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4X5Y Haddock 2016 Framework Assessment: Modelling and Reference Points

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

The 4X5Y Haddock Framework Assessment: Modeling and Reference Points meeting, held on April 26-27, 2016, was the second of two Maritimes Region of Fisheries and Oceans Canada peer review meetings for 4X5Y Haddock. This meeting was preceded by a 4X5Y Haddock 2014 Framework Assessment: Data inputs and Exploratory Modelling meeting, held on October 22, 2014. This research document summarizes the conclusions from the 'data inputs' meeting and describes the methodologies developed for estimating current stock status, fishery reference points, forecasting methodology for providing advice, guidance on inter-framework review activities and events that would trigger an earlier-than-scheduled assessment.

To resolve the retrospective pattern and other model fit issues observed in past 4X5Y Haddock stock assessments, Virtual Population Analysis (VPA) models with random walk in M (natural mortality) for different age groups were explored. A VPA model with M at Ages 10 and older fixed at 0.3, 0.6, and 0.9 for three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively) was recommended as the new framework model for the 4X5Y Haddock stock assessment. Despite the uncertainties in estimating F_{msy}, it was agreed at this framework meeting that an F_{ref} of 0.25 would be a removal fishing mortality reference when the stock is in the Healthy Zone, and an F of 0.15 would be an appropriate target when the stock is in the Cautious Zone. Given that the poor stock recruit relationship precludes the calculation of an appropriate B_{msy}, a more conservative $B_{recover}$ (19,700 metric tonnes (t)) was recommended as B_{lim} for 4X5Y Haddock.

Évaluation du cadre de 2016 pour l'aiglefin de la division 4X5Y : Modélisation et points de référence

RÉSUMÉ

La réunion sur l'évaluation du cadre pour l'aiglefin de la division 4X5Y : Modélisation et points de référence tenue les 26 et 27 avril 2016 a été la seconde de deux réunions d'examen par les pairs de Pêches et Océans Canada de la région des Maritimes organisées pour l'aiglefin de cette zone. Cette réunion a été précédée d'une réunion sur l'évaluation du cadre de 2014 pour l'aiglefin de la division 4X5Y : Saisie de données et modélisation exploratoire, tenue le 22 octobre 2014. Le présent document de recherche résume les conclusions de la réunion sur la « saisie de données » et décrit les méthodes mises au point pour estimer l'état des stocks actuels et les points de référence des pêches, et fournir les prévisions qui guident les activités de l'examen intercadres et les événements qui peuvent nécessiter une évaluation plus tôt que prévu.

Afin de résoudre les problèmes observés lors des évaluations du stock d'aiglefin de la division 4X5Y réalisées par le passé (problèmes avec la tendance rétrospective et l'intégration des autres modèles), on a examiné des modèles d'analyse de la population virtuelle (APV) comportant une marche aléatoire du M (mortalité naturelle) pour différents groupes d'âge. Comme nouveau modèle de cadre pour l'évaluation du stock d'aiglefin de la division 4X5Y, on a recommandé un modèle d'APV avec une valeur M de 10 ans et plus fixée à 0,3; 0,6, et 0,9 pour trois blocs de cinq ans (2000-2004, 2005-2009 et 2010-2014, respectivement). Malgré les incertitudes sur le plan de l'estimation de la valeur F_{rms}, on a convenu à cette réunion sur le cadre que la valeur de référence pour la mortalité par capture serait un $F_{réf}$ de 0,25 lorsque le stock se situe dans la zone saine, et qu'une valeur F de 0,15 serait une cible adéquate lorsque le stock se situe dans la zone de prudence. Étant donné que la faible corrélation entre stock et recrutement empêche de calculer un B_{rms} approprié, on a recommandé un $B_{rétablissement}$ plus conservateur (19 700 tonnes métriques [t]) comme B_{lim} pour l'aiglefin de la division 4X5Y.

INTRODUCTION

Haddock (*Melanogrammus aeglefinus*) are found on both sides of the North Atlantic and occur in the northwestern Atlantic from southwest Greenland to Cape Hatteras. A major stock exists on the western Scotian Shelf and in the Bay of Fundy (Northwest Atlantic Fisheries Organization (NAFO) Divisions 4X5Y) (Figure 1). Growth rates of Haddock in the Bay of Fundy (4Xqrs5Y), are higher than those of Haddock on the western Scotian Shelf (4Xmnop) (Hurley et al. 1998) so separate age length keys (ALKs) have been used in the past for calculating the fishery catch at age (CAA) and survey indices of abundance. Major spawning grounds are found on Browns Bank and peak spawning occurs from April to May, although it can occur as early as February if conditions are favourable (Head et al. 2005). A seasonal spawning closure, implemented in 1970, currently extends from February 1st June 15th (Halliday 1988).

NAFO Divs. 4X5Y Haddock are harvested as part of a mixed, multi-species fishery that includes Atlantic Cod, Atlantic Halibut, redfish, Pollock, White Hake, and flounders. The Haddock fishery is limited by the incidental catch of Cod which has strict bycatch limits. The mandatory use of a 130 mm square mesh Cod end for bottom trawl was implemented in 1991 to allow for escapement of smaller fish; however, Haddock are also captured as bycatch in the redfish fishery, which uses smaller 100-112 mm diamond mesh Cod ends.

In past assessments, the 4X5Y Haddock stock has been modelled using Sequential Population Analysis (SPA) tuned to two surveys: the Fisheries and Oceans Canada (DFO) Summer Multispecies Ecosystem survey (1970 to present) and a joint Industry/DFO survey (Individual Transfer Quota (ITQ) survey) (Showell et al. 2013), with the latter discontinued after 2012. The fishery has been managed using a removal reference (F_{ref} = 0.25). A limit reference point (LRP) of 40% SSB_{MSY} (20,800 metric tonnes(t)) and upper stock reference point (USR) of 80% SSB_{MSY} (41,600 t) based on estimates from a Sissenwine-Sheppard stock production model (Mohn et al. 2010) have been calculated as illustrative biological reference points for this stock.

The last analytical assessment conducted in 2012 (Showell et al. 2013) suggested that Age 4+ biomass (a proxy for spawning stock biomass (SSB)) has remained relatively stable over the past two decades and is likely within the Cautious Zone. However, a strong retrospective pattern in the model results (i.e. a tendency to overestimate Age 4+ biomass and underestimate Ages 6-9 F when additional years of data were added), and a miss-match between survey and catch information, indicated that the recent increases in Age 4+ biomass were likely overestimates (Figure 2). Consequently, the SPA model results were not considered sufficiently reliable to produce meaningful projections for 2013 and 2014. A framework review for the 4X5Y Haddock assessment was recommended, given the continuing strong retrospective pattern in the model and its poor fit to the survey indices.

FRAMEWORK REVIEW PROCESS

In 2014, the Maritimes Region of DFO initiated a 2-part framework assessment review of 4X5Y Haddock. The first part focused on commercial fishery and survey data inputs, which were evaluated during a meeting conducted at the Bedford Institute of Oceanography in Dartmouth, NS, on October 22, 2014, and documented in Stone and Hansen (2015). The main elements of the data inputs review included:

- Stock Structure.
- Fishery spatial and temporal distribution, bycatch, CAA, weight at age (WAA), length at age (LAA), maturity, growth and the appropriateness of using area-specific age-length keys (Bay of Fundy, Scotian Shelf).

- Research Vessel survey age-specific indices of abundance, weight/length at age, maturity, growth, condition and age-specific spatial distribution.
- Exploratory Virtual Population Analysis (VPA) runs to evaluate the influence of input data revisions (i.e. exclusion of the ITQ index, revised ageing for 1985-1989, use of 2 cm groupings, inclusion of a small mesh category), truncating the CAA time series (i.e. 1985-2013 vs. 1970-2013), and the effects of removing mixed stock (i.e. 5Zjm and 4X5Y) Haddock catches near the 4X5Y NAFO boundary line.

The main conclusions from the data input review (also summarized in Stone and Hansen 2015) are provided below.

Commercial Fishery

- The current 4X5Y Management Area is appropriate for this stock; there is no new information to indicate otherwise.
- Landings have been less than 4,000 t (below the Total Allowable Catch, TAC) since 2012, and have been taken mainly by small otter trawlers (Tonnage Class (TC) 1-3, 80%), followed by longline (20%). The share taken by longline has declined since 2011.
- Most landings currently come from Scotian Shelf statistical Unit Areas 4Xn and 4Xp during the 1st and 3rd quarters; a general seasonal/geographic pattern in areas fished has evolved to reduce Cod bycatch.
- Haddock landings from the mixed stock area in 4Xp south (i.e. within 5 nautical miles north of the 4X5Z NAFO Area line) were as high as 1,350 t and 2,400 t in 2005 and 2007, respectively, but have declined to low levels in recent years.
- Past occurrences of high catches in 4Xp south may reflect periods when above average year classes from the eastern Georges Bank stock (i.e. 2000, 2003) expanded into the Fundian Channel and were captured in 4Xp during the summer/fall fishery.

Fishery Catch at Age (CAA), Weight at Age (WAA), and Length at Age (LAA)

- The CAA time series was re-calculated using 2 cm groupings for 1985-2010 and revised age determinations for 1985-1989, and it is now considered to be more consistent in terms of the approach used.
- Revised fishery WAA did not have the precipitous drop in WAA values for Ages 9 and 11, which occurred in the old series from 1987-1988; the revised series continues to show a declining trend from 2000-2008, then levels off.

DFO Summer Survey

- Survey indices, WAA and LAA were recalculated for Scotian Shelf (470-481) and Bay of Fundy Strata (482-495) and then combined.
- The main areas of Haddock abundance were on Browns, Baccaro and LaHave banks; there was an increase in biomass in the Bay of Fundy in the 1980s and 1990s followed by a decline in the 2000s.
- There has been a decline in survey WAA for Ages 5 and older beginning in the early 1980s, similar to the trend in fishery WAA. Current stock productivity is lower now compared to the past.

- Von Bertalanffy growth model parameters indicate that Haddock from Bay of Fundy Strata grow faster and attain a larger size than Haddock from Scotian Shelf Strata.
- There has been a temporal shift in the size at 50% mature for both sexes such that fish are currently maturing at smaller sizes in the recent period (2011-2014) compared to the early part of the time series (1979-1986). Haddock Age 4+ will continue to be used as a proxy for spawning stock biomass.
- Fulton's K has been declining since 1990; more rapidly for Bay of Fundy Haddock.
- There has been an improvement in age structure since the late 1990s (increase in Age 6+).
- Indications from 2013 and 2014 surveys are that the 2013 year class is the strongest in the 44 year time series.

Observer Coverage and Bycatch

- Observer coverage for directed Haddock trips over the past 10 years has averaged approximately 4% for mobile gear and approximately 2% for fixed gear, too low for estimating bycatch rates.
- Discard estimates are low in Haddock directed and non-directed fisheries; dogfish, Lobster, and skates are the primary discarded species.

Exploratory Virtual Population Analysis (VPA) Model Comparisons

- Removing the ITQ Survey series as a tuning index had a small influence on estimates of Age 1 recruitment, Age 4+ biomass and Ages 6-9 fishing mortality for the recent period up to 2010. The ITQ Survey has been discontinued as of 2013 and will not be used as a tuning index in future modelling.
- Revisions to the CAA up to 2010 resulted in only minor changes to past estimates of 4+B and 6-9F. The revised CAA has been calculated using a more consistent approach than the previous CAA.
- Removing early years from the CAA time series (1970-1984), which were not re-aged using revised ageing criteria, had no impact on model results. The proposed time series for input data (i.e. fishery and survey CAA, WAA) used for framework modelling will start from 1985.
- VPA analysis using data inputs extended to 2013 illustrated the persistence of the retrospective issue. The various data revisions were not enough to alleviate the retrospective problem and there are other issues with the VPA model that need to be resolved.
- Removing catches and port sample length frequencies (LF)/ages from 4Xp South, an area where 5Zjm and 4X5Y stocks may overlap, particularly when there are strong year classes in 5Z, had little effect on estimates of R, 4+B, and 6-9 F and will not be considered for further analysis.
- Allowing the model to estimate natural mortality (M) on Ages 8+ from 1995 to present indicated that M had increased on older fish in the recent period. Using higher M in the VPA model may help to reduce the retrospective pattern. Further exploration of models that use higher M (i.e. Random Walk M) is recommended.

The second part of the framework review process took place at the Biological Station in St. Andrews, NB, from April 26-27, 2016, and focused on the model(s) used to determine stock status, reference points, risk analysis and the inter-framework assessment strategy. The primary elements of this review include:

- Determining the methodology to estimate the current status of the stock, including methods for estimating stock size and fishing mortality.
- Determining the methodology to characterize stock productivity including reference points for fishing mortality and spawning stock biomass.
- Determining the forecasting methodology for providing advice on harvest levels including the risk of falling below biological reference points.
- Providing guidance on inter-framework review activities, including the procedure and frequency of providing fisheries management advice and events that would trigger an earlier-than-scheduled assessment.

This research document provides an overview of the framework methodology used to provide future assessments of stock status.

FISHERY UPDATE

Commercial Landings

Reported annual landings of 4X5Y Haddock averaged18,500 t during the 1970s and 19,800 t during the 1980s with peaks occurring in the late 1960s and early 1980s (Table 1; Figure 3). Noteworthy is that from 1982-1984, the TAC peaked at 32,000 t, but was quickly reduced to 4,600 t by 1989. In 1991 and 1992, there was no TAC for Haddock under a Management Plan that called for a bycatch fishery only, although landings exceeded 9,000 t during these years (Hurley et al. 2009). The TAC of 8,100 t established for the 12-month fishery in 1999 was extended to 9,800 t for the 15-month period ending March 31, 2000. The fishing year since then has been April 1st to March 31st. Annual landings dropped substantially in the 1990s and 2000s, averaging 6,681 t and 4,260 t, respectively. Since 2010, landings have been below 5,000 t and in 2014 and 2015 they were 2,718 t and 2,789 t,respectively, the lowest in the 40 year time series. The Fishing Year (FY) TAC (FY, April 1st - March 31st) was 7,000 t from 2006-2009, but was subsequently reduced to 6,000 t for FYs 2010/2011 and 2011/2012 and to 5,100 t for FYs 2012/2013 through 2015/2016 (Table 1). Fishing year landings for 2014/2015 and 2015/2016 were 2,825 t and 2,964 t, respectively, well below the TAC.

Since the mid-1970s, the small mobile gear component (bottom trawl, TC 1-3) has accounted for most of the total landings, with the exception of the early 1990s when the percentage taken by fixed gear (longline) was greater (Figure 4; Table 2). The percentage of landings from longline has steadily declined since 1994, whereas the small mobile gear share has increased. Over the past 10 years, small otter trawlers (TC 1-3) have taken an average of about 80% of the catch and longline vessels about 20%. There has been a declining trend in longline catches since 2011, with the 2015 catch representing only 4% of total landings (compared to 96% for mobile gear). Large otter trawlers (TC 4+) contributed 30-40% of total landings in the 1970s but there are few left in the fishery at present (their contribution is currently < 1%). The contribution by the handline and gillnet sectors has also declined to very low levels (< 1%) since the late 1990s.

Since 2010, most landings have occurred during the 1st quarter (44%), followed by the 3rd (24%), 4th (19%) and 2nd (13%) quarters (Table 3). The change to an April-March fishing year in 2000 has led to an increase in the proportion of fish landed during January to March, a seasonal change that has helped to reduce the bycatch of Cod (Hurley et al. 2009). This is also when the Georges Bank fishery for Haddock is closed (i.e. mid-February to May 31st), so there is likely a shift to fishing the 4X5Y stock at this time of year. Over the past decade, about 75% of total landings have been taken from Scotian Shelf Statistical Unit Areas 4Xn and 4Xp (Figure 5). While the increase in 4Xn is largely a result of the winter (January-March) fishery, the increase in 4Xp reflects directing for larger Haddock in the deeper waters of the Fundian Channel where the bycatch of Cod also tends to be lower (Hurley et al. 2009).

Most of the 4X5Y Haddock fishery catch is currently taken on the Scotian Shelf (4Xmnop) by the mobile gear sector followed by fixed gear, with the remainder taken in the Bay of Fundy (4Xqrs5Y) by mobile gear (Table 4; Figure 6). Fixed gear catches from the Bay of Fundy region (4Xqrs5Y) are now very low and there has been an overall decline in catches from this area by both gear sectors since 2005 (Figure 7).

Showell et al. (2013) reported that the distribution of the fishery has changed in the last decade with effort shifting from the Bay of Fundy to Statistical Unit Area 4Xp, which, over the past 10 years, is where about 43% of the total Haddock catches have occurred. Noteworthy is that in 2004, 2005, 2007 and 2009, 14-35% of total annual landings occurred in the southern portion of 4Xp in the Fundian Channel close to the 4X5Z NAFO boundary line (Figure 8). Showell et al. (2013) hypothesized that these fish may be from the eastern Georges Bank (5Zjm) stock, rather than 4X5Y. Stone and Hansen (2015) examined the impact or removing catches and port sample length frequencies/ages from VPA model input data and showed that there was little or no effect on model results (i.e. estimates of Age 4+ biomass, Age 1 recruits and Age 6-9 fishing mortality) when this data was excluded, therefore, it is included in the CAA time series.

Fishery Catch at Age and Length/Weight at Age

The 4X5Y Haddock fishery CAA, WAA and LAA was updated for 2011-2014 and revised for 1985-2010 (see Stone and Hansen 2015 for revision history). For CAA calculations, the length frequencies obtained by port samplers were grouped by Gear (Mobile, Fixed), Season (QTR or Half Year) and Area (Bay of Fundy: 4Xqrs5Y; Scotian Shelf: 4Xmnop). Age length keys were grouped by Area and Season (Qtr or Half Year). Annual length-weight relationships (a's and b's) for Haddock from the DFO Summer survey were calculated separately for Bay of Fundy Strata (482-495) and Scotian Shelf Strata (470-481) and applied to matching sample areas for CAA determinations.

Catch at Age calculations for 2011, 2012 and 2013 included a separate category for Haddock catches from the 4X redfish fishery, which uses a smaller Cod end mesh size (i.e. 100-112 mm diamond mesh) and has a tendency to retain more small fish (i.e. Ages 2-3). Haddock catches from the 4X redfish fishery increased from <1% of total landings in the early 1990s to 8% by 2002, declined to <2% in 2003-2004, then increased steadily reaching 15% in 2012 and 13% in 2013 before dropping off to 6% in 2014 (Figure 9). For 2011-2014, small mesh gear landings of Haddock were 325 t, 623 t, 460 t, and 128 t, respectively. With the exception of 2011-2013, there were too few port samples available to size the small mesh catches in CAA calculations from earlier years and for 2014.

The revised 4X5Y Haddock fishery CAA data for framework modelling includes Ages 1-14 for 1985-2014 (Table 5; Figure 10). This series shows the presence of some recent strong year classes (i.e. 2003, 2010) and a reduction in the catches of Age 2 fish beginning in the early 1990s. The latter coincides with the mandatory use of 130 mm square mesh in 1991, but also there has been a decline in WAA and LAA during this period, which has reduced the partial recruitment/selectivity of this age group (Table 6; Figure 11 and 12). In the 2014 fishery, the 2010 year class at Age 4 (the most recent strong year class) was predominant and represented 42% of the CAA followed by the 2011 year class at 21%. The 2003 year class, which made a significant contribution to the fishery back to 2006, represented only 1% of the 2014 fishery catch at Age 11. Noteworthy is that older fish (Age 10+) continue to appear in the time series right up to 2014.

There have been significant changes in the catch at size by gear type (mobile vs. fixed) and area (Bay of Fundy vs. Scotian Shelf) over the 30 year time period (1985-2014), which could contribute to changes in selectivity and partial recruitment to the fishery (Figure 13). Not only are Haddock captured in the recent period (2010-2014) considerably smaller than they were in the past, but the contribution from the fixed gear sector, which generally captured larger fish than mobile gear, has greatly diminished, especially from the Bay of Fundy. Catches by mobile gear from the Bay of Fundy have declined as well, so that the fishery is now largely conducted on the Scotian Shelf by this sector.

A revised time series of fishery mean weights at age (WAA, kg) and lengths at age (LAA, cm) for 1985-2014 was calculated from the catch at age application (Table 6; Figure 11 and 12). The weighting of WAA is done internally in the CAA workspace. Separate ALK's are used for Scotian Shelf and Bay of Fundy samples to generate numbers at age (NAA), which are then used for weighting the calculations of the overall fishery WAA. Both series indicate a declining trend in WAA and LAA from the early 1990s to mid-2000s and then either show a modest increase or leveling off in the recent period. While it is not clear what caused the declining trend over this time period, the effect on stock productivity is significant and has been discussed in previous assessments (Hurley et al. 2009; Mohn et al. 2010).

DFO SUMMER RESEARCH VESSEL (RV) SURVEY UPDATE

Catch Distribution, Indices of Abundance, Length/Weight at Age

DFO has conducted a stratified random bottom trawl survey of the Scotian Shelf and Bay of Fundy every summer since 1970. Over the 45-year DFO Summer survey time series (1970-2015), the main areas of Haddock abundance have been on Browns Bank, Baccaro Bank and the outer Bay of Fundy area. In the 1980s and 1990s, there was an increase in biomass in the Bay of Fundy, followed by decline in the 2000s that persists to 2015 (Figure 14).

Due to differences in growth rates (Hurley et al. 1998), the total biomass index is calculated separately for the Bay of Fundy (Strata 482-495) and western Scotian Shelf (Strata 470-481) for 1970-2015 (Figure 15). While both indices show high variability over the time series, the general pattern is one of decreasing biomass from the mid-1980s to mid-1990s, followed by a period of increasing biomass through the late 1990s to the early 2000s, lower biomass from 2004-2013, after which it increases (Table 7; Figure 16). The total biomass index has been below the long term mean for the western Scotian Shelf since 2011 and for the Bay of Fundy since 2003. Scotian Shelf Strata have accounted for approximately 64% of total biomass since 2006. In 2015, the total biomass estimate for the Bay of Fundy was 32,200 t (1970-2015 mean: 21,800 t) and for the Scotian Shelf it was 37,600 t (1970-2015 mean: 33,500 t). The total biomass index in 2015 for both areas combined was 70,000 t.

The age-specific indices of abundance (total numbers at age) for 1970-2014 were calculated separately for Bay of Fundy Strata (482-495) and western Scotian Shelf Strata (470-481) and then combined to generate the indices of abundance for the entire 4X5Y management area (Strata 470-495) (Table 8). Since the early portion of the series was not re-aged, only data from 1985-2014 will be used as a tuning index in VPA modelling (Figure 17). During the late 1980s, there was a period of diminished numbers at age for all ages that persisted until the early 1990s. The abundance at age increased from 1995-2002, especially for Ages 1-5, and was followed by an overall improvement in age structure, with increased abundance of Ages 6+ up to about 2011. The 2003, 2006, and 2010 year classes all appear to have been moderately strong, with indications that the 2013 year class (Age 1 in 2014) is the strongest in the time series. In 2014, Ages 1-4 made up most of the survey catch (the 2013, 2012, 2011, and 2010 year classes) and represented 77%, 7%, 6%, and 6% of the survey CAA, respectively.

DFO Summer survey mean weight at age (WAA, kg) and mean length at age (LAA, cm) for 4X5Y Haddock was calculated separately for Bay of Fundy and western Scotian Shelf Strata, then combined after weighting using total abundance at age for each area (Tables 9 and 10). The revised survey WAA time series for 1985-2014 is used for calculations of beginning of year biomass after applying the Rivard back-calculation method. Similar to the trends observed for the commercial fishery, the DFO Summer survey values for mean WAA and LAA show a decline from the early 1990s to the mid-2000s then level off or show a modest increase (Tables 9 and 10; Figures 18 and 19).

A comparison of 4X5Y Haddock mean WAA for Ages 3, 5, 7, and 9 from the commercial fishery and the DFO Summer survey indicates a higher mean weight at Age 3 in the fishery compared to the survey, with diminishing differences as age increases (Figure 20). Beginning of year and projected Age 4+ (spawning stock) biomass calculations use DFO Summer survey WAA values, while projected catch yields are based on fishery WAA.

DATA FEATURES THAT MODELS NEED TO FIT/EXPLAIN

FISHERY AND SURVEY CATCH AT AGE

The Coefficient of Variation (CVs) values for 1985-2014 Bay of Fundy and Scotian Shelf combined fishery catch at age are shown in Table 11. CVs were generally less than 30% for the younger ages (1-10). There was considerable uncertainty in the estimates of catch at age among some of the older ages (11-16). Considering the small contribution of the older age groups (11-16) to the total fishery catch (ranged from 0.2% to 6.1% by number, 1% to 8% by weight), an age-aggregated 11+ group was used in the model input (Table 5).

The DFO Summer survey catch at age CVs are shown in Table 12. The average CVs were below 30% for Ages 2-10. Considering the higher CVs and zero observations in the older age groups, the survey catch at age 1-10 was used as abundance indices (Table 8).

FISHERY SELECTIVITY CHANGES

The spatial distribution of the 4X5Y Haddock fishery has changed in the last decade with effort shifting from the Bay of Fundy to the western Scotian Shelf. Most landings currently come from Scotian Shelf Unit Areas 4Xn and 4Xp (Figure 5). The change to an April-March fishing year in 2000 resulted in an increase in the proportion of fish landed during January to March. The proportion of the landings from mobile and fixed gear has also changed since the mid-1990s with fixed gear catches currently representing < 10% of total landings (Figure 4). A reduced price for Haddock and the inability to avoid Cod bycatch has likely contributed to the decline in catches from the longline gear sector. Changes in the geographic and seasonal distribution of the fishery as well as in the proportion of catch by gear type have likely affected fishery selectivity over time (Figure 13). The length and age composition of Haddock show differences between gear sectors, with more older, larger fish captured by longline compared to mobile gear (Figures 19-21; Stone and Hansen 2015); however, the contribution from fixed gear has greatly declined in recent years.

Clark (2014) proposed a method to calculate the ratio of selectivity of two fisheries or surveys at each age or length directly from the age or length composition data. This method calculated a relative value of fishery selectivity and survey selectivity. Under the assumption of no temporal changes in survey selectivity, these values could be used to detect temporal changes of fishery selectivity relative to the survey. Results using data from the fishery and RV survey CAA from 1985-2013 indicated a flat relative fishery selectivity for the post-1994 period, while the selectivity on older fish (10+) in the pre-1994 period was double that for post-1994 (Figure 1). This information in a model independent framework was used to understand the possible fishery partial recruitment (PR) changes (dome- or flat-shaped PR) and to help determine future model setup.

RELATIVE F AND SURVEY Z

Total mortality (Z) at age was calculated from the DFO Summer survey catch at age. Relative fishing mortality at age (Relative F) was calculated as the ratio of fishery catch at age over the survey catch at age (Figure 22). Relative F has generally declined on younger ages (2-7) in the mid-1990s and again after 2000 for the older ages (8+). However, survey Z on Ages 10+ has not declined and has remained high throughout the time series.

Catch curve analyses were conducted on log-transformed relative abundance data from a cohort in successive years, which removed the confounding effects of differential year class strength on the interpretation of catch curve results. Using Age 5 as the fully recruited age, Figure 23 shows survey Z for Ages 5-9 and Ages 10-14 and Relative F from a cohort in successive years for the same age groups. Relative F on both age groups dropped significantly around the mid-1990s, while Z on the older age groups (10-14) has stayed at even higher levels.

Discarding and high-grading of Haddock appeared to be negligible (Hurley et al. 2009) because catches have been lower than the TAC since 2005. Based on the above analysis, there may be factors other than the fishery contributing to population dynamics.

POPULATION MODEL: VIRTUAL POPULATION ANALYSIS (VPA) WITH RANDOM WALK IN NATURAL MORTALITY (M)

In order to address retrospective patterns and other data and model fit issues, a VPA model with time-varying natural mortality (M) was fit to 4X5Y Haddock data. This model was used to determine when M increased (in time) and which age groups were affected. Simulation tests of these VPA models for eastern Georges Bank and southern Gulf of St. Lawrence Cod indicated that they resulted in reliable conclusions about changes in M (Swain 2013, Swain and Benoit 2015).

For 4X5Y Haddock, the data inputs to this model were fishery catch at age for Ages 1-11+ (1985-2014) and DFO Summer survey swept area abundance indices for Ages 1-10 (1985-2014). Zero observations for abundance indices were treated as missing data. In this model, independent time series of M were modelled as a random walk for different age groups,

$$M_{j,1985} = Minit_j \qquad (1)$$

$$M_{j,y} = M_{j,y-1} e^{Mdev_{j,y}} \quad \text{if } y > 1985 \qquad (2)$$

where *j* is the age group, *y* is the year. $Minit_j$ is the M for age group *j* at first year (1985).

Based on the analysis for possible fishery selectivity changes, F on the Age 11+ group (F_{11+}) was assumed equal to 2 times F on Age 10 (F_{10}) for 1985-1994, and F_{11+} was set equal to F_{10} for 1995-2013. $Minit_j$, $Mdev_{j,y}$, survey catchability at age, and terminal year (2015) population abundance at age were the model parameters. These parameters were estimated by minimizing an objective function with the following components:

1. a component for the discrepancy between observed and predicted values of the abundance indices at age, which were assumed to be log-normally distributed;
2. a penalty for departures of $Minit_j$ from its prior value (normal priors for $Minit_j$ were set at mean of 0.2 and a standard deviation of 0.05 for all the age groups); and
3. a penalty for departures of $Mdev_{j,y}$ from its prior value. A normal prior for $Mdev_{j,y}$ was set at a mean of 0 and a standard deviation of 0.05. For model details, see Swain (2013).

