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**Recovery Potential Assessment for the
Laurentian South Designatable Unit of
Atlantic Cod (*Gadus morhua*): The
Eastern Scotian Shelf Cod Stock
(NAFO Div. 4VsW)**

**Évaluation du potentiel de
rétablissement de la morue franche
(*Gadus morhua*) de l'unité désignable du
Sud laurentien : morue franche de l'est
du plateau néo-écossais (division 4VsW
de l'OPANO)**

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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.

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ABSTRACT

In its 2010 assessment of Atlantic Cod, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Laurentian South Designatable Unit (DU) as Endangered due to a 90% decline in abundance of mature individuals over the previous three generations. The Laurentian South DU consists of three populations or stocks: southern Gulf of St. Lawrence cod (management unit 4T and 4Vn (Nov-Apr)), 4Vn resident cod (4Vn (May-Oct)), and eastern Scotian Shelf cod (4VsW).

Recovery potential assessments (RPAs) were introduced by DFO Science to provide the information and scientific advice necessary to meet various requirements of the *Species at Risk Act* (SARA), including decisions regarding the listing of a species under the *Act* and the development of a recovery strategy. Specifically, as part of the assessment process, scientific information is needed to support the development of social and economic cost assessment scenarios for recovery, to better inform public consultations, and to support other entities involved in the decision of whether to add the species to Schedule 1 of the *Species at Risk Act*. The recovery team also requires this information to develop a recovery strategy, and if necessary, one or more action plans.

The objective of this research document is to address the terms of reference for the Atlantic Cod RPA as it relates to the eastern Scotian Shelf cod stock, a component of the Laurentian South DU. Historic stock trajectories are described and the stock is projected into the future to assess the probability of achieving recovery targets assuming that current productivity conditions were to persist in the future. This research document also addresses the major threats to the survival and recovery of eastern Scotian Shelf cod and the limiting factors. Measures that can help its recovery are listed.

The spawning stock biomass (SSB) of 4VsW cod reached the lowest level observed in the 53-year record in 2003 at about 7,500 t. Recently, it has rapidly grown to 64,000 t and is approaching the long term mean (75,000 t). Natural mortality of 4VsW cod aged 5 years and older (5+) was estimated to be unusually high in the 1990s and early 2000s (peaking at approximately 1.1) but has recently declined to 0.36. For 4VsW cod, most other components of productivity were at their lowest values in the period 1990-2000 and then have shown some recovery since then. Weight-at-age, condition, and area occupied all show such a pattern. There have also been improvements in recruitment rate in some recent years. Since the closure of the directed fishery in 1993 fishing mortality (ages 5-15) is estimated to have been 0.035, a small fraction of natural mortality. More recently it has dropped further to about 0.01, a negligible level. A limit reference point (LRP) has been established for 4VsW cod, based on 40% of the spawning stock biomass at maximum sustainable yield (MSY) during the productive period before 1990. The LRP is estimated to be 50,000 t. Estimated SSB has been below the LRP since 1992 with the exception of the 2009 estimate of 64,000 t, 25% above the LRP. If 1994-2009 productivity conditions persist in the future, projections indicate that SSB of the 4VsW population would be expected to decline below the LRP and then stabilize in the long term at a

low level, even with no fishing. Productivity conditions have improved in the past few years compared to the average of those used in the projections. Removals of 4VsW cod at the level of the bycatch fishery since closure of the cod-directed fishery in 1993 have no detectable effect on the probability of survival or recovery. The only additional action that can be taken to improve the chances for recovery of 4VsW cod would appear to be action to reduce the rate of natural mortality on adult (5+) cod. Predation by grey seals is considered to be a significant component of natural mortality but its relative contribution is of unknown magnitude. Even without establishing the degree of causality, it is noted that the Sable Island grey seal population was under 50,000 animals when 4VsW cod was productive; the current Sable herd size is around 300,000, six times larger.

RÉSUMÉ

Dans son évaluation de la morue franche en 2010, le Comité sur la situation des espèces en péril au Canada (COSEPAC) a désigné l'unité désignable (UD) du Sud laurentien comme en voie de disparition, en raison d'un déclin de 90 % de l'abondance des individus adultes au cours des trois dernières générations. L'UD du Sud laurentien se compose de trois populations ou stocks : morue du sud du Golfe Saint-Laurent (unité de gestion 4T et 4Vn [nov.-avr.]), morue résidente de 4Vn (4Vn [mai-oct.]) et morue de l'est du plateau néo-écossais (4VsW).

Pêches et Océans Canada a établi les évaluations du potentiel de rétablissement afin de fournir les renseignements et les avis scientifiques nécessaires au respect des exigences de la *Loi sur les espèces en péril* (LEP), notamment pour guider les décisions concernant la liste des espèces protégées en vertu de la LEP et l'élaboration de programmes de rétablissement. En particulier, dans le cadre du processus d'évaluation, l'information scientifique sert de fondement à la conception des scénarios d'évaluation des coûts sociaux et économiques du rétablissement; elle permet de présenter de meilleurs renseignements dans le cadre des consultations publiques et d'appuyer les autres entités concernées par la décision d'ajouter une espèce à l'annexe 1 de la *Loi sur les espèces en péril*. L'équipe chargée du rétablissement utilise aussi ces données pour élaborer un programme de rétablissement et, si nécessaire, un ou plusieurs plans d'action.

Le présent document de recherche traite du cadre de référence de l'évaluation du potentiel de rétablissement de la morue franche en ce qui a trait au stock de morues de l'est du plateau néo-écossais, une composante de l'unité désignable du Sud laurentien. L'historique des trajectoires du stock est décrit et une projection est réalisée pour évaluer la probabilité d'atteindre les objectifs de rétablissement, en supposant que les conditions de productivité actuelles se maintiennent. Le présent document de recherche étudie également les principales menaces à la survie et au rétablissement de la morue de l'est du plateau néo-écossais et les facteurs les limitant. Il énumère les mesures susceptibles de contribuer à son rétablissement.

La biomasse du stock reproducteur (BSR) de la morue de 4VsW a atteint le plus bas niveau observé depuis 53 ans en 2003, à environ 7500 t. Depuis quelques années, la biomasse a connu une croissance rapide pour atteindre 64 000 tonnes et approcher de sa moyenne à long terme (75 000 t). La mortalité naturelle des morues de 4VsW âgées de cinq ans ou plus (5+) était, selon les estimations, anormalement élevée dans les années 1990 et au début des années 2000 (culminant à environ 1,1), mais a récemment baissé pour s'établir à 0,36. Pour la morue de 4VsW, la plupart des autres paramètres de productivité étaient à leurs valeurs les plus faibles de 1990 à 2000, puis se sont améliorés par la suite. Le poids selon l'âge, la condition et le territoire occupé affichent tous des tendances semblables. Récemment, on a également observé des améliorations dans le taux de recrutement certaines années. Depuis la fermeture de la pêche dirigée en 1993, la mortalité par la pêche (âges de 5 à 15 ans) est, selon les estimations, de 0,035, ce qui correspond à une petite fraction de la mortalité naturelle. Plus récemment, la mortalité par la pêche a diminué davantage pour s'établir à environ 0,01, soit un niveau négligeable. On a établi un point de référence limite (PRL) pour la morue de 4VsW à 40 % de la biomasse du stock reproducteur au niveau du rendement maximal soutenu (RMS) pendant la période productive antérieure à 1990. Le PRL est évalué à 50 000 t. La BSR estimée est inférieure au PRL depuis 1992, sauf en 2009 où l'estimation était de 64 000 t, soit 25 % au-dessus du PRL. Si les conditions de productivité de 1994 à 2009 persistent, les projections indiquent que la BSR de la population de 4VsW devrait décliner sous le PRL, puis se stabiliser à long terme à un niveau faible, même en l'absence de pêche. Les conditions de productivité se sont améliorées au cours des dernières années comparativement à la moyenne de celles

utilisées dans les projections. Un niveau de prélèvement de morue de 4VsW équivalent aux prises accessoires depuis la fermeture de la pêche dirigée à la morue en 1993 n'a aucun effet décelable sur la probabilité de survie ou de rétablissement. La seule autre mesure pour améliorer les possibilités de rétablissement de la morue de 4VsW semble être une réduction du taux de mortalité naturelle chez les morues adultes (âgées de cinq ans ou plus). La prédation par les phoques gris est considérée comme étant une cause importante de la mortalité naturelle, mais l'ampleur de son incidence relative demeure inconnue. Même si l'on n'établit pas de degré de causalité, on a constaté que la population de phoques gris de l'île de Sable était inférieure à 50 000 individus lorsque la morue de 4VsW était productive; or, la taille actuelle du troupeau de l'île de Sable se situe à environ 300 000 individus, soit six fois plus.

INTRODUCTION

In its 2010 assessment of Atlantic Cod, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Laurentian South Designatable Unit (DU) as Endangered due to a 90% decline in abundance of mature individuals over the previous three generations (COSEWIC 2010). The Laurentian South DU consists of three populations or stocks: southern Gulf of St. Lawrence cod (management unit 4T and 4Vn (Nov-Apr)), 4Vn resident cod (4Vn (May-Oct)), and eastern Scotian Shelf cod (4VsW).

Southern Gulf cod overwinter along the southern slope of the Laurentian Channel in 4Vn. In April and early May, they migrate into the southern Gulf of St. Lawrence to spawn, and then disperse throughout the southern Gulf to feed. They migrate back out of the Gulf to their overwintering grounds in 4Vn in November. The timing of this fall migration has shifted over time, from late November-early December in the early 1980s to early November in the late 1990s. Until recently, this was the largest component of the DU.

4VsW cod is composed of several spawning components, including summer and fall components. This stock does not undertake the long migration seen for southern Gulf cod. There is, however, a movement to deeper and warmer water in the winter months.

Substantial evidence supports the presence of a distinct spawning component of cod in 4Vn (known as the 4Vn resident stock), separate from the Southern Gulf component. However, there is substantial mixing with other components of the Laurentian South DU, particularly with the Southern Gulf stock in winter, but also with the eastern Scotian Shelf stock following spawning in summer. The 4Vn stock is present in the Sydney Bight area from May to October, but migrates offshore in winter, mixing with the southern Gulf stock during this period. The 4Vn stock is by far the smallest component of the DU, comprising only 2-4% of the total biomass.

Recovery potential assessments (RPAs) were introduced by DFO Science to provide the information and scientific advice necessary to meet various requirements of the Species at Risk Act (SARA), including decisions regarding the listing of a species under the Act and the development of a recovery strategy. Specifically, as part of the assessment process, scientific information is needed to support the development of social and economic cost assessment scenarios for recovery, to better inform public consultations, and to support other entities involved in the decision of whether to add the species to Schedule 1 of the Species at Risk Act. The recovery team also requires this information to develop a recovery strategy, and if necessary, one or more action plans.

The objective of this research document is to address the terms of reference for the Atlantic Cod RPA (Appendix 1) as it relates to the Eastern Scotian Shelf cod stock (Northwest Atlantic Fishery Organization (NAFO) Div. 4VsW), a component of the Laurentian South DU. Historic stock trajectories are described and the stock is projected into the future to assess the probability of achieving recovery targets assuming that current productivity conditions were to persist in the future. This research document also addresses the major threats to the survival and recovery of Eastern Scotian Shelf cod and the limiting factors. Measures that can help its recovery are listed. For ease of presentation, the remainder of this research document is organized in point form to expedite the identification of individual objectives contained within the terms of reference (Appendix 1) and the associated responses. A separate research document will combine results of the present analyses with results from similar analyses for southern Gulf of St. Lawrence cod and 4Vn resident cod to examine historical trends and projections at the

DU level (see Canadian Science Advisory Secretariat website for additional publications from this meeting).

TERMS OF REFERENCE AND RESPONSES

ASSESS CURRENT/RECENT SPECIES/ATLANTIC COD STATUS

1. Evaluate present Atlantic Cod status for abundance (i.e., numbers and biomass focusing on matures) and range and number of populations for each DU.

The status of the 4VsW stock is currently monitored by a research vessel stratified random (design based on depth and geographic area) bottom-trawl survey in July (1970-2010), a sentinel fixed gear survey (1995-2010), and a March bottom trawl survey (1986-2010). The March survey does not track cohorts well and the sentinel survey covers only a small portion of the stock area so neither is used in the estimation of stock status. In the last few years, the July survey series has shown some improvement in both recruitment and survivorship (Fig. 1). Note that these estimates are not corrected for survey gear selectivity. The summer survey data which has been expanded to the area covered is shown in Figure 2. The recent (since 2005) improvement in the stock is seen in both the total biomass and spawning stock (age 5+) biomass. Figure 3 is the total survey numbers and numbers mature using decadal maturity ogives.

A population model is available for this stock. The stock has not been assessed since 2003, but a new population model was developed for the RPA. Historic catch and survey data are combined in a Virtual Population Model (VPA) which is described in Appendix 2. The model estimates abundance at age since 1958 and separate trends in natural mortality for ages 1-4 and 5+ since 1970 (the period covered by the summer RV survey). The earlier years were filled in using the cohort equation but without survey data for tuning. The natural mortality for this period was set at 0.2 for all ages. An alternative for the earlier untuned years would be to use the estimated M from a later period, e.g., 1970-1974. The total biomass (ages 1-15) and spawning stock biomass using maturity data for 5 periods (1958-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009) are shown in Figure 4 (the maturity ogives are shown in Figure 30). For comparison, the 5+ biomass is plotted on the same figure and it can be seen to closely follow the ogive based estimates in recent years. Although 5+ does not include known changes in maturity, it was the metric presented at the framework meeting (DFO 2011a) and is shown for comparison. Given the good agreement between SSB and 5+ biomass, the SSB will be used hereafter unless otherwise noted. Figure 5 shows the total and mature abundance from the VPA.

The SSB started at a high level and then fell in the early 1970s (Figure 4). It rebounded quickly after a period of strong recruitment, but then collapsed a second time in the late 1980s and early 1990s (Figure 4). SSB remained at the lowest levels observed from the mid-1990s to the mid-2000s. Although a couple of recruitment events happened after the closure of cod-directed fishing in 1993, it was not until the last few years that the SSB responded. Both mature biomass and mature abundance have shown a recent improvement to the vicinity of the long term mean (Figures 4 and 5).

The uncertainty in the estimation of numbers at age in the VPA and the uncertainty in the resultant abundances and biomass is shown using MCMC replicate for the tuned years (1970-2010). Because of the convergence properties of the untuned VPA, the error bars would be smaller and vanish back in time. Figure 6 shows the SSB for 1970-2009 with the 2.5 and

97.5 percentiles from 2,500 MCMC replicates. The MCMC was run for 0.25 million times and every hundredth run retained. Similarly, the SSN and its 2.5 and 97.5 percentiles are shown in Figure 7.

The distribution of Atlantic cod in NAFO 4VsW as indicated by the summer RV survey, 1970-2010, is shown in Figure 8. The panels include all fish, individuals measuring 1-38 cm in total length, and those individuals greater than 38 cm. Figure 8 shows that cod are widely distributed across the shelf with peak abundance on the banks. These data were broken into decadal periods in Figure 9 for all sizes combined and it can be seen that fish become increasingly aggregated over time as the stock declines in size. Considering fish measuring 1-38 cm in total length, Figure 10 shows that they are now located predominantly in 4W. This pattern of aggregation is more pronounced in the larger fish (Figure 11).

The 4VWCOD (spring) survey has been conducted annually since 1986 (except 1998 and 2004) on the eastern half of the Scotian Shelf (Div. 4VsW) using a Western IIA trawl and a stratification scheme intended to optimize the abundance estimates of cod. Deep-water strata (365-549 m) in the Laurentian Channel were added to this survey in 1993 and although not included in abundance trend analysis, the catches in these strata are included in the distribution maps. Based on this survey, it would seem that the winter distribution is more offshore (Figures 12-15). The decadal plots including fish of all sizes (Figure 13) show a tendency for cod to be in deeper water and more aggregated than during summer. Both small (Figure 14) and large (Figure 15) fish have increasingly been observed on the edge of Banquereau and Western Banks in recent years.

The Div. 4VsW Sentinel Survey is a stratified random longline survey conducted by industry participants. The series began in fall 1995 and includes all areas surveyed by the RV survey in Div. 4VsW as well as three additional inshore strata. In 2005, the survey was reduced to the two western inshore strata as well as four core strata that were thought to be the centre of distribution for haddock. This survey samples inshore areas that are not covered by the RV series and aggregations of cod have been observed in these areas (Figure 16). Catch rates in this survey decreased in the inshore strata (468-469) around 2001 and the recent improvement observed in the RV series is not seen in the inshore data (Figure 17).

