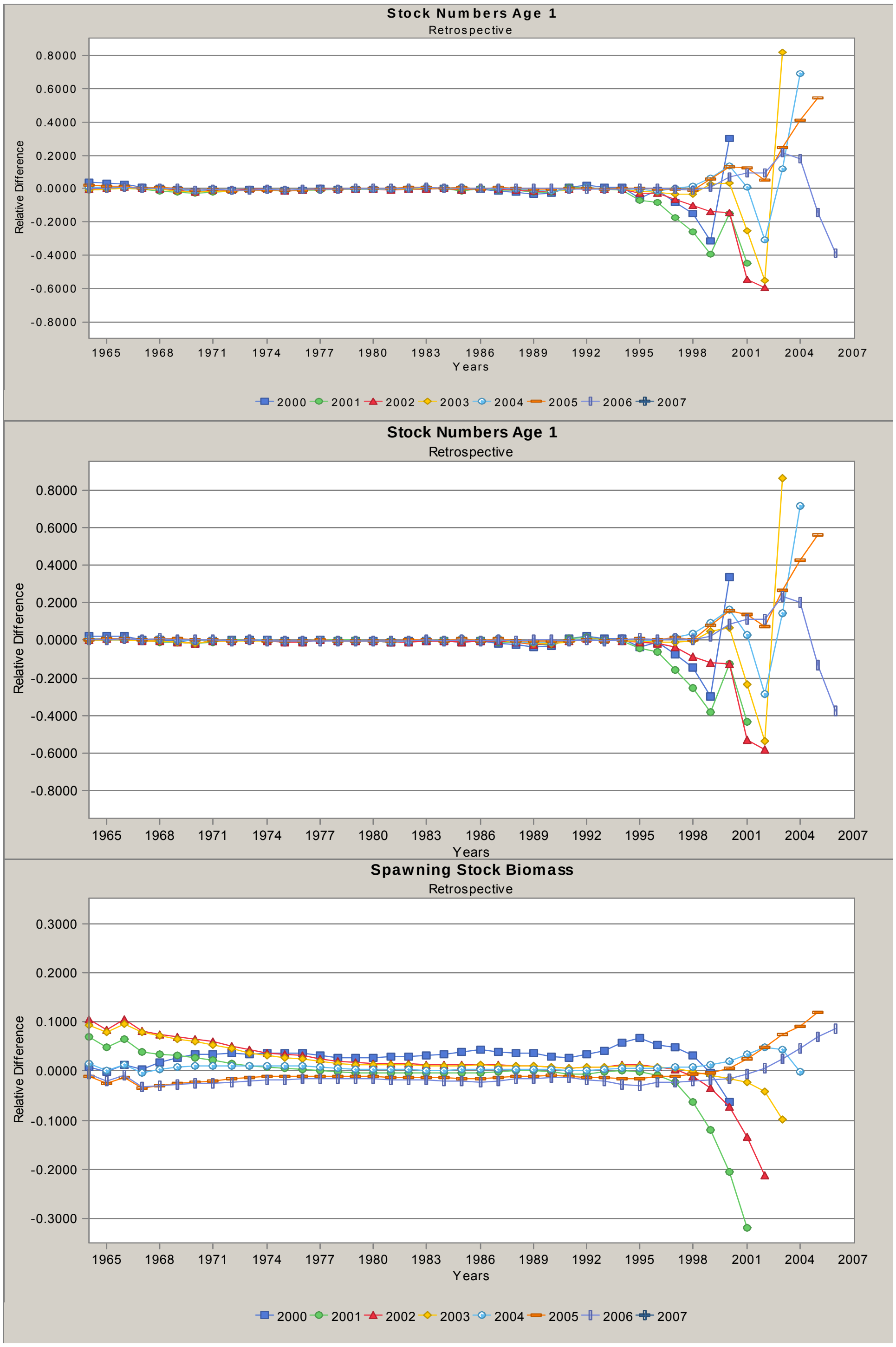
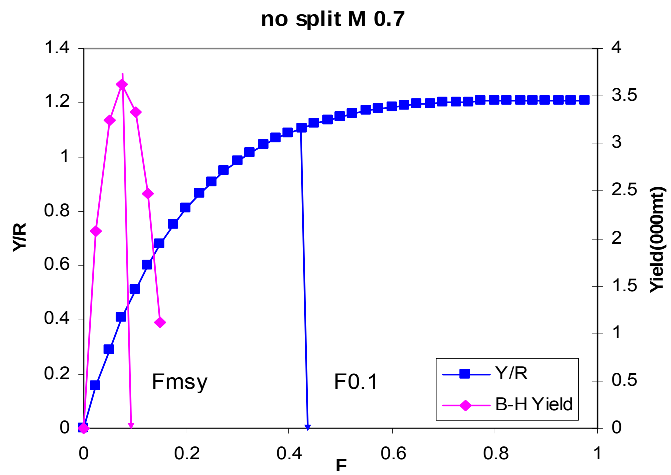


Figure 82. Retrospective pattern for age 1 recruits from ASAP runs with different partial recruitment: base (top panel), flat (middle panel), and dome (lower panel) for cod on Georges Bank (5Z).