Three models with trends in M were estimated separately for different age groups:

A. 2 M age groups: 1-3 and 4+;

B. 3 M age groups: 1-3, 4-6, and 7+;

C. 4 M age groups: 1-3, 4-6, 7-9, and 10+.

The results from the three model runs suggested:

A. Estimated M for Ages 1-3 was about 0.2, but estimated M for Ages 4+ started to increase from 2000 and stayed at a higher level of 0.4 from 2005 onwards.

B. Both the estimated M for Ages 1-3 and 4-6 were around 0.2 with no significant trend, but M for older Ages 7+ showed a clear increase from 2000 and stayed at a higher level of 0.6 from 2005 onwards.

C. Estimated M for the 3 younger age groups 1-3, 4-6, and 7-9 were relatively stable and stayed around 0.2, but M for older Ages 10+ were greater and estimated as about 0.27 in the early years, then increased since 2000 and reached a higher level of 0.8 in most recent years (Figure 24).

There was no obvious temporal pattern in the residuals from model C (Figure 25); however, some cohort patterns exist. There was still a retrospective pattern for SSB (4+) and F (Figure 26), but it was greatly improved compared with the past model retrospective and residual patterns (Figures 2 and 27).

POPULATION MODEL: VPA WITH M IN AGE AND TIME BLOCKS

The adaptive framework, ADAPT (Gavaris 1988), was used for calibrating VPA with the trends in abundance from the DFO Summer survey. The model input data was the same as the random walk of M models. Fishing mortality on the plus group (F11+) was set up using the F_{ratio} method in ADAPT. Based on the results from the random walk of M model, M was fixed at 0.2 for all the ages and years except for the Ages 10-11+ after 2000. The M for Ages 10-11+ was estimated by three 5-year time blocks beginning in 2000. The three time blocks were for years 2000-2004, 2005-2009, and 2010-2014. Other model parameters included survey catchability at age for Ages 1-10 and terminal year population abundance at age for Ages 2-11+. All the parameters were estimated by minimization of the discrepancy between observed and predicted values of the abundance indices at age, which were assumed to be log-normally distributed. Statistical properties of the estimators were determined using conditional non-parametric bootstrapping of model residuals (Rivard and Gavaris 2003).

Natural mortality was estimated as 0.26 with CV of 30%, 0.62 with CV of 8%, and 0.9 with CV of 8% for years 2000-2004, 2005-2009, and 2010-2014, respectively. Based on the above analysis, a VPA model with M fixed at 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014) was recommended as the framework model for 4X5Y Haddock. The model residuals (Figure 28) have similar patterns to the random walk M model. Some of the stronger cohorts at younger ages were underestimated by the model. Survey catchability started at 0.5 for Age 1 and gradually increased to around 1.0 at the fully recruited Age 4 with a relatively flat topped selectivity for the older ages (Figure 29). The retrospective analysis still showed some minor retrospective patterns. For the most recent 3 years, the model tended to overestimate the biomass and underestimate F when each year of data was peeled off (Figure 30).

The calculated F (population number weighted average over Ages 6-10) is shown in Figure 31 and Table 13. The model results showed high fishing mortality early in the time series until about 1998, after which fishing mortality remained low, and was estimated at 0.08 in 2014. Spawning stock biomass (4+) decreased from 42,000 t in 1985 to 20,000 t in 1990, and started to increase in 1996 due to the contribution of the strong cohorts of 1993, 1994, 1998, 1999 and 2000; the estimated SSB at the beginning of 2015 was 27,000 t (Figure 32 and Table 14). Preliminary estimates for the 2013 year class at Age 1 were extraordinarily high for this stock at 317 million recruits.

REFERENCE POINTS

The terms of reference for the 2016 framework for 4X5Y Haddock requested the estimation of a removal fishing mortality reference (F_{ref}) and a biomass limit reference point (B_{lim}). The output data from the VPA formulation with M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively) was used for reference point calculations. Although errors in aging are likely in the earlier time period in the fishery and survey age samples (1970-1984), the productivity during this period appears high based on the research survey biomass index trends (Figure 16). Ignoring this period of higher productivity information could have significant implications on reference point calculations. Therefore, a trial VPA run including the earlier time period (1970-1984) fishery and survey data was conducted. The survey abundance time series was split in 1985 in order to reduce the impact of the ageing error in the earlier period (1970-1984) on the recent period (1985-2014) population abundance estimate. The Ages 4-10 biomass from the “model predicted” and “survey observed” were compared, and the fit was deemed acceptable (Figure 33). The SSB and recruitment data from this run was then used as sensitivity run for the reference points calculations.

F_{REF}

For the harvest strategy to be compliant with the DFO Precautionary Approach, F_{ref} is the maximum acceptable removal rate for the stock and is adjusted depending on the stock's status. For 4X5Y Haddock, the proxy $F_{0.1}$ or $F_{40\%}$ = 0.25 was the current F_{ref} that was derived using output data from an earlier assessment. For the new proposed framework model, and considering the significant changes in fishery selectivity, growth and natural mortality since 2000, the average of the most recent 15 years (2000-2014) of PR, natural mortality, fishery weight at age, spawning stock weight at age and maturity at age were used for the per recruit analysis (Table 15). $F_{0.1}$ was calculated as 0.44 and $F_{40\%}$ as 0.4, which are much greater than 0.25. Changes in M on the Ages 10-11+ potentially caused this difference. For the per recruit analysis, M only impacts the trade-off between the gains from leaving fish in the water to grow bigger versus the losses of fish over time due to natural mortality. However, when there is a positive stock-recruitment (SR) relationship, per recruit analyses will tend to overestimate F_{ref} since it does not consider the relationship between conserving biomass in the water to increased recruitment and yield in the future (sustainable recruitment) (Duplisea 2012). Several studies have demonstrated that using reference point estimates that do not incorporate variation in recruitment are likely to result in unexpected population declines or even collapse when productivity is low (Brooks 2013, Morgan et al. 2014).

Fishing mortality at Maximum Sustainable Yield (F_{msy}) has been internationally accepted as the limit of F_{ref}. The Sissenwine-Shepherd age structured production model (Sissenwine and Shepherd 1987), which incorporates a stock-recruitment relationship with the per-recruit results, was applied to 4X5Y Haddock. F_{loss}, the fishing mortality under which the replacement line gives an equilibrium at the lowest observed spawning stock biomass, has been suggested as a proxy for F_{crash} (Cook 1998; O'Brien 1999), and was calculated here for 4X5Y Haddock. It is known that Haddock recruitment events are highly episodic and not well described by traditional stock recruitment relationships. Considering the importance of model uncertainty on reference point calculations, a range of parametric and non-parametric SR models were compared: Ricker, Beverton-Holt (B-H), Hockey Stick (HS), and LOESS smoother (Cleveland 1979).

The estimated proxy values for F_{ref} are shown in Table 16 and Figures 34-38. The Ricker model estimated F_{msy} at 0.25 and F_{loss} at 0.29 using the long time series SR data (1970-2014). However, with fitting the shorter time series data (1985-2014), the F_{msy} was estimated as high as 0.6 with estimated SSB_{msy} below the lowest observed SSB (Table 16 and Figure 34), which was not considered precautionary and 0.6 was not valid as F_{ref}. For the B-H model, the profile likelihoods and likelihood surfaces showed that the SR parameters and hence the corresponding production model reference points were not well determined (Figure 35). For the HS model, an iterative grid search method was used for parameter estimation (O'Brien et al. 2003) and calculated F_{msy}=F_{crash}=0.3 (Table 16 and Figure 36). For the LOESS smooth model, there can be large uncertainties with the selection of the LOESS smooth parameter so the joint probability of F_{loss} under different smoothing parameter values was calculated. For the current F_{ref}=0.25, there was a 25% probability that this value would exceed F_{loss} (Figure 37).

Sissenwine and Shepherd (1987) suggest when SR relationships are poorly determined, an alternative reference point based on SR data, F_{rep}, can be found by finding the fishing mortality rate that produces a replacement line with a slope that equals the average survival ratio. F_{rep} could be estimated from the median survival ratio (F_{median}). For 4X5Y Haddock, the estimated F_{median}=0.15 (Table 16, Figure 38), which is the level of fishing mortality where recruitment has been more than sufficient to balance losses to fishing mortality in half the observed years (Gibson and Myers 2003). However, the current F_{ref}=0.25 corresponded to a replacement line where only 35% of the observed years of R/S were above this line (Figure 38), which means that at this level of fishing, it was expected the stock would be fished below the average level.

F_{ref} is used in fishery management as a tool to help ensure that removals are at a level that can be sustained by the population.

Despite the uncertainties with the estimate of F_{ref} for 4X5Y Haddock (Table 16), the framework meeting participants agreed that F_{ref} of 0.25, an estimated F_{msy} value from the Ricker model with a 25% probability exceeding F_{loss} based on LOESS analysis, would be a removal fishing reference when the stock is in the Healthy Zone. However, the current estimated population biomass is at low levels compared to the historic data. F_{median} = 0.15 from the replacement line analysis was suggested as a more appropriate target for 4X5Y Haddock in the Cautious Zone.

B_{LIM}

According to the DFO precautionary approach, B_{lim} is the stock level below which productivity is sufficiently impaired to cause serious harm to the resource.

At the 2002 National Workshop on Reference Points for Gadoids (DFO 2002), five computational methods were considered for defining limit reference points in terms of SSB. These five methods were (DFO 2002, p. 10):

$B_{recover}$: the lowest historical biomass level from which the stock has recovered readily.

$Sb_{50/90}$: the SSB corresponding to the intersection of the 50th percentile of the recruitment observations and the replacement line for which 10% of the stock-recruitment (S-R) points are above the line.

BH_{50}: the SSB at which expected average recruitment is one half of the maximum recruitment predicted by assuming an underlying B-H stock-recruit relationship (i.e. the recruitment that is 50% of the value at the asymptote).

RK_{50}: the lower SSB at which expected average recruitment is one half of the maximum recruitment predicted by assuming an underlying Ricker-type stock-recruit relationship (i.e. the recruitment that is 50% of the value at the peak of the dome).

NP_{50}: estimate of the lowest SSB where the expected median recruitment is one half of the maximum recruitment calculated by non-parametric analysis (i.e. the recruitment that is 50% of the largest median recruitment achievable at any SSB within the range of historic observations).

At the workshop it was felt that a comparison amongst the five B_{lim} candidates provided some insight into the certainty of advice. These methods were applied to the full 4X5Y Haddock stock-recruitment data time series (1970-2014).

For 4X5Y Haddock, BH_{50} was not well defined (Figure 35). NP_{50} was not considered for the LOESS smoother model due to the uncertainties of model fit. RK_{50} was estimated as 9,564 t and $Sb_{50/90}$ was calculated as 15,866 t for this stock, both using the longer time series of SR data (Figure 39). However, the two values were below the lowest observed biomass of 16,800 t in 2012. For resources that are considered fully exploited, B_{lim} proxies that are lower than the lowest observed biomass may not be consistent with the intent of the precautionary approach. B_{lim} is defined as the biomass level below which serious harm is occurring and secure recovery cannot be achieved. From the biomass history, the 4X5Y Haddock stock has been exposed to full exploitation over an extended time series and has recovered from a low level, 19,700 t in 1994 ($B_{recover}$, Figure 40).

At the Framework meeting, it was agreed that the poor stock recruit relationship precludes the calculation of an appropriate B_{lim}, so $B_{recover}$ (19,700 t) was recommended as a lower reference. In this context, $B_{recover}$ is defined as the lowest point on record from which the stock has recovered readily, but it is not necessarily the lowest level from which recovery is possible (B_{lim}). It is therefore a more conservative reference point than B_{lim}.

PROJECTION AND RISK ANALYSIS

The terms of reference for this framework also requested determining the forecasting methodology for providing advice on harvest levels including the risk of falling below biological reference points. The 4X5Y Haddock age-structured fishery and survey information were updated to 2014. Beginning of terminal year (2015) population abundance was estimated from the proposed three 5-year block (2000-2004, 2005-2009, and 2010-2014) VPA model. The projection and risk analysis shown here is only to illustrate how this outlook can be provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2016 and 2017 had they been pursued in 2015. Uncertainty about current biomass generates uncertainty in forecast results, which was expressed here as the risk of exceeding the proposed limit F_{ref}=0.25 in 2016 and 2017, and the probability of adult biomass changes relative to 2016 and to 2017.

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, and/or retrospective bias. These projections assume that the current productivity conditions will persist over the projection period. The most recent 5 year average of fishery weight at age, beginning of year population weights at age and fishery PR, as well as the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class), were used as inputs for the projection (Table 17). The catch in 2015 was assumed to be equal to the 5,100 t quota.

Illustrative projections were conducted to evaluate the differences in stock status and catch levels using different harvest strategies. Deterministic projections under a constant quota of 5,100 t are summarized in Table 18. A stochastic projection to provide the risk of F in 2016 exceeding F_{ref} = 0.25 under different catch levels and that risk that the 2017 biomass would not increase by 20% compared to 2016 are shown in Figure 41. The absolute size of the 2013 year class was the largest source of uncertainty in this exercise. As the projection horizon increases, the contribution of the 2013 year class becomes more important. Therefore, another sensitivity projection was conducted by assuming the 2013 year class recruitment equals the second largest recruitment in the history at 52 million. The deterministic and stochastic results for this sensitivity projection are shown in Table 19 and Figure 42.

GUIDANCE ON INTER-FRAMEWORK REVIEW

Haddock stocks are known for dramatic changes in recruitment. The fishery PR used in the projection was 0.2 for Age 3 and 0.5 for Age 4. The assumptions on the strength of upcoming year classes will have significant impacts on stock size and catch advice in the multi-year projections. The following approach for the years between frameworks is proposed:

A two year projection, based on the VPA results, using the most recently available survey and fishery information will be conducted in the full assessment year. The catch advice in the following year will be based on the first year projection.

For the second year, science will provide catch advice based on an interim stock status update, which will be reported as a CSAS Special Science Response. This report will be created by comparing the projections from the full assessment with the updated fishery and survey information, which includes total fishery catch and swept area survey biomass. If age-structured survey and fishery information is available, the document will include a comparison of the strong year classes to the proportion expected from the projection and will monitor possible growth changes. The format is shown in Appendix 1.

For the third year, 2018, the random walk model will be re-run to ensure the M estimates from the framework are still valid. If the M estimates are similar, VPA will be run using an 8 year block (2010-2018) for the most recent years and another 2-year projection will be created. The catch advice for the third year will be based on this projection and reported as CSAS Science Response.

For the fourth year, a similar approach to the second year will be used.

At the framework meeting, it was agreed that the above schedule will be followed unless the following triggers for a full assessment occur:

A difference in strong year class projected versus realised. In this case, if the perception of 2013 year class strength goes below the second highest observed year class, (i.e. below the value used for sensitivity analysis (1999 year class) and outside the range of sensitivity projections), then a more complete review will be conducted.

Low survey biomass trigger (Suggested a 3 year running q adjusted average below B_{lim}) using the previous year's q values.

RESEARCH RECOMMENDATIONS

The high M used in the recommended framework model could be aliasing fish moving to adjacent areas or deeper waters where the fishery or survey cannot catch them. Noteworthy is that the adjacent Haddock stock on Eastern Georges Bank also shows high Z on older (Age 8+) fish (Stone et al. 2015). Research on a possible mechanism for high M on older ages would help to understand the population dynamics of 4X5Y Haddock. In addition, research on changes in growth/productivity over time and factors influencing the production of exceptionally strong year classes would also be helpful.

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TABLES

Table 1. Reported annual and fishing year catch (t) of Haddock from NAFO Division 4X, 1970-2015. Canadian landings include 5Y. FY: Fishing Year; TAC: Total Allowable Catch.

Year	Catch	TAC	FY Catch[1]	FY TAC[1]
1970	18,072	18,000	-	-
1971	17,592	18,000	-	-
1972	13,483	9,000	-	-
1973	13,106	9,000	-	-
1974	13,378	0	-	-
1975	18,298	15,000	-	-
1976	17,498	15,000	-	-
1977	21,281	15,000	-	-
1978	27,323	21,500	-	-
1979	25,193	26,000	-	-
1980	29,210	28,000	-	-
1981	31,475	27,850	-	-
1982	25,729	32,000	-	-
1983	27,405	32,000	-	-
1984	21,156	32,000	-	-
1985	16,131	15,000	-	-
1986	15,555	15,000	-	-
1987	13,780	15,000	-	-
1988	11,272	12,400	-	-
1989	6,800	4,600	-	-
1990	7,556	4,600	-	-
1991	9,826	0	-	-
1992	10,530	0	-	-
1993	6,968	6,000	-	-
1994	4,406	4,500	-	-
1995	5,669	6,000	-	-
1996	6,245	6,500	-	-
1997	6,527	6,700	-	-
1998	7,843	8,100	-	-
1999	6,621	8,100	9,291	9,800
2000	6,961	-	7,761	8,100
2001	8,466	-	7,411	8,100
2002	7,997	-	7,930	8,100
2003	8,706	-	8,617	8,100
2004	6,553	-	5,964	10,000
2005	5,633	-	5,142	8,000
2006	4,746	-	4,687	7,000
2007	6,876	-	6,767	7,000
2008	5,372	-	5,684	7,000
2009	5,504	-	5,831	7,000
2010	5,663	-	5,379	6,000
2011	3,733	-	4,467	6,000
2012	4,127	-	3,323	5,100
2013	3,518	-	3,393	5,100
2014	2,718	-	2,825	5,100
2015	2,789	-	2,964	5,100

[1] Fishing year in 1999 was extended to March 3, 2000. TAC prorated upwards. Subsequent fishing years begin on April 1st.

Table 2. Reported annual catch (t) of Haddock from NAFO Division 4X5Y landed in the Maritimes by gear type and tonnage class, 1970-2015. MG = mobile gear tonnage class 1-3 and 4+, LL = longline, HL = handline, GN = gillnet, TC = tonnage class.

Year	MG[1] (TC 1-3)	MG (TC 4+)	LL	HL	GN	Misc[2]	Total of Gear Categories
1970	5,519	6,503	2,961	539	88	402	16,012
1971	4,743	7,716	3,227	456	79	183	16,404
1972	2,942	4,755	4,048	498	59	268	12,570
1973	1,929	4,233	5,853	377	143	145	12,680
1974	4,113	1,628	6,211	258	166	58	12,434
1975	6,183	4,406	4,944	275	176	75	16,059
1976	4,390	6,157	4,642	714	389	46	16,338
1977	6,290	8,346	4,032	411	337	177	19,593
1978	9,588	8,099	6,072	865	573	198	25,395
1979	10,293	8,638	4,349	838	399	63	24,580
1980	13,131	7,444	5,723	1,281	797	228	28,604
1981	14,912	6,649	7,008	923	856	17	30,365
1982	11,960	3,122	6,763	875	814	31	23,565
1983	12,988	2,560	7,787	786	664	56	24,841
1984	12,081	615	6,307	492	183	4	19,682
1985	10,244	563	4,028	336	110	33	15,314
1986	9,854	209	4,875	469	88	13	15,507
1987	8,177	511	4,572	286	215	3	13,763
1988	7,269	377	3,356	126	81	23	11,233
1989	3,829	90	2,469	221	158	27	6,794
1990	3,329	110	3,391	396	278	0	7,504
1991	4,182	206	4,588	539	257	1	9,772
1992	3,469	258	5,587	974	215	5	10,508
1993	2,632	123	3,227	865	100	1	6,947
1994	2,081	97	1,578	600	48	2	4,405
1995	3,062	106	2,171	250	69	2	5,660
1996	3,685	151	2,053	298	50	0	6,237
1997	4,238	65	2,066	110	58	0	6,538
1998	5,155	80	2,461	141	50	0	7,887
1999	4,475	120	1,955	40	31	0	6,621
2000	4,129	105	2,670	29	28	0	6,961
2001	6,140	88	2,227	11	21	0	8,486
2002	5,630	37	2,252	55	23	0	7,997
2003	6,616	29	2,008	26	26	0	8,706
2004	5,376	0	1,140	15	22	0	6,553
2005	4,611	53	950	5	13	0	5,633
2006	3,255	174	1,309	3	6	0	4,746
2007	5,240	50	1,583	0	3	0	6,876
2008	4,185	0	1,176	0	8	0	5,369
2009	4,563	0	933	0	7	0	5,504
2010	4,371	0	1,263	0	4	25	5,663
2011	2,800	22	906	0	4	0	3,733
2012	3,297	38	790	0	2	0	4,122
2013	3,048	46	412	0	2	0	3,518
2014	2,436	23	258	0	1	1	2,718
2015	2,675	0	110	0	4	0	2,789

[1] Mobile gears include all kinds of trawls (e.g. otter, midwater, shrimp) and pair sSeine.
[2] Miscellaneous gears include trap, unknown gears, dredge, jigger, pot, squid jig and weir.

Table 3. Reported commercial Haddock landings (t) by month and quarter from NAFO Divisions 4X and 5Y, 1985-2015 (from ZIF and MARFIS databases).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Qtr1	Qtr2	Qtr3	Qtr4	Total
1985	789	3,898	626	1,000	1,164	2,060	1,599	1,291	1,585	1,096	436	562	5,313	4,224	4,475	2,094	16,106
1986	859	2,913	1,071	481	1,109	1,059	1,262	1,254	2,652	1,613	635	599	4,843	2,649	5,168	2,847	15,507
1987	1,168	2,320	2,085	594	1,363	1,381	961	777	1,458	1,057	347	253	5,573	3,338	3,196	1,657	13,764
1988	2,119	1,523	216	637	808	1,289	876	529	1,697	790	231	503	3,858	2,734	3,102	1,524	11,218
1989	996	1,447	836	371	245	906	485	504	444	330	147	83	3,279	1,522	1,433	560	6,794
1990	1,371	1,262	288	293	429	597	739	640	864	408	309	305	2,921	1,319	2,243	1,022	7,505
1991	1,057	1,361	318	241	542	942	1,086	877	978	742	585	1,042	2,736	1,725	2,941	2,369	9,771
1992	1,519	1,052	366	228	606	1,131	1,297	1,027	1,127	801	529	825	2,937	1,965	3,451	2,155	10,508
1993	361	924	452	316	676	897	909	1,085	797	267	195	69	1,737	1,889	2,791	531	6,948
1994	404	280	139	209	278	692	838	366	421	289	220	268	823	1,179	1,625	777	4,404
1995	539	387	518	230	314	445	697	570	572	492	256	640	1,444	989	1,839	1,388	5,660
1996	396	463	481	282	273	539	659	578	602	699	707	559	1,340	1,094	1,839	1,965	6,238
1997	109	614	572	439	194	395	642	664	899	867	598	544	1,295	1,028	2,205	2,009	6,537
1998	419	939	1,103	650	132	354	743	654	1,042	645	503	705	2,461	1,136	2,439	1,853	7,889
1999	531	526	252	269	324	420	716	976	1,114	587	495	412	1,309	1,012	2,807	1,494	6,621
2000	644	1,129	897	146	325	383	769	745	788	609	344	182	2,670	853	2,302	1,135	6,961
2001	1,371	603	1,496	343	413	389	606	840	942	628	545	292	3,469	1,145	2,388	1,464	8,466
2002	982	670	772	568	361	599	902	936	816	578	428	388	2,424	1,528	2,654	1,394	8,000
2003	809	398	1,190	277	569	323	760	903	1,243	898	832	503	2,397	1,169	2,906	2,233	8,705
2004	340	617	1,351	245	366	228	397	618	855	596	550	391	2,308	838	1,870	1,537	6,553
2005	402	577	741	191	176	178	420	823	875	636	456	157	1,720	546	2,118	1,249	5,633
2006	206	589	435	82	141	390	688	570	706	370	409	160	1,230	614	1,964	939	4,746
2007	278	362	531	284	209	306	313	1,059	1,269	1,384	522	359	1,171	799	2,641	2,264	6,876
2008	150	375	537	288	90	142	413	492	727	1,008	835	314	1,063	520	1,632	2,157	5,372
2009	179	846	350	72	159	288	1,021	488	837	672	349	243	1,375	519	2,346	1,264	5,504
2010	302	860	540	608	183	337	500	588	777	472	319	177	1,702	1,129	1,864	968	5,663
2011	235	886	290	47	122	295	230	353	369	351	310	245	1,411	464	952	906	3,733
2012	820	848	478	95	94	107	149	387	265	255	389	241	2,145	296	801	885	4,127
2013	272	267	802	115	97	130	538	436	241	268	193	158	1,341	342	1,216	619	3,518
2014	143	504	568	237	129	67	104	147	257	179	181	202	1,215	433	508	563	2,718
2015	35	385	903	372	64	124	109	160	295	191	89	62	1,322	559	565	343	2,789

Table 4. Landings (t) of 4X5Y Haddock for mobile and fixed gear aggregated for Scotian Shelf (4Xmnop) and Bay of Fundy (4Xqrs) unit areas used in catch at cge calculations for 1985-2014.

	Mobile		**Fixed**	
Year	**4Xmnop**	**4Xqrs**	**4Xmnop**	**4Xqrs**
1985	5876	5504	4456	259
1986	5255	4826	5308	129
1987	6152	2535	4911	165
1988	5969	1672	3384	309
1989	2796	1118	2803	134
1990	2107	1332	3879	340
1991	2366	2039	5120	266
1992	2143	1582	6107	673
1993	1390	1364	3725	467
1994	740	1438	2044	183
1995	1527	1641	2278	212
1996	1528	2308	2192	210
1997	1661	2642	2090	144
1998	2956	2279	2466	187
1999	2395	2202	1948	78
2000	2406	1828	2526	201
2001	3696	2531	2155	86
2002	2702	2966	2206	138
2003	2830	3816	1949	113
2004	3083	2293	1074	103
2005	3221	1443	873	96
2006	2240	1188	1231	87
2007	4197	1093	1506	81
2008	3346	839	1136	48
2009	3994	569	906	35
2010	3965	429	1212	55
2011	2531	291	876	35
2012	2833	502	780	12
2013	2496	608	397	17
2014	1802	657	251	8

Table 5. Commercial fishery catch at age (000's) for 4X5Y Haddock, 1970-2014. Separate length-weight relationships and age-length keys were applied to landings and catch at size for unit areas 4Xmnop and 4Xqrs5Y. CAA data from 1985-2014 is used for framework modelling.

	Age																
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**% of 11+**
1970	0	1088	747	1549	391	541	4679	1922	137	99	181	28	38	0	0	0	2%
1971	0	809	1660	809	1460	415	71	3404	1047	167	186	150	108	0	0	0	4%
1972	42	22	3490	1871	517	656	91	58	1185	520	26	196	93	0	0	0	4%
1973	152	3114	114	2274	1080	533	607	326	262	621	56	13	6	0	0	0	1%
1974	1	713	4783	318	1829	523	194	277	191	277	567	25	4	0	0	0	6%
1975	37	2198	4617	5220	490	1115	250	174	63	32	167	231	11	0	0	0	3%
1976	18	1306	1657	4295	3712	437	813	155	72	96	39	104	158	0	0	0	2%
1977	2	1289	3137	2026	3204	2891	361	390	107	72	23	8	87	0	0	0	1%
1978	0	77	3453	7221	2156	2916	1071	141	110	27	9	6	49	0	0	0	0%
1979	0	83	1184	6862	3970	1094	1272	269	58	70	11	1	18	0	0	0	0%
1980	16	164	2497	3071	5527	3573	538	636	173	35	21	3	10	0	0	0	0%
1981	1	1210	2268	6369	4300	3272	1191	366	331	99	14	24	9	0	0	0	0%
1982	0	526	3895	2648	4954	1823	1560	364	196	101	48	17	15	0	0	0	0%
1983	0	70	3621	6020	4104	2454	1033	434	206	131	76	27	27	0	0	0	1%
1984	2	763	1195	5046	3708	2583	1022	367	119	83	39	22	13	0	0	0	0%
1985	3	769	3778	1285	3844	1419	684	472	397	277	111	42	19	16	6	0	1%
1986	0	547	1466	3981	1781	2660	689	383	283	112	68	38	21	6	2	0	1%
1987	0	156	951	1256	3273	1252	2227	581	224	212	53	38	20	3	2	2	1%
1988	9	172	468	933	905	1839	841	947	421	245	161	56	39	23	8	4	4%
1989	0	118	461	457	825	358	836	433	476	222	80	65	33	14	4	0	4%
1990	0	314	1280	385	373	550	424	734	307	229	84	51	10	10	3	1	3%
1991	1	45	1053	2509	644	356	380	278	339	291	129	149	62	16	4	6	6%
1992	30	199	261	2699	2358	214	241	351	236	234	130	158	31	8	2	0	5%
1993	0	135	741	566	1814	1143	192	98	74	48	60	48	12	8	1	0	3%
1994	8	154	448	689	302	950	255	21	13	14	19	14	5	0	0	1	1%
1995	1	56	835	836	659	295	534	371	144	24	26	18	10	11	4	2	2%
1996	0	29	990	1084	672	428	350	467	377	130	15	1	2	1	1	3	1%
1997	0	19	578	1810	1049	457	268	146	117	108	36	8	1	0	0	1	1%
1998	0	43	143	1153	1841	1203	592	380	174	169	114	34	2	5	5	1	3%
1999	0	38	464	563	1237	942	598	230	55	49	54	25	5	0	0	0	2%
2000	0	253	456	836	561	1328	930	558	223	114	36	8	11	7	5	0	1%
2001	0	100	1654	1053	776	646	1326	923	379	124	25	16	4	15	0	0	1%
2002	1	43	511	2557	710	489	494	737	527	232	111	42	7	0	0	0	2%
2003	0	25	710	1530	2889	648	366	280	249	133	51	21	11	0	0	0	1%

	Age																
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**% of 11+**
2004	0	12	247	940	1207	1818	601	290	229	162	64	43	20	6	0	0	2%
2005	1	36	70	493	1509	1166	965	335	111	90	76	29	1	0	0	9	2%
2006	0	36	806	256	702	1000	868	585	193	27	50	12	10	4	0	0	2%
2007	0	206	421	3855	296	462	792	563	391	142	39	16	5	1	0	0	1%
2008	0	96	328	597	2179	352	382	689	484	261	90	33	35	1	0	0	3%
2009	4	31	372	505	589	1772	418	256	406	238	169	34	9	4	0	0	5%
2010	0	14	73	585	541	734	1837	369	170	347	161	106	17	18	0	0	6%
2011	3	68	85	284	877	422	625	794	176	73	31	30	38	5	0	0	3%
2012	8	289	307	279	272	1016	410	569	702	200	56	90	32	10	17	0	5%
2013	35	315	1721	512	240	194	468	320	140	288	106	16	21	8	3	0	4%
2014	3	314	724	1422	325	123	120	159	112	35	35	8	1	2	0	1	1%

Table 6. Commercial fishery mean weight at age (kg) for 4X5Y Haddock, Ages 1-16, 1970-2014. Cells with dashes have no data available. Ages 1-14 WAA data from 1985-2014 is used for framework modelling. See Fishery Catch at Age and Length/Weight at Age section for WAA calculation details.