Trends in design weighted area of occupancy (DWAO) for Atlantic cod within NAFO 4VsW were examined based on the DFO annual bottom-trawl surveys in this area during 1970-2010. Area of occupancy (A_t) was calculated for year t as follows:

$$A_t = \sum_{i=1}^n a_i I \quad \text{where } I = \begin{cases} 1 & \text{if } Y_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

where n is the number of tows in the survey in year t , Y_i is the number of cod caught in tow i , and a_i is the area of the stratum fished by tow i divided by the number of sites fished in that stratum (Smedbol et al. 2002).

Based on the DFO summer RV survey, the area of occupancy of Atlantic cod was approximately 75,000 km² through the 1970s and early 1980s but declined dramatically during the 1990s to reach a low of approximately 33,000 km² in 2002 (Figure 18). The decline in area of occupancy that occurred during the 1990s was more pronounced in large fish (>38 cm) than small individuals (≤38 cm). All size classes have shown some increase in the area of occupancy during the last few years.

Similarly, based on the DFO March RV survey, the area of occupancy declined from almost 60,000 km² during the mid-1980s to reach a low of approximately 11,000 km² in 2006 (Figure 19). Again, the distribution of large fish appears to have contracted more than that of small individuals although both have experienced some improvement in recent years. These trends in DWAO are consistent with distributional patterns presented in Figures 8-15.

Historically, fall and spring spawning components were identified for 4VsW cod. However, based on reduced abundance of cod larvae in ichthyoplankton surveys during the early 1990s and declining mean size of one year old cod in the summer RV surveys, Frank et al. (1994) reported a potential loss of the spring spawning component. Updated analysis of mean size of one year old cod indicates a return to high levels since the mid-1990s, consistent with the hypothesis that spring spawning is occurring again (Figure 20). Similarly, examination of the proportion of cod in each of the various maturity stages during the March survey shows an increase in the proportion of females in spawning condition in recent years (Figure 21). Unfortunately, there has not been a fall survey since 1984 to examine this component of the resource.

In 4VsW, the distribution of spawners closely matches that of other mature individuals. Figure 22 shows the distribution of spawning and non-spawning mature females observed in the March survey. Spawners, though rare, have occurred on the edge of Western Bank, the Gully, the Laurentian Channel, and deeper waters northwest of Banquereau Bank. Unfortunately, there has been no fall research vessel survey since 1984 to examine this component of the resource.

2. Evaluate recent species trajectory for abundance (i.e., numbers and biomass focusing on matures) and range and number of populations for each DU.

Survey based trajectories since 1970 and model based trajectories since 1958, as well as information on range and number of populations, were presented in response to the first term of reference.

3. Estimate, to the extent that information allows, the current or recent life-history parameters for Atlantic Cod (total mortality, natural mortality, fecundity, maturity, recruitment, etc.) or reasonable surrogates; and associated uncertainties for all parameters.

Figures 23 and 24 show the instantaneous mortality rate (Z) estimated from the survey indices using a catch curve approach. These results have been smoothed with a 5 year moving average. In Figure 23, the data were given arbitrary catchability coefficients (q) to scale the input to compensate for reduced survey gear efficiency at younger ages. In Figure 24, catchability coefficients were used from a simple VPA using constant natural mortality (M). The pattern (though not the magnitude) of the Z s is the same using either approach. Z for the younger fish is recently the lowest in the series. Z for the older fish reached a maximum in the early 1990s.

Figure 25 is the relative F (total minimum trawlable biomass from the survey divided into the landings) and clearly shows the fishery closure in 1993. Any change in Z since 1993 is not due to fishery removals.

Figures 26 and 27 are the estimates of natural mortality (M) for two age ranges: 1-4 years and 5-15 years. The M on older fish falls off more rapidly than the Z s shown in Figures 23 and 24.

This is because the random walk model estimates a more dome shaped gear efficiency than was used for the Z estimation. Several attempts were made to remove this dome by fixing it in the model or introducing a plus group. These models did not fit the data as well and were not pursued. Natural mortality of 4VsW cod aged 5 years and older (5+) was estimated to be unusually high in the 1990s and early 2000s (peaking at approximately 1.1) but has recently declined to a low of 0.36 (Figure 27). The mortality on young fish (1-4) has also had several peaks and valleys over the assessment period and fallen to the lowest values in the series recently (Figure 26). The M on these younger fish is much less important on the productivity of the stock because it acts on only a few ages.

Fecundity of cod in NAFO 4VsW was examined by McIntyre and Hutchings (2003) who reported a fecundity-weight relationship best described by a linear model of the following form:

$$F = 240.86 W + 83046$$

where F is fecundity (i.e., the number of vitellogenic oocytes) and W is weight in grams. The proportion of explained variation in fecundity was 0.25. This study sampled 29 females during 1998-2000 that ranged in length from approximately 35 to 85 cm and reflects the only known fecundity estimates for cod in this area. That the fecundity is linear with weight suggests that an SSB based index should be linear with fecundity. Unfortunately, the sample size was very limited and the linear regression with length was also significant. Available information suggests that size-specific fecundity of cod is lower in 4VsW than the southern Gulf of St. Lawrence (4T) or Sydney Bight (4Vn).

Figure 28 shows the length at 50% maturity for cohorts of female cod in 4VsW from spring surveys. These points were found by fitting probits to the data and then interpolating to the 50% point. Similarly, Figure 29 shows the change over time in maturity as a function of age using the same data source. Age and length at 50% maturity of female 4VsW cod have shown reductions since the beginning of the time series (1950s). Age at 50% maturity has declined from greater than 5 years of age for cohorts in the 1950s to less than 4 years in recent years. Length at 50% maturity has fallen from about 50 cm for cohorts in the 1950s to less than 40 cm in recent years. The causes for these declines are unknown.

The proportion of females mature as a function of age for 5 time periods is shown in Figure 30. These values were used to define spawning stock biomass in some of the production analysis, although the approximate 5+ biomass was also used.

Figure 31 shows a recruitment index from the summer survey series which is the average of numbers at age for ages 1 and 2 for each cohort. Two ages are used in this index to reduce some of the noise seen in the data. The numbers for each age were divided by the mean over all years to standardize and remove the effect of unknown catchability for these ages in the survey gear. Recruitment during the early 1980s was higher than other periods in the series. Figure 32 is this index divided by the survey 5+ biomass of the year that produced the cohort. The recruitment rate is quite noisy and a 5 year moving average is shown as well as the individual estimates. The very low 5+ biomass in recent years results in higher recruitment rate for that period.

Analogous results from the VPA model are shown in Figures 33 and 34. The population model extends further back in time than the summer RV series and shows moderate recruitment and recruitment rate in the early years. It also shows the enhanced recruitment rate seen recently in the survey data. When the VPA was extended using estimated M and time varying maturity rates, the results are as shown in Figures 35 and 36. This approach produces about the same

5+ biomass as the model presented at the framework meeting (DFO 2011a) but many more recruits – it is provided only for comparison. Overall, recruitment has not returned to the levels seen in the 1970s. Since 1990, there have been three peaks in recruitment: 1992, 1998, and 2004 year-classes.

Recruitment is plotted as a function of the 5+ biomass in Figure 37. A Ricker curve is fit to the data.

Figure 38 is the length at age for ages 2, 4, 6 and 8 from the summer survey series. It is seen to have a maximum in the late 1970s and fall to a minimum during the early 1990s with recovery to the long term mean by the end of the series. Figure 39 contains the weights at age which show the same general pattern. When the weights at age are normalized by the long term mean (Figure 40), they are seen to superimpose one another which seems unusual because the affects would be expected to accumulate over age.

Figure 41 is the condition index expressed as Fulton's K for two size ranges (29-31 cm and 44-46 cm). The 30 cm fish would be immature throughout the time series while the 45 cm fish would be increasingly comprised of mature fish as time goes on (Figure 28). For fish of both sizes, there is a general trend of decreasing condition from the 1970s until the early 1990s with a slight recovery thereafter.

4. Estimate expected population and distribution targets for recovery, according to DFO guidelines (DFO 2005) and based on the limit reference points developed under the Precautionary Approach Framework.

The LRP is based on the spawning stock biomass producing maximum sustainable yield (BMSY) during a productive period, defined here as the period up to 1990. The LRP was defined as 40% of BMSY and is estimated to be 50,000 t of SSB. SSB has been beneath the LRP since 1992 except the most recent year (2009) which was 25% above it. Other methods were investigated for completeness.

Limit reference points have been suggested based on three types of information: stock history, recruitment, and production. The simplest is B_{recovery} which is a low point after which there has been sustained improvement. While that might be said of 2001 when the SSB was at a minimum of 6.3 kt, given that there has been little time to gauge the degree to which recent improvements might be sustained, a better candidate for B_{recovery} would be 32 kt in 1976. A family of methods based on stock-recruit data was recommended for gadoid stocks (DFO 2002) in which a relationship was fit and the SSB point at which half of the maximum recruitment was observed was chosen as a candidate B_{lim} . Figure 42 shows the stock and recruit data, as well as Ricker, Beverton-Holt, and non-parametric fits.

Table 42 Candidate B_{lims} and where appropriate B_{MSY} . Bracketed values are from the framework meeting (DFO 2011a).

Metric	B_{MSY} (kt)	LRP (kt)
$B_{recovery}$ (1976)		39 (34)
Ricker 50		26 (24)
Beverton-Holt 50		30 (33)
Non-parametric 50		38 (23)
Long term B_{MSY}	83 (73)	33 (29)
Productive regime B_{MSY}	135 (123)	54 (50)

Production based estimates of B_{lim} incorporate the most information on stock dynamics. The method used is based on the Sissenwine-Shepherd approach (stock-recruit, growth, survivorship, and maturation; Sissenwine and Shepherd 1987). The surplus production is the annual change in biomass plus the landings for a stock. Figure 43 shows the surplus production since the late 1950s as well as the landings. The landings are seen to exceed the production starting in the early 1980s which was followed by the stock's collapse. In the last few years, the surplus production has become positive, averaging about 10,000 t per year. The Sissenwine-Shepherd analysis is shown in Figures 44 and 45.

Because the long term production data fit the production analysis so poorly and because major determinants of stock production are known to have varied over the analysis period, a moving window production analysis was conducted (Mohn and Chouinard 2007). Data were sampled in 10 year windows and the equilibrium production estimated. The windows were chosen as small as possible to give better temporal resolution. The consequence was that the individual estimates were more poorly defined. Figure 46 shows the time varying MSY and SSB_{MSY} from this analysis. The SSB_{MSY} in the earliest years was in excess of 200 kt and fell to about zero in the 1990s. Similarly, the MSY averaged about 60 kt up to the 1980s and also fell to about zero in the 1990s. The productive period was arbitrarily chosen to be the period up to 1990 and the average SSB_{MSY} for this period was 135 kt which is the last candidate for defining B_{lim} .

Figures 47 and 48 decompose the factors affecting the productivity. The influence of each factor is the amount the time varying MSY deviates from the long term mean. If only natural mortality is windowed and all the others are set at the MSY based on long term mean inputs (Figure 47 red line), it's seen to be a major contribution to the MSY. The stock-recruit contribution (Figure 47 blue line) which starts near the 25 kt mean grows in the 1970s and then falls rapidly in the mid 1980s. In Figure 48 (red line), the contribution of growth is seen to have had a similar temporal pattern to the stock-recruit influence but is of a smaller magnitude. And, finally, the change in maturation would appear to have had a very small influence (Figure 48 blue line).

5. Project expected Atlantic Cod population trajectories over 36 years, which represents at least three generations for all populations, and trajectories over time to the recovery target (if possible to achieve), given current Atlantic Cod population dynamics parameters and associated uncertainties using DFO guidelines on long-term projections (Shelton et al. 2007). See Annex 1 for details.

Long-term stochastic projections were undertaken to examine the consequences of current productivity conditions, defined here as the conditions that occurred between 1994 and 2009 (i.e., since the initial closure of cod-directed fisheries in September 1993). These projections should not be interpreted as forecasts of future stock status because they depend on assumptions about future productivity. Future productivity conditions are very uncertain, and the probability of current conditions continuing for a long period of time is unknown. The 4VsW population was projected forward over 36 years, taking into account uncertainty in estimated abundance at age and uncertainty and variability in estimated components of productivity in the current period. Projections are illustrated using the median and the 2.5th and 97.5th percentiles. The full range of uncertainty should be considered when interpreting these projections.

Stochastic projections were carried out using the MCMC populations from the random walk VPAs. Stock-recruit, natural mortality, growth, and maturity data were chosen from the 1994 to 2009 period. Natural mortality, weight at age, and maturity at age were selected randomly from this time interval. A Ricker stock recruit relationship was fit and the multiplicative residuals were sampled for the projections. Additive residuals could not be used directly because they tended to produce negative recruitments at low biomass.

Figure 49 shows projections at $F = 0.0$ and $F = 0.01$ for the 36 year required duration. They are virtually indistinguishable. Figure 50 shows a projection at $F = 0.01$ along with the historic SSB, B_{lim} of 50 kt, and probability of the stock exceeding the B_{lim} . If current productivity conditions (as defined by the period 1994-2009) were to persist in the future, the population would be expected to continue to decline, even with no fishery removals. The average fishing mortality on older fish (5-15) has been around 0.01 for the last few years. This level of F has no detectable effect on the projected population trajectory. The recent strong year-classes persist in the projections for a few years and then the stock settles to a low equilibrium size. Under these conditions, the probability of reaching the LRP is zero.

Figure 51 is the same scenario as shown in Figure 50 except that the projection uses the scenario proposed by Newfoundland Region (DFO 2011b) in which the values used in the projection are sampled with increasing windows backwards in time until 1994. A small plateau occurs during the first five years of the projection which is not seen in Figure 50. This is because the recent M on older animals is reduced. Figure 52 shows the average M and its 95 percent range from the MCMCs. The M is seen to climb rapidly in the projection period and stabilize around 0.7.

Figure 53 is the history and projection of spawning stock numbers. The reference limit is defined as a 30% reduction in numbers over three generations. For the purpose of this analysis, three generations was set at 36 years while the actual period of three generations is much shorter, on the order of 20 years.

6. Evaluate residence requirements for the species, if any.

The *Species at Risk Act* 2(1) defines a residences as “a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals

during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating”.

4VsW cod do not have any known dwelling-place similar to a den or nest during any part of their life-cycle. Therefore, the concept of residence does not apply.

ASSESS THE HABITAT USE OF ATLANTIC COD

7. Provide functional descriptions (as defined in DFO 2007b) of the properties of the aquatic habitat that Atlantic Cod needs for successful completion of all life-history stages.

Functional descriptions of the properties of the aquatic habitat that Atlantic Cod needs for successful completion of all life-history stages were provided in general terms by Gregory et al. (see Canadian Science Advisory Secretariat for additional publications from this meeting). With respect to 4VsW specifically, we determined the relationship between species distribution and the habitat variables salinity, temperature, and depth for trawl data using the methods outlined by Perry and Smith (1994). Briefly, cumulative distribution functions (cdf) described species associations with salinity, temperature, and depth for each habitat variable (x) for each set (i) in a stratum (h) incorporating the survey design:

$$f(t) = \sum_h \sum_i \frac{W_h}{n_h} I(x_{hi}) \quad I(x_{hi}) = \begin{cases} 1, & \text{if } x_{hi} \leq t; \\ 0, & \text{otherwise.} \end{cases} \quad \text{Eq. 1.1}$$

where W_h is the proportion of the survey area in stratum h, n_h is the number of sets performed within the stratum and t is an index ranging between the minimum and maximum levels of the observed habitat variable. Similarly, the cdf for catch of a particular species within a set (y_{hi}) with specific habitat conditions is:

$$g(t) = \sum_h \sum_i \frac{W_h}{n_h} \frac{y_{hi}}{\bar{y}_{st}} I(x_{hi}) \quad I(x_{hi}) = \begin{cases} 1, & \text{if } x_{hi} \leq t; \\ 0, & \text{otherwise.} \end{cases} \quad \text{Eq. 1.2}$$

By scaling the catch to the stratified mean (\bar{y}_{st}), the sum of g(t) equals 1 across all values of t. If

large values of $\frac{y_{hi}}{\bar{y}_{st}}$ are consistently associated with a particular habitat condition then it would suggest strong associations. Randomization tests were used to test the significance of habitat associations. The test statistic, L, is the maximum absolute difference between the f(t) and g(t) curves. Statistical significance of L was determined by its comparison to the distribution of values from 2999 random perturbations of the data (3000 repetitions, including L; Perry and Smith 1994).

Figure 54 shows an example in which the f(t) is the effort as a function of depth and g(t) is the catch. The median of the catch and the maximum difference in the two cumulatives are shown. These metrics are shown as time series in Figure 55.

Cumulative catch of Atlantic cod was examined in relation to salinity, temperature, and depth encountered during the surveys with the location of the maximum deviation of cumulative distributions from catch and effort interpreted to be indicative of habitat preference.