	F0.1	F40%	Fmsy
no split M 0.7	0.43	0.45	0.08
split M 0.2	0.27	0.23	0.18
split M 0.5	0.39	0.40	0.13



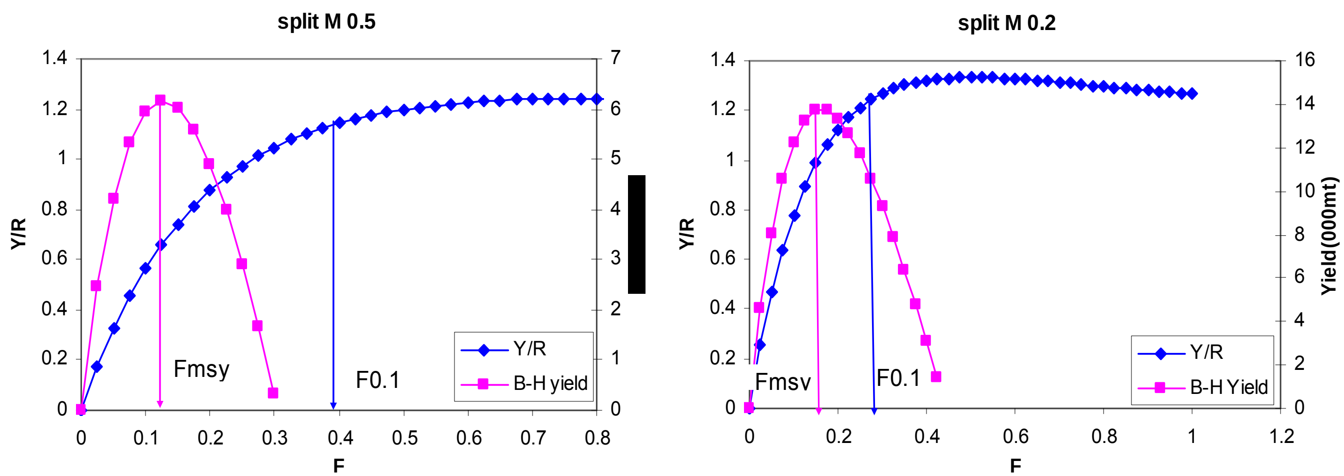


Figure 83. Comparison of F reference points from the three models for cod on eastern Georges Bank.

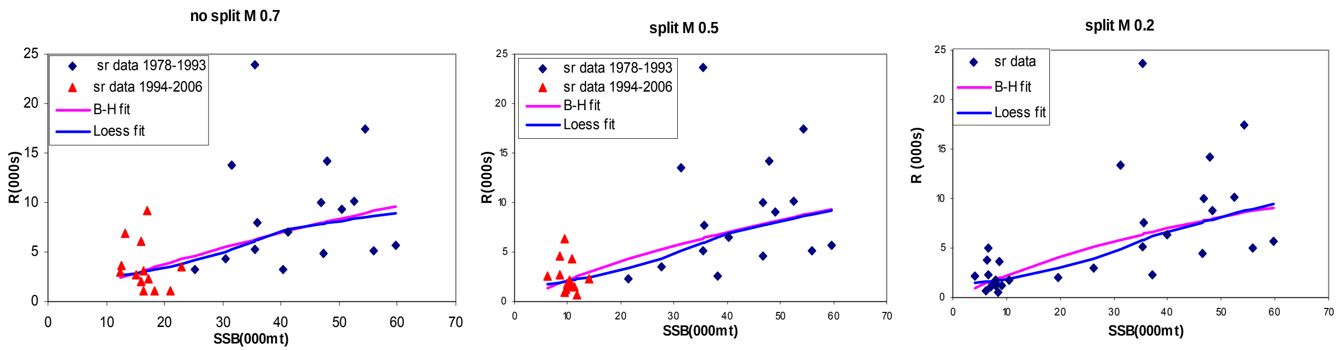


Figure 84. Comparison of the spawning stock biomass (SSB) to recruitment (R) relationships from the three models for cod on eastern Georges Bank.