	Age															
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1970	0.290	0.570	0.900	1.050	1.160	1.430	1.650	1.950	2.300	2.820	2.800	2.850	3.600	-	-	-
1971	0.290	0.500	0.960	1.250	1.400	1.500	1.750	1.950	2.300	2.650	3.250	3.000	3.000	-	-	-
1972	0.290	0.450	0.900	1.350	1.600	1.750	1.900	2.100	2.300	2.800	3.000	3.700	3.300	-	-	-
1973	0.270	0.510	0.750	1.250	1.800	2.000	2.200	2.300	2.500	2.700	3.300	3.400	4.200	-	-	-
1974	0.180	0.460	0.820	1.100	1.700	2.300	2.500	2.600	2.800	2.950	3.200	3.800	3.900	-	-	-
1975	0.230	0.520	0.820	1.200	1.550	2.250	2.850	3.000	3.200	3.450	3.500	3.700	4.400	-	-	-
1976	0.230	0.520	0.810	1.190	1.600	2.100	2.950	3.500	3.600	3.800	4.100	4.000	4.200	-	-	-
1977	0.280	0.460	0.710	1.220	1.720	2.200	2.940	3.300	3.570	3.770	3.690	3.940	3.910	-	-	-
1978	0.290	0.440	0.870	1.330	1.850	2.330	2.700	3.390	3.770	4.170	4.030	3.620	4.630	-	-	-
1979	0.290	0.510	0.870	1.330	1.840	2.360	2.830	3.300	4.030	4.150	4.960	6.000	5.680	-	-	-
1980	0.160	0.522	0.882	1.326	1.777	2.355	2.906	3.278	3.811	4.332	4.200	4.963	5.711	-	-	-
1981	0.230	0.593	0.877	1.260	1.721	2.219	2.654	3.134	3.608	3.688	4.546	4.823	4.680	-	-	-
1982	-	0.493	0.907	1.294	1.653	2.130	2.577	2.947	3.470	4.033	3.946	4.033	4.908	-	-	-
1983	-	0.394	0.758	1.141	1.714	2.146	2.607	2.869	3.108	3.550	3.630	3.780	4.064	-	-	-
1984	0.250	0.527	0.785	1.069	1.411	1.932	2.287	2.683	3.054	3.431	3.841	4.114	4.000	-	-	-
1985	0.300	0.624	0.841	1.025	1.243	1.506	1.860	2.003	2.085	2.195	2.585	3.034	3.268	3.259	3.359	4.125
1986	-	0.581	0.919	1.089	1.244	1.449	1.748	2.007	2.313	2.710	3.172	3.703	4.618	6.554	9.079	-
1987	-	0.694	0.840	1.073	1.191	1.377	1.573	1.872	2.116	2.365	2.716	2.607	2.307	3.570	3.765	4.527
1988	0.438	0.768	1.097	1.183	1.501	1.547	1.716	1.843	2.070	2.269	2.417	2.706	2.524	3.352	3.518	4.415
1989	-	0.703	1.105	1.286	1.419	1.531	1.694	1.725	1.823	2.005	2.363	2.391	2.490	2.785	3.064	6.008
1990	-	0.648	1.064	1.447	1.781	1.782	1.997	2.030	2.113	2.281	2.235	2.510	2.551	3.062	3.182	4.427
1991	0.492	1.053	1.006	1.364	1.684	1.948	1.983	2.038	2.104	2.107	2.208	2.198	2.360	2.579	3.355	3.190
1992	0.528	0.824	1.088	1.234	1.524	1.870	1.798	1.884	2.059	2.115	1.884	1.892	2.363	2.400	3.082	5.465
1993	0.000	0.733	0.933	1.092	1.352	1.695	1.994	2.077	2.267	2.216	2.296	2.057	2.347	2.620	4.297	4.668
1994	0.580	0.853	1.151	1.310	1.468	1.764	2.041	2.439	2.182	2.584	2.187	2.261	2.711	4.128	3.951	2.401
1995	0.145	0.703	1.004	1.274	1.490	1.594	1.827	1.982	2.262	2.116	2.390	2.185	2.436	2.638	2.945	3.038
1996	-	0.828	0.988	1.167	1.342	1.540	1.530	1.742	1.962	1.987	2.357	3.275	2.836	3.071	3.384	2.948
1997	-	0.758	0.968	1.230	1.472	1.758	1.932	1.908	2.082	2.193	2.521	2.035	2.698	4.163	0.000	3.451
1998	-	0.625	0.916	0.979	1.189	1.405	1.628	1.821	1.962	2.044	2.261	2.656	2.681	2.361	2.190	2.982
1999	-	0.916	1.136	1.380	1.373	1.597	1.928	2.162	2.075	2.091	2.600	2.418	2.118	5.496	5.090	-
2000	-	0.717	0.877	1.133	1.199	1.237	1.441	1.626	2.044	2.237	2.034	2.907	2.506	3.124	2.507	-
2001	-	0.714	0.958	1.054	1.177	1.171	1.270	1.449	1.636	2.018	2.320	2.409	2.530	1.743	3.002	-
2002	0.274	0.766	0.973	1.140	1.228	1.265	1.267	1.286	1.484	1.726	2.004	1.916	2.830	-	3.678	-
2003	-	0.856	1.008	1.106	1.318	1.326	1.335	1.405	1.330	1.671	2.041	2.194	2.218	-	-	-
2004	-	0.475	0.799	0.980	0.969	1.214	1.344	1.470	1.388	1.553	1.836	1.722	2.008	2.834	-	-

Year	Age															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2005	0.181	0.583	0.675	0.808	1.055	1.129	1.325	1.375	1.646	1.652	1.595	1.773	3.129	-	-	1.147
2006	-	0.738	0.769	0.808	0.924	1.114	1.133	1.243	1.271	1.522	1.561	1.871	2.023	2.088	-	-
2007	-	0.736	0.718	0.895	0.876	0.995	1.138	1.089	1.190	1.297	1.413	1.665	1.357	2.188	-	-
2008	-	0.626	0.731	0.827	0.971	0.895	0.995	1.047	1.089	1.197	1.243	1.352	1.290	1.854	-	3.979
2009	0.484	0.612	0.697	0.937	1.060	1.192	1.284	1.352	1.285	1.316	1.322	1.487	1.302	2.177	-	0.000
2010	0.000	0.610	0.744	0.832	1.006	1.119	1.218	1.209	1.279	1.210	1.407	1.338	1.835	1.427	-	2.191
2011	0.222	0.626	0.731	0.772	0.910	1.065	1.061	1.270	1.372	1.368	1.508	1.465	1.284	1.624	-	4.045
2012	0.358	0.582	0.686	0.766	0.885	0.919	1.013	1.089	1.154	1.274	1.269	1.268	1.319	0.971	1.115	-
2013	0.358	0.473	0.672	0.736	0.876	0.868	0.968	0.998	1.129	1.161	1.320	1.348	1.225	1.124	1.535	-
2014	0.294	0.512	0.606	0.821	0.886	1.011	1.008	1.105	1.156	1.125	1.525	1.721	2.272	1.572	3.046	1.495

Table 7. DFO Summer survey total biomass index (t) for 4X5Y Haddock calculated separately for Bay of Fundy Strata (482-495), western Scotian Shelf Strata (470-481) and both areas combined, 1970-2015. (Average is for 1970-2015). A conversion factor of 1.2 has been applied to indices from 1970-1981 to account for vessel and gear changes.

	Total Biomass Index (t)		
Year	**Strata 482-495 (BoF)**	**Strata 470-481 (Western SS)**	**Strata 470-495 (Combined)**
1970	17,822	21,262	39,083
1971	13,963	36,963	50,925
1972	6,271	17,682	23,953
1973	10,112	21,207	31,319
1974	19,146	47,486	66,632
1975	8,985	28,773	37,758
1976	14,996	24,808	39,804
1977	31,059	200,867	231,926
1978	16,485	32,625	49,110
1979	45,566	36,244	81,810
1980	36,446	60,651	97,098
1981	46,729	33,594	80,323
1982	65,379	26,365	91,744
1983	21,164	25,852	47,016
1984	38,019	29,227	67,246
1985	24,561	50,678	75,239
1986	13,795	45,613	59,409
1987	9,685	20,011	29,696
1988	13,265	15,001	28,266
1989	8,686	12,855	21,541
1990	23,768	17,525	41,293
1991	32,407	28,573	60,981
1992	16,806	17,832	34,638
1993	5,109	7,692	12,800
1994	11,997	11,855	23,853
1995	28,661	20,681	49,342
1996	58,139	24,929	83,068
1997	19,550	25,661	45,210
1998	23,372	20,153	43,525
1999	15,475	40,958	56,433
2000	32,001	28,230	60,231
2001	23,239	62,160	85,399
2002	21,530	44,263	65,793
2003	36,754	31,176	67,929
2004	12,231	28,044	40,275
2005	10,639	32,882	43,522
2006	13,763	32,882	46,646
2007	20,511	34,316	54,827
2008	14,866	28,428	43,293
2009	11,262	49,565	60,827
2010	18,702	26,835	45,537
2011	12,901	34,961	47,862
2012	13,821	15,160	28,981
2013	12,729	23,852	36,581
2014	16,875	26,038	42,913
2015	32,237	37,586	69,823
Average	**21,771**	**33,478**	**55,250**

Table 8. DFO Summer survey total abundance index at age (000's) for 4X5Y Haddock calculated separately for Scotian Shelf Strata (470-481) and Bay of Fundy Strata (482-495) then combined, 1970-2014. A conversion factor of 1.2 has been applied to indices from 1970-1981 to account for vessel and gear changes. Abundance at age data from 1985-2014 is used for framework modelling.

	Age													
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**% of 11+**
1970	8,194	6,550	1,932	3,640	1,471	3,377	8,671	1,203	494	470	111	28	0	0%
1971	165	15,854	6,879	3,017	4,258	2,030	3,094	8,671	1,115	131	61	160	0	0%
1972	7,425	327	4,836	2,051	1,312	1,428	918	1,466	2,273	78	9	8	19	0%
1973	9,082	32,303	1,108	4,514	2,109	714	1,143	846	510	970	10	0	20	0%
1974	16,193	32,610	46,851	1,490	5,917	1,340	790	869	472	381	563	0	0	1%
1975	9,471	5,090	7,600	11,273	584	2,545	646	485	202	166	529	410	0	2%
1976	7,828	9,216	5,928	6,201	10,452	918	1,138	206	108	28	13	215	152	1%
1977	9,074	57,182	89,094	25,359	24,567	13,536	1,845	2,220	256	221	29	237	120	0%
1978	8,711	7,374	17,294	5,856	2,442	4,668	1,889	120	0	0	65	50	31	0%
1979	2,891	19,505	11,732	14,866	7,510	3,148	4,701	2,032	347	162	0	0	0	0%
1980	31,199	9,933	21,875	11,254	17,467	6,697	2,481	1,790	960	370	54	0	0	0%
1981	51,826	39,958	9,373	13,386	5,398	6,091	1,951	258	504	241	122	61	0	0%
1982	18,418	39,422	18,736	7,413	12,041	5,027	5,403	945	567	333	220	0	0	0%
1983	9,600	6,352	20,262	8,964	5,288	3,331	1,374	485	458	330	265	83	85	1%
1984	5,895	33,711	17,271	26,029	8,177	4,177	2,005	856	564	132	46	47	56	0%
1985	9,921	13,649	32,716	15,005	20,684	5,308	2,636	1,675	921	339	98	46	46	0%
1986	5,415	13,421	10,615	21,302	8,342	8,900	3,179	1,637	929	532	89	151	97	0%
1987	1,885	2,169	3,855	4,763	5,763	4,015	2,924	1,273	382	453	103	22	0	0%
1988	10,122	3,017	1,438	2,995	4,167	4,412	2,114	1,647	1,020	565	185	22	0	1%
1989	8,470	13,828	2,765	1,296	2,606	1,110	2,307	825	688	203	164	129	0	1%
1990	107	15,039	13,520	2,491	2,014	2,233	2,036	1,702	711	579	287	129	84	1%
1991	6,063	1,950	17,855	16,311	3,420	1,886	1,670	1,428	1,054	1,254	126	121	27	1%
1992	4,418	3,527	1,379	10,876	7,730	1,482	545	563	413	305	59	24	6	0%
1993	6,551	1,501	2,473	942	2,706	1,634	268	199	81	68	145	31	41	1%
1994	30,025	8,397	3,117	2,792	564	2,751	1,602	213	74	121	15	79	141	0%
1995	65,744	35,234	16,710	5,933	2,693	1,097	2,254	586	145	0	0	30	0	0%
1996	7,124	38,001	35,704	18,176	7,349	2,414	1,688	2,356	576	477	191	35	105	0%
1997	14,188	8,328	30,275	18,268	5,655	2,361	863	263	448	276	30	14	0	0%
1998	14,127	10,919	6,704	19,686	10,591	2,706	2,187	1,423	400	249	178	21	0	0%
1999	51,122	28,975	13,702	9,190	15,602	8,693	4,273	1,644	1,240	274	267	172	65	0%
2000	38,697	63,060	9,735	6,743	5,475	7,562	2,687	1,068	472	94	33	20	0	0%
2001	43,613	45,158	58,527	17,149	6,528	3,116	7,957	3,071	1,695	1,149	124	0	48	0%
2002	5,986	24,017	32,706	36,171	8,609	4,509	3,282	4,998	2,696	1,431	982	43	56	1%
2003	3,317	7,516	20,246	22,433	19,375	3,689	4,107	2,379	4,077	1,497	622	0	53	1%

Year	Age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	% of 11+
2004	11,651	5,254	7,652	15,912	11,900	10,059	3,494	2,134	790	920	423	172	12	1%
2005	3,365	21,234	5,056	7,306	12,913	12,368	7,104	3,528	1,149	1,042	512	189	0	1%
2006	9,539	5,163	21,094	7,640	4,664	10,719	6,646	9,327	2,059	1,478	884	184	7	1%
2007	14,461	15,744	7,266	25,721	3,742	4,477	9,176	5,694	3,559	859	685	127	68	1%
2008	961	19,145	8,983	6,292	16,109	2,052	2,249	4,967	3,806	2,176	1,324	96	187	2%
2009	2,007	1,899	22,183	12,096	7,070	13,719	3,186	3,262	5,835	5,463	1,457	524	0	3%
2010	5,259	3,203	1,586	12,893	6,387	6,623	9,388	4,870	2,014	1,512	1,021	581	296	3%
2011	17,701	10,722	3,564	3,584	15,157	5,174	5,715	7,258	3,030	1,263	2,133	523	670	4%
2012	10,427	16,385	8,745	1,935	2,117	4,879	2,937	2,170	2,326	1,990	145	380	140	1%
2013	25,684	20,310	23,063	6,651	910	1,900	2,943	2,758	1,147	878	440	26	37	1%
2014	168,470	16,291	13,648	12,655	3,320	1,228	417	1,066	1,149	191	224	93	26	0%

Table 9. Weighted DFO Summer survey mean weight at age (kg) of 4X5Y Haddock for Ages 0-14 calculated separately for Scotian Shelf Strata (470-481) and Bay of Fundy Strata (482-495) then combined after weighting by total number, 1970-2014. Cells with dashes have no data available. WAA data from 1985-2014 is used for framework modelling.

	Age														
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1970	-	0.082	0.393	0.771	1.086	1.403	1.607	2.035	2.346	2.384	2.951	3.632	2.225	-	-
1971	-	0.102	0.250	0.761	1.098	1.435	1.617	1.717	2.180	2.590	4.073	3.516	4.738	-	-
1972	-	0.078	0.203	0.666	1.287	1.638	1.985	2.079	2.476	2.895	3.966	3.700	4.600	6.200	-
1973	-	0.096	0.297	0.511	1.343	1.815	2.362	2.396	2.452	2.685	2.886	3.600	-	4.000	-
1974	-	0.093	0.310	0.708	1.010	1.713	2.204	2.516	2.704	2.705	2.803	3.395	-	-	-
1975	-	0.104	0.369	0.759	1.271	1.800	2.317	2.828	3.013	3.251	3.169	3.314	3.326	-	-
1976	-	0.093	0.367	0.695	1.160	1.523	1.926	2.411	2.384	2.685	2.600	3.500	3.056	3.374	-
1977	-	0.103	0.463	0.838	1.258	1.771	2.009	2.870	2.973	4.021	2.972	3.500	3.531	3.631	3.693
1978	-	0.078	0.411	0.900	1.466	1.955	2.260	2.644	3.422	-	-	2.600	4.200	3.900	4.195
1979	-	0.084	0.347	0.786	1.369	1.757	2.383	2.738	3.368	4.034	3.477	-	-	-	3.600
1980	-	0.086	0.440	0.794	1.309	1.752	2.112	2.502	2.730	3.455	3.323	3.400	-	-	-
1981	-	0.093	0.401	0.861	1.193	1.852	2.294	2.747	3.098	3.302	4.102	3.811	4.000	-	-
1982	-	0.065	0.224	0.680	1.308	1.698	2.315	2.870	3.333	3.477	4.212	4.468	-	-	-
1983	-	0.067	0.250	0.560	1.103	1.586	1.886	2.383	2.665	2.818	3.176	3.146	3.690	4.366	-
1984	-	0.095	0.290	0.468	0.836	1.273	1.847	2.073	2.447	2.830	3.769	2.350	3.500	2.300	-
1985	-	0.076	0.331	0.550	0.728	1.010	1.380	2.023	1.977	1.936	2.483	2.635	3.200	3.100	3.036
1986	-	0.072	0.285	0.603	0.776	1.017	1.178	1.431	1.693	2.173	2.200	2.803	2.836	2.119	-
1987	-	0.099	0.345	0.581	0.968	1.154	1.139	1.436	1.660	2.090	1.816	2.328	6.000	-	2.870
1988	-	0.097	0.520	0.689	1.001	1.348	1.384	1.654	1.645	1.989	1.903	2.203	2.900	-	-
1989	-	0.090	0.356	0.747	0.911	1.292	1.510	1.543	1.612	1.555	1.799	2.310	1.310	-	2.400
1990	-	0.109	0.424	0.819	1.338	1.690	1.879	2.132	2.187	2.531	1.644	2.450	2.479	3.513	3.300
1991	-	0.089	0.600	0.839	1.331	1.503	2.083	2.064	2.123	2.005	1.679	3.511	2.564	3.555	3.400
1992	-	0.082	0.307	0.624	1.141	1.666	2.010	2.299	1.761	2.004	2.537	2.786	2.760	3.500	0.000
1993	-	0.098	0.366	0.770	1.109	1.394	1.777	1.941	1.859	1.396	2.226	2.191	1.995	1.682	4.540
1994	0.007	0.139	0.423	0.865	1.234	1.341	1.657	1.926	2.319	1.567	1.705	2.195	1.274	2.179	-
1995	0.005	0.063	0.353	0.829	1.157	1.436	1.536	1.793	2.197	2.648	-	-	1.510	-	-
1996	0.010	0.053	0.210	0.680	1.210	1.450	1.780	1.878	1.898	2.503	2.454	2.233	2.019	3.879	-
1997	0.005	0.114	0.231	0.428	0.793	1.187	1.392	1.648	1.902	1.895	1.535	2.045	1.358	-	-
1998	0.007	0.065	0.261	0.409	0.621	1.069	1.448	1.790	2.136	2.024	1.581	2.171	1.465	-	-
1999	0.009	0.104	0.188	0.540	0.606	0.820	0.966	1.171	1.314	1.373	1.890	1.809	1.642	1.347	3.260
2000	0.010	0.108	0.393	0.569	0.888	0.802	1.013	1.332	1.574	1.991	2.458	1.858	2.200	-	-
2001	0.007	0.087	0.235	0.542	0.642	0.925	0.933	1.040	1.211	1.424	1.143	1.644	-	1.450	3.810
2002	0.003	0.078	0.209	0.396	0.635	0.711	0.915	0.980	0.993	1.147	1.167	0.905	1.887	2.430	-
2003	0.005	0.068	0.215	0.356	0.670	1.076	1.045	1.109	1.133	1.288	1.316	1.442	-	2.802	-
2004	0.005	0.088	0.175	0.457	0.569	0.704	0.868	0.949	0.922	1.045	1.123	1.310	1.805	1.304	-

	Age														
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
2005	0.002	0.080	0.236	0.408	0.608	0.661	0.771	0.941	0.991	1.143	1.095	1.126	1.204	-	1.830
2006	0.005	0.089	0.180	0.446	0.490	0.638	0.814	0.870	0.924	1.163	1.028	1.195	0.988	1.765	-
2007	0.003	0.075	0.184	0.419	0.721	0.780	0.897	0.928	1.089	1.100	1.403	1.200	2.180	1.491	-
2008	0.005	0.111	0.324	0.475	0.615	0.743	0.899	0.970	0.911	1.013	1.033	1.053	1.390	1.260	1.867
2009	0.006	0.118	0.299	0.484	0.650	0.744	1.002	0.937	0.949	1.025	1.047	1.148	1.247	-	1.382
2010	0.007	0.143	0.308	0.574	0.694	0.799	0.965	1.120	1.076	1.009	1.064	1.277	1.268	1.589	0.998
2011	0.006	0.120	0.318	0.646	0.672	0.782	0.904	0.873	1.040	1.086	0.912	1.027	1.292	1.102	1.342
2012	0.011	0.118	0.336	0.474	0.708	0.749	0.856	0.898	0.944	1.134	1.157	1.136	1.077	1.176	0.917
2013	0.007	0.146	0.300	0.507	0.651	0.782	0.866	0.829	0.881	1.038	1.284	1.075	1.108	1.882	-
2014	0.011	0.091	0.288	0.471	0.661	0.773	0.830	1.022	0.901	0.964	1.260	1.460	1.598	1.237	1.329

Table 10. Weighted mean length at age (fork length, cm) for the DFO Summer survey of 4X5Y Haddock for Ages 0-12, calculated separately for Scotian Shelf Strata (470-481) and Bay of Fundy Strata (482-495) then combined after weighting by total number; 1970-2014. Cells with dashes have no data available.

	Age												
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1970	-	20.98	33.83	41.05	45.70	49.86	52.02	56.20	59.57	60.54	65.10	68.17	60.50
1971	-	20.64	29.28	41.61	46.95	51.34	53.08	54.82	58.73	63.02	70.54	69.44	72.92
1972	-	19.92	26.92	39.40	48.56	52.83	55.93	56.36	60.07	63.21	69.13	68.50	76.50
1973	-	21.27	30.14	35.70	49.60	54.74	59.26	60.04	60.74	62.66	64.01	70.50	-
1974	-	21.02	31.10	40.02	45.23	54.38	59.19	61.26	63.12	62.80	63.50	67.97	-
1975	-	21.93	32.60	41.36	48.54	54.18	59.27	63.63	64.69	65.60	67.52	67.01	66.80
1976	-	20.99	32.34	40.01	48.41	53.12	58.07	62.82	61.32	65.69	66.50	72.50	66.88
1977	8.50	21.86	35.08	42.39	48.13	54.06	56.62	63.56	65.20	69.78	65.15	66.50	68.98
1978	-	18.97	33.72	43.00	50.22	54.74	57.66	61.25	66.17	-	-	62.50	68.50
1979	7.28	19.86	31.95	41.01	49.64	54.39	60.23	62.78	65.59	71.62	69.07	-	-
1980	6.50	19.95	33.26	40.81	49.27	54.81	58.11	61.49	62.99	67.17	67.52	70.50	-
1981	8.29	19.86	32.81	41.34	47.63	55.09	59.75	62.65	64.34	67.40	73.70	72.27	74.50
1982	6.50	17.90	26.86	38.79	48.80	53.50	59.50	63.90	67.65	68.90	74.56	74.86	0.00
1983	7.84	18.65	28.22	37.13	46.73	53.50	56.80	61.39	63.71	64.76	66.93	67.57	70.83
1984	8.18	20.53	29.39	34.49	42.22	49.13	55.77	58.92	61.43	65.54	69.43	70.50	72.50
1985	-	19.47	30.77	36.58	41.18	45.73	50.71	57.49	58.13	57.78	62.91	62.73	66.50
1986	6.50	19.50	30.07	38.20	41.01	45.38	48.27	51.21	54.22	59.77	60.10	64.82	65.53
1987		20.98	31.90	37.46	44.09	47.07	47.22	51.34	53.62	58.04	56.79	61.67	76.50
1988	6.50	20.87	34.61	40.11	44.86	49.63	49.13	51.63	52.88	54.82	54.40	59.16	62.50
1989	10.50	20.42	32.04	40.72	43.44	49.00	52.02	51.97	52.12	52.66	55.96	60.86	50.90
1990	8.50	21.53	33.12	41.64	48.80	53.84	54.66	57.25	57.69	59.82	52.33	60.67	58.09
1991	-	20.72	37.51	42.68	49.69	52.10	58.26	58.40	57.92	55.83	53.85	66.32	61.04
1992	-	19.38	30.75	39.28	47.23	53.36	57.34	59.15	54.69	55.16	61.09	64.23	62.50
1993	-	22.10	32.67	41.80	47.26	51.47	55.95	57.41	56.64	51.03	58.03	58.29	56.50
1994	8.69	23.82	34.23	42.67	48.89	49.86	53.23	56.02	60.43	53.29	54.50	58.50	51.48
1995	7.46	18.63	32.64	42.85	48.60	52.49	53.65	56.34	59.68	65.65	-	-	54.50
1996	9.66	17.84	27.37	39.94	48.62	51.66	54.77	56.82	57.55	62.51	60.51	58.50	59.55
1997	8.38	22.11	28.10	34.21	42.06	48.35	50.32	53.96	57.86	56.45	53.97	60.35	62.50
1998	8.72	18.68	29.48	34.18	38.86	46.72	51.68	54.64	58.38	56.40	54.53	60.40	54.50
1999	9.74	21.67	25.81	37.10	38.60	42.48	45.09	47.65	49.82	50.00	55.25	55.59	55.08
2000	10.01	22.33	33.68	37.86	43.78	42.72	45.59	49.95	52.00	56.36	61.52	56.50	62.50
2001	9.03	20.57	28.66	37.24	39.45	45.11	45.39	46.68	49.10	51.63	46.88	53.86	-
2002	6.50	19.93	27.59	33.97	39.76	41.41	45.54	46.54	46.57	48.87	49.06	41.64	59.60
2003	7.84	18.85	27.46	32.31	39.92	46.95	46.82	48.11	48.88	50.45	50.76	53.57	-
2004	8.51	21.57	25.94	35.92	38.39	41.28	44.01	45.81	45.46	46.89	48.58	51.11	58.28

	Age												
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2005	4.88	20.40	28.55	33.68	39.11	39.98	41.85	45.16	45.80	48.76	46.77	47.66	48.52
2006	8.27	21.08	26.42	35.18	36.67	40.39	43.04	43.91	45.07	48.51	46.80	49.64	47.63
2007	6.81	19.69	25.65	34.47	40.73	42.12	43.74	44.60	46.61	47.07	51.62	48.99	59.32
2008	7.96	22.02	31.83	36.45	39.02	41.68	44.23	46.01	44.53	45.83	46.08	46.98	52.30
2009	8.93	22.70	30.78	36.03	39.75	41.00	45.32	44.68	44.67	45.45	45.39	48.41	48.53
2010	9.33	24.99	31.53	37.78	41.42	43.41	45.86	48.23	47.45	46.82	47.05	50.15	50.64
2011	8.56	23.21	31.94	40.12	41.51	43.23	45.08	44.61	47.10	47.62	44.75	46.43	51.60
2012	10.61	22.99	31.85	36.70	41.56	42.48	44.70	45.47	45.82	48.81	48.70	51.50	49.82
2013	9.07	24.43	30.77	36.87	40.09	42.50	44.67	43.91	44.69	47.73	50.39	48.08	50.50
2014	10.24	20.92	30.24	36.11	40.33	42.55	43.32	47.31	45.34	45.49	50.06	52.13	53.73

Table 11. Coefficient of variation for fishery catch at age of 4X5Y Haddock for Ages 1-16, 1985-2014.