The lower left panel of Figure 55 is the summer survey where depth is the explanatory variable. Until about 1996, cod tended to be concentrated in waters less than 50 fathoms and then the signal is less stable. The March survey shows cod distributed in deeper water. These results suggest that the surveys are not missing much of the resource in deeper waters in either series. However, based on Figures 16 and 17, the RV series may be missing cod in more shallow waters.

In the summer, median temperature and median cod abundance generally track one another. During the March survey, the abundance is seen in warmer water than the median.

The spatial distribution of juveniles, adults, and spawning females was reported in response to the first term of reference.

8. Provide information on the spatial extent of the areas in Atlantic Cod's range that are likely to have these habitat properties.

Information on the spatial extent of the areas in Atlantic Cod's range that are likely to have these habitat properties was provided in general terms by Gregory et al. (see Canadian Science Advisory Secretariat for additional publications from this meeting). In summary, the geographic distribution of Atlantic Cod ranges from Cape Hatteras, North Carolina to Greenland in the western Atlantic and the Barents Sea south to Spain and Portugal in the eastern Atlantic. Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating suitable habitat exists throughout their range. However, very little information is currently available at the appropriate spatial resolution to identify the extent of the habitat available to demersal juvenile Atlantic Cod – such as gravel and cobble, eelgrass beds or macroalgae – especially in the offshore. There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

9. Identify the activities most likely to threaten the habitat properties that give the sites their value, and provide information on the extent and consequences of these activities.

Identification of activities most likely to threaten the habitat properties that give the sites their value, and provision of information on the extent and consequences of these activities was undertaken in general terms by Gregory et al. (see Canadian Science Advisory Secretariat for additional publications from this meeting). Gregory et al. indicated that the potential for anthropogenic disturbance is highest in the coastal zone and with proximity to human population centres and industrial activity. Key threats included habitat alteration by mobile bottom-contacting fishing gears, eutrophication causing damage to eelgrass beds and macroalgae, and physical disturbance or contamination of habitat through oil and gas development.

10. Quantify how the biological function(s) that specific habitat feature(s) provide to the species varies with the state or amount of the habitat, including carrying capacity limits, if any.

Gregory et al. (see Canadian Science Advisory Secretariat for additional publications from this meeting) identified how the biological functions that specific habitat features provide to the species varies with the state or amount of the habitat, including carrying capacity limits. There is no additional information particular to 4VsW.

11. Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.

Spatial configuration constraints such as connectivity and barriers to access are not a current limiting factor for Atlantic Cod recovery.

12. Provide advice on how much habitat of various qualities / properties exists at present.

A review of how much habitat of various qualities/properties exists at present was provided by in general terms by Gregory et al. (see Canadian Science Advisory Secretariat for additional publications from this meeting). Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating that some amount of suitable habitat exists within this range. However, very little information is currently available at the appropriate spatial resolution to identify the extent of the habitat available to demersal juvenile Atlantic Cod – such as gravel and cobble, eelgrass beds or macroalgae – especially in the offshore.

13. Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present, and when the species reaches biologically based recovery targets for abundance and range and number of populations.

There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

14. Provide advice on feasibility of restoring habitat to higher values, if supply may not meet demand by the time recovery targets would be reached, in the context of all available options for achieving recovery targets for population size and range.

There is no indication that habitat restoration is required for population recovery.

15. Provide advice on risks associated with habitat “allocation” decisions, if any options would be available at the time when specific areas are designated as Critical Habitat.

The degree to which a habitat can be defined as a discrete area with clear edges or a gradient of features in the marine environment has not been identified. The associated risks of habitat allocation decisions have not been evaluated for Atlantic Cod. However, as noted earlier, there is no indication that the amount of suitable habitat is currently limiting recovery of cod.

16. Provide advice on the extent to which various threats can alter the quality and/or quantity of habitat that is available.

Advice on the extent to which various threats can alter the quality and/or quantity of habitat that is available was provided by Gregory et al. (see Canadian Science Advisory Secretariat for additional publications from this meeting) and also described under the ninth term of reference involving activities most likely to threaten the habitat properties.

SCOPE FOR MANAGEMENT TO FACILITATE RECOVERY OF ATLANTIC COD**17. Assess the probability that the recovery targets (see Annex 1) can be achieved under current rates of Atlantic Cod population dynamics parameters, and how that probability would vary with different mortality (especially lower) parameters.**

Figures 50 and 51 show the probability of achieving a recovery target of $B_{lim} = 50$ kt (SSB) under two sampling scenarios. Because the cause of the recent improvement in productivity is unknown, it is impossible to anticipate its duration or trajectory. Nonetheless, both projections end at a low equilibrium biomass with high uncertainty as to its exact magnitude.

As recent fishing mortality is very low (<0.01), only changes in natural mortality can be expected to significantly affect productivity. To explore a range of scenarios, two sets of projections were performed. In the first set, projections were carried out at 10 levels of adult M ranging from the lowest to the highest seen in the assessment period (Figure 56). All other aspects of productivity were sampled from the 1994-2009 window. The spawning biomass in the last 10 years of the 36 year projections was averaged as a summary of the final state. Because most aspects productivity, especially natural mortality, have changed recently for this stock, it is not possible to anticipate future productivity except to say that the near future would probably be like the recent past. Similarly, conditions that pertained to the relatively productive period before the 1990s, are less likely than those from the more recent period. Figure 56 shows the relationship between the average M and the resulting SSB. Although there are other determinants of production to be considered, it appears that the adult M will have to fall low enough that the average M is about 0.3 to have an equilibrium SSB much above a B_{lim} of 50 kt.

Figure 57 is a similar analysis to that contained in Figure 56 except that the average M on older cod is fixed and the range on the 1-4 year olds is varied over the observed range. As the age 1-4 M is less important and did not vary as much as M on older cod, the impact is much less. These runs show that if the age 5+ M is at the average of the last 10 years, the age 1-4 M makes little difference. Although, at the lowest observed levels, there is a probability of being above the B_{lim} .

18. Quantify to the extent possible the magnitude of each major potential source of mortality identified in the pre-COSEWIC assessment, the COSEWIC Status Report, information from DFO sectors, and other sources.

There is no directed fishery for 4VsW cod at this time. Bycatch mortality is very small and is negligible relative to natural mortality (Figure 58).

Natural mortality of 4VsW cod aged 5 years and older (5+) was estimated to be unusually high in the 1990s and early 2000s (averaging 0.8 in 1990-2004) but in the last five years the average fell to 0.6. Predation by grey seals is considered to be a significant component of natural mortality but its relative contribution is of unknown magnitude.

Several models of the effect of seal predation on cod have been developed over the years (Mohn and Bowen 1996; Fu et al. 2001; Trzcinski et al. 2006, 2009) including some which were presented at the recent Zonal Advisory Process on the impacts of grey seals on fish populations in eastern Canada (DFO 2011c). These models have used reconstructed seal diets that showed cod in the age range of 1-8 years, a range that includes both of the age ranges in the random walk model. These models all have an explicit predation term and an unattributed M (often called M_{other}). While seal predation has been large in recent years, the unattributed portion is

also large depending on the model. The proportion of seal mortality in all sources of natural mortality range from about 25 to 75%.

Bundy (2004) used mass balance models to explore seal predation of cod within an ecosystem context. For the 1980s and 1990s, seal predation was the largest identified contributor among the 17 modeled predators of cod. For small cod (< 40 cm) in the 1990s, the predation mortality was about 0.025 while that on older cod was about 0.02.

The various models seem to agree that seal predation is the largest component of the cod natural mortality, but vary considerably in what fraction this is of the total natural mortality. Another confounding factor is the reduction in natural mortality during the last few years, while the seal population continues to increase.

19. Quantify to the extent possible the likelihood that the current quantity and quality of habitat is sufficient to allow population increase, and would be sufficient to support a population that has reached its recovery targets.

There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

20. Assess to the extent possible the magnitude by which current threats to habitats have reduced habitat quantity and quality.

There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

SCENARIOS FOR MITIGATION AND ALTERNATIVE TO ACTIVITIES

21. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all feasible measures to minimize/mitigate the impacts of activities that are threats to the species and its habitat (Steps 18 and 20).

There is no directed fishery for this stock at present. Bycatch mortality is very limited and is negligible relative to natural mortality.

22. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable alternatives to the activities that are threats to the species and its habitat (Steps 18 and 20).

There is no directed fishery for this stock at present. Bycatch mortality is very limited and is negligible relative to natural mortality.

23. Using input from all DFO sectors and other sources as appropriate, develop an inventory of activities that could increase the survivorship parameters (Steps 3 and 17).

Though grey seal predation is a major contributor to natural mortality, the size of this component relative to all components of mortality is very difficult to quantify. Various estimates have been published and several were presented at a recent zonal assessment meeting (DFO 2010b). Estimates of the component of total mortality by seal predation generally range between 10 to 50% on cod less than 9 years old. Even without establishing the degree of causality, it is noted that the Sable Island grey seal population was under 50,000 animals when 4VsW cod was productive; the current Sable Island herd size is around 300,000, six times larger.

A model to examine the impact of a reduction in the seal herd was presented by Mohn at the recent Zonal Advisory Process on the impacts of grey seals on fish populations in eastern Canada (DFO 2011c). This simulation study showed that the reduction in natural mortality from interventions up to removal of 10,000 seals per year would be unlikely to be detectable.

24. Estimate, to the extent possible, the reduction in mortality rate expected by each of the mitigation measures in step 21 or alternatives in step 22 and the increase in survivorship associated with each measure in step 23.

Interventions of 30,000 seal removals or sterilizations per year for five years were investigated by Mohn at the recent Zonal Advisory Process on the impacts of grey seals on fish populations in eastern Canada (DFO 2011c). The results showed that even an intervention of this magnitude would not reduce the Sable seal herd to levels seen during the productive period (i.e., less than 50,000 animals; Figure 59).

Also, see point 23.

25. Project expected population trajectory (and uncertainties) over 36 years, which represents at least three generations for all stocks, and to the time of reaching recovery targets when recovery is feasible; given mortality rates associated with specific scenarios identified for exploration (see Annex 1). Include scenarios which provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.

Figures 56 and 57 described above show expected equilibrium biomass under two ranges of natural mortality while fishing mortality is fixed at recent by-catch levels of 1%.

26. Recommend parameter values for starting mortality rates, and where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts of listing the species.

No parameter values or model attributes are recommended to augment the biological investigation. An improved empirical basis for many of those that were used would be valuable.

ALLOWABLE HARM ASSESSMENT

27. Evaluate maximum human-induced mortality which the species can sustain and not jeopardize survival or recovery of the species.

Based on the projections undertaken above, even with the elimination of all catch and bycatch, the stock is not expected to recover to a productive status.

Following the closure of the directed cod fishery in 1993, fishing mortality due to cod bycatch in other groundfish fisheries and scientific monitoring programs has been low, on the order of a few percent. Because the recent bycatch of cod represents an F of about 0.01, there is no detectable effect on the probability of survival or recovery of this stock. However, there is no clear threshold when bycatch would be considered a factor affecting the projected status. Furthermore, at recent biomass levels, catch corresponding to an F of 0.01 would amount to several hundred tons.

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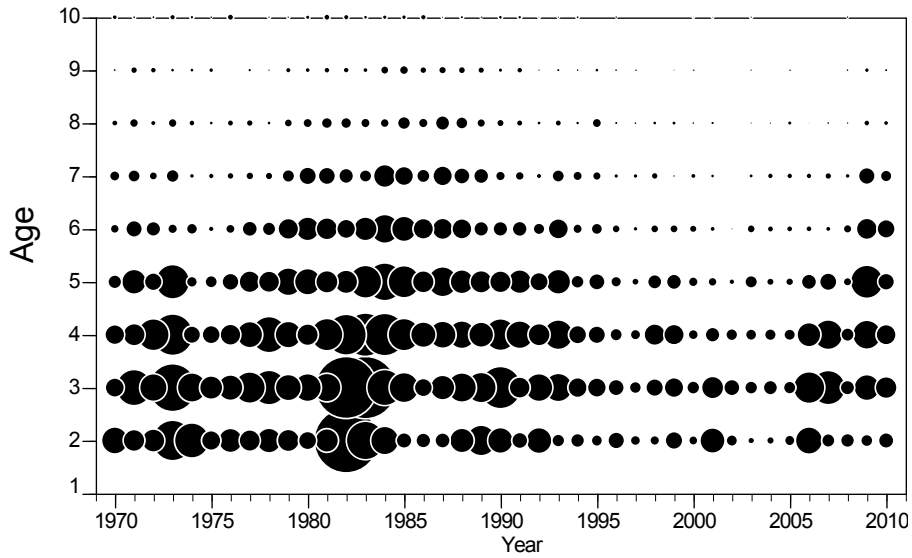
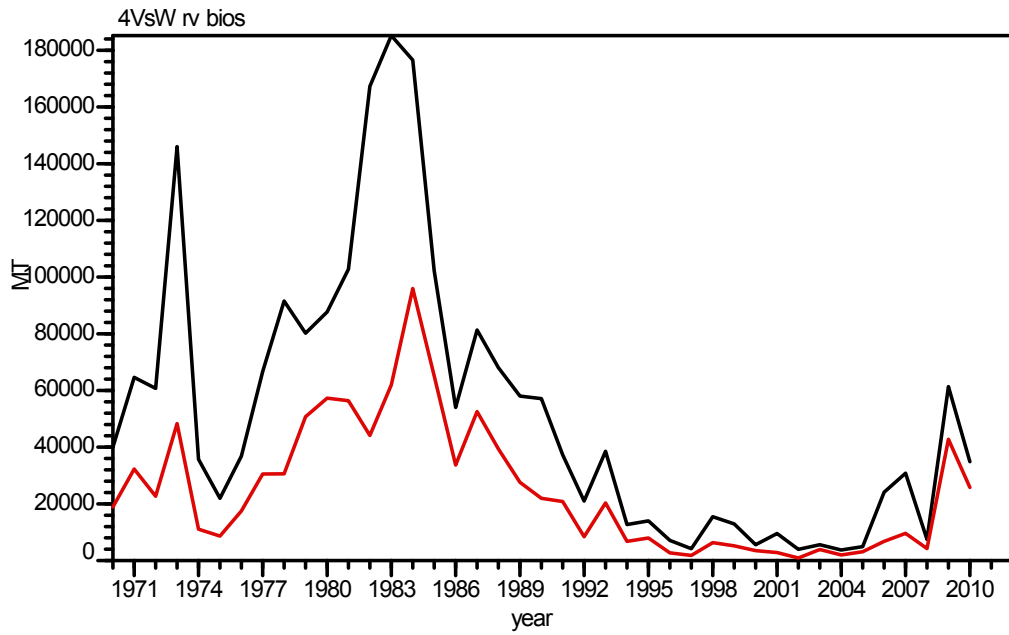
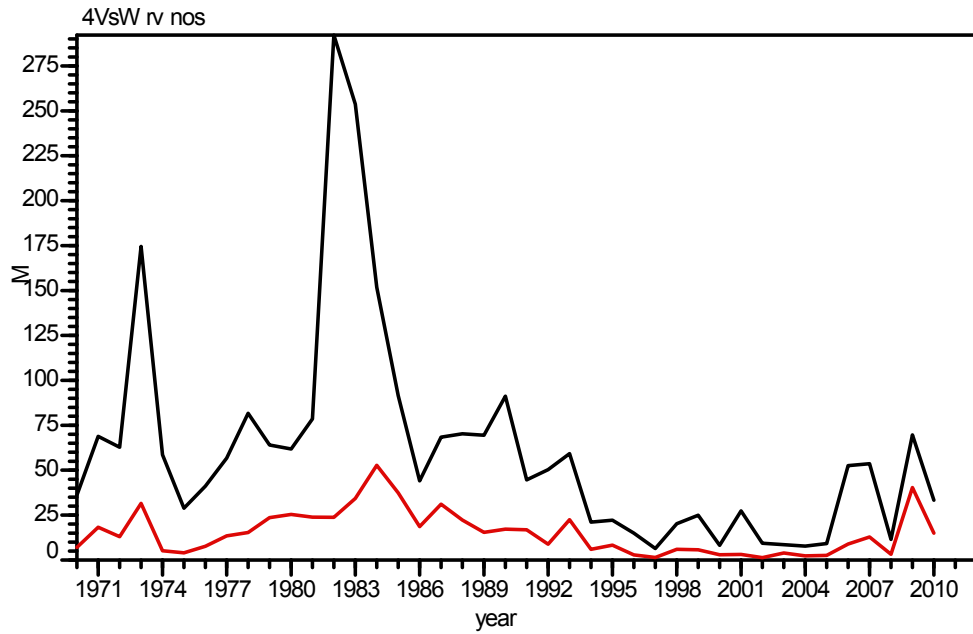


Figure 1. Numbers at age for 4VsW cod from the July survey. The area of the symbol represents the relative abundance at age.