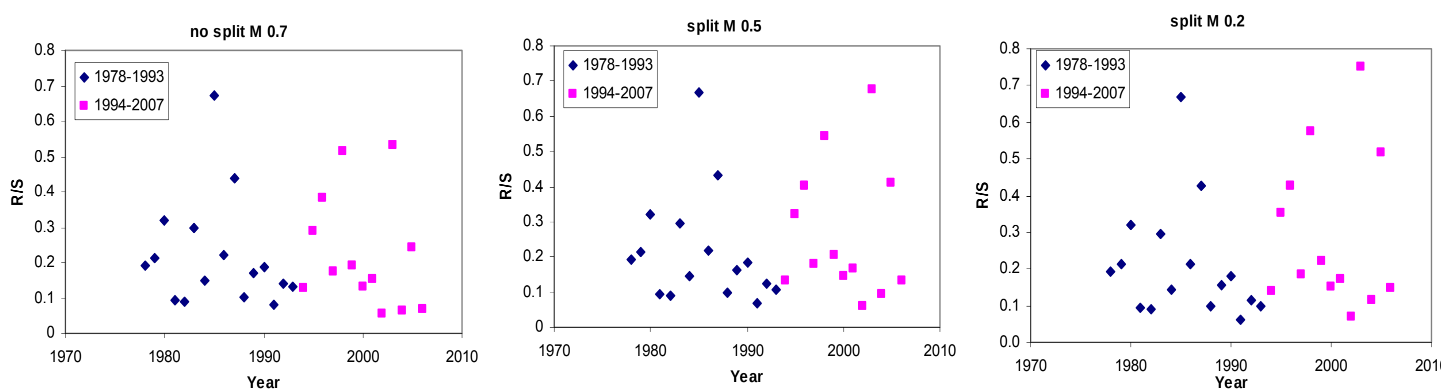


Figure 85. Comparison of recruitment rate, recruit per spawner (R/S), for the two time periods (1978-1993 and 1994-2007) from the three models for cod on eastern Georges Bank.

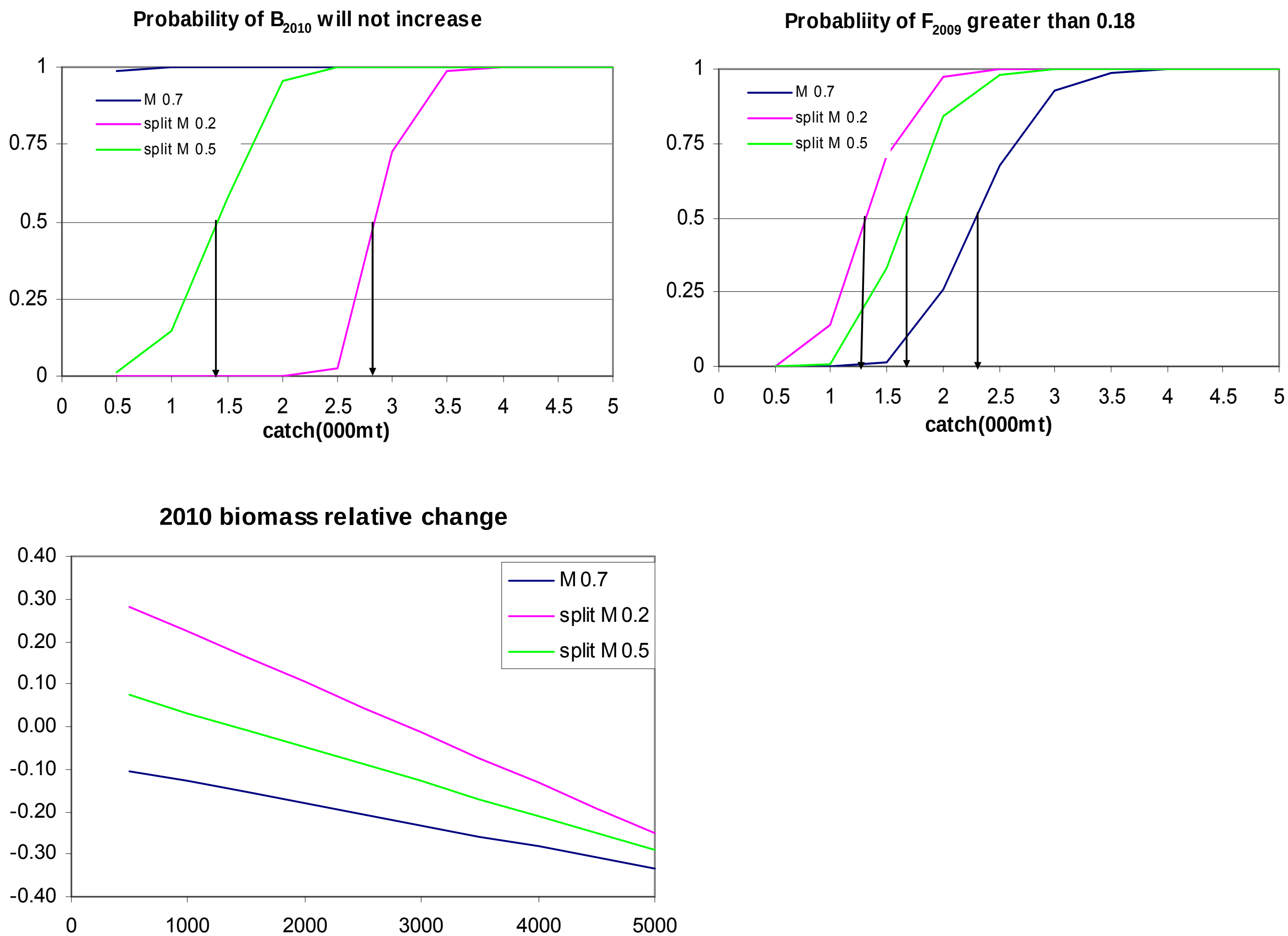


Figure 86. Comparison of risk analysis from the three models, “M 0.7”, “split M 0.5” and “split M 0.2”, for cod on eastern Georges Bank.