	Age															
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1985	1.02	0.10	0.03	0.07	0.03	0.06	0.07	0.09	0.09	0.11	0.13	0.19	0.20	0.22	0.37	1.03
1986	0.00	0.08	0.06	0.03	0.05	0.04	0.08	0.10	0.10	0.12	0.14	0.18	0.21	0.38	0.46	1.03
1987	0.00	0.21	0.09	0.08	0.03	0.06	0.04	0.07	0.09	0.08	0.16	0.21	0.31	0.34	0.56	0.45
1988	0.26	0.09	0.07	0.06	0.06	0.04	0.07	0.06	0.08	0.11	0.12	0.18	0.25	0.21	0.35	0.39
1989	0.00	0.11	0.08	0.09	0.06	0.10	0.06	0.08	0.08	0.12	0.19	0.18	0.26	0.35	0.51	1.47
1990	0.00	0.08	0.04	0.12	0.12	0.12	0.12	0.09	0.10	0.13	0.38	0.22	0.43	0.16	0.54	0.27
1991	0.14	0.38	0.05	0.04	0.10	0.14	0.14	0.13	0.11	0.11	0.18	0.18	0.31	0.35	0.41	0.59
1992	0.51	0.16	0.21	0.05	0.06	0.15	0.16	0.17	0.19	0.14	0.28	0.23	0.28	0.58	0.59	0.09
1993	0.00	0.11	0.08	0.14	0.06	0.07	0.23	0.22	0.21	0.25	0.27	0.37	0.66	0.56	0.75	0.01
1994	0.68	0.11	0.08	0.09	0.13	0.06	0.10	0.21	0.32	0.31	0.35	0.27	0.31	0.39	0.93	0.67
1995	0.01	0.10	0.08	0.13	0.11	0.12	0.08	0.11	0.23	0.25	0.28	0.34	0.38	0.48	0.42	0.76
1996	0.00	0.63	0.07	0.08	0.11	0.13	0.16	0.11	0.12	0.19	0.39	0.01	0.64	0.64	0.76	0.89
1997	0.00	0.29	0.06	0.03	0.04	0.06	0.07	0.10	0.11	0.10	0.15	0.43	0.52	0.70	0.00	0.62
1998	0.00	0.21	0.16	0.05	0.04	0.05	0.08	0.09	0.14	0.13	0.14	0.33	0.50	0.47	0.54	0.60
1999	0.00	0.30	0.11	0.10	0.06	0.05	0.06	0.08	0.15	0.18	0.17	0.27	0.47	0.02	0.00	0.00
2000	0.00	0.05	0.06	0.05	0.06	0.03	0.04	0.06	0.08	0.11	0.21	0.25	0.32	0.30	0.62	0.00
2001	0.00	0.16	0.03	0.05	0.06	0.07	0.05	0.06	0.09	0.12	0.19	0.29	0.37	0.53	0.75	0.00
2002	0.12	0.17	0.07	0.02	0.06	0.08	0.08	0.06	0.08	0.11	0.15	0.27	0.51	0.00	1.02	0.00
2003	0.00	0.41	0.07	0.05	0.03	0.08	0.11	0.12	0.14	0.15	0.21	0.26	0.53	0.00	0.00	0.00
2004	0.00	0.35	0.11	0.05	0.05	0.04	0.08	0.10	0.13	0.14	0.18	0.25	0.28	0.38	0.00	0.00
2005	0.01	0.20	0.24	0.10	0.05	0.06	0.06	0.12	0.17	0.18	0.21	0.37	0.45	0.00	0.00	0.51
2006	0.00	0.28	0.05	0.14	0.09	0.07	0.08	0.10	0.19	0.27	0.32	0.56	0.56	0.67	0.00	0.00
2007	0.00	0.12	0.10	0.02	0.14	0.11	0.07	0.09	0.10	0.18	0.22	0.30	0.60	0.85	0.00	0.00
2008	0.00	0.11	0.08	0.08	0.03	0.12	0.10	0.08	0.09	0.12	0.21	0.29	0.32	0.86	0.00	0.01
2009	0.30	0.19	0.09	0.10	0.09	0.04	0.10	0.13	0.11	0.14	0.19	0.37	0.59	0.40	0.00	0.00
2010	0.00	0.23	0.33	0.08	0.10	0.11	0.05	0.12	0.22	0.18	0.19	0.32	0.36	0.40	0.00	0.98
2011	0.07	0.33	0.14	0.23	0.11	0.13	0.15	0.08	0.11	0.19	0.19	0.20	0.39	0.38	0.00	0.01
2012	0.26	0.05	0.07	0.10	0.11	0.05	0.09	0.08	0.06	0.11	0.23	0.19	0.26	0.65	0.57	0.00
2013	0.21	0.07	0.03	0.07	0.12	0.13	0.08	0.10	0.15	0.10	0.13	0.33	0.32	0.55	0.48	0.00
2014	0.27	0.08	0.07	0.04	0.12	0.18	0.16	0.13	0.15	0.32	0.17	0.31	0.47	0.57	1.18	0.97

Table 12. Coefficient of variation for DFO Summer survey catch at age of 4X5Y Haddock for Ages 0-14, 1985-2014.

	Age														
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1985	-	0.24	0.23	0.29	0.49	0.45	0.31	0.18	0.14	0.15	0.13	0.32	0.33	0.33	0.42
1986	0.39	0.13	0.27	0.25	0.23	0.20	0.20	0.23	0.30	0.34	0.29	0.64	0.43	0.45	-
1987		0.34	0.29	0.22	0.16	0.16	0.16	0.18	0.18	0.20	0.21	0.32	1.00	-	0.54
1988	1.00	0.40	0.48	0.21	0.16	0.15	0.14	0.17	0.14	0.17	0.17	0.24	0.61	-	-
1989	1.00	0.23	0.28	0.19	0.16	0.18	0.21	0.20	0.25	0.19	0.24	0.29	0.20	-	1.00
1990	1.00	0.61	0.32	0.24	0.18	0.21	0.20	0.23	0.21	0.23	0.20	0.20	0.20	0.46	1.00
1991	-	0.32	0.24	0.24	0.27	0.24	0.28	0.26	0.22	0.23	0.22	0.30	0.27	0.52	1.00
1992	-	0.48	0.31	0.29	0.27	0.29	0.35	0.29	0.26	0.27	0.40	0.39	0.39	1.00	-
1993	-	0.37	0.22	0.21	0.19	0.20	0.24	0.29	0.29	0.23	0.47	0.30	0.30	0.38	1.00
1994	0.28	0.42	0.27	0.22	0.20	0.14	0.18	0.21	0.27	0.20	0.19	0.33	0.16	0.26	-
1995	0.48	0.25	0.20	0.17	0.14	0.14	0.14	0.13	0.13	0.43	-	-	0.21	-	-
1996	0.53	0.29	0.18	0.24	0.31	0.35	0.36	0.35	0.35	0.50	0.40	0.58	0.27	0.57	-
1997	0.53	0.49	0.24	0.20	0.17	0.18	0.19	0.20	0.26	0.19	0.21	0.36	0.67	-	-
1998	0.29	0.30	0.27	0.19	0.14	0.22	0.28	0.33	0.35	0.26	0.27	0.23	0.43	-	-
1999	0.35	0.32	0.32	0.15	0.14	0.13	0.11	0.12	0.14	0.12	0.22	0.16	0.24	0.24	0.58
2000	0.47	0.28	0.27	0.17	0.14	0.11	0.11	0.12	0.15	0.16	0.38	0.43	0.80	-	-
2001	0.64	0.42	0.32	0.23	0.21	0.16	0.19	0.20	0.19	0.26	0.22	0.48	-	0.46	1.00
2002	1.00	0.23	0.18	0.15	0.12	0.14	0.12	0.12	0.14	0.14	0.14	0.13	0.37	0.55	-
2003	0.25	0.28	0.17	0.16	0.23	0.46	0.31	0.34	0.35	0.42	0.35	0.47	-	0.73	-
2004	0.31	0.22	0.20	0.27	0.28	0.25	0.24	0.24	0.27	0.23	0.18	0.17	0.45	0.60	-
2005	0.66	0.23	0.21	0.20	0.16	0.14	0.13	0.15	0.14	0.16	0.18	0.15	0.19	-	0.57
2006	0.42	0.62	0.21	0.14	0.14	0.14	0.14	0.16	0.16	0.16	0.20	0.24	0.26	1.00	-
2007	0.53	0.47	0.24	0.16	0.19	0.16	0.21	0.19	0.21	0.20	0.33	0.21	0.35	0.44	-
2008	0.53	0.53	0.45	0.25	0.28	0.20	0.23	0.20	0.22	0.19	0.19	0.20	0.30	0.23	0.69
2009	0.44	0.35	0.36	0.27	0.25	0.23	0.20	0.23	0.22	0.24	0.24	0.25	0.24	-	0.37
2010	0.26	0.30	0.24	0.24	0.21	0.22	0.22	0.23	0.23	0.22	0.24	0.27	0.27	0.37	0.32
2011	0.28	0.31	0.26	0.33	0.43	0.41	0.38	0.43	0.36	0.35	0.49	0.43	0.30	0.45	0.26
2012	0.43	0.33	0.26	0.17	0.21	0.17	0.18	0.16	0.19	0.17	0.22	0.22	0.19	0.20	0.20
2013	0.43	0.33	0.22	0.17	0.19	0.20	0.21	0.20	0.21	0.22	0.39	0.20	0.40	0.50	-
2014	0.51	0.23	0.19	0.22	0.20	0.22	0.22	0.23	0.24	0.25	0.27	0.29	0.49	0.39	0.72
Average	**0.52**	**0.34**	**0.26**	**0.21**	**0.22**	**0.21**	**0.21**	**0.22**	**0.22**	**0.24**	**0.26**	**0.30**	**0.37**	**0.48**	**0.64**

Table 13. Estimated fishing mortality (F) from the VPA model formulation of M fixed at 0.2, except at 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014, respectively) for 4X5Y Haddock.

	Age											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**F6-10**
1985	0.00	0.08	0.18	0.13	0.29	0.33	0.34	0.32	0.76	0.82	1.63	0.39
1986	0.00	0.07	0.20	0.28	0.26	0.34	0.27	0.32	0.33	0.50	1.00	0.33
1987	0.00	0.04	0.15	0.27	0.40	0.30	0.53	0.38	0.32	0.44	0.88	0.41
1988	0.00	0.03	0.16	0.22	0.32	0.41	0.33	0.45	0.53	0.68	1.37	0.42
1989	0.00	0.01	0.11	0.23	0.31	0.20	0.33	0.28	0.43	0.59	1.18	0.32
1990	0.00	0.02	0.09	0.13	0.29	0.35	0.38	0.54	0.34	0.38	0.77	0.41
1991	0.00	0.01	0.08	0.27	0.32	0.50	0.45	0.46	0.52	0.61	1.23	0.50
1992	0.00	0.02	0.06	0.32	0.43	0.17	0.75	0.98	0.93	0.83	1.67	0.57
1993	0.00	0.01	0.12	0.19	0.38	0.39	0.22	0.81	0.57	0.49	0.99	0.38
1994	0.00	0.01	0.05	0.15	0.14	0.35	0.14	0.03	0.24	0.20	0.40	0.24
1995	0.00	0.00	0.06	0.13	0.21	0.20	0.33	0.31	0.33	0.90	0.90	0.29
1996	0.00	0.00	0.05	0.11	0.15	0.21	0.40	0.55	0.59	0.57	0.57	0.39
1997	0.00	0.00	0.03	0.13	0.15	0.14	0.19	0.29	0.25	0.33	0.33	0.19
1998	0.00	0.00	0.01	0.08	0.19	0.25	0.28	0.45	0.65	0.70	0.70	0.31
1999	0.00	0.00	0.06	0.06	0.12	0.14	0.19	0.17	0.11	0.38	0.38	0.16
2000	0.00	0.01	0.02	0.15	0.08	0.18	0.20	0.28	0.24	0.36	0.36	0.21
2001	0.00	0.00	0.05	0.07	0.20	0.13	0.28	0.32	0.31	0.22	0.22	0.24
2002	0.00	0.00	0.02	0.11	0.07	0.18	0.13	0.24	0.30	0.33	0.33	0.21
2003	0.00	0.00	0.03	0.08	0.18	0.08	0.20	0.11	0.12	0.12	0.12	0.11
2004	0.00	0.00	0.02	0.05	0.09	0.16	0.10	0.24	0.12	0.11	0.11	0.14
2005	0.00	0.00	0.01	0.06	0.10	0.11	0.12	0.07	0.14	0.07	0.07	0.11
2006	0.00	0.00	0.03	0.03	0.11	0.09	0.12	0.10	0.05	0.05	0.05	0.09
2007	0.00	0.02	0.05	0.19	0.05	0.10	0.10	0.10	0.09	0.06	0.06	0.09
2008	0.00	0.01	0.03	0.09	0.16	0.08	0.11	0.12	0.12	0.09	0.09	0.10
2009	0.00	0.01	0.03	0.06	0.12	0.19	0.12	0.10	0.09	0.10	0.10	0.14
2010	0.00	0.00	0.03	0.06	0.09	0.21	0.31	0.15	0.09	0.15	0.15	0.21
2011	0.00	0.01	0.03	0.14	0.11	0.09	0.27	0.21	0.10	0.07	0.07	0.15
2012	0.00	0.01	0.04	0.13	0.20	0.19	0.12	0.42	0.29	0.22	0.22	0.22
2013	0.00	0.01	0.09	0.08	0.16	0.20	0.12	0.13	0.17	0.26	0.26	0.16
2014	0.00	0.01	0.04	0.09	0.07	0.11	0.18	0.05	0.06	0.08	0.08	0.08

*Table 14. Estimated population abundance at age and Ages 4+ biomass from the VPA model formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014, respectively) for 4X5Y Haddock. *The abundance at age 1 for 2015 is an assigned value, as the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).*

	Age											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**4+biomass**
1985	11,674	11,547	25,796	11,808	16,614	5,483	2,616	1,877	811	539	260	42,280
1986	5,512	9,556	8,760	17,717	8,509	10,147	3,214	1,527	1,112	310	233	40,872
1987	7,522	4,513	7,330	5,852	10,926	5,365	5,919	2,012	906	656	222	34,966
1988	23,603	6,158	3,554	5,144	3,662	6,009	3,267	2,851	1,126	541	421	28,557
1989	21,673	19,316	4,887	2,488	3,371	2,185	3,270	1,919	1,485	544	307	20,829
1990	7,123	17,744	15,708	3,585	1,626	2,019	1,467	1,926	1,182	789	322	19,269
1991	11,369	5,832	14,245	11,706	2,589	996	1,160	820	919	691	561	26,546
1992	14,432	9,306	4,734	10,713	7,327	1,541	496	608	422	449	436	29,281
1993	22,322	11,789	7,440	3,640	6,346	3,884	1,069	191	186	136	221	21,314
1994	31,146	18,276	9,531	5,423	2,470	3,567	2,154	703	69	86	134	19,709
1995	30,316	25,493	14,824	7,399	3,819	1,750	2,068	1,533	556	45	132	23,414
1996	19,000	24,820	20,821	11,383	5,304	2,533	1,168	1,214	922	326	59	29,666
1997	13,175	15,556	20,295	16,153	8,342	3,737	1,689	642	575	417	178	33,554
1998	30,438	10,787	12,719	16,094	11,593	5,885	2,648	1,141	394	366	349	35,048
1999	52,083	24,920	8,792	10,284	12,137	7,834	3,736	1,636	594	168	291	30,960
2000	39,210	42,642	20,369	6,780	7,912	8,822	5,565	2,520	1,132	436	256	31,107
2001	40,086	32,103	34,684	16,264	4,797	5,971	6,027	3,719	1,561	726	359	34,384
2002	18,087	32,820	26,193	26,904	12,366	3,228	4,306	3,741	2,216	937	645	39,564
2003	15,681	14,808	26,831	20,984	19,721	9,484	2,203	3,080	2,400	1,341	840	46,267
2004	44,962	12,838	12,101	21,327	15,800	13,544	7,180	1,474	2,269	1,741	1,430	48,750
2005	15,110	36,812	10,500	9,685	16,613	11,848	9,451	5,337	946	1,651	2,097	42,908
2006	17,393	12,371	30,107	8,534	7,484	12,240	8,649	6,867	4,067	674	1,909	38,197
2007	21,350	14,241	10,096	23,922	6,756	5,494	9,120	6,298	5,095	3,155	1,342	46,721
2008	4,360	17,480	11,473	7,886	16,114	5,264	4,082	6,752	4,649	3,819	2,321	42,125
2009	4,501	3,570	14,225	9,098	5,918	11,230	3,992	2,998	4,907	3,370	3,065	36,883
2010	12,983	3,682	2,895	11,310	6,992	4,314	7,599	2,891	2,223	3,652	3,201	36,068
2011	32,892	10,629	3,002	2,304	8,732	5,237	2,871	4,571	2,035	1,667	2,389	26,335
2012	26,472	26,927	8,641	2,382	1,631	6,358	3,908	1,788	3,028	1,507	1,540	19,759
2013	38,190	21,667	21,785	6,798	1,698	1,090	4,291	2,830	954	1,848	993	16,353
2014	317,721	31,236	17,454	16,284	5,104	1,174	718	3,091	2,029	655	887	21,146
2015	16,839*	260,125	25,291	13,637	12,050	3,885	851	479	2,387	1,560	577	26,193

Table 15. The natural mortality (M), partial recruitment (PR), fishery weight at age (WAA), spawning stock weight at age (WAA), and maturity at age used for the per recruit analysis for 4X5Y Haddock.

Age	M	PR	Fishery WAA	Spawning WAA	Maturity
1	0.20	0.00	0.31	0.06	0
2	0.20	0.05	0.64	0.16	0
3	0.20	0.20	0.78	0.35	0
4	0.20	0.70	0.91	0.56	1
5	0.20	0.80	1.02	0.71	1
6	0.20	1.00	1.10	0.84	1
7	0.20	1.00	1.19	0.95	1
8	0.20	1.00	1.27	1.01	1
9	0.20	1.00	1.36	1.11	1
10	0.60	1.00	1.49	1.20	1
11	0.60	1.00	1.65	1.30	1

Table 16. Summary of F_{ref} (16a.) and B_{lim} (16b.) for 4X5Y haddock, estimate of F_{loss} was shown in bracket with F_{ref}.

a.

F_{ref} proxies	long(1970-2014)	short(1985-2014)
$F_{0.1}$	0.44(-)	
$F_{40\%SPR}$	0.4(-)	
F_{msy} (Ricker)	0.25(0.29)	-
F_{msy} (B-H)	-	-
F_{msy} (HS)	0.3 (0.3)	0.3(0.3)
F_{msy} (LOWESS)	- (0.35*)	-
F_{median} (Replacement Line)	0.15(-)	-

**: the median value*

b.

B_{lim} proxies (mt)	long(1970-2014)	short(1985-2014)
$SSB_{50\%Rmax}$(Ricker)	9,564	-
$SSB_{50\%Rmax}$(B-H)	-	-
$SSB_{50\%Rmax}$(HS)	10,673	9,824
$Sb_{50/90}$	15,866	-
$SSB_{recover}$	19,708	19,708

Table 17. The most recent 5 year (2010-2014) average of natural mortality, fishery partial recruitment, fishery weight at age and population beginning of year weights at age used in 2016-2018 projection and risk analysis for 4X5Y Haddock.

Input	**Year**	**Age Group**										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
Natural mortality	2015-2017	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.9	0.9
Fishery Partial Recruitment	2015-2017	0	0.05	0.2	0.5	0.6	1	1	1	0.8	0.8	0.8
Fishery Weight at Age	2015-2017	0.30	0.56	0.69	0.78	0.91	1.00	1.05	1.14	1.21	1.23	1.39
Population Beginning of Year Weight at Age	2015-2018	0.08	0.20	0.41	0.60	0.72	0.83	0.93	0.95	1.01	1.09	1.18

Table 18. Deterministic projections for 2016-2018 under a constant quota of 5,100 t scenario for 4X5Y Haddock. The Age 1 of 2014-2017 year classes was fixed at the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).

Year/Age	1	2	3	4	5	6	7	8	9	10	11+	1+	4+
Fishing Mortality													
2015	0	0.009	0.04	0.09	0.11	0.18	0.18	0.18	0.15	0.15	0.15	-	-
2016	0	0.005	0.02	0.05	0.06	0.10	0.10	0.10	0.08	0.08	0.08	-	-
2017	0	0.003	0.012	0.03	0.036	0.06	0.06	0.06	0.048	0.048	0.048	-	-
Projected Population Numbers													
2015	16839	260125	25291	13637	12050	3885	851	479	2387	1560	577	-	-
2016	16839	13787	211019	19957	10182	8833	2646	579	326	1686	750	-	-
2017	16839	13787	11231	169328	15538	7849	6540	1959	429	247	914	-	-
2018	16839	13787	11253	9085	134508	12269	6049	5040	1510	334	450	-	-
Projected Population Biomass													
2015	1347	52025	10369	8182	8676	3225	791	455	2411	1700	681	89863	26121
2016	1347	2757	86518	11974	7331	7331	2460	550	330	1838	885	123322	32699
2017	1347	2757	4605	101597	11188	6514	6082	1861	433	269	1078	137731	129022
2018	1347	2757	4614	5451	96846	10183	5626	4788	1525	365	530	134032	125313
Projected Catch Numbers													
2015	0	2163	830	1090	1146	595	130	73	297	143	53	-	-
2016	0	63	3808	887	541	767	230	50	23	86	38	-	-
2017	0	38	122	4570	502	418	348	104	18	8	29	-	-
Projected Catch Biomass													
2015	0	1211	573	850	1042	595	137	84	360	175	73	5100	3316
2016	0	35	2628	692	492	767	241	57	28	106	53	5100	2437
2017	0	21	84	3565	457	418	365	119	22	9	40	5100	4994

Table19. A sensitivity projection run by adjusting the 2013 year class to the maximum recruitment in the time series and F_{ref} = 0.25 for 4X5Y Haddock. The Age 1 of 2014-2017 year classes was fixed at the most recent 10 years of geometric mean of recruitment at Age 1 (excluding the exceptional strong 2013 year class).

Year/Age	1	2	3	4	5	6	7	8	9	10	11+	1+	4+
Fishing Mortality													
2015	0	0.012	0.048	0.121	0.145	0.242	0.242	0.242	0.194	0.194	0.194	-	-
2016	0	0.013	0.05	0.125	0.15	0.25	0.25	0.25	0.2	0.2	0.2	-	-
2017	0	0.013	0.05	0.125	0.15	0.25	0.25	0.25	0.2	0.2	0.2	-	-
Projected Population Numbers													
2015	16839	42969	23415	13151	11649	3824	833	454	2303	1531	556	-	-
2016	16839	13787	34757	18264	9539	8248	2458	535	292	1554	699	-	-
2017	16839	13787	11147	27069	13196	6722	5259	1567	341	196	750	-	-
2018	16839	13787	11147	8682	19558	9299	4286	3353	999	229	315	-	-
Projected Population Biomass													
2015	1347	8594	9600	7891	8388	3174	774	432	2326	1669	657	44851	25310
2016	1347	2757	14250	10959	6868	6846	2286	508	295	1693	825	48635	30280
2017	1347	2757	4570	16241	9501	5579	4891	1489	345	213	885	47819	39145
2018	1347	2757	4570	5209	14082	7719	3986	3186	1009	249	371	44486	35811
Projected Catch Numbers													
2015	0	469	1004	1362	1431	748	163	89	369	180	66	-	-
2016	0	155	1538	1949	1207	1660	495	108	48	188	85	-	-
2017	0	155	493	2889	1670	1353	1059	315	56	24	91	-	-
Projected Catch Biomass													
2015	0	263	693	1062	1302	748	171	101	446	222	91	5100	4145
2016	0	87	1061	1520	1099	1660	519	123	58	232	118	6478	5330
2017	0	87	340	2253	1520	1353	1112	360	68	29	126	7249	6821

FIGURES

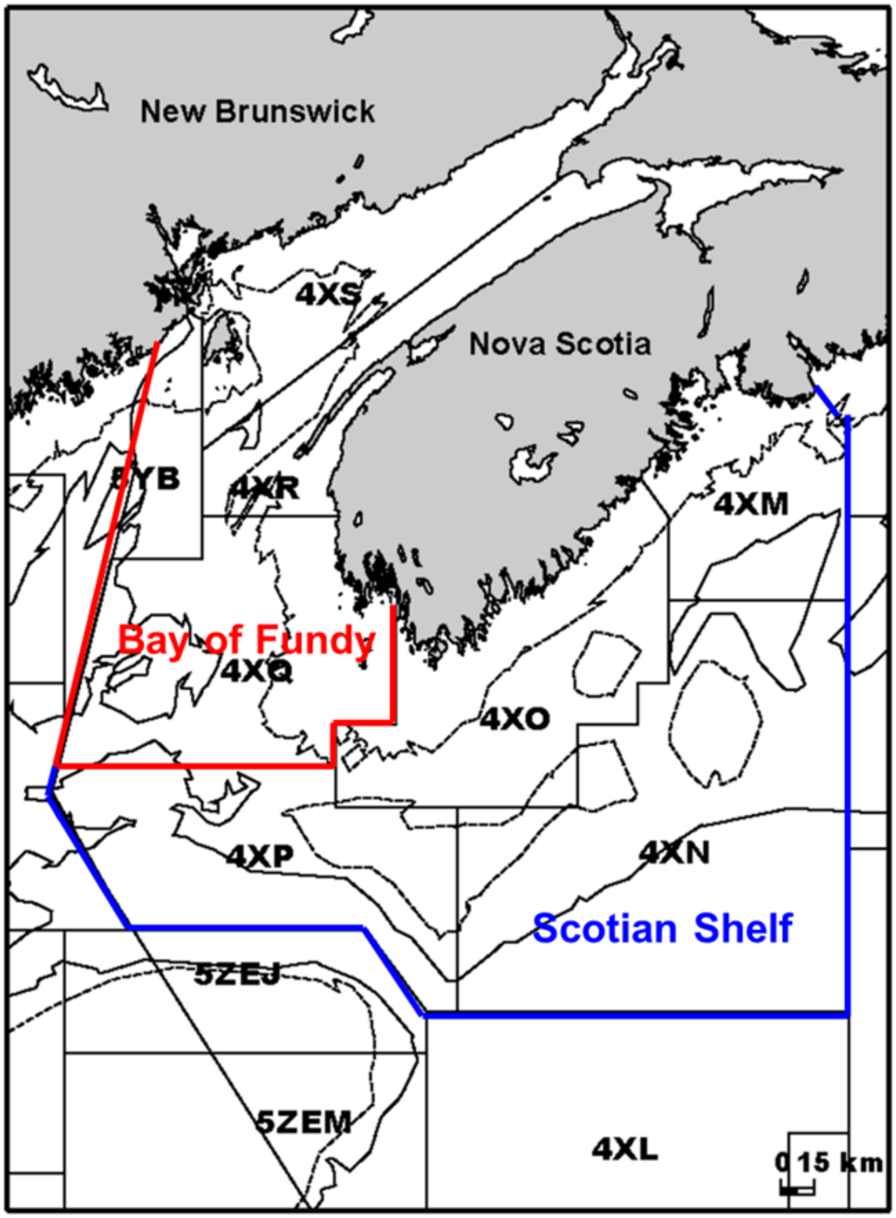


Figure1. Map of the 4X5Y Haddock management area and Canadian Statistical unit areas for the Bay of Fundy (4Xqrs) and western Scotian Shelf (4Xmnop). Separate age length keys for the western Scotian Shelf and Bay of Fundy are used for calculating the catch at age and survey age-specific indices of abundance. Haddock landed from statistical areas 5Zem and 5Zej are not included in the 4X5Y Haddock stock assessment.