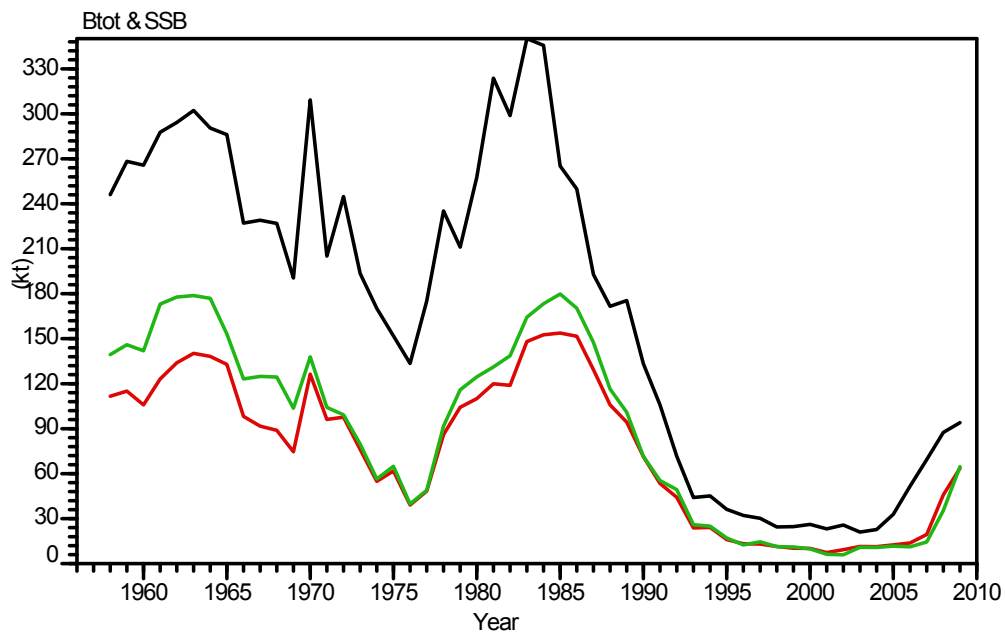
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Figure 2. Survey total biomass (black line) and spawning stock biomass (SSB; red line) using decadal maturity ogives for 4VsW cod.



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Figure 3. Survey total (black line) and spawning (red line) numbers using decadal maturity ogives.



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Figure 4. Total VPA biomass (black line), SSB using decadal maturity ogives (red line), and 5+ biomass (green line).

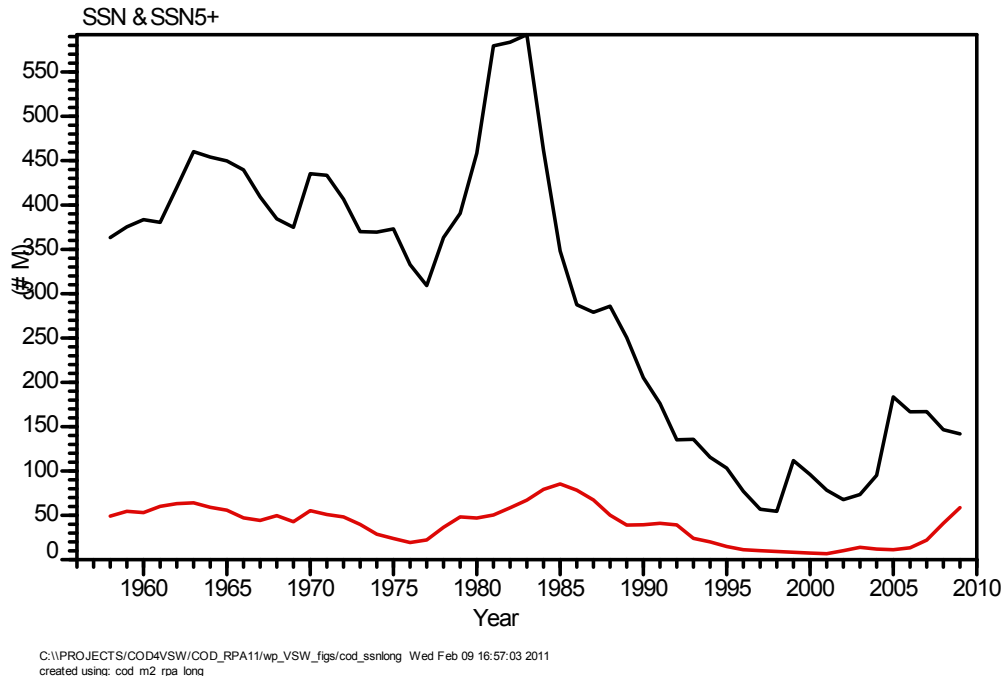


Figure 5. Total VPA numbers (black line) and SSN using decadal maturity ogives (red line).

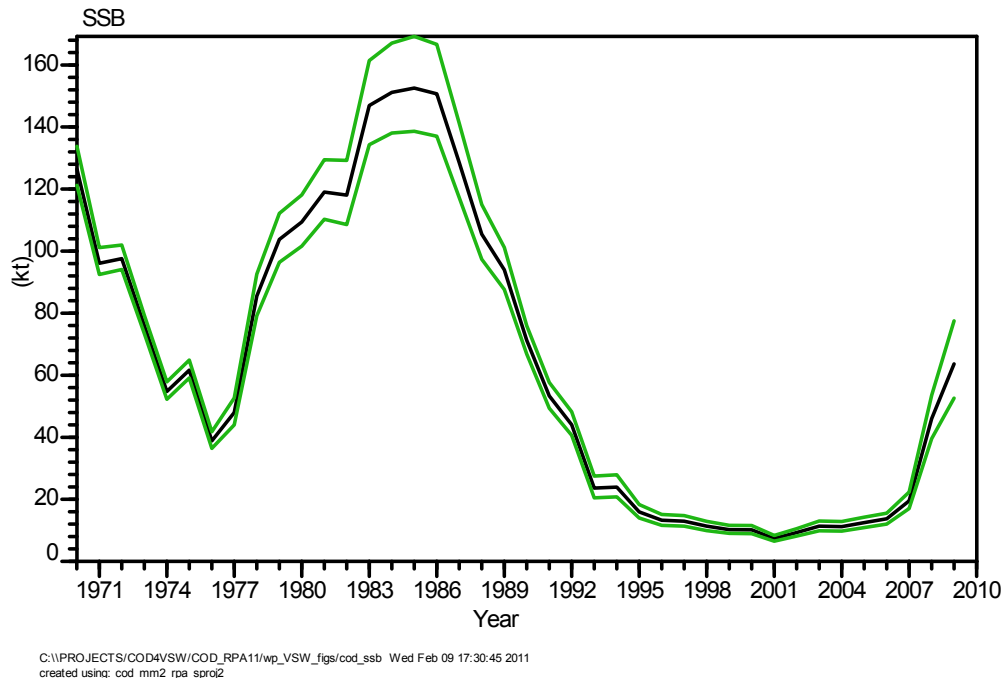
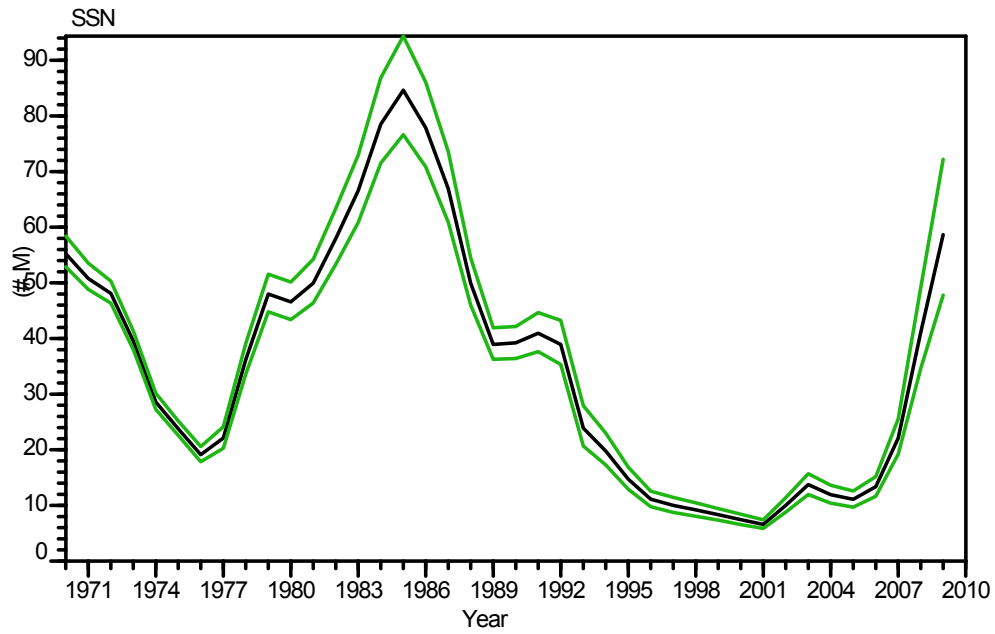


Figure 6. Median SSB (black line) and 2.5 and 97.5 percentiles from 2,500 MCMC replicates (green lines).



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Figure 7. Median SSN (black line) and 2.5 and 97.5 percentiles from 2,500 MCMC replicates (green lines).

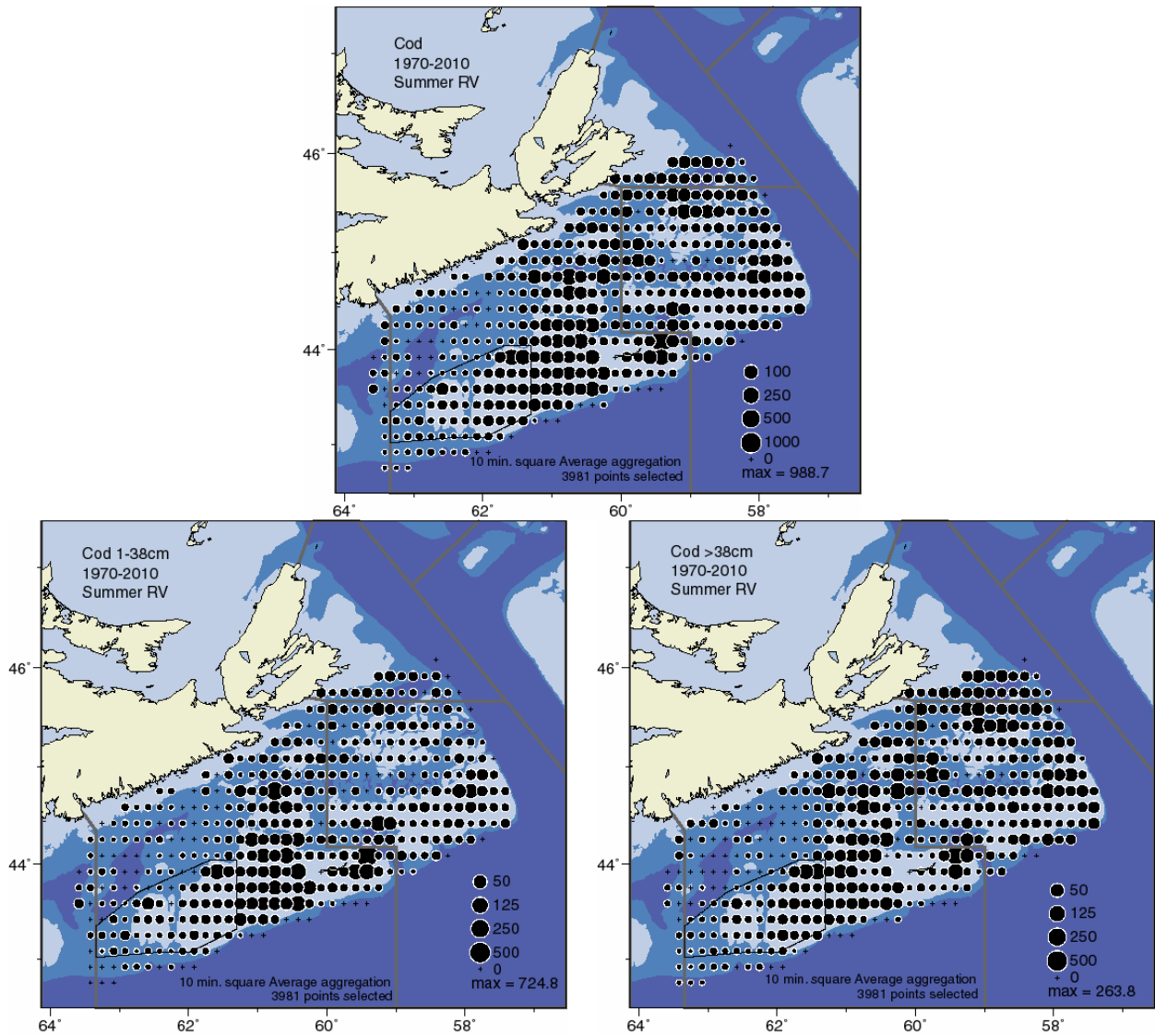


Figure 8. Distribution of Atlantic cod in NAFO 4VsW as indicated by the summer RV survey, 1970-2010.

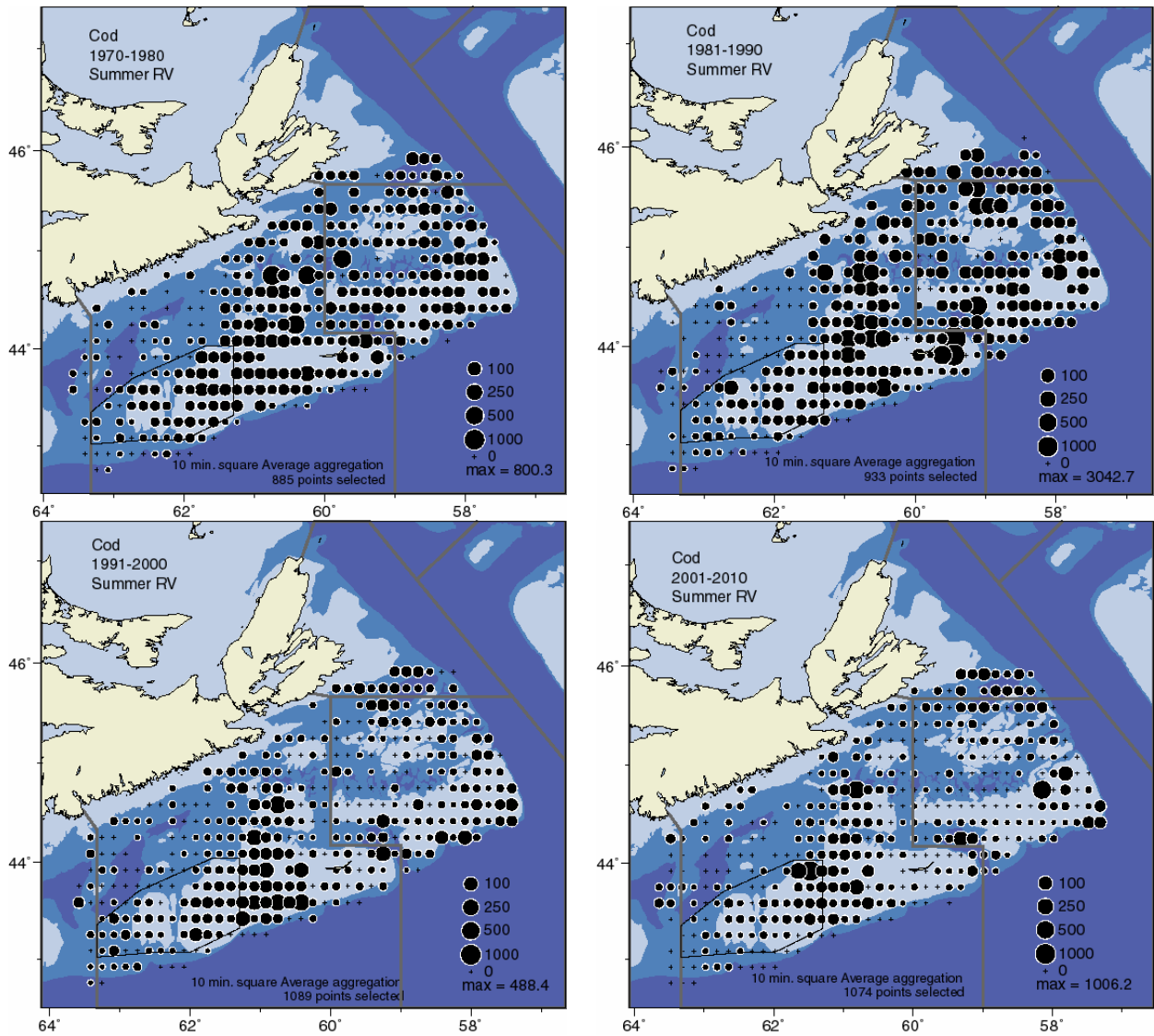


Figure 9. Distribution of Atlantic cod (all sizes) in NAFO 4VsW by decade as indicated by the summer RV survey, 1970-2010.