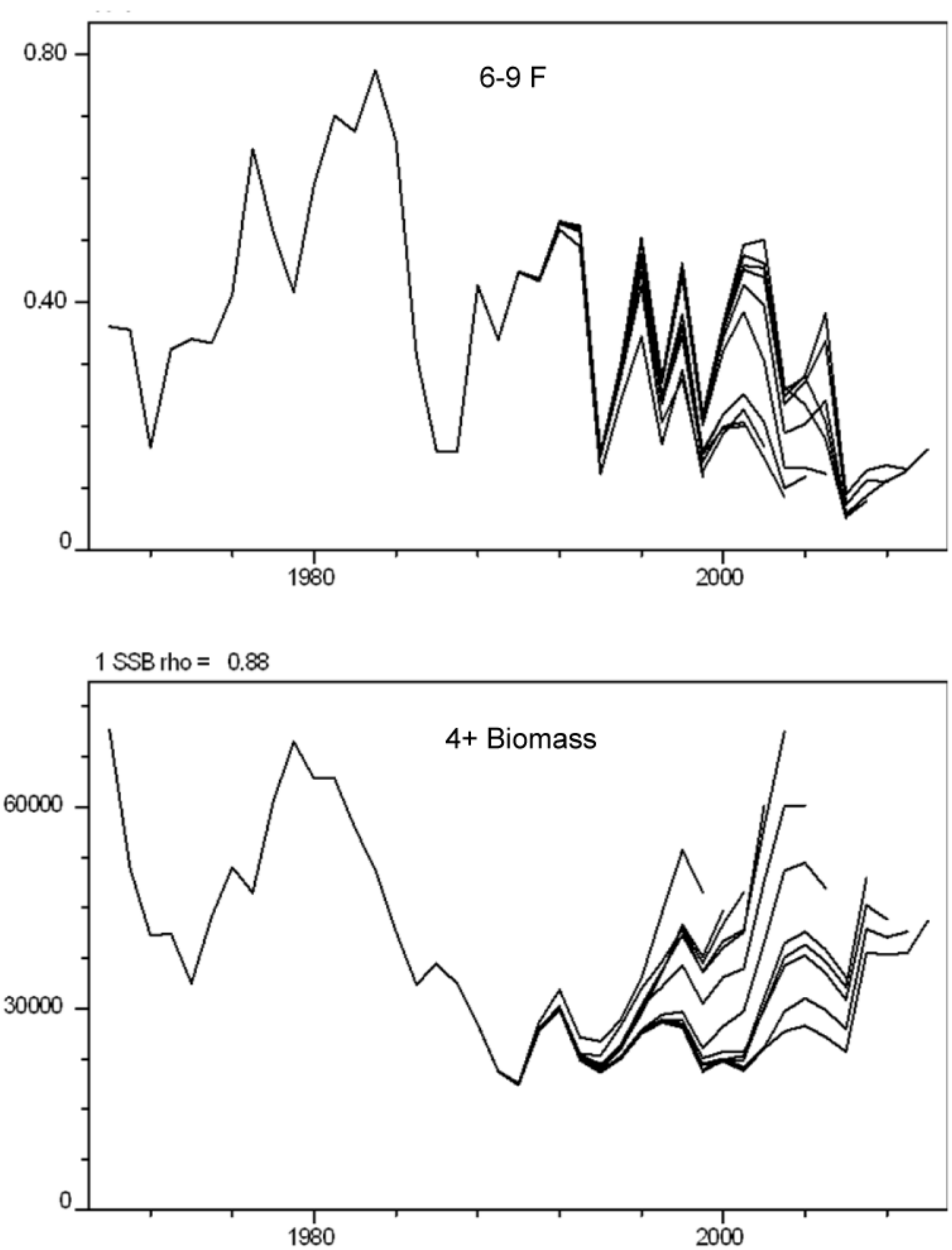


Figure 2. Retrospective results from sequential population analysis (SPA) for 4X5Y Haddock from the 2012 assessment (Showell et al. 2013) for Ages 6-9 fishing mortality (top panel), and 4+ biomass (bottom panel) as successive years of data were removed from the assessment.

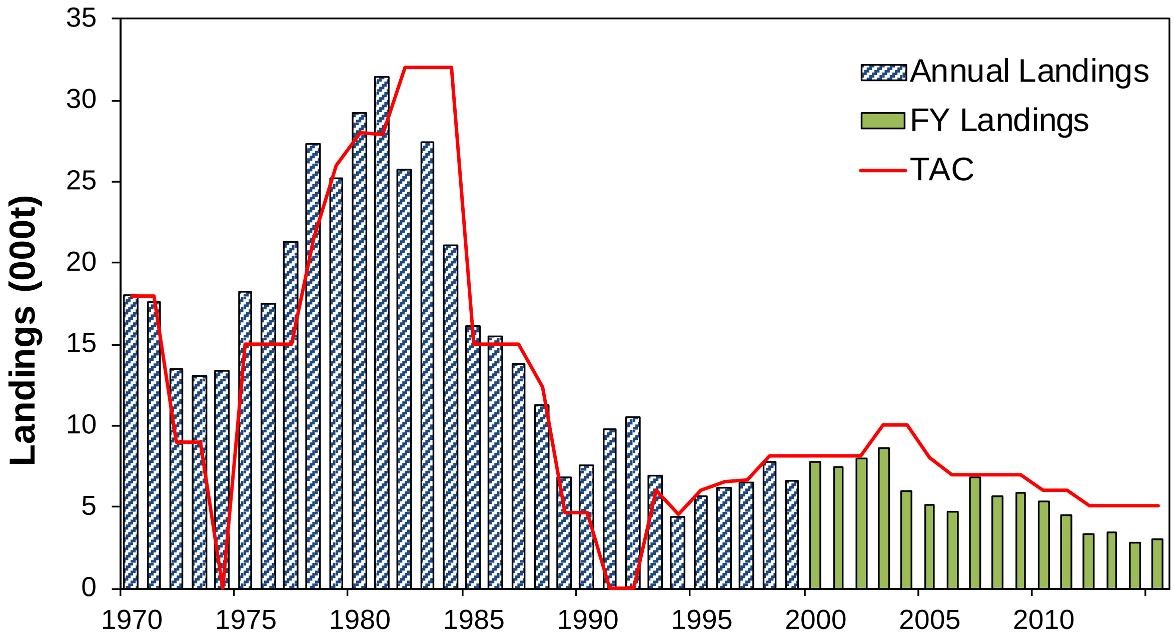


Figure 3. Reported annual landings (t), fishing year landings (FY; April 1st – March 31st) and TAC for the 4X5Y Haddock fishery, 1970-2015.

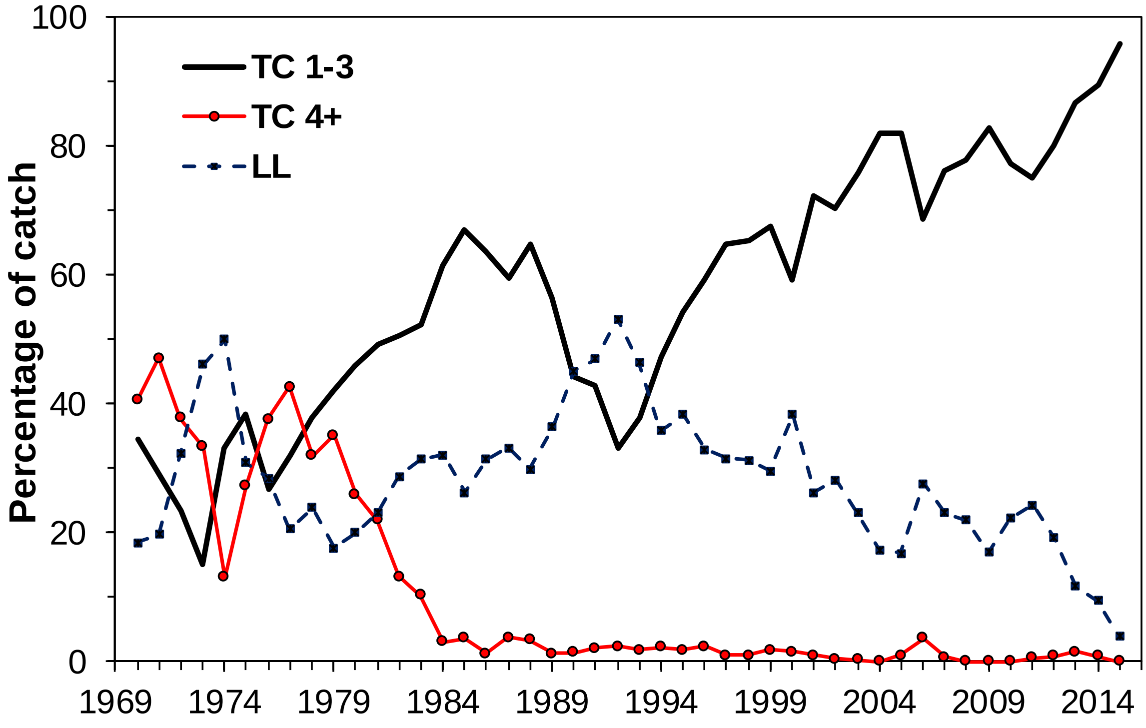


Figure 4. Percentage of annual landings (t) by gear type for the 4X5Y Haddock fishery, 1970-2015. TC 1-3 = otter trawl tonnage class 1-3; TC 4+ = otter trawl tonnage class 4+; LL = longline.

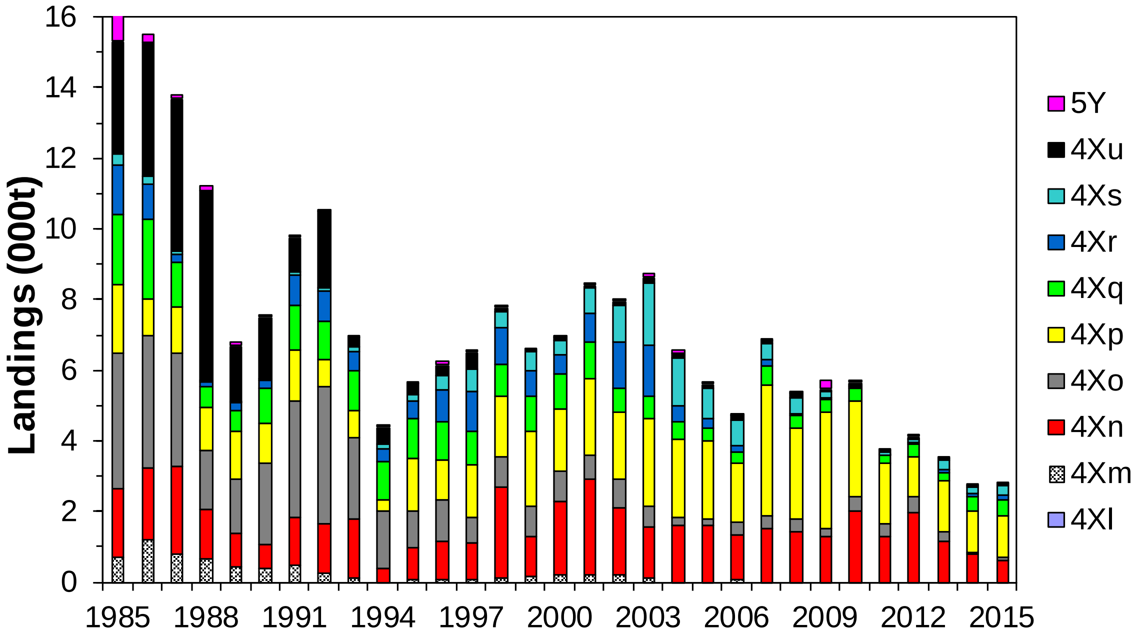


Figure 5. Annual landings (t) by Canadian statistical unit area for the 4X5Y Haddock fishery, 1985-2015.

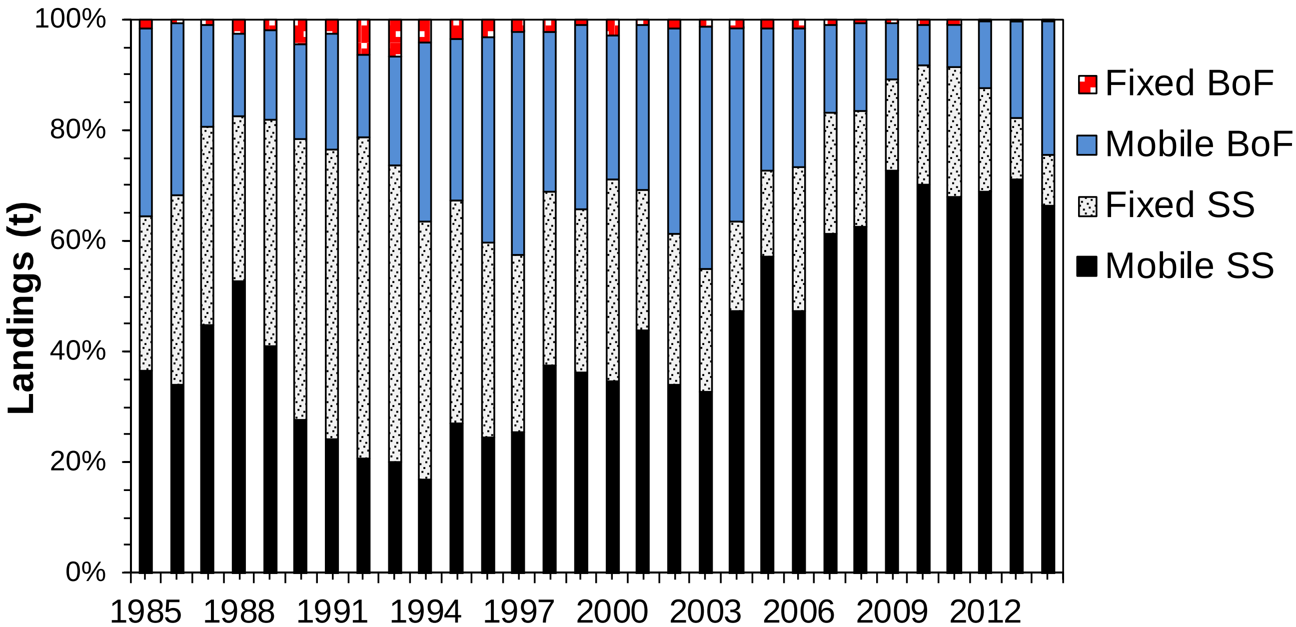


Figure 6. Annual landings (%) by gear sector for Canadian statistical unit areas representing the western Scotian Shelf (SS; 4Xmnop) and Bay of Fundy (BoF; 4Xqrs5Y) areas of the 4X5Y Haddock fishery, used in catch at age calculations for 1985-2014.

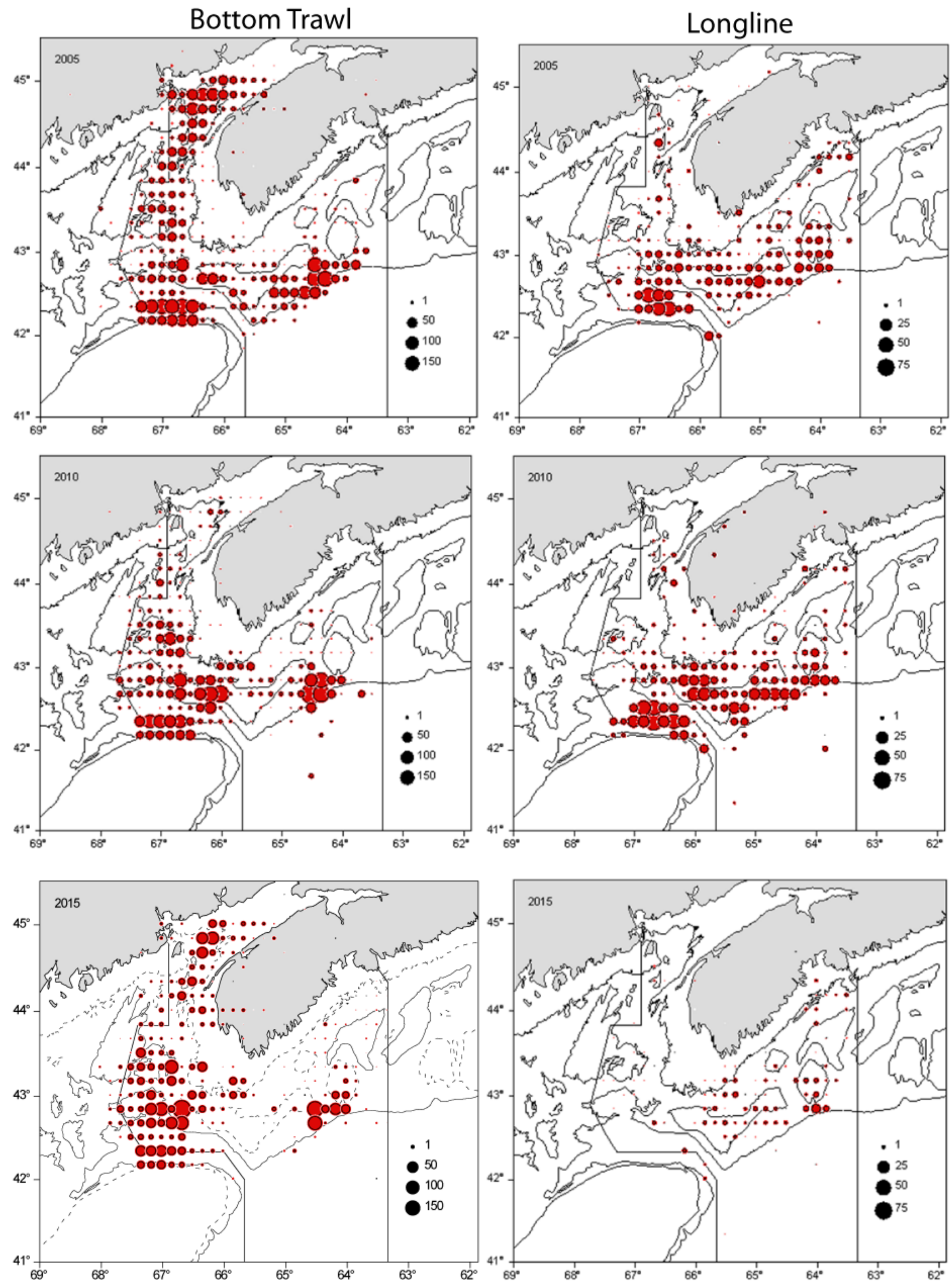


Figure 7. Distribution of 4X5Y Haddock catches (t) by gear type for 2005, 2010 and 2015.

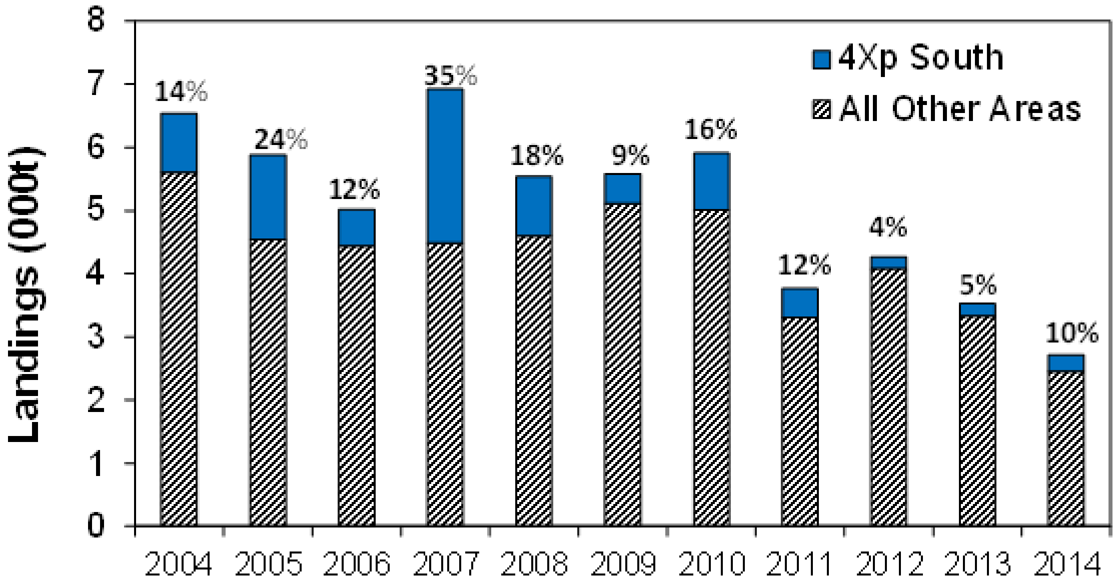


Figure 8. Haddock landings (000s t) from 4Xp south (i.e. within 5 nautical miles north of 4X5Z line), and all other statistical unit areas within the 4X5Y management unit for 2004-2014. Numerical values represent the percentage of total catch taken from the 4Xp south area.

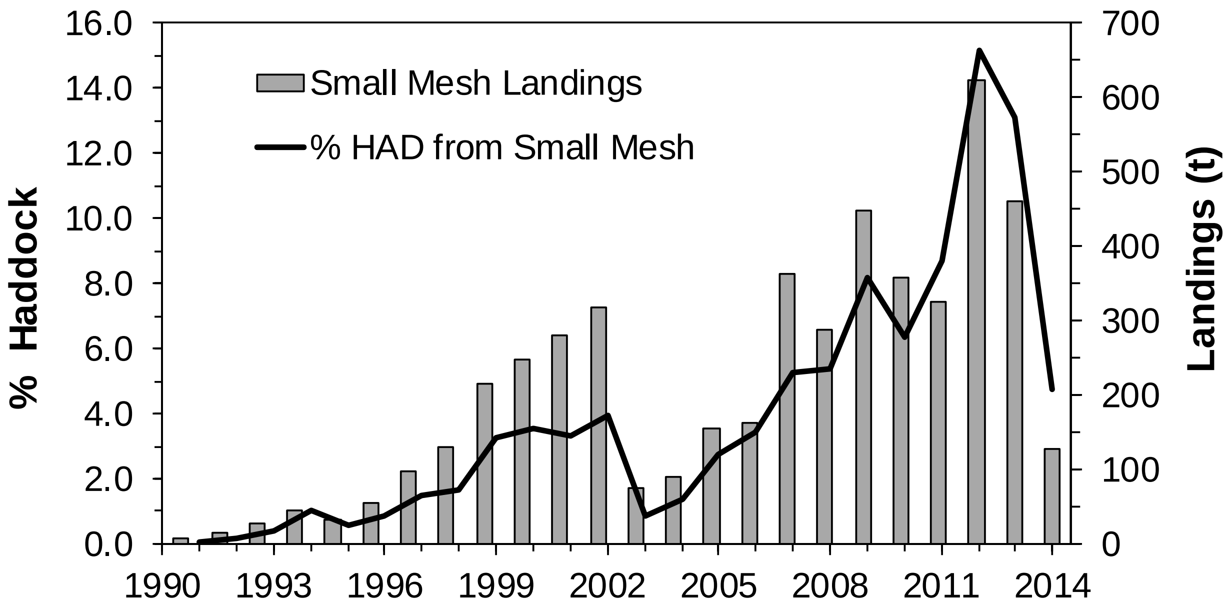


Figure 9. 4X5Y Haddock landings (t) from Small Mesh Otter trawl (Cod end mesh size: 110-112 mm diamond) and % of total annual landings,1991-2014.

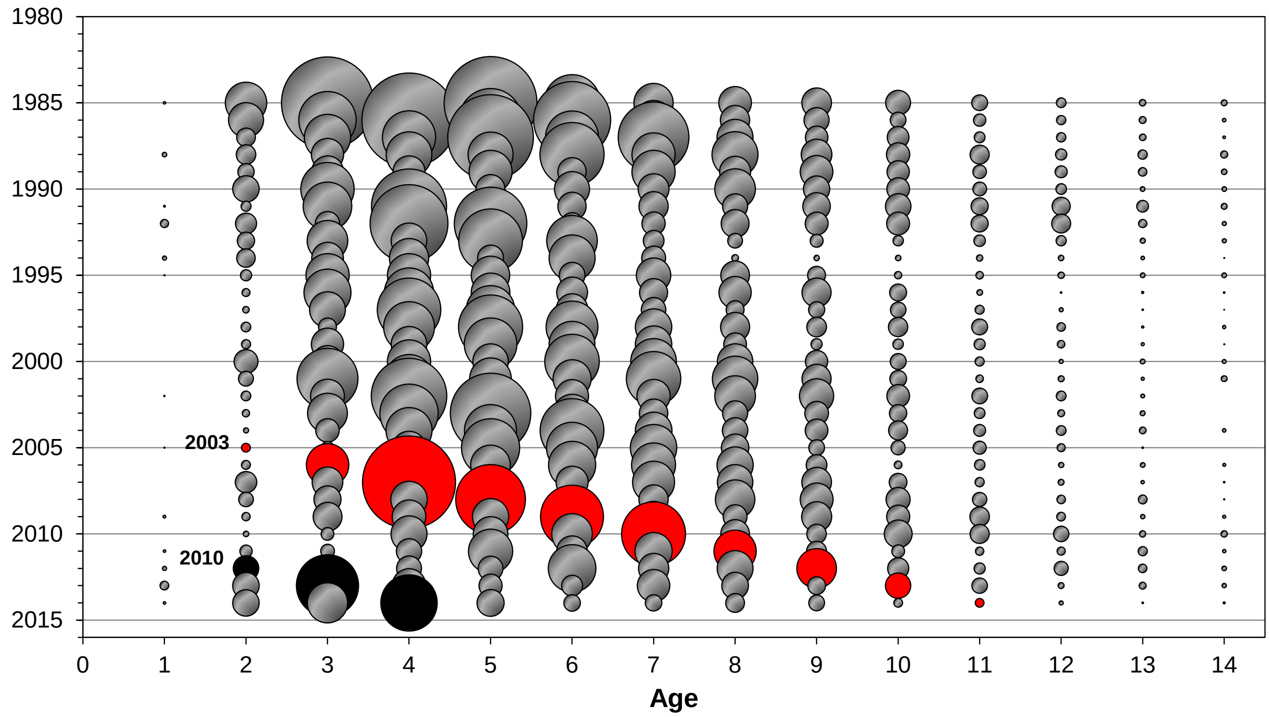


Figure 10. Catch at age for 4X5Y Haddock for Ages 1-14, 1985-2014. The area of the circle is proportional to the catch at that age and year. Two examples of recent strong cohorts are highlighted: 2003 (red) and 2010 (black). Data from 1985-2014 is used for framework modelling.

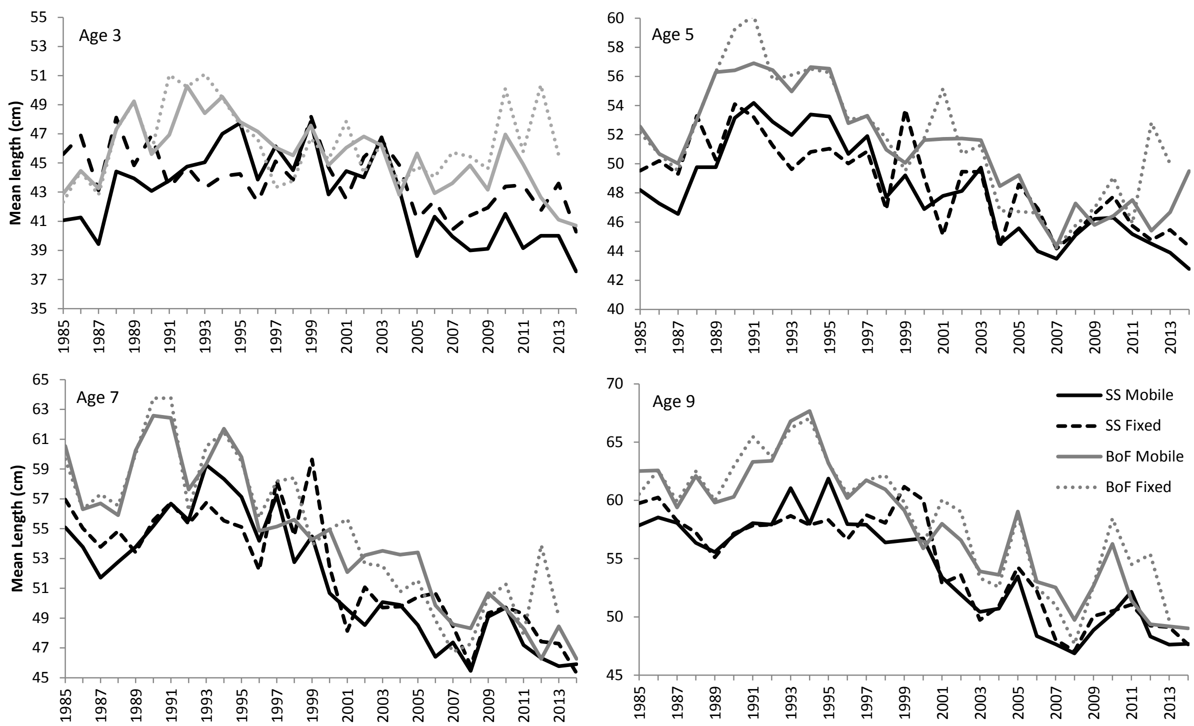


Figure 11. Commercial fishery mean length at age (cm) by area [Scotian Shelf (SS) and Bay of Fundy (BoF)] and gear type(mobile and fixed) for 4X5Y Haddock Ages 3, 5, 7, and 9 for 1985-2014.