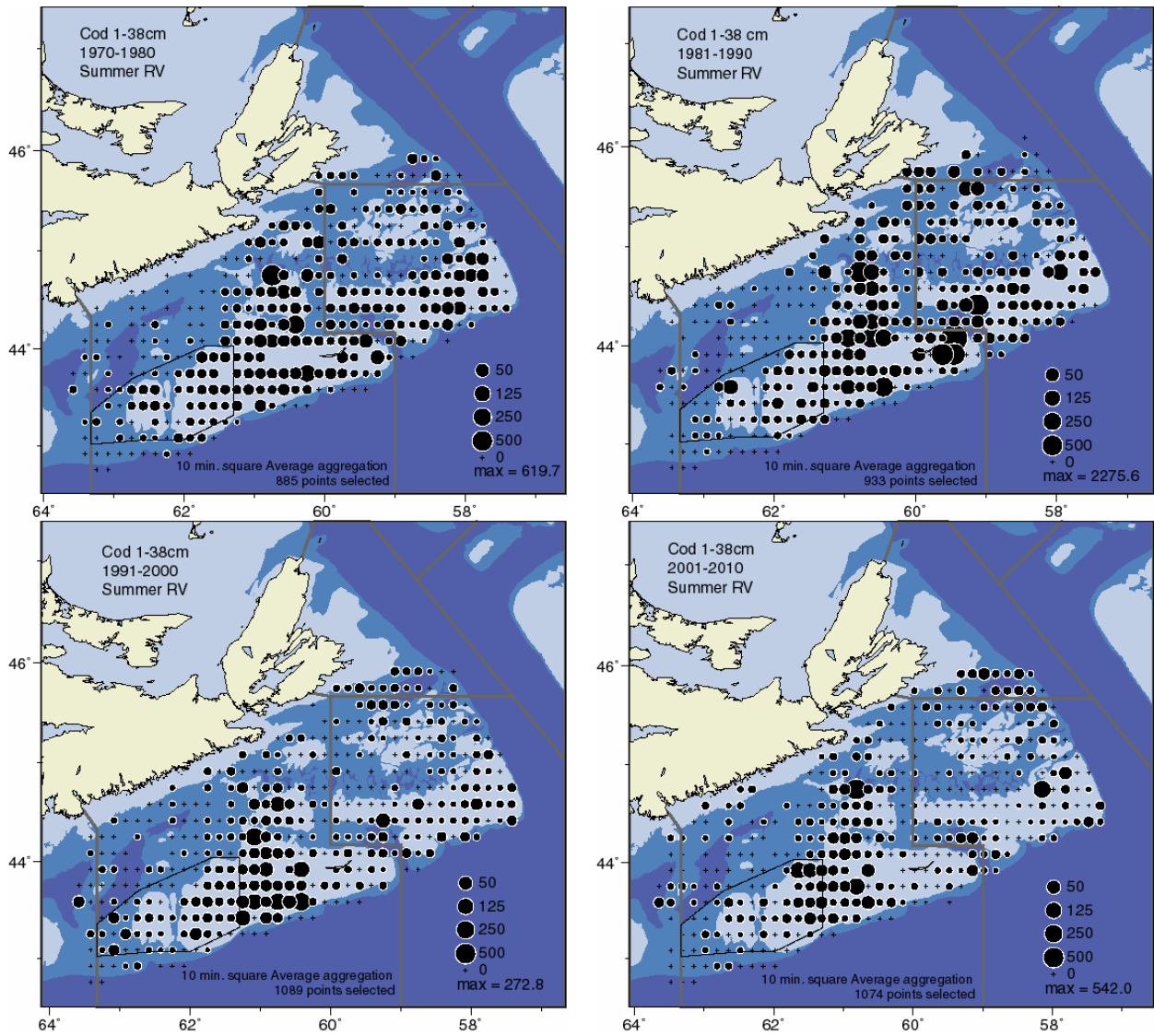


Figure 10. Distribution of Atlantic cod (1-38 cm) in NAFO 4VsW by decade as indicated by the summer RV survey, 1970-2010.

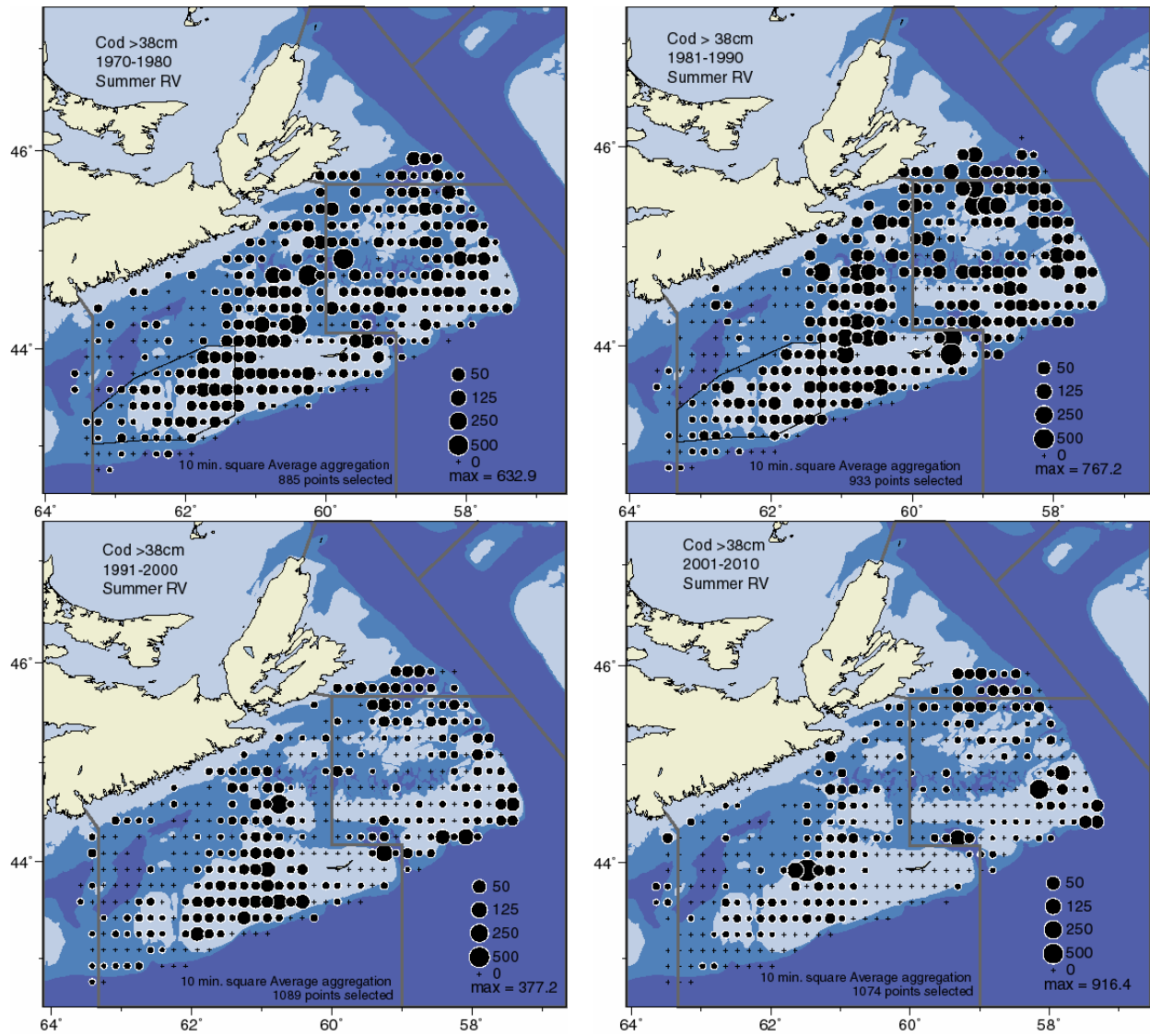


Figure 11. Distribution of Atlantic cod (>38 cm) in NAFO 4VsW by decade as indicated by the summer RV survey, 1970-2010.

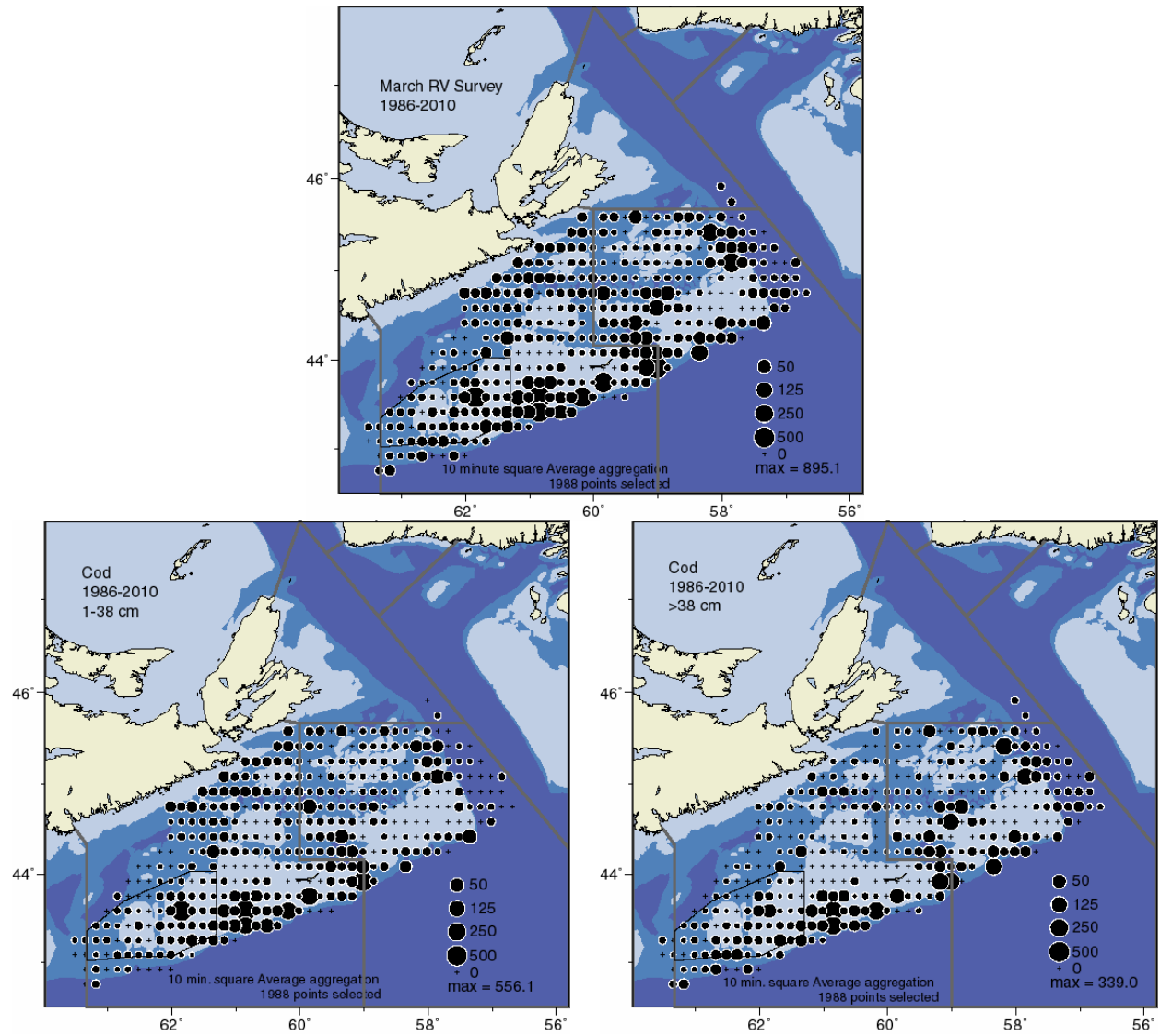


Figure 12. Distribution of Atlantic cod in NAFO 4VsW as indicated by the March RV survey, 1986-2010. Note that coverage was incomplete during some years and the survey was not conducted during 1998 and 2004.

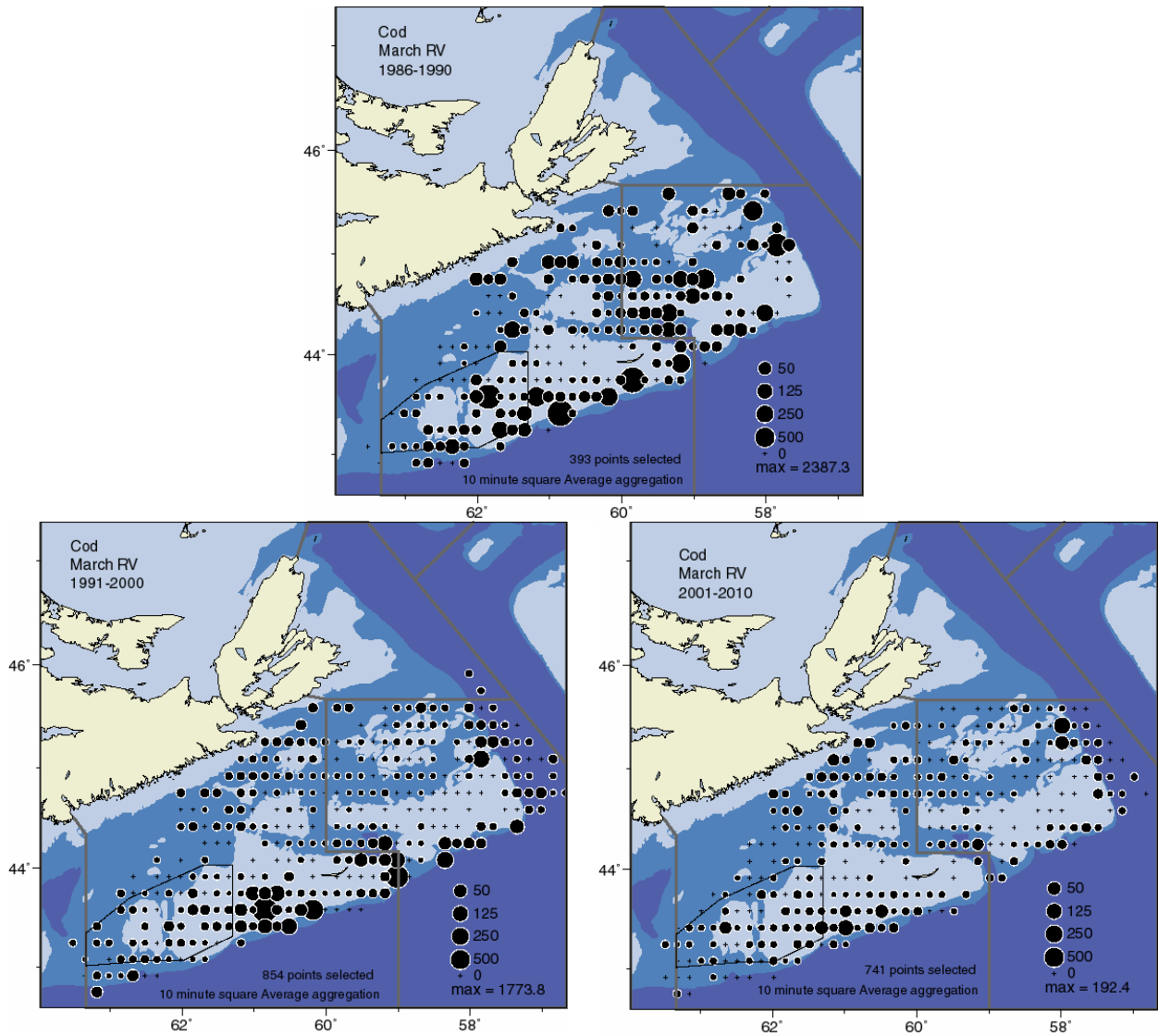


Figure 13. Distribution of Atlantic cod (all sizes) in NAFO 4VsW by decade as indicated by the March RV survey, 1986-2010. Note that coverage was incomplete during some years and the survey was not conducted during 1998 and 2004.

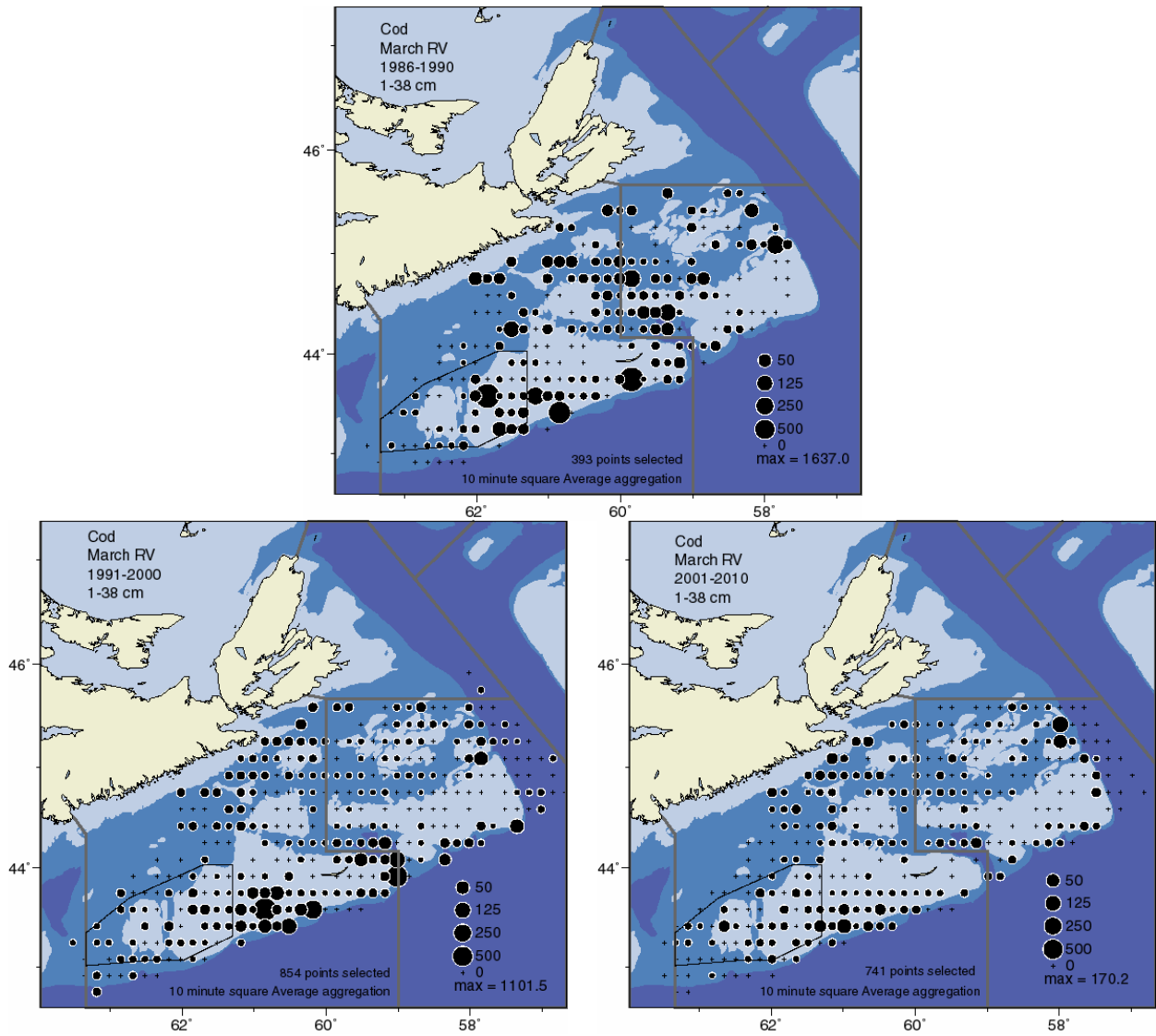


Figure 14. Distribution of Atlantic cod (1-38 cm) in NAFO 4VsW by decade as indicated by the March RV survey, 1986-2010. Note that coverage was incomplete during some years and the survey was not conducted during 1998 and 2004.

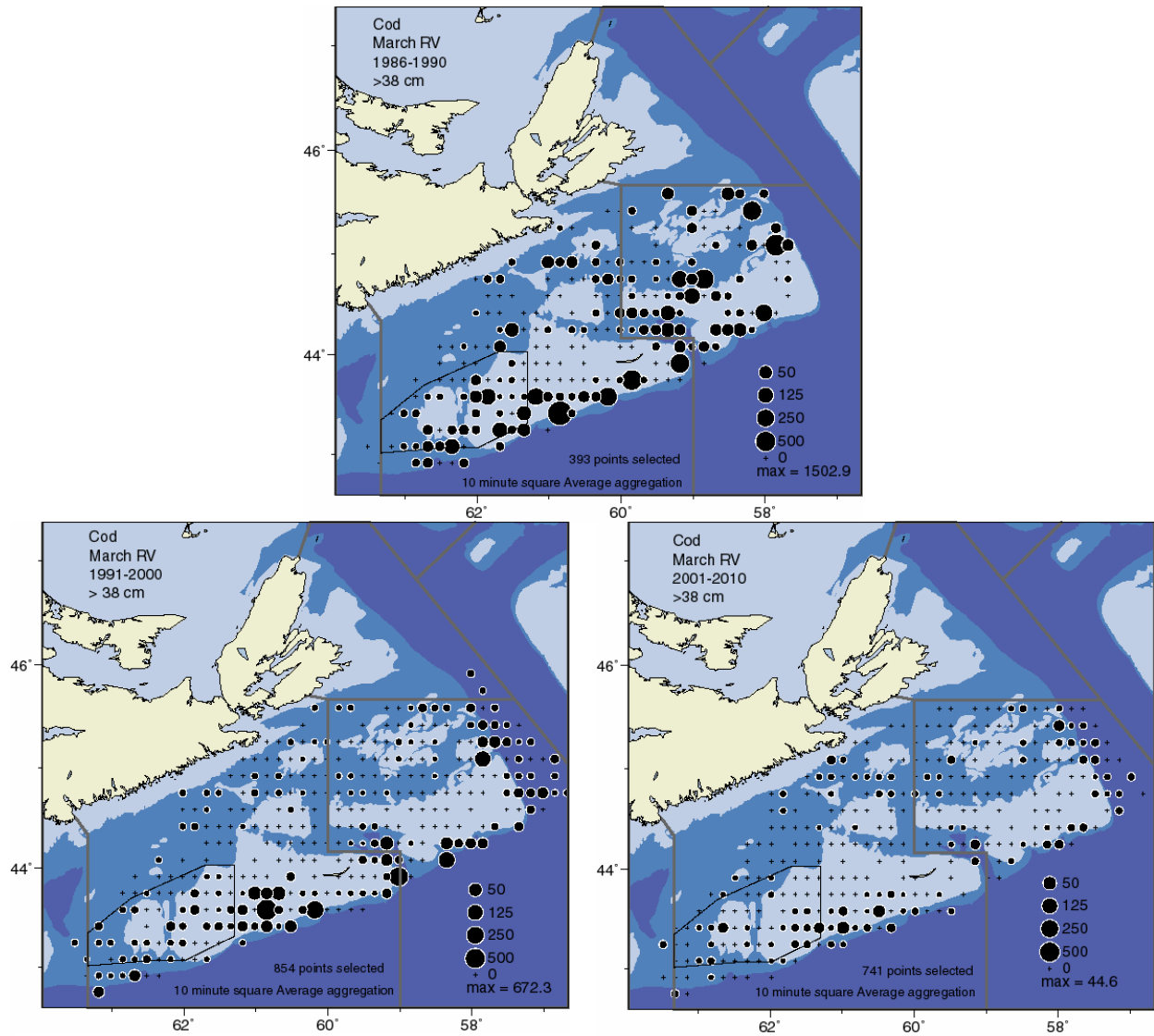


Figure 15. Distribution of Atlantic cod (>38 cm) in NAFO 4VsW by decade as indicated by the March RV survey, 1986-2010. Note that coverage was incomplete during some years and the survey was not conducted during 1998 and 2004.

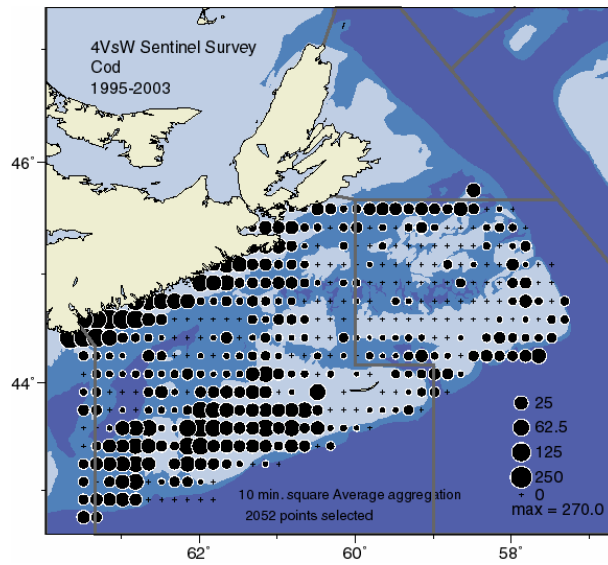
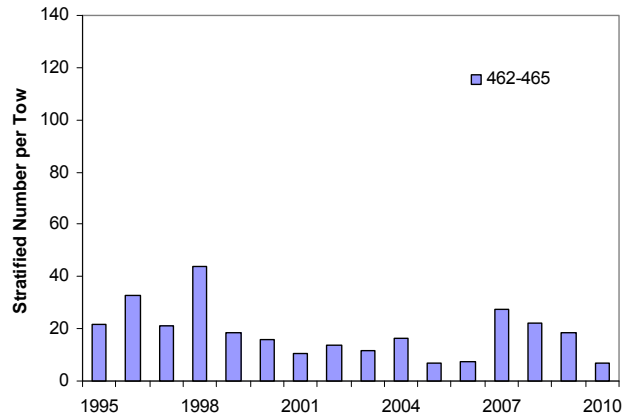


Figure 16. Distribution of Atlantic cod in NAFO 4VsW as indicated by the sentinel survey, 1995-2003. Note that after 2003, survey was reduced to comprise six strata in NAFO 4W only.

(a)



(b)

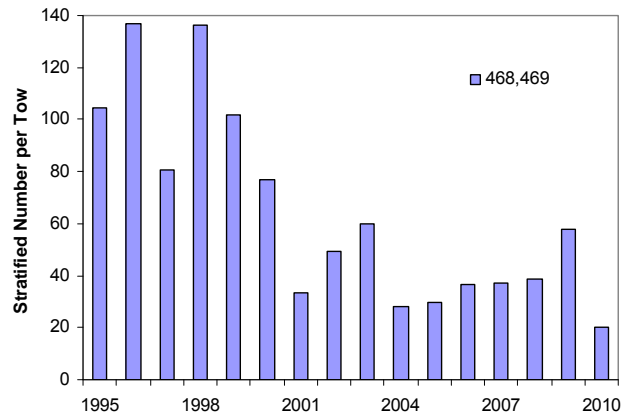
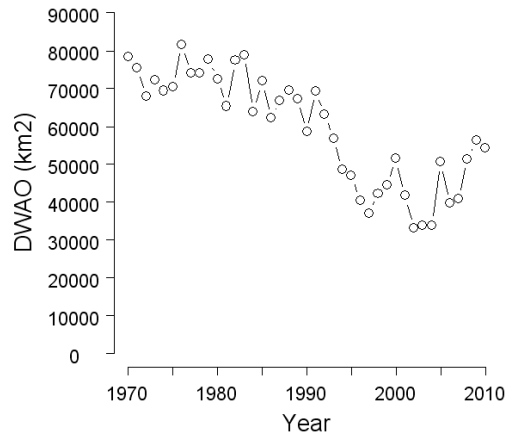
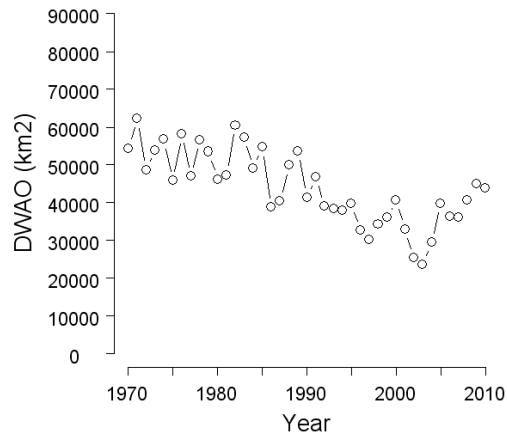


Figure 17. Abundance of Atlantic cod in NAFO 4VsW over time as indicated by the sentinel survey, 1995-2010. Note that while the survey included a larger area prior to 2004, only strata consistently sampled over time were included above. Strata 462-465 (a) represent areas in the vicinity of the haddock box in offshore 4W, strata 468-469 represent inshore areas.

(a)



(b)



(c)

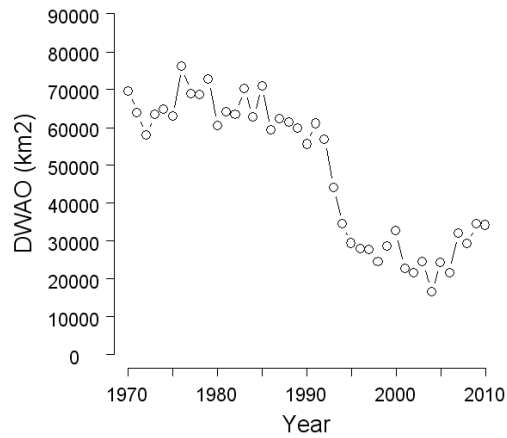
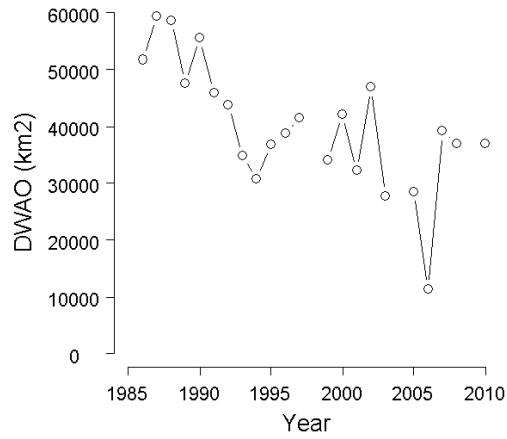
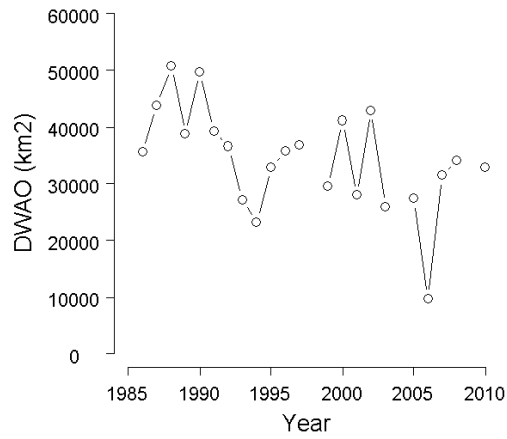


Figure 18. Design weighted area of occupancy (km^2) for Atlantic cod (a) all sizes, (b) 1-38 cm, and (c) >38 cm in NAFO 4VsW from the summer RV survey, 1970-2010.

(a)



(b)



(c)

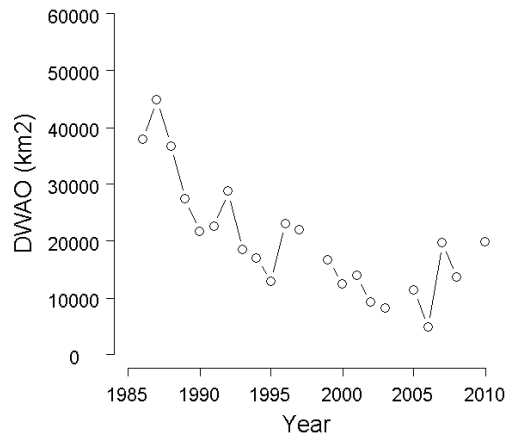


Figure 19. Design weighted area of occupancy for Atlantic cod (a) all sizes, (b) 1-38 cm, and (c) >38 cm in NAFO 4VsW from the March RV survey, 1986-2010. Note that coverage was incomplete during some years and the survey was not conducted during 1998 and 2004.

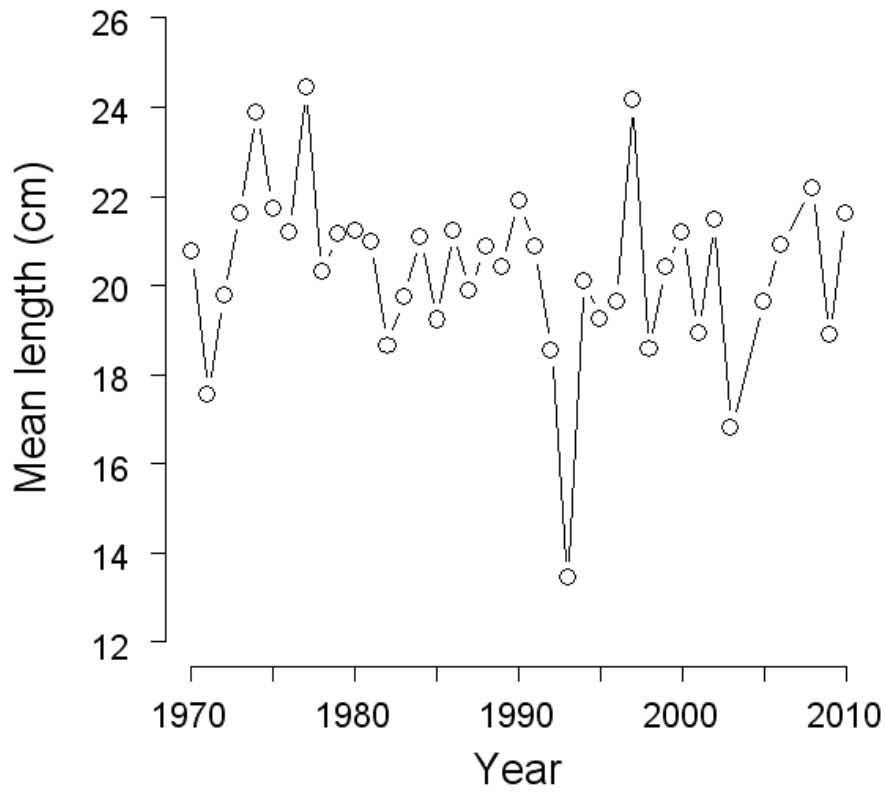


Figure 20. Mean length of age 1 cod in NAFO 4VsW as indicated by the Summer RV survey, 1970-2010.