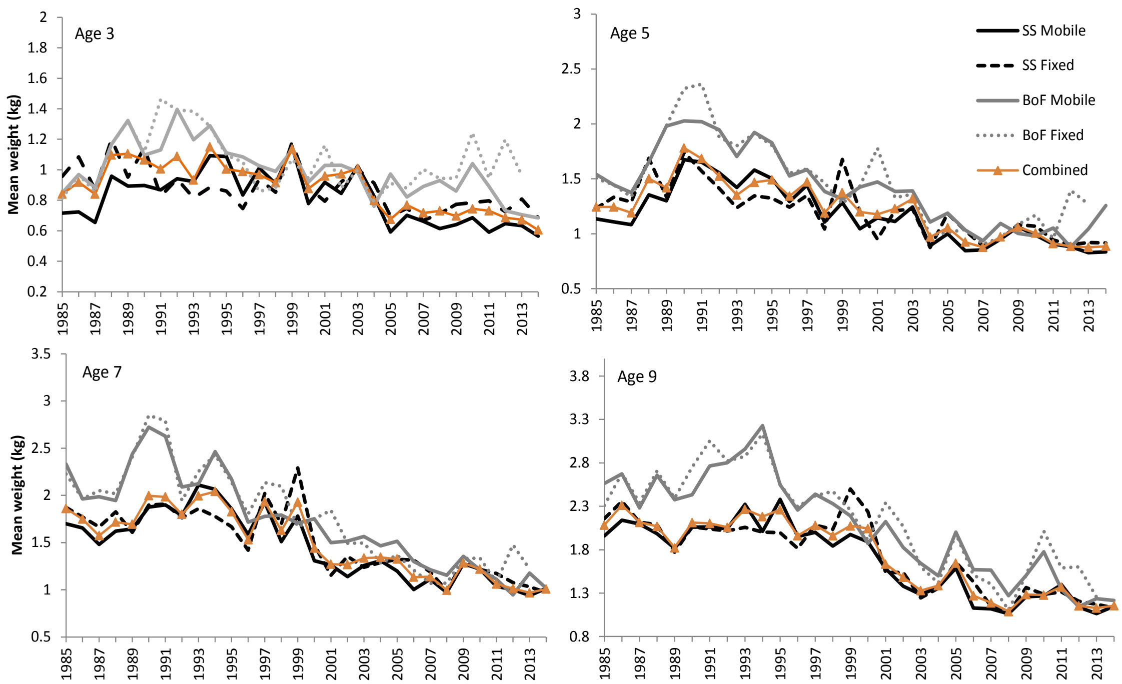


Figure 12. Commercial fishery mean weight at age (kg) by area [Scotian Shelf (SS) and Bay of Fundy (BoF)] and gear type (mobile and fixed), as well as the combined weight at age for 4X5Y Haddock Ages 3, 5, 7, and 9 for years 1985-2014.

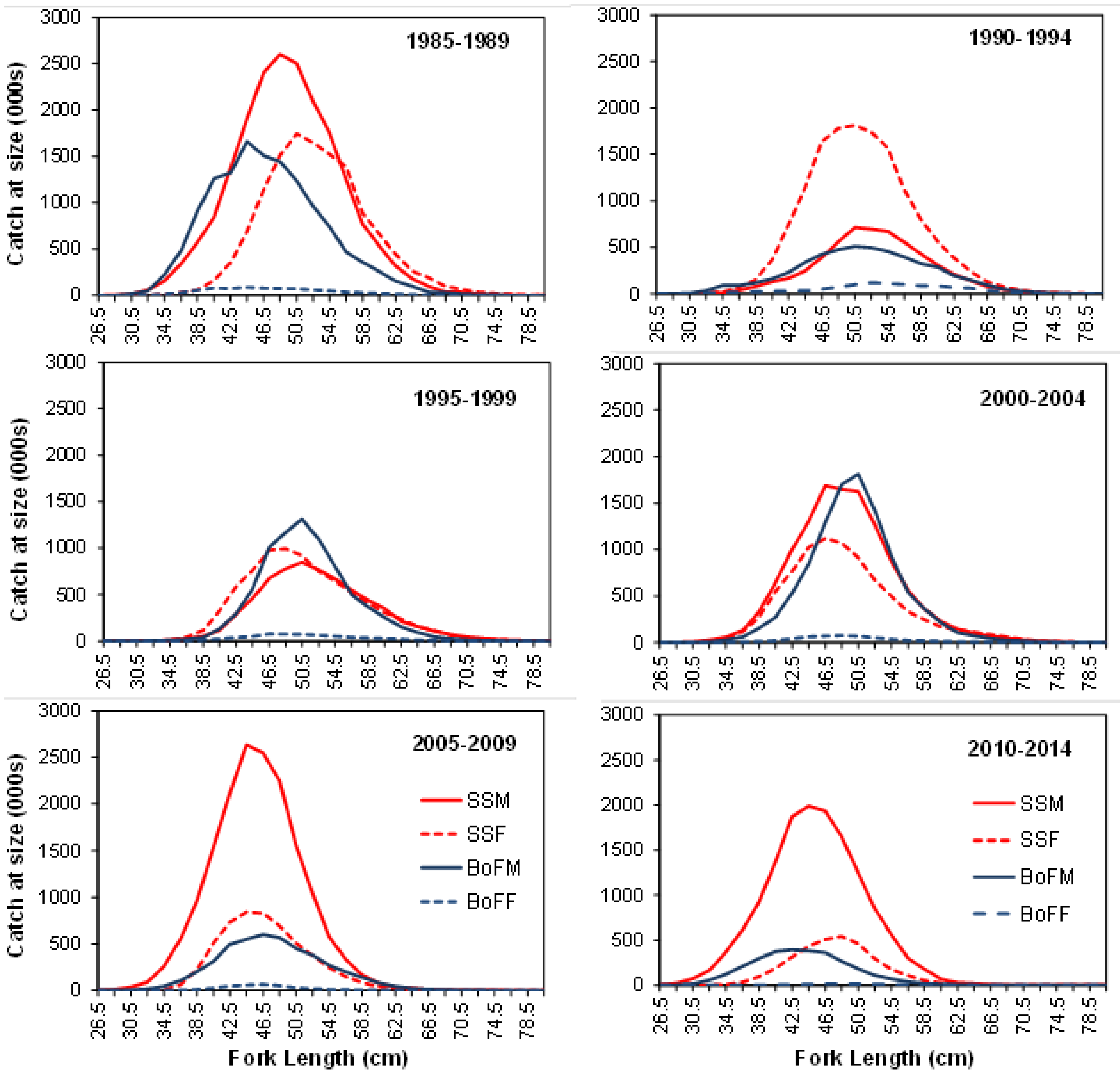


Figure 13. 4X5Y Haddock commercial fishery catch at size by area (SS: Scotian Shelf; BoF: Bay of Fundy) and gear type (M: mobile; F: fixed) summed over year intervals, 1985-2015.

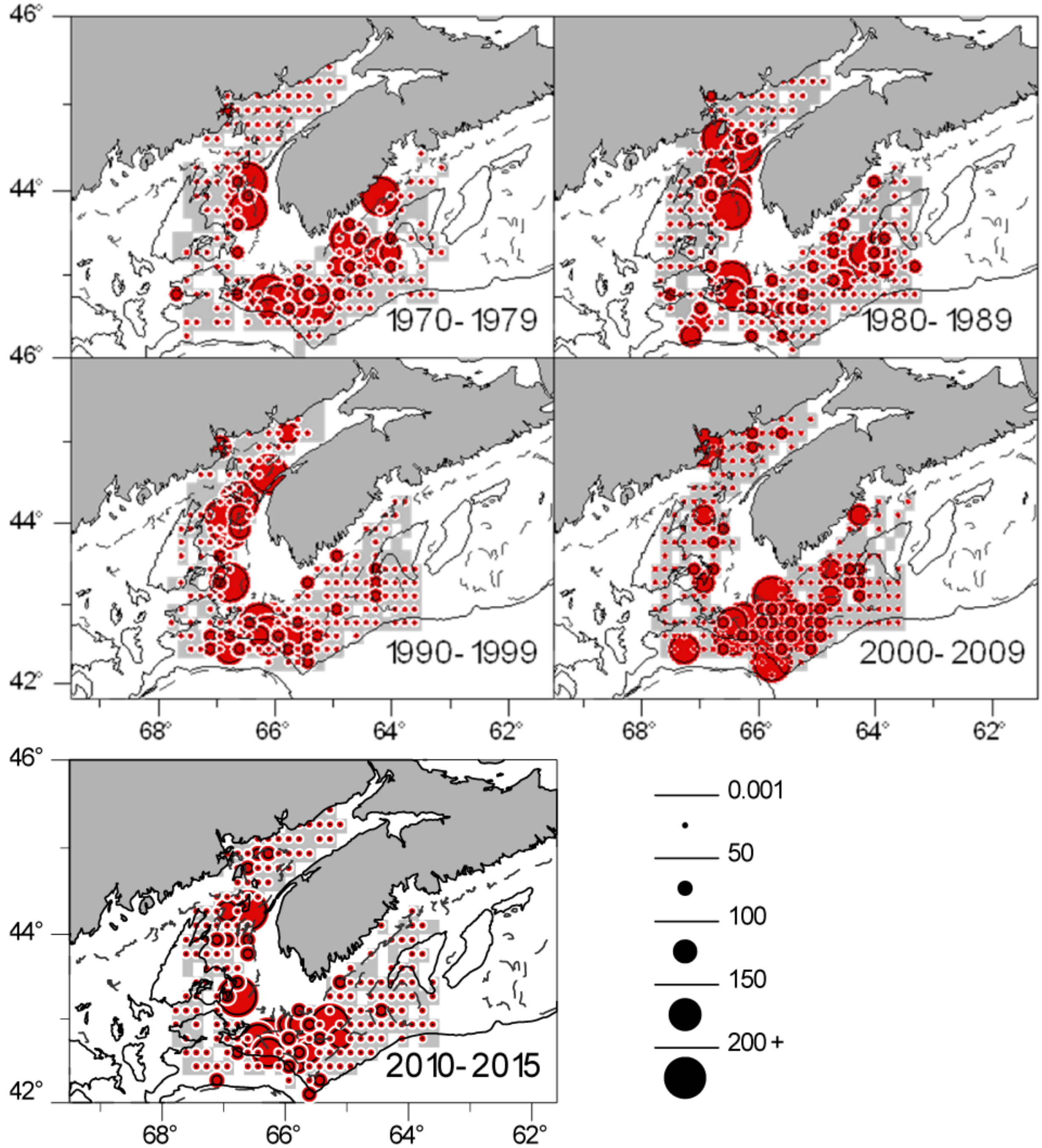


Figure 14. Distribution of 4X5Y Haddock catches (5 and 10 year average weight (kg)/tow aggregated by 10 minute squares) from DFO Summer survey Strata 470-495, 1970-2015. Grey shading indicates extent of area surveyed.

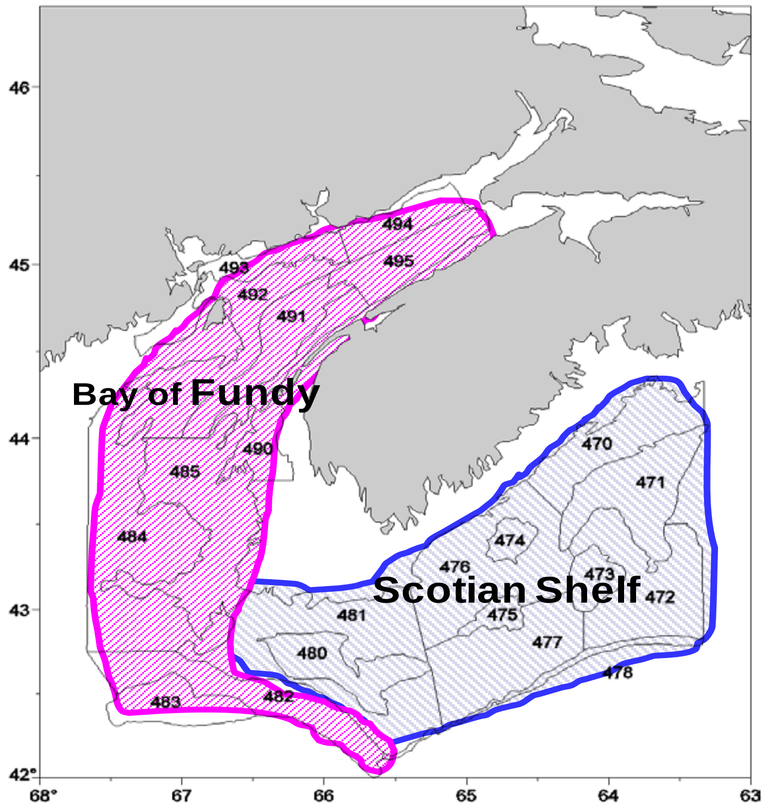


Figure 15. DFO Summer survey strata and area of coverage for Scotian Shelf (Strata 470-481, blue shading) and Bay of Fundy (Strata 482-495; pink shading) areas of 4X5Y.

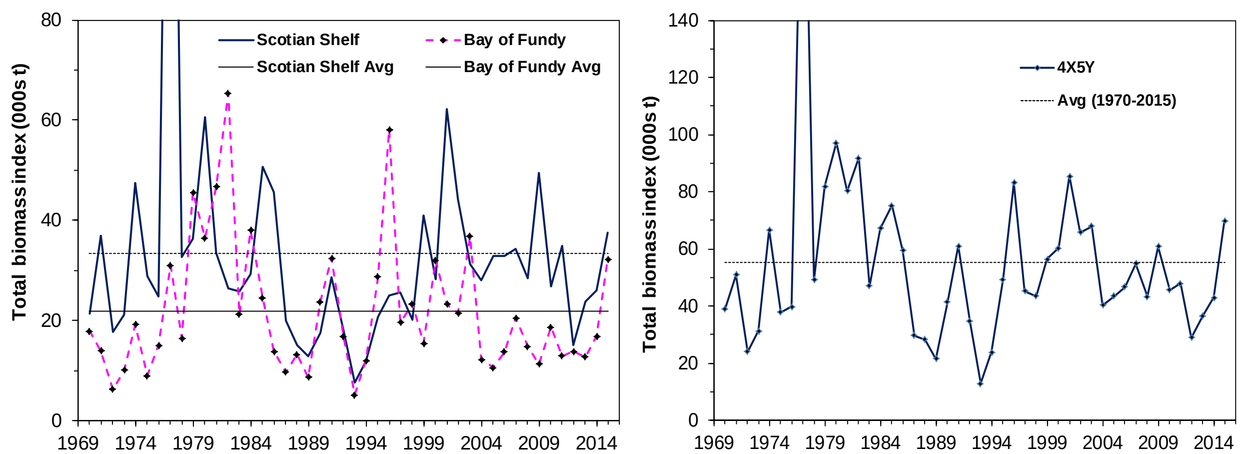


Figure 16. Trends in the total biomass index (000 t), including all ages, from the DFO Summer survey for Scotian Shelf (Strata 470-481), Bay of Fundy (Strata 482-495) (left panel) and both areas combined (4X5Y; right panel) compared to the long term average for each series from 1970-2015. A conversion factor of 1.2 has been applied to total biomass estimated for 1970-1981 to account for vessel and gear changes.

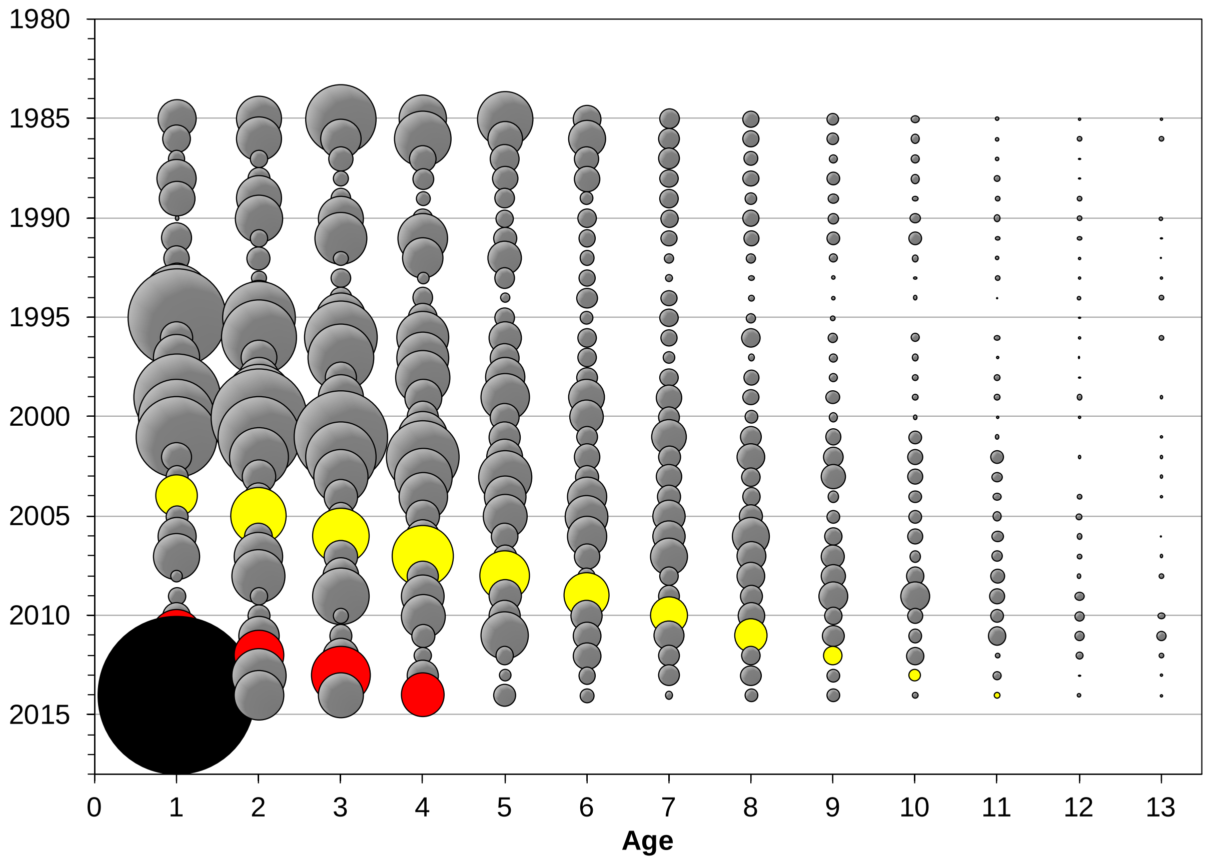


Figure 17. Stratified total number per tow at age (1-13) for 4X5Y Haddock from the DFO Summer survey, Strata 470-495, 1985-2014. Recent strong year classes are indicated by the yellow (2003) and red (2010) circles. The black circle represents the 2013 year class at Age 1 in 2014. The area of the circle is proportional to the catch at that age and year. Abundance at age data from 1985-2014 is used for framework modelling.

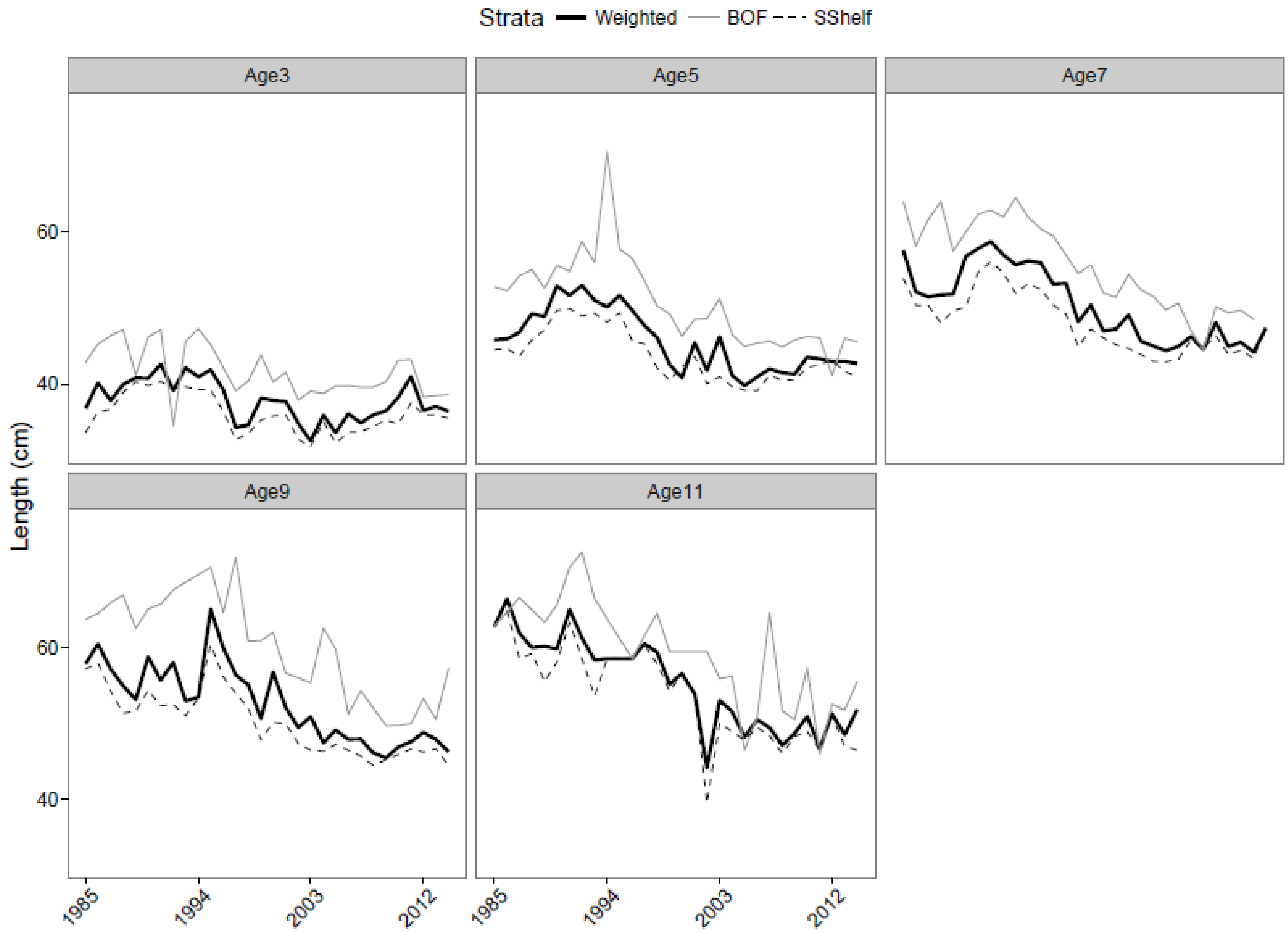


Figure 18. DFO Summer survey mean length at age (cm) for each strata (Scotian Shelf and Bay of Fundy); as well as the mean weighted length at age for 4X5Y Haddock Ages 3, 5, 7, 9, and 11 1985-2014. Mean weighted lengths at age were calculated separately for Bay of Fundy and western Scotian Shelf Strata then combined after weighting using total abundance at age from each strata.

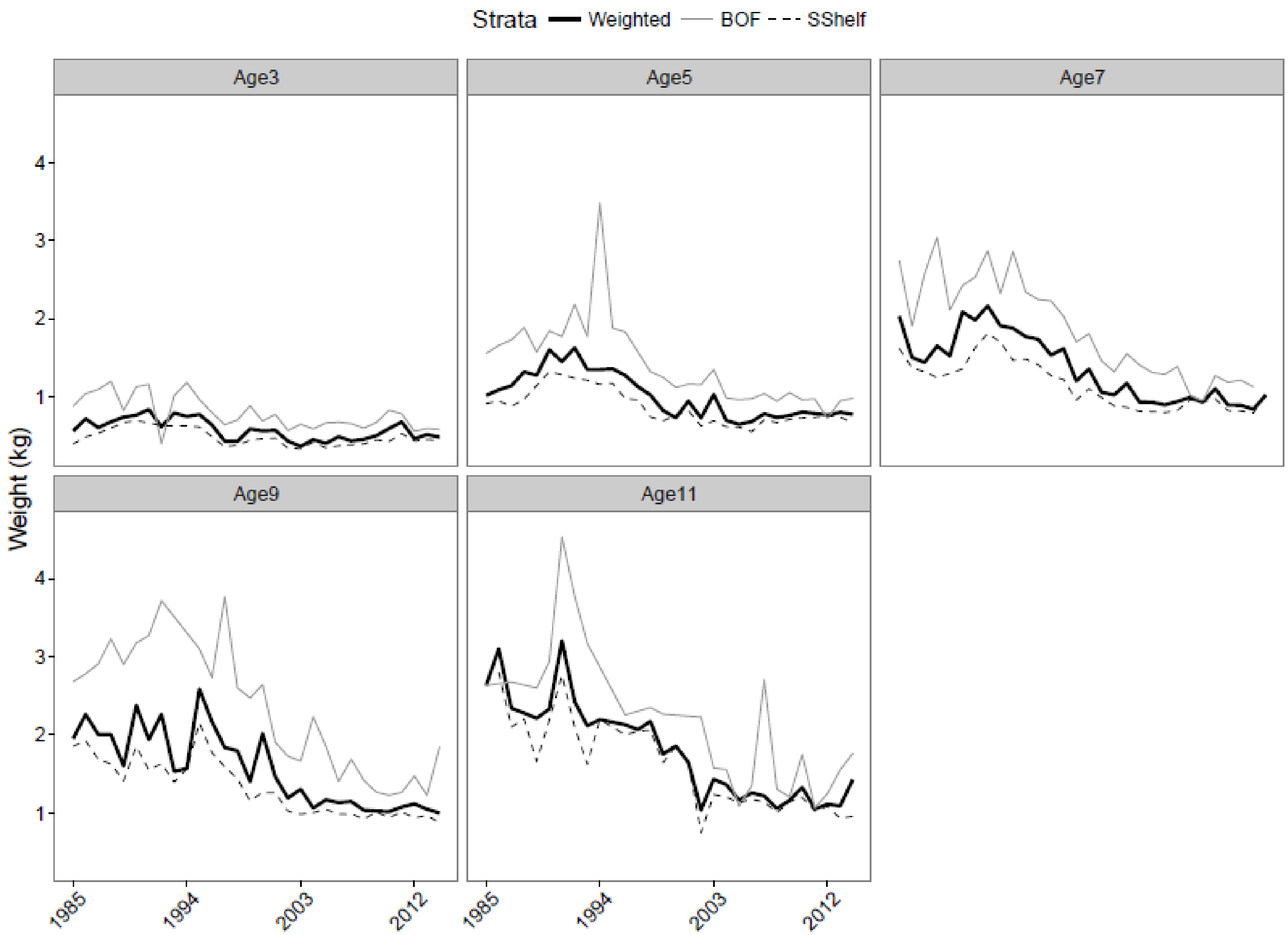


Figure 19. DFO Summer survey mean weight at age (kg) for each strata (Scotian Shelf and Bay of Fundy); as well as the mean weighted weight at age (Combined) for 4X5Y Haddock Ages 3, 5, 7, 9, and 11 for 1985-2014. Mean weighted weights at age were calculated separately for Bay of Fundy and western Scotian Shelf Strata then combined after weighting using total abundance at age from each strata.

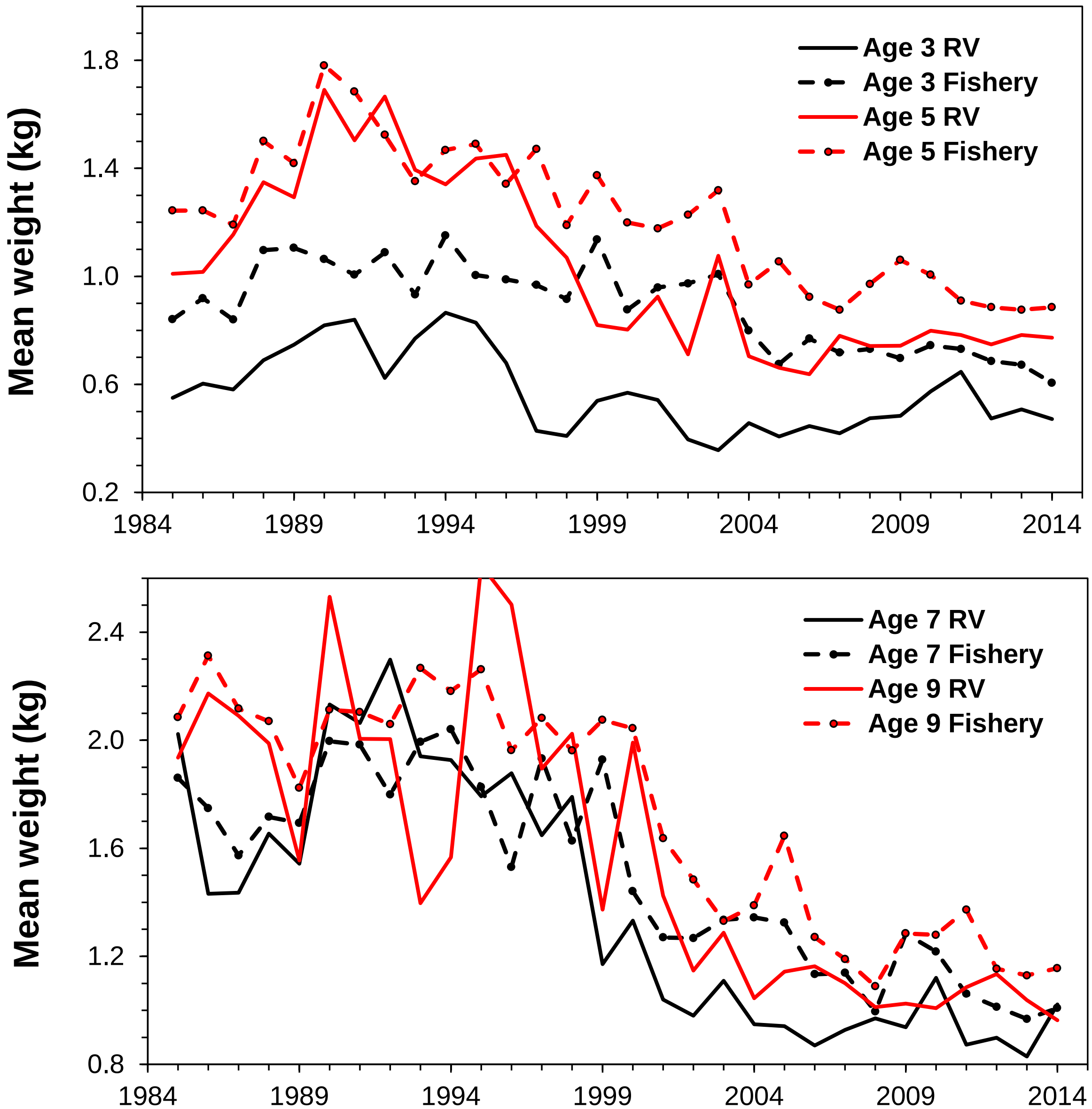


Figure 20. Comparison of DFO Summer survey and commercial fishery mean weight at age (kg) for Ages 3 and 5 (upper panel) and Ages 7 and 9 (lower panel) for Haddock from the 4X5Y management area, 1985-2014.