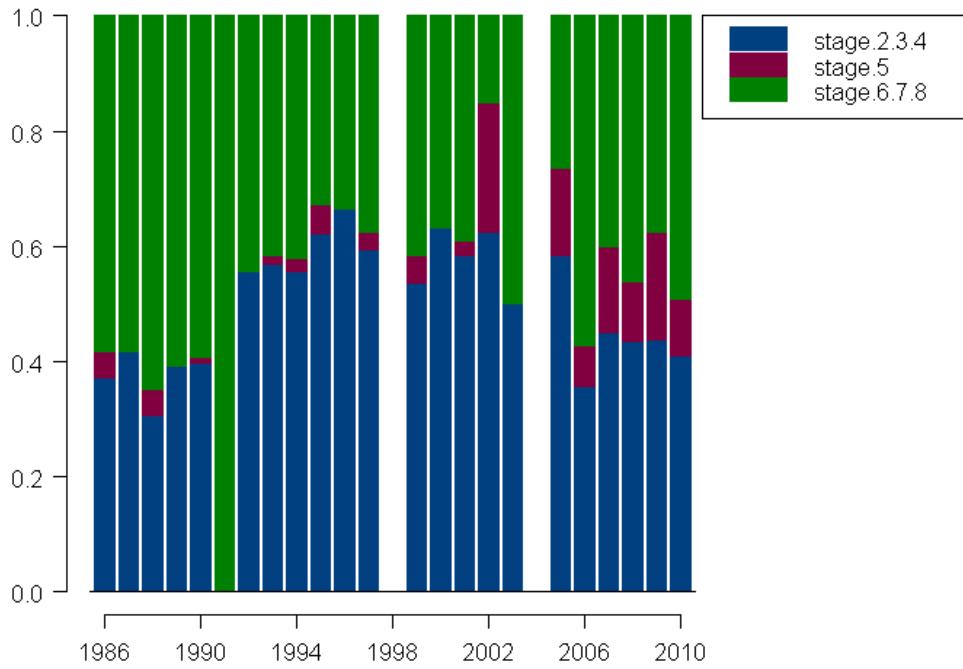


Figure 21. Histogram of mature Atlantic cod females by maturity stage as observed during the March RV survey, 1986-2010 (stages 2-4: ripening/ripe; stage 5: spawning; stages 6-8: spent/resting).

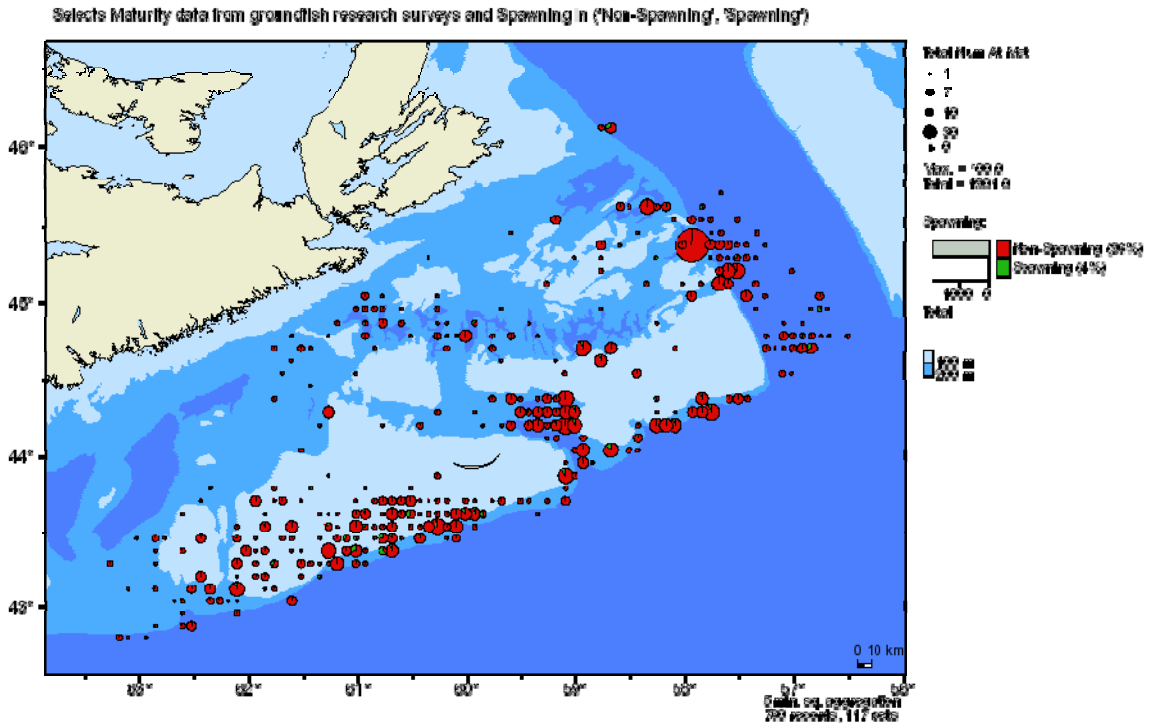
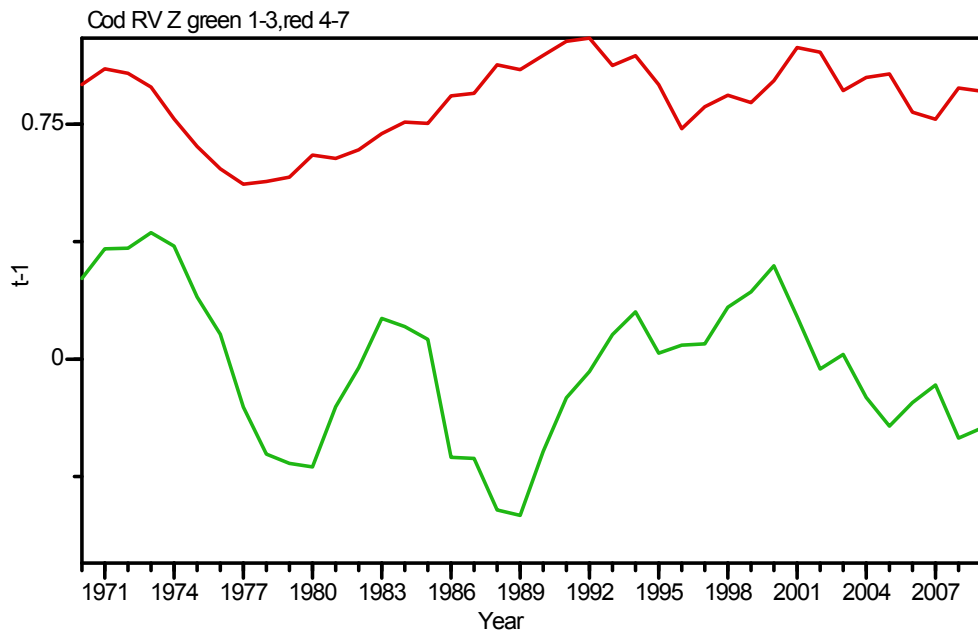
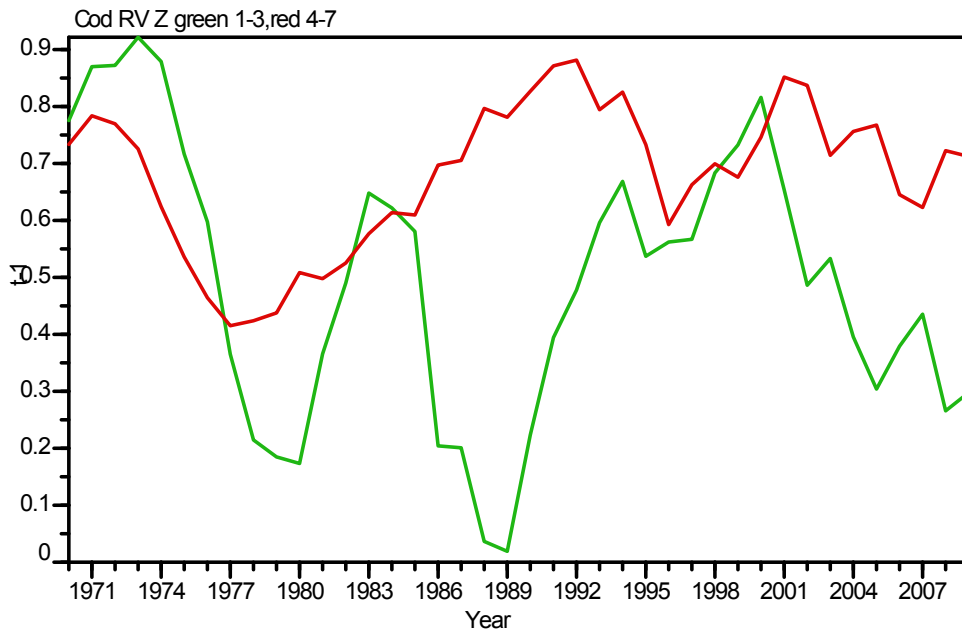


Figure 22. Distribution of spawning and non-spawning mature female Atlantic cod as observed during the March RV survey, 1986-2010.



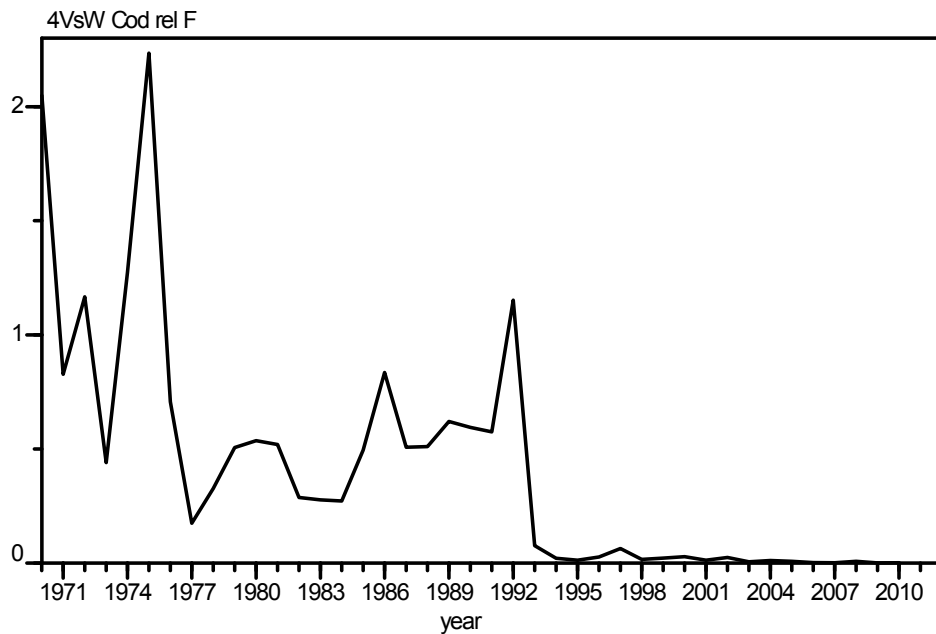
C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\cod_rvz Tue Feb 08 14:02:01 2011
created using: cod zap rv2

Figure 23. Instantaneous total mortality (Z) estimated from the summer survey series for 2 age groups: 1-3 years (green line) and 4-7 years (red line). Arbitrary catchability coefficients (q) at age of 0.1, 0.2, 0.4, 1, 1, 1, 1, and 1 were used to help scale the input data.



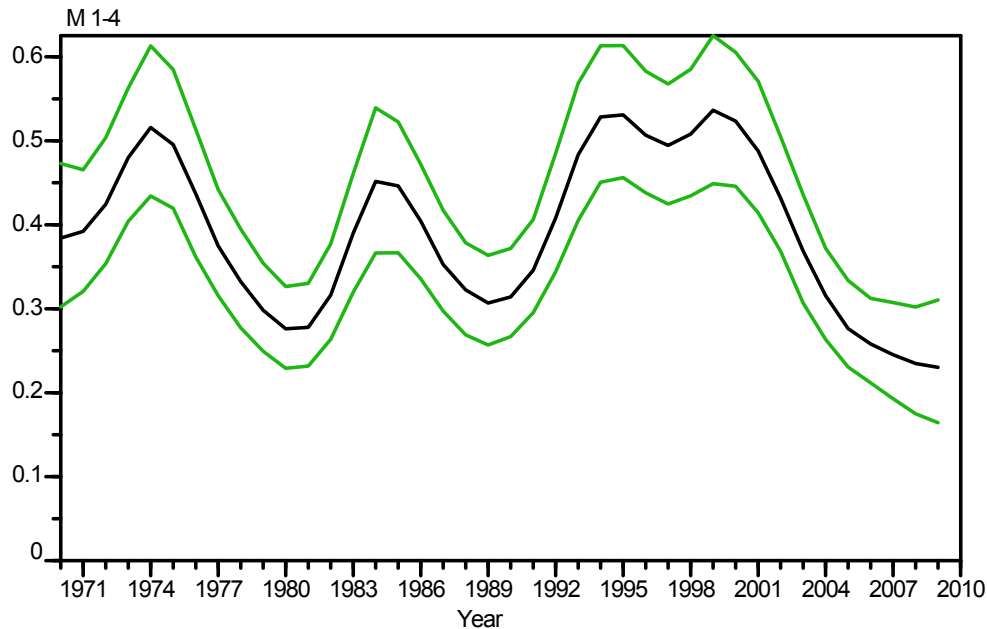
C:\PROJECTS\COD4VSW\COD_MODELS_10\cwp_figs\cod_rvz Wed Sep 29 13:00:25 2010
created using: cod zap rv

Figure 24. Instantaneous total mortality (Z) estimated from the summer survey series for 2 age groups: 1-3 years (green line) and 4-7 years (red line). Catchability coefficients (q) from a VPA were used to scale the input data.



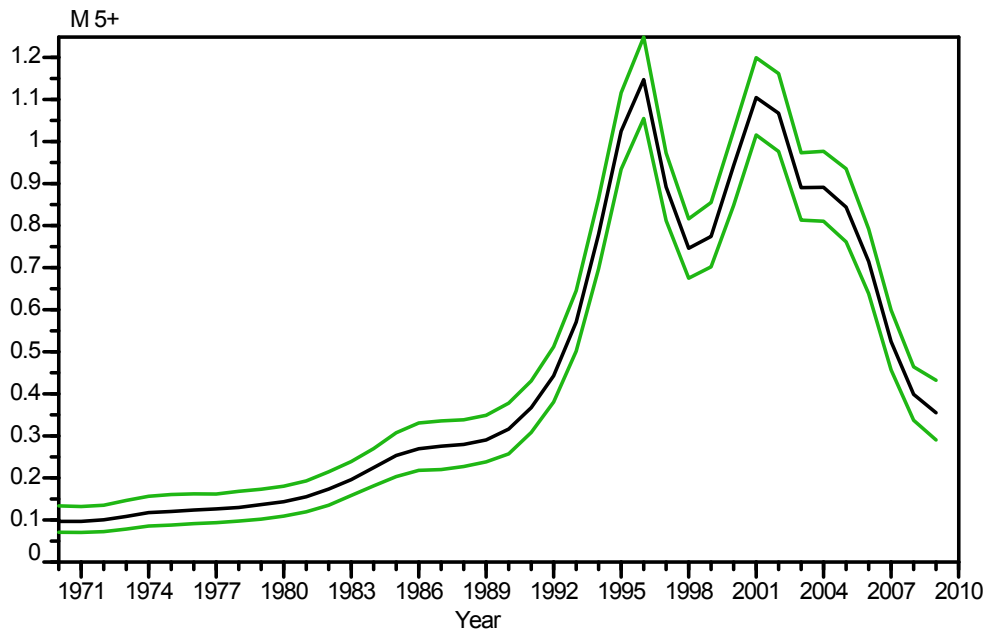
C:\PROJECTS\COD4VSW\COD_MODELS_10\cwp_figs\cod_rel_f Thu Sep 30 12:30:21 2010
created using: cod zap rv

Figure 25. Relative F estimated as the recorded landings divided by the total (ages 1-15) summer survey biomass.