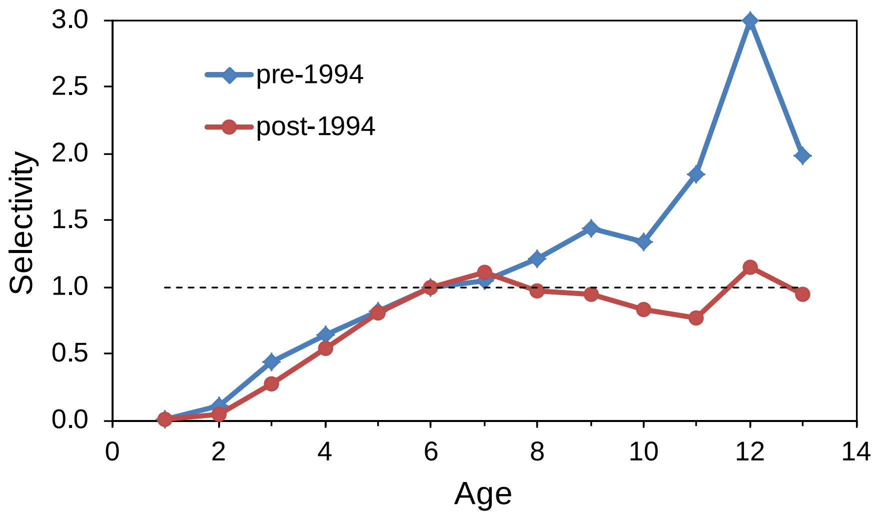


Figure 21. Relative fishery selectivity at age for 4X5Y Haddock from two time periods before and after 1994 calculated using the method of Clark (2014).

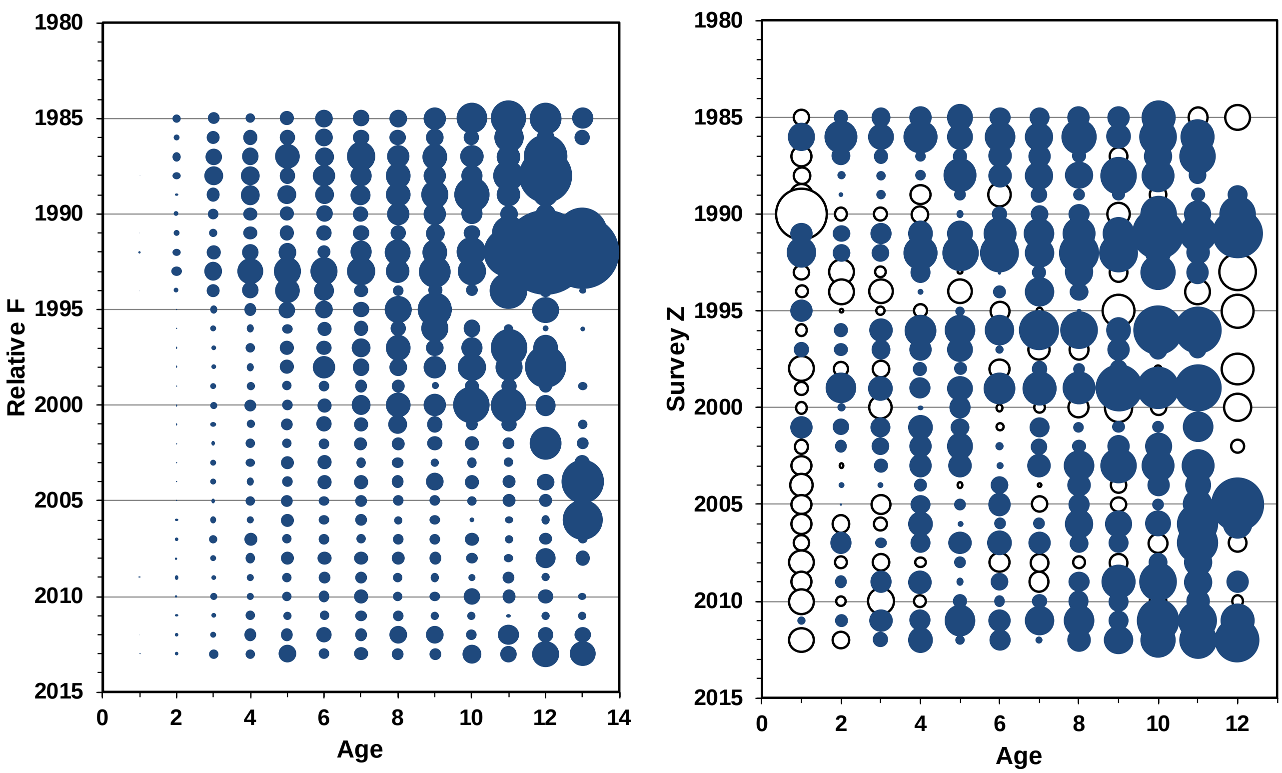
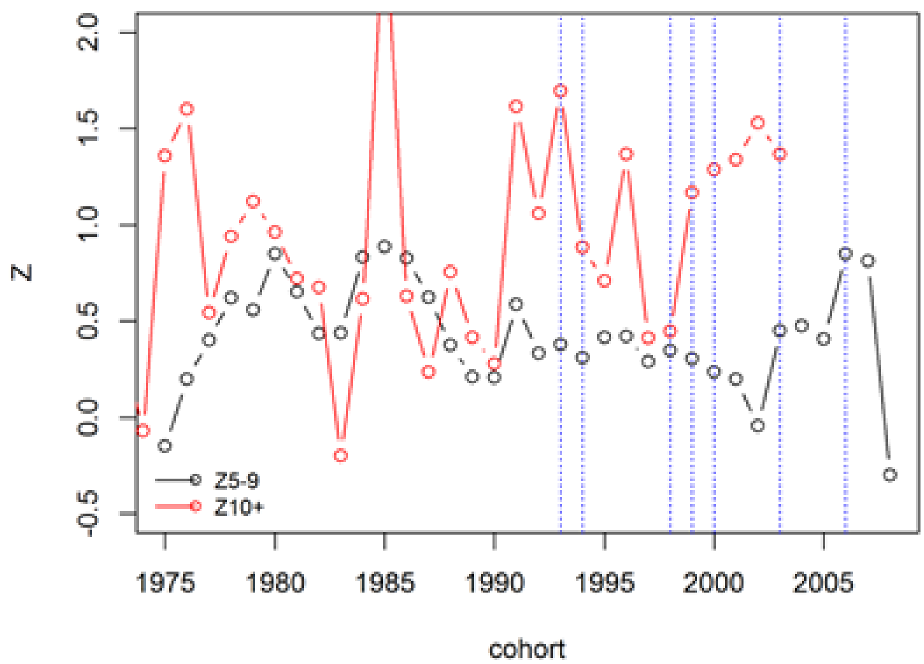


Figure 22. The 1985-2014 relative F (left) calculated as the ratio of fishery catch at age over the survey catch at age; and survey Z (right) calculated from the DFO Summer survey catch at age for 4X5Y Haddock.



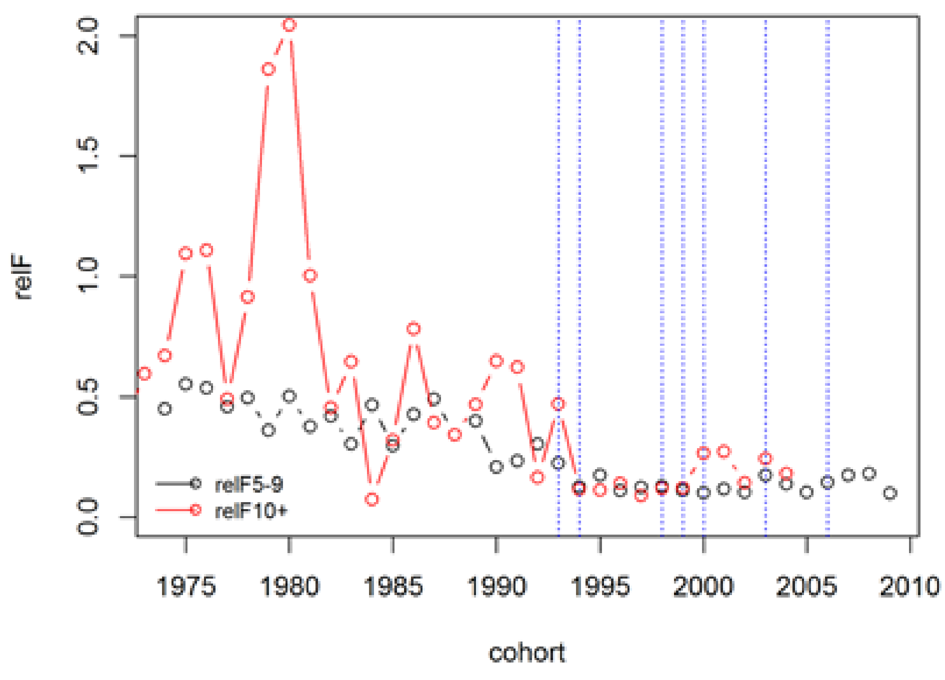


Figure 23. Estimated survey Z (top) and relative F (bottom) on Ages 5-9 and Ages 10+ by tracking each cohort for 4X5Y Haddock. The blue vertical reference lines represent strong cohorts.

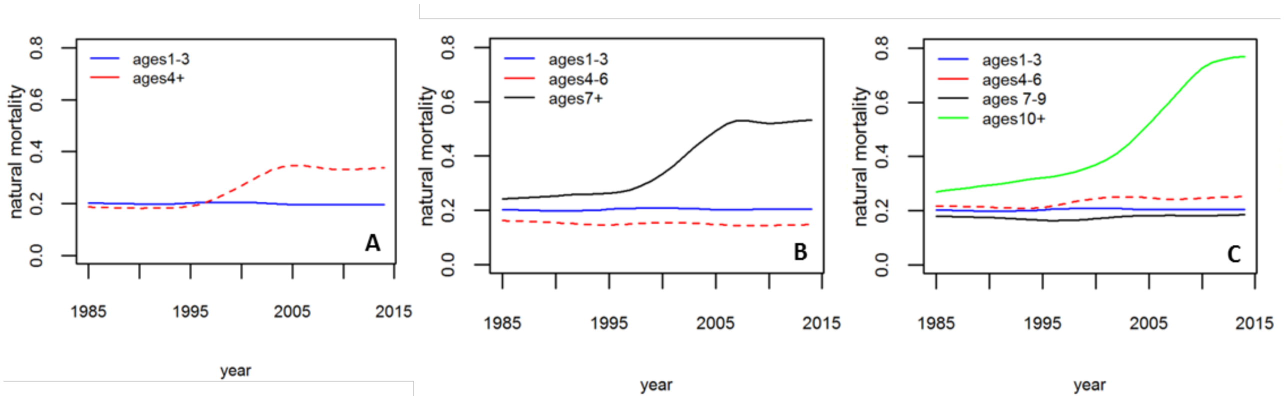


Figure 24. Natural mortality estimated from the 3 VPA models with time-varying natural mortality (M) on different age groups for 4X5Y Haddock. A) from the model with 2 M age groups: 1-3 and 4+; B) from the model with 3 M age groups: 1-3, 4-6, and 7+; C) from the model with 4 M age groups: 1-3, 4-6, 7-9, and 10+.

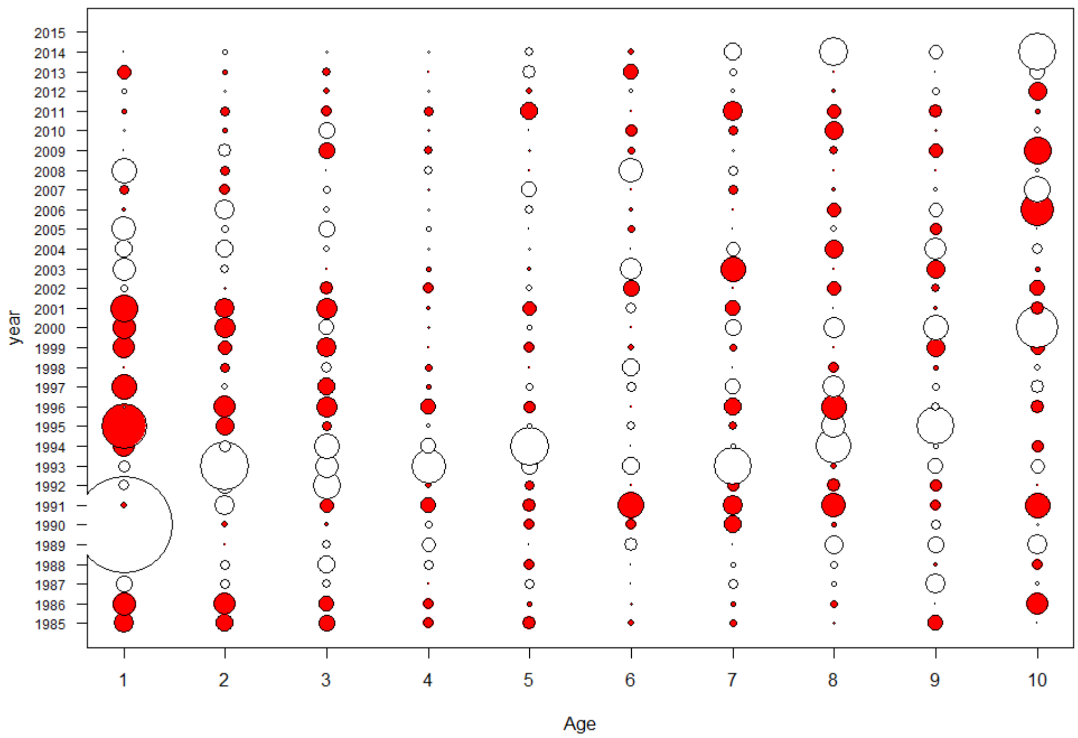


Figure 25. Residuals from the VPA model with time-varying natural mortality on 4 age groups: 1-3, 4-6, 7-9, and 10+ for 4X5Y Haddock.

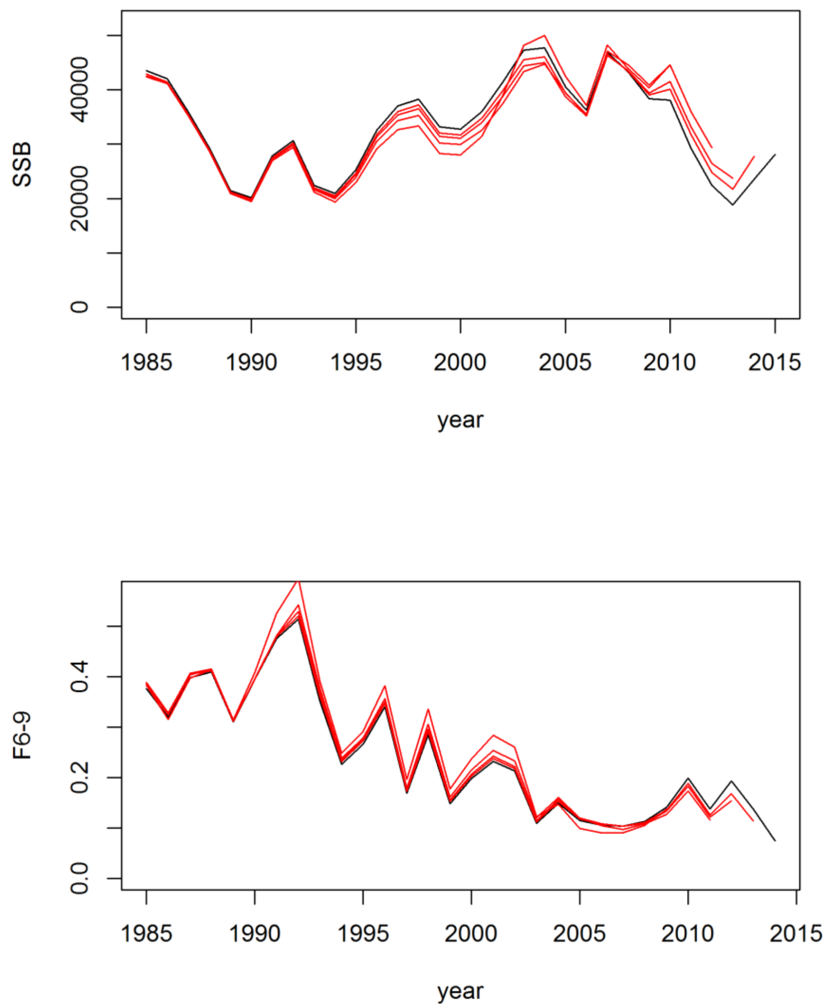


Figure 26. The retrospective analysis from the VPA model with time-varying natural mortality on 4 age groups: 1-3, 4-6, 7-9 and 10+ for 4X5Y Haddock. The top panel shows the spawning stock biomass (SSB) and bottom panel shows the fishing mortality (F6-9).

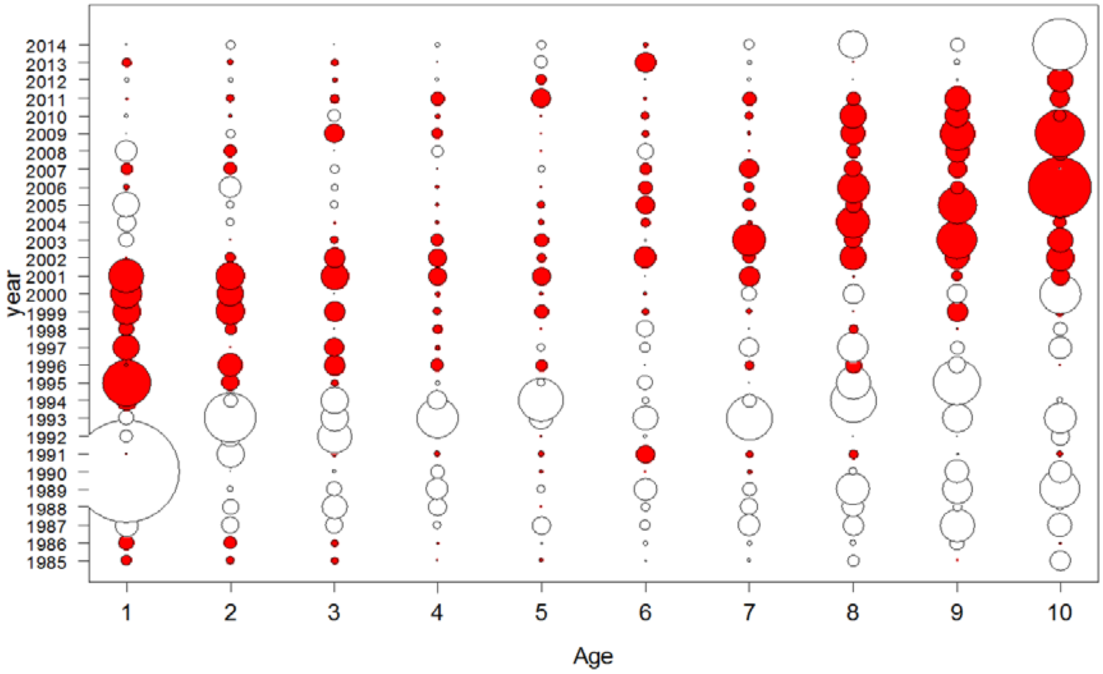


Figure 27. Residuals from the VPA model with a constant natural mortality of 0.2 for 4X5Y Haddock.

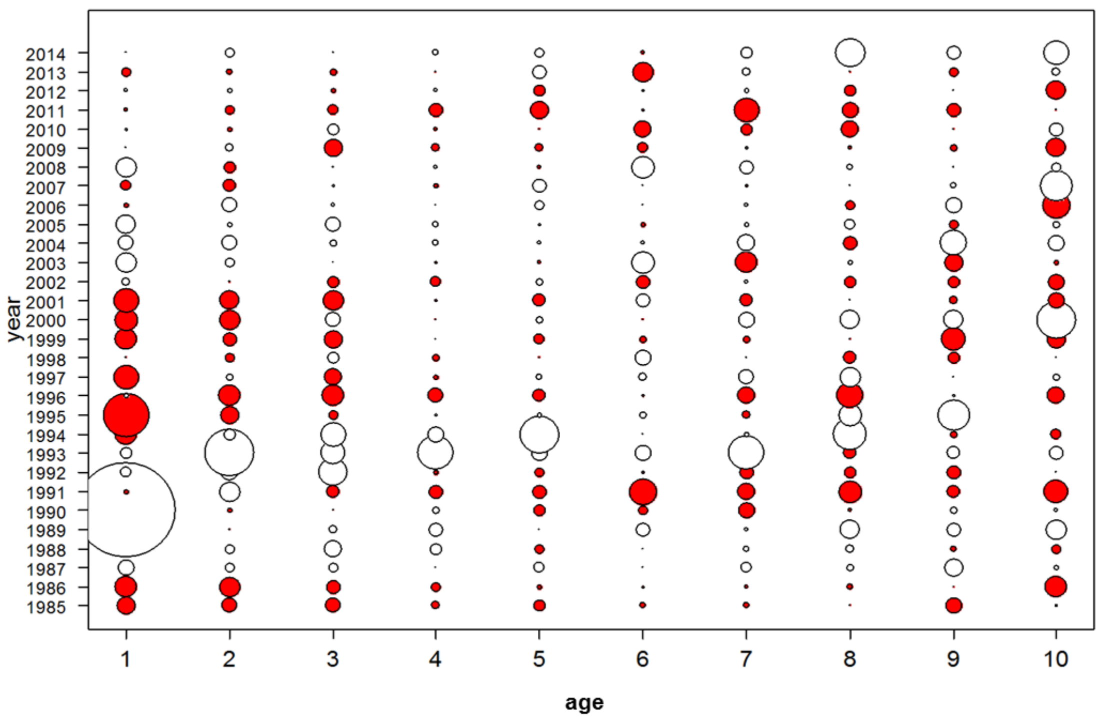


Figure 28. Residuals from the ADAPT VPA model formulation of M fixed 0.2, except at 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year times block (2000-2004, 2005-2009, and 2010-2014, respectively) for 4X5Y Haddock.

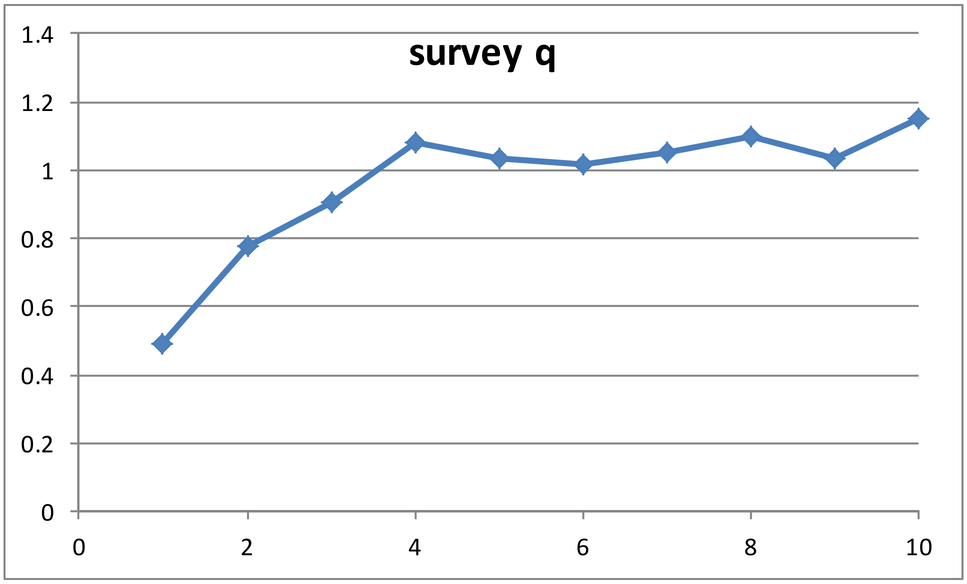


Figure 29. Survey catchability (q) at age estimated from ADAPT VPA model formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively) for 4X5Y Haddock.

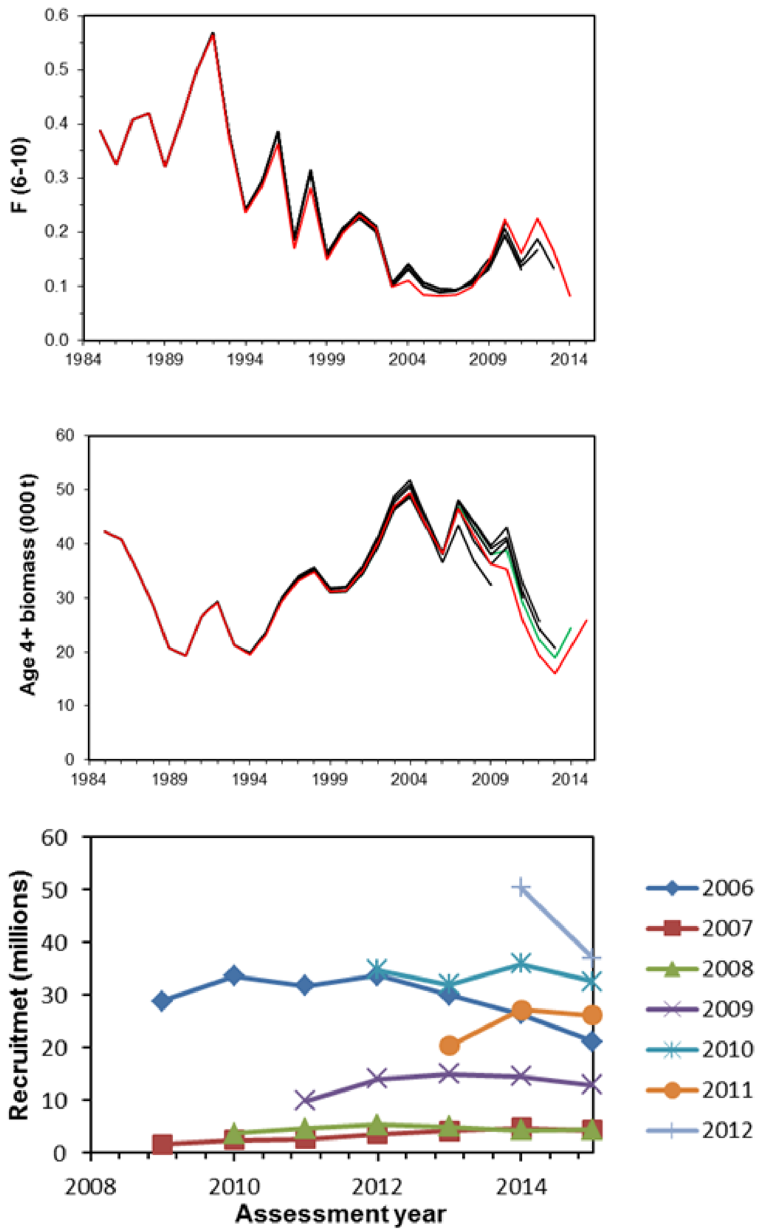


Figure 30. Retrospective analysis for the ADAPT VPA model formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively) for 4X5Y Haddock.

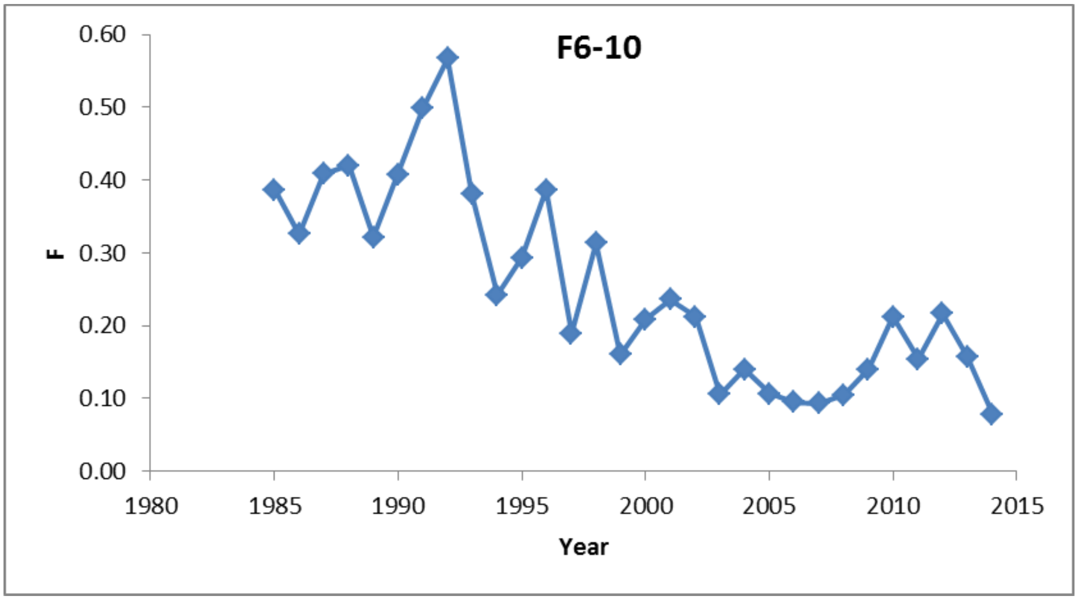


Figure 31. The population number weighted average fishing mortality over Ages 6-10 ($F_{6\text{-}10}$) from the ADAPT VPA model formulation with M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014, respectively) for 4X5Y Haddock.

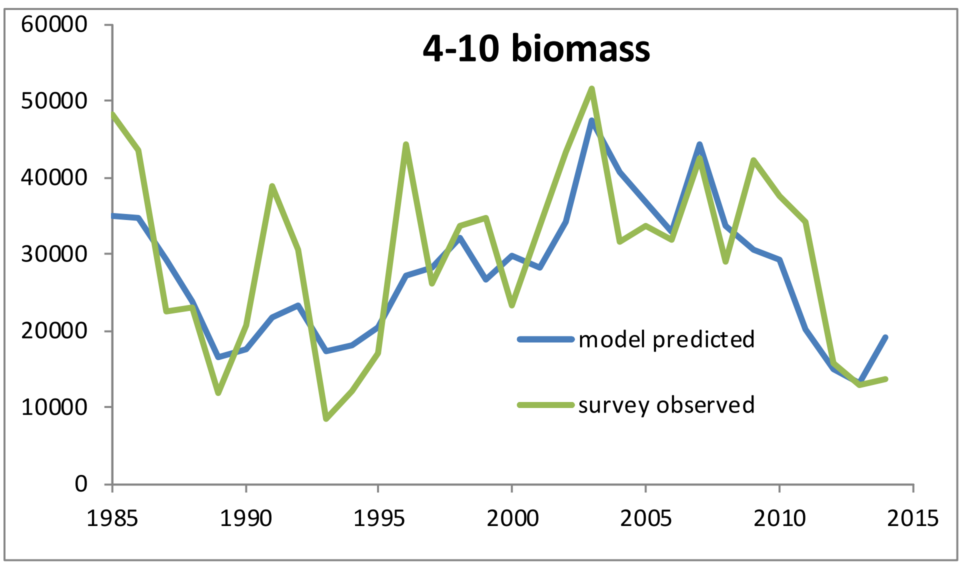


Figure 32. Biomass (000s t) of Ages 4-10 for 4X5Y Haddock from ADAPT VPA model formulation with M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively) compared with q adjusted DFO Summer survey biomass.

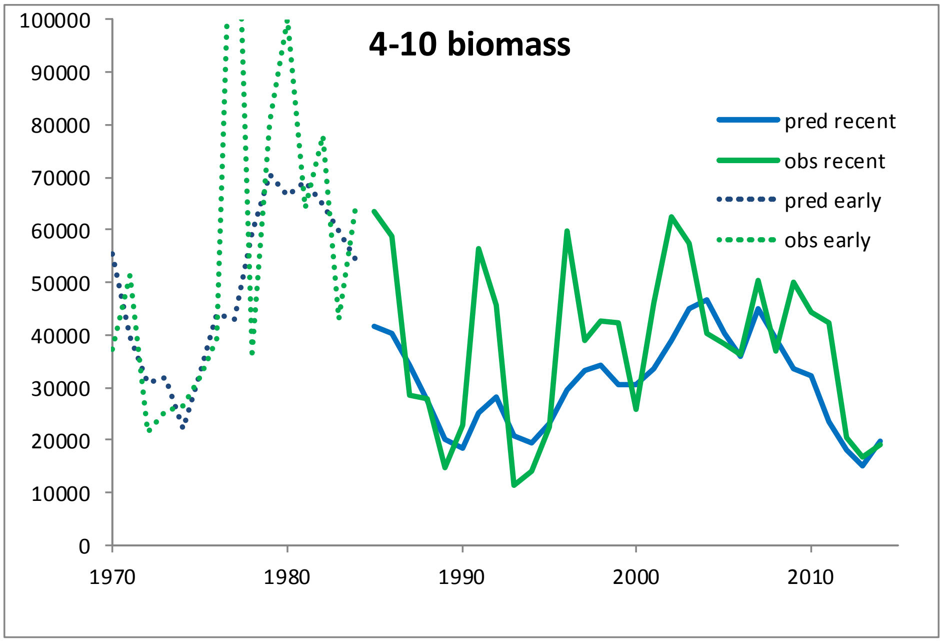
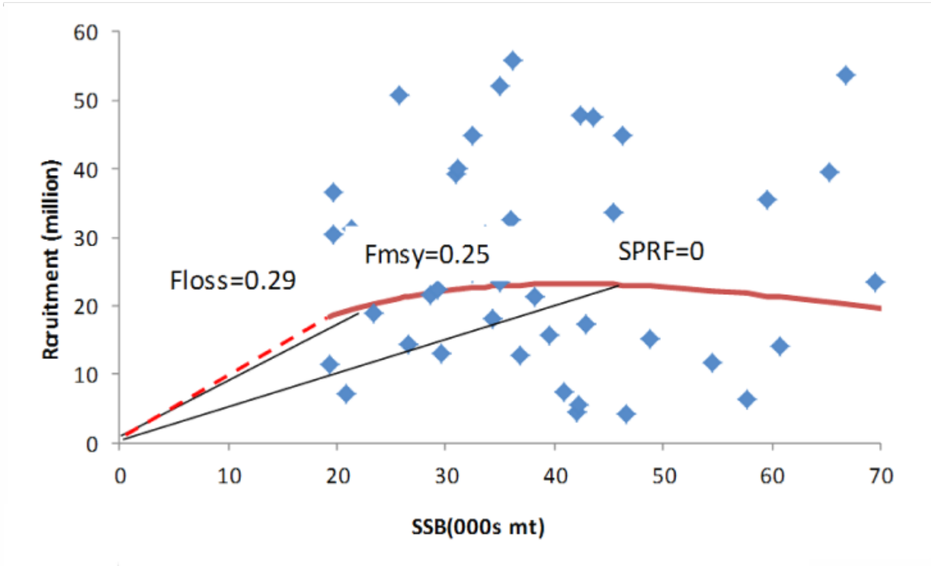


Figure 33. The model predicted and observed q adjusted DFO Summer survey biomass, Ages 4-10, for 4X5Y Haddock. The solid lines indicate more recent years (1985-2014), when aging data is believed to be more accurate and broken lines indicate the early portion of the series that was not re-aged.



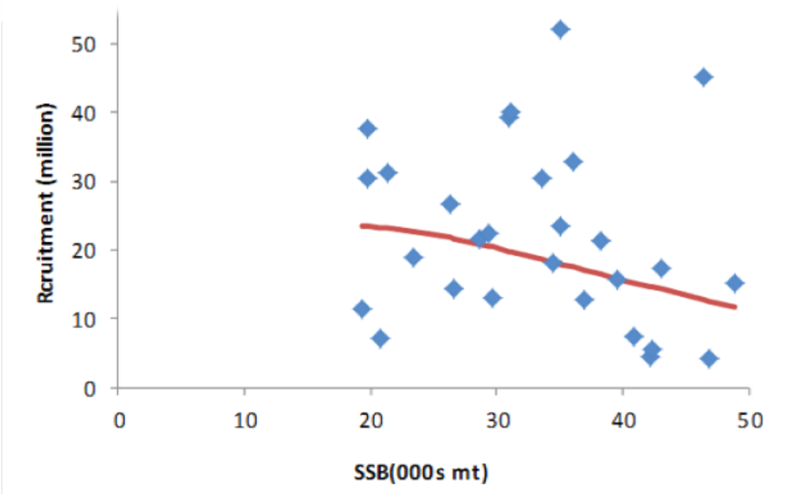


Figure 34. The fitted stock recruitment (SR) relationship with the Ricker SR model for 4X5Y Haddock using the output data from the ADAPT VPA formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively). The upper panel shows the result using a longer time series (1970-2014) and the lower panel with a shorter time series (1985-2014) of SR data. F_{loss}, F_{msy} and the replacement line when there was no fishing ($SPR_{F=0}$) are shown when applicable.

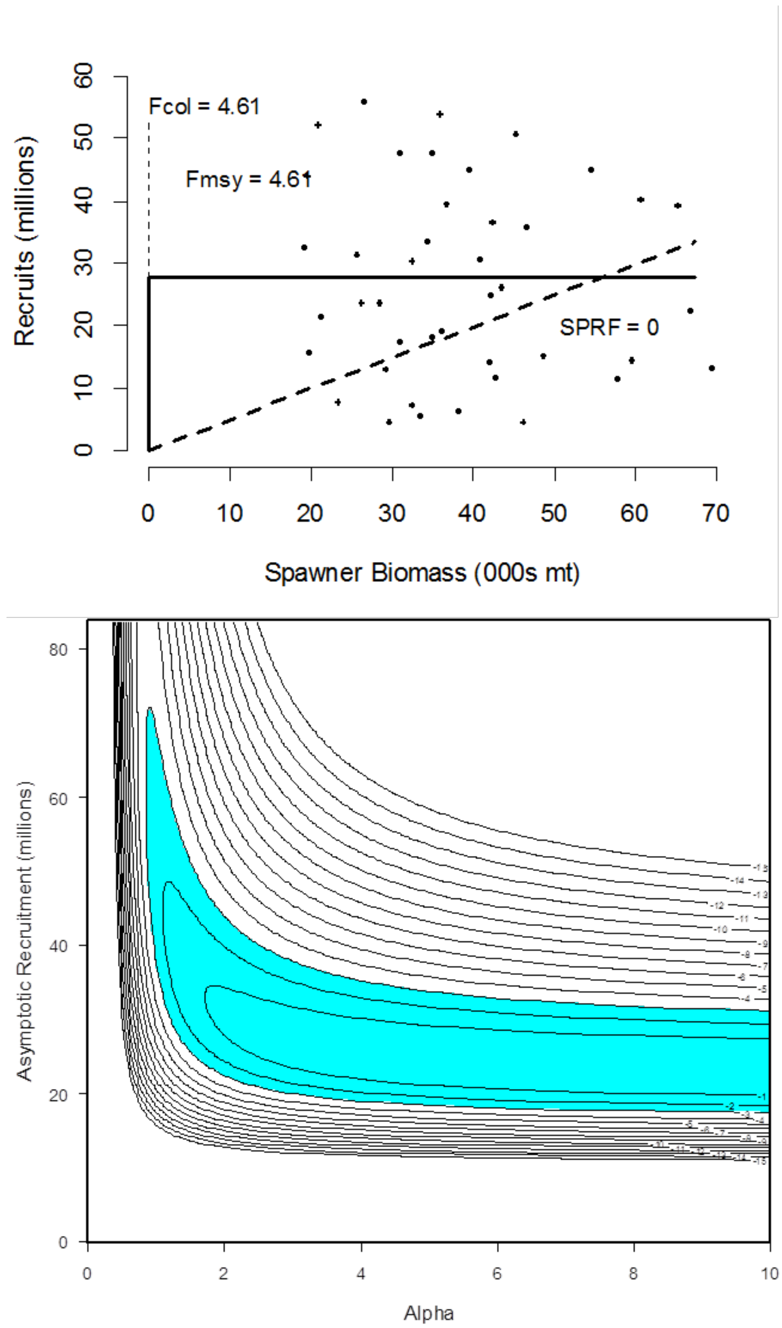
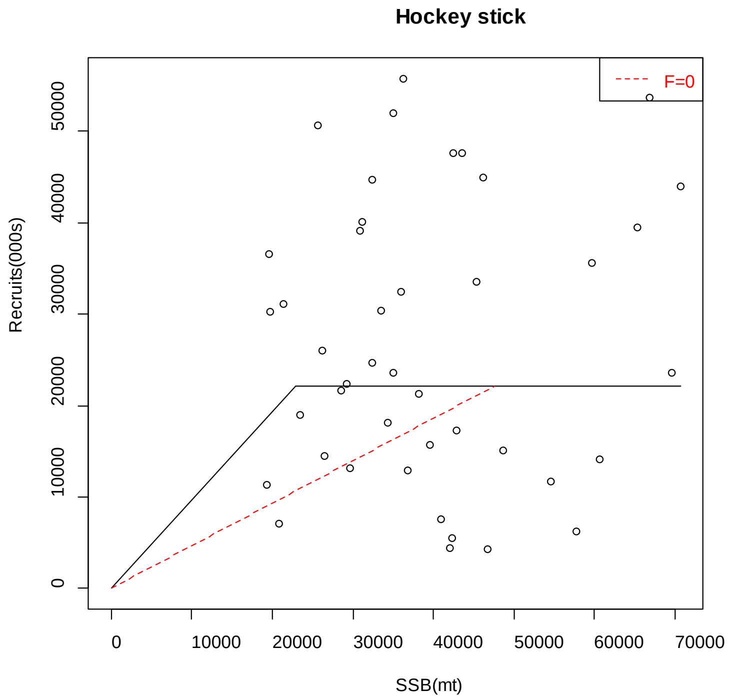


Figure 35. The fitted stock recruitment (SR) relationship with the B-H SR model for 4X5Y Haddock using the output from the ADAPT VPA formulation of M fixed at 0.2, except 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively). The upper panel shows the point estimate using maximum likelihood method. The lower panel shows the likelihood profile of B-H model parameters.



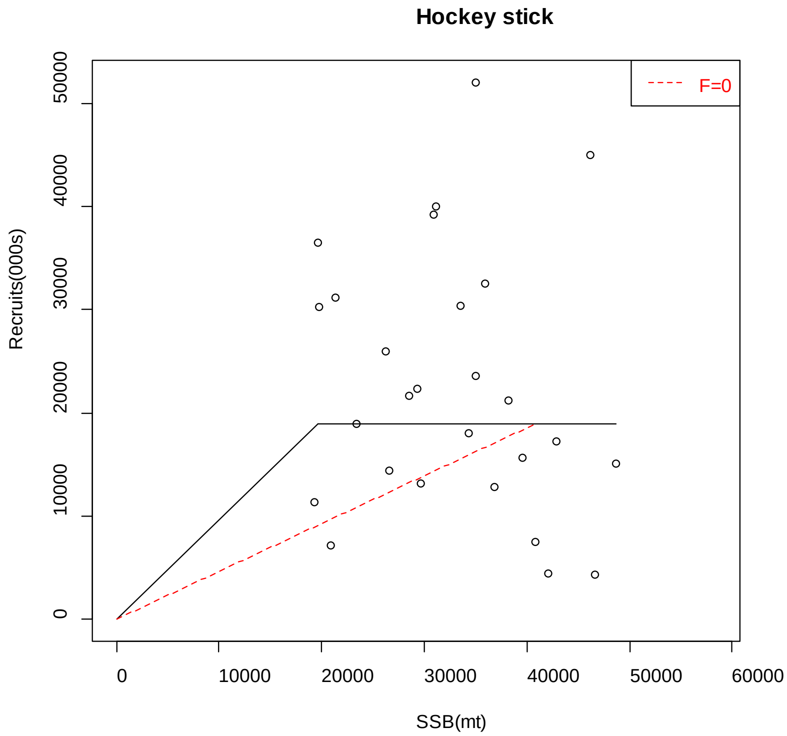


Figure 36. The fitted stock recruitment (SR) relationship with HS model I for 4X5Y Haddock using the output from the ADAPT VPA formulation of M fixed at 0.2 except, 0.3, 0.6, and 0.9 for Ages 10-11+ for the three 5-year time blocks (2000-2004, 2005-2009, and 2010-2014; respectively). The upper panel shows the result using a longer time series (1970-2014) and the lower panel with a shorter time series(1985-2014) of SR data. The dashed red line represents the replacement line, when there is no fishing ($SPR_{F=0}$).

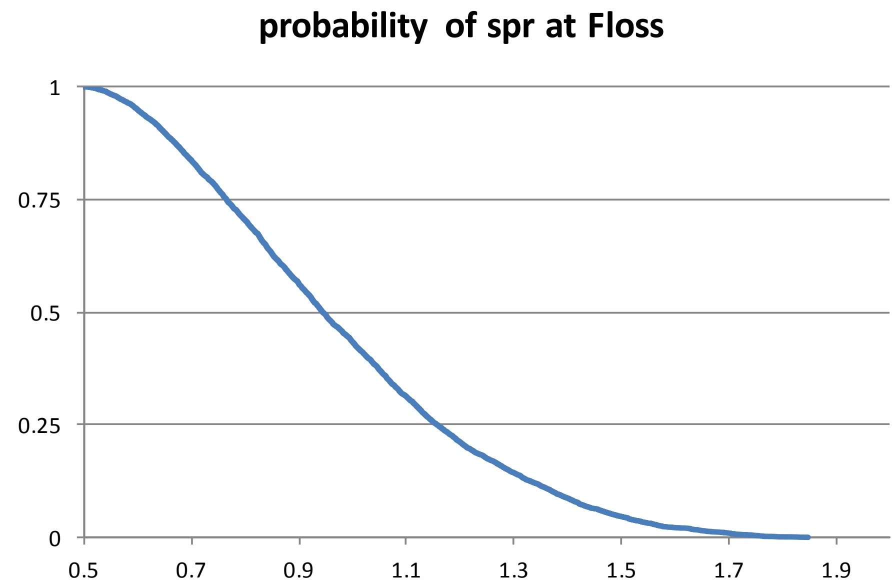


Figure 37. The probability of Spawner per Recruitment at F_{loss} when the SR relationship was fitted using the LOESS smooth method for 4X5Y Haddock.

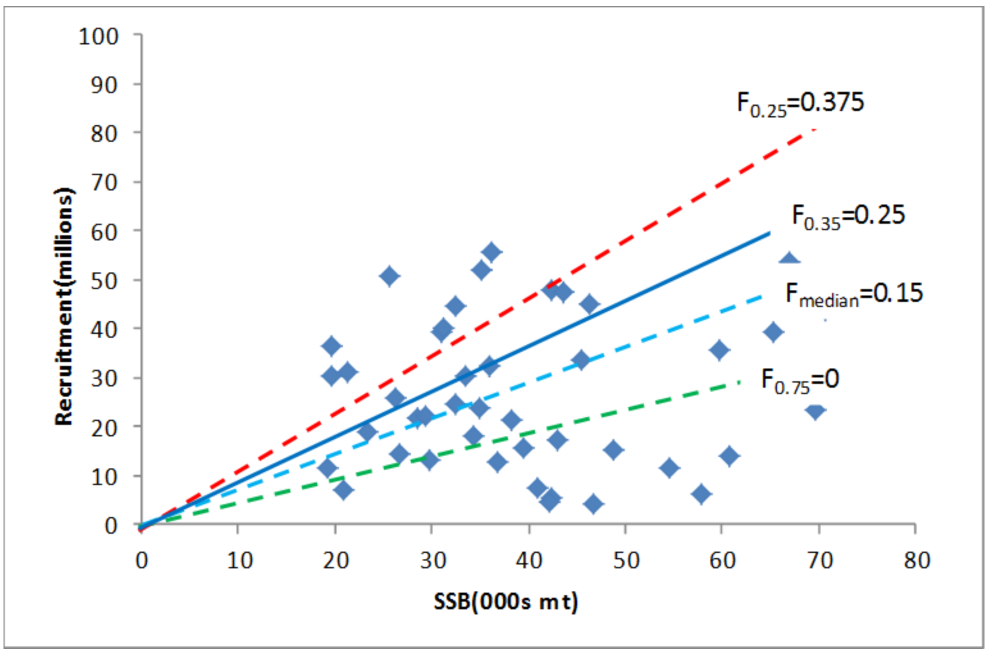


Figure 38. The fishing mortality corresponding to different percentile of replacement line for 4X5Y Haddock.

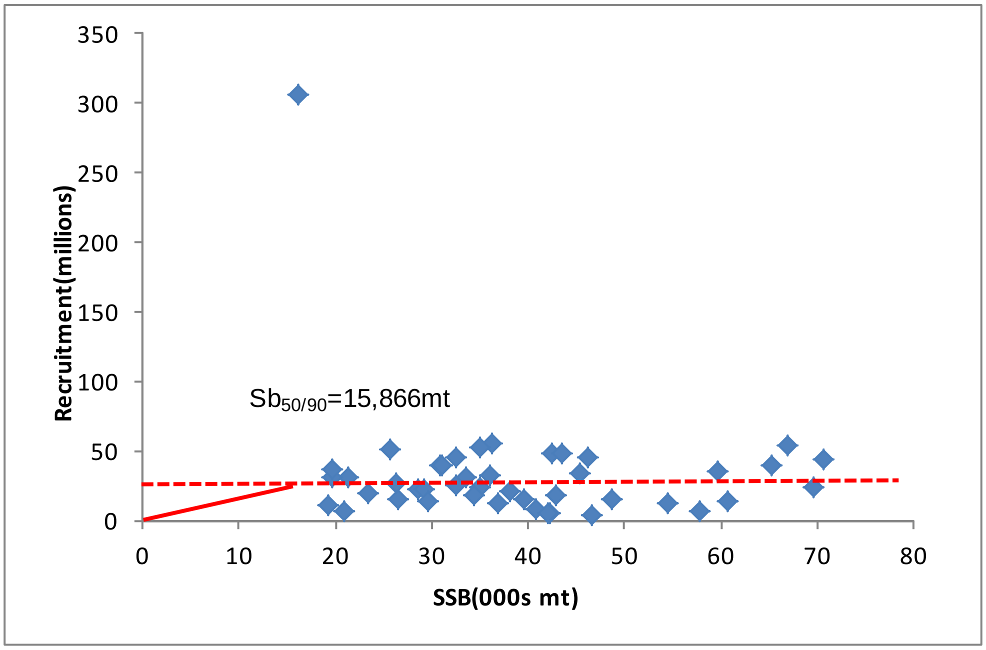


Figure 39. The $Sb_{50/90}$ for 4X5Y Haddock. The dashed line represents the 50^{th} percentile of the recruitment observations and the solid line represents the replacement line for which 10% of the stock-recruitment points are above.

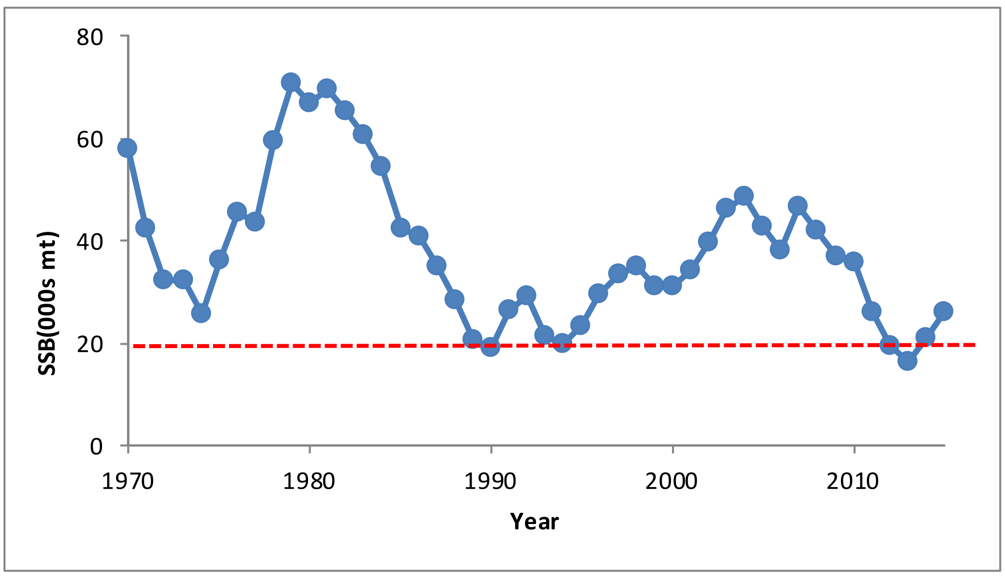


Figure 40. $B_{recover}$ for 4X5Y Haddock.

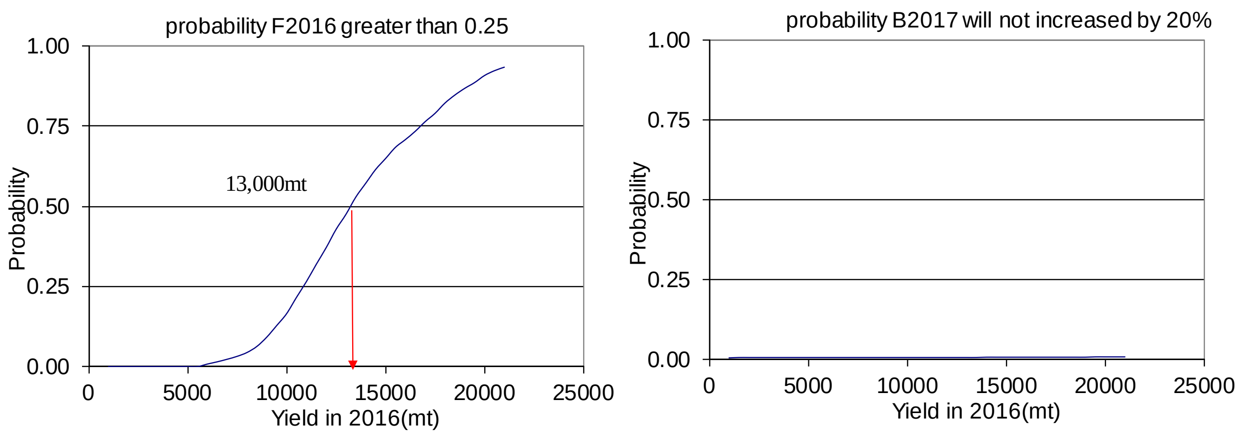


Figure 41. Stochastic projection to provide the risk of exceeding F_{ref}=0.25 and the probability of 2017 biomass will not increase by 20% under different catch in 2016 for 4X5Y Haddock.

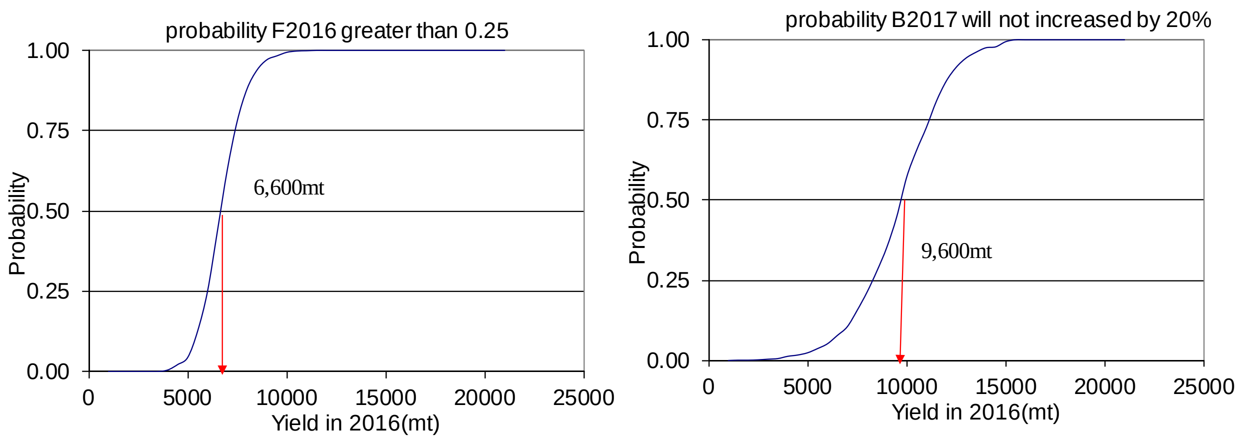


Figure 42. Sensitivity run for stochastic projection to provide the risk of exceeding F_{ref}=0.25 and the probability of 2017 biomass will not increase by 20% under different catch in 2016 for 4X5Y Haddock. The 2013 year class was adjusted to second largest recruitment in the time series.

APPENDIX: CSAS SCIENCE RESPONSE FORMAT FOR 4X5Y HADDOCK

SUMMARY

A brief list of summary bullets.

Context

Based on two-year projection approach.

Provide the history on the assessment/update schedule.

FISHERY

An update on fishery landings, include a brief paragraph description and data in table format (e.g. a shortened version of Table 1).

Document any changes in fishing practices, if applicable.

Indicators and Recommendations

- Provide updated DFO Summer RV survey total biomass index.
  - Describe the 2016 biomass estimate from survey relative to long term trends and include a biomass index figure (Figure 15).
  - Compare q-adjusted survey biomass with the long term mean and projected biomass from the most recent full assessment.
  - Note any changes to survey (e.g. timing) that should be considered in next full stock assessment.
- If survey and fishery ageing is available for the survey and fishery:
  - Update age-specific indices and fishery catch, describe the features of the age distribution, noting if there are any unexpected apparent differences in the year class strength compared to the projection from the most recent full assessment.
  - Update DFO survey WAA (beginning of year population), and compare with what was used in the projection from most recent full assessment.
- Comment on performance of recent quotas relative to expected risk and the most recent retrospective pattern:
  - Describe recent quotas and their associated risk (for F exceeding F_{ref} and for B not increasing), recent catch (as a fraction of those quotas), and whether the estimated F and B were consistent with the risk level for the specified quota.
  - Describe the direction and magnitude of retrospective pattern from recent assessments.

CONCLUSIONS

Using interim results described in the previous section (comparison of survey results to historical time series, comparison of survey results to VPA projections, weights at age, quota performance and retrospective pattern), determine whether the catch advice from the projection is still valid and include a table of indicators that provide support for either 1) maintaining existing catches advice, or 2) reducing catch advice.