C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\M 1-4 Tue Feb 01 11:45:28 2011
created using: cod mm2 rpa spro2

Figure 26. Natural mortality (M) estimated from VPA for Atlantic cod aged 1-4 years. Black line is median estimated from 2,500 MCMC replicates and green lines are the 2.5 and 97.5 percentiles.



C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\M 5+ Tue Feb 01 11:45:29 2011
 created using: cod mm2 rpa spro2

Figure 27. Natural mortality (M) estimated from VPA for Atlantic cod aged 5 years or older. Black line is median estimated from 2,500 MCMC replicates and green lines are the 2.5 and 97.5 percentiles.

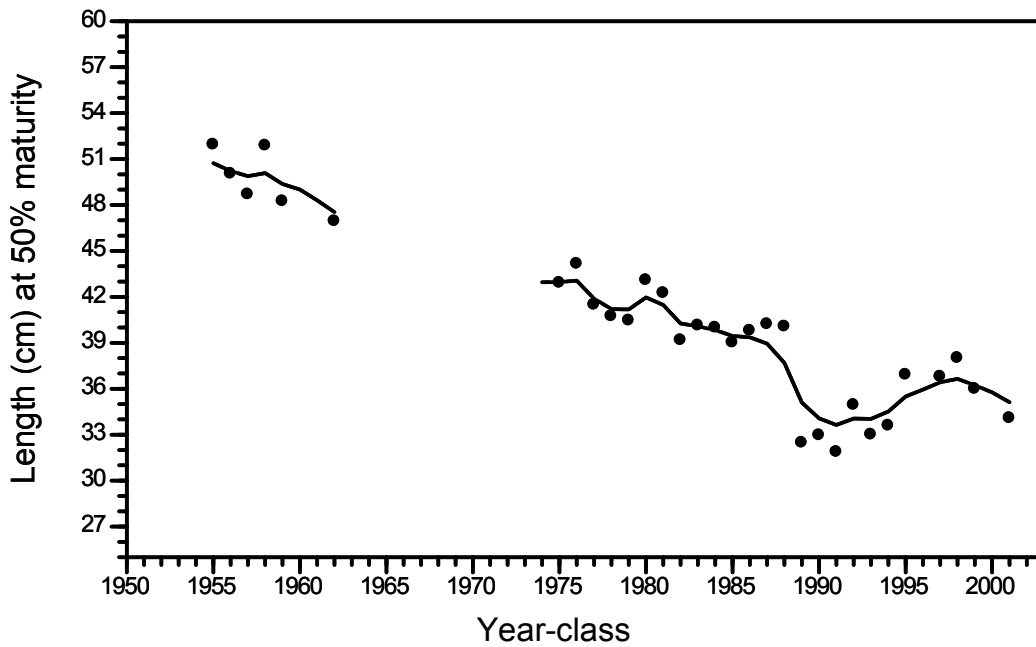


Figure 28. Length at 50% maturity for cohorts of female Atlantic cod in 4VsW from spring surveys.

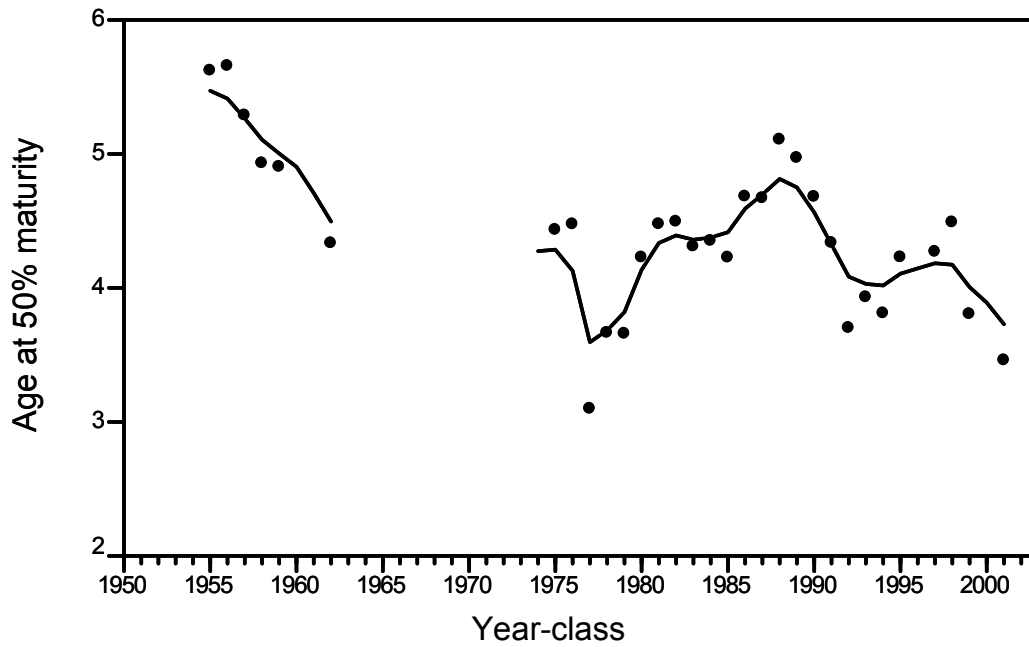


Figure 29. Age at 50% maturity for cohorts of female Atlantic cod in 4VsW from spring surveys.

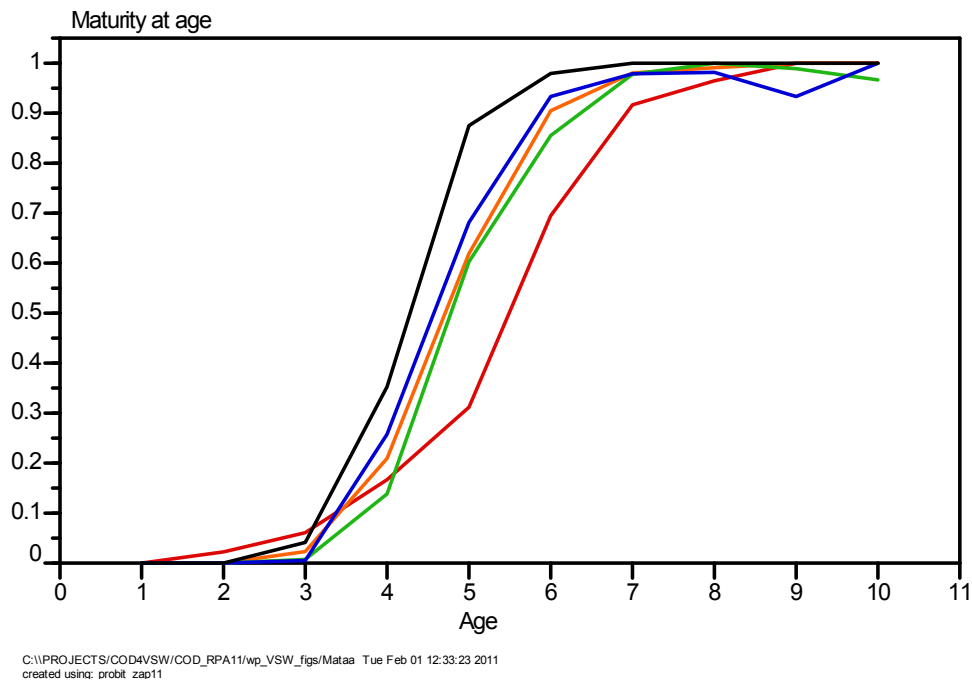
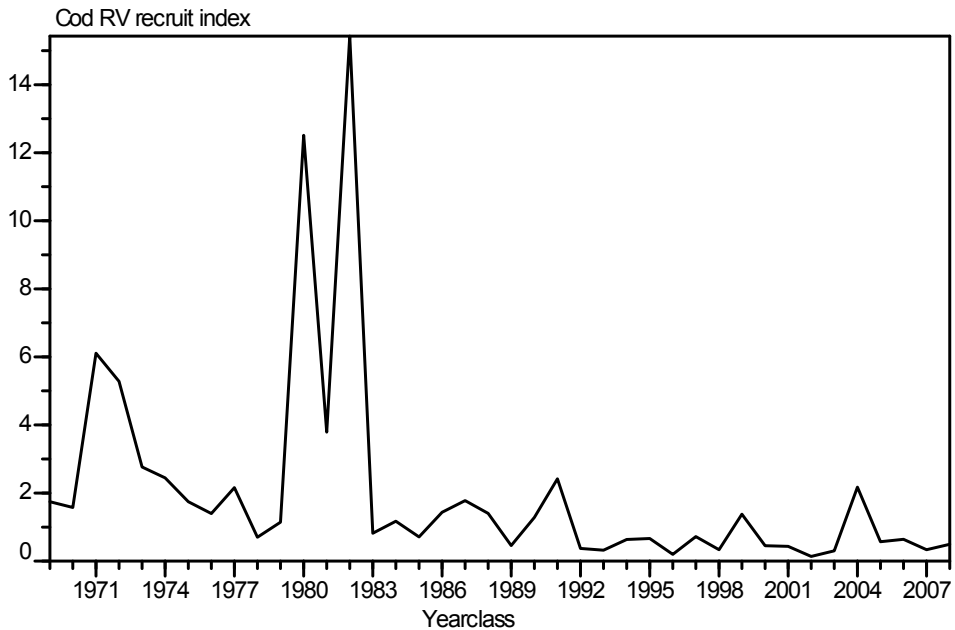
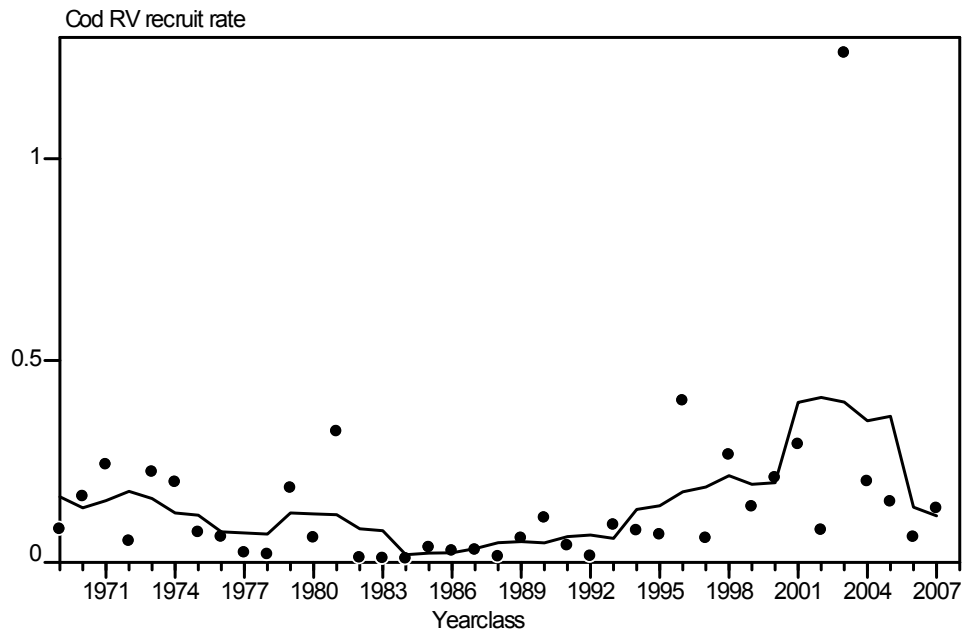


Figure 30. Maturity at age for female Atlantic cod in 4VsW during five time periods: 1958-1969 (red line), 1970-1979 (orange), 1980-1989 (green), 1990-1999 (blue), and 2000-2009 (black).



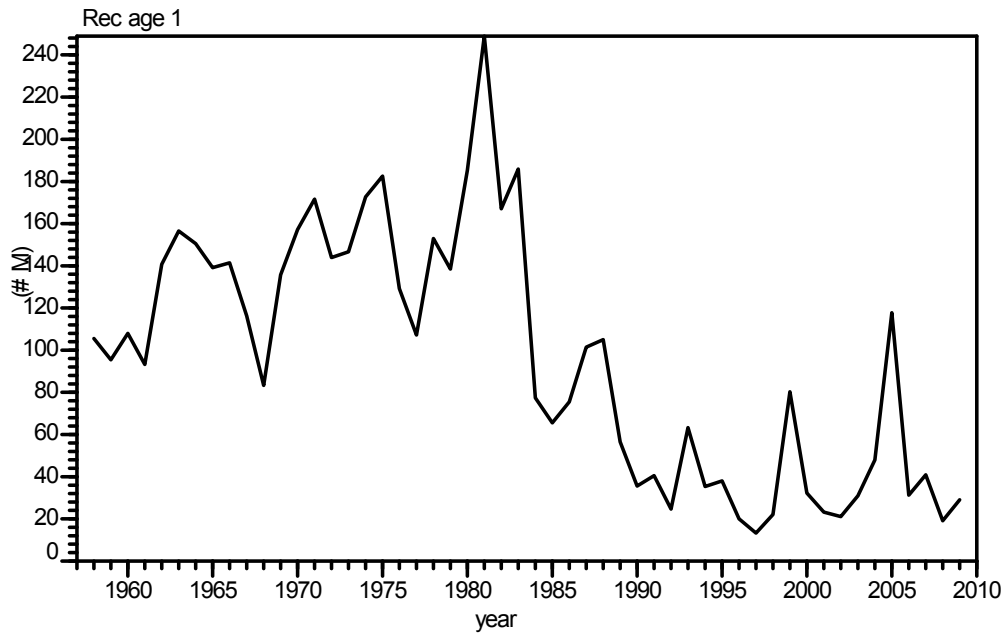
C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\cod_rv_recr Tue Feb 01 14:59:01 2011
 created using: cod zap rv2

Figure 31. Recruitment index for 4VsW Atlantic cod from the summer survey. The index is the sum down the cohort of the normalized numbers for ages 1 and 2.



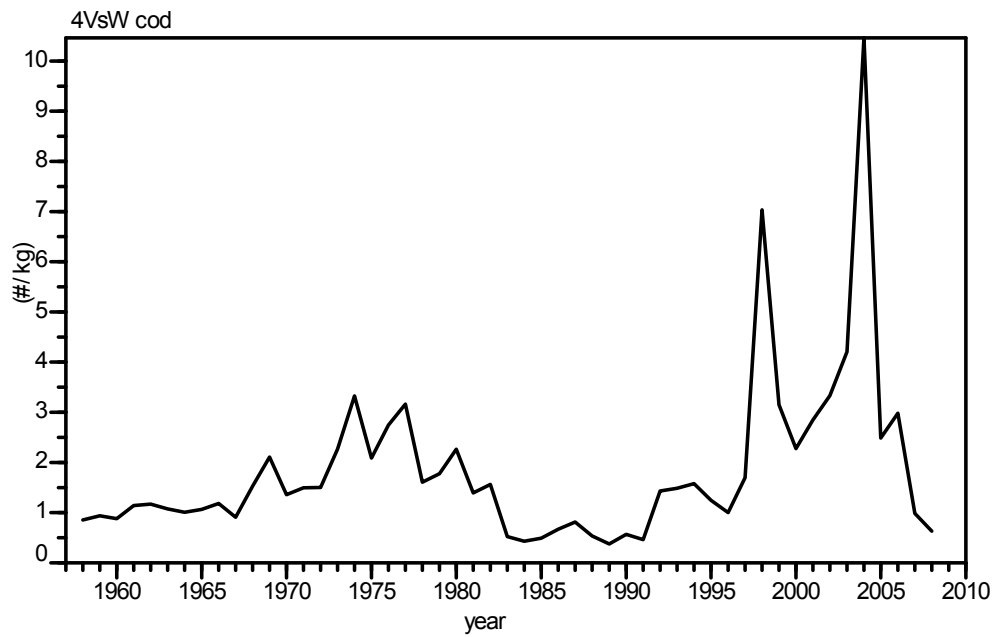
C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\cod_rv_recr_rate Tue Feb 01 14:59:04 2011
 created using: cod zap rv2

Figure 32. Recruitment rate index from the summer survey. The index is the summed down the cohort of the normalized numbers for ages 1 and 2 and then divided by the 5+ survey biomass that produced the cohort. The data are shown as points while the line is a 5 year moving average tapered at the ends.



c:\projects\cod4vsw\cod_rpa11\wp_VSW_figs\VPA_reclongben Tue Feb 08 16:21:33 2011
 created using: cod m2 rpa long

Figure 33. Recruitment index at age 1 from VPA.



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 created using: cod m2 rpa long

Figure 34. Recruitment rate index from VPA. The number of age 1 is divided by the 5+ biomass that produced the cohort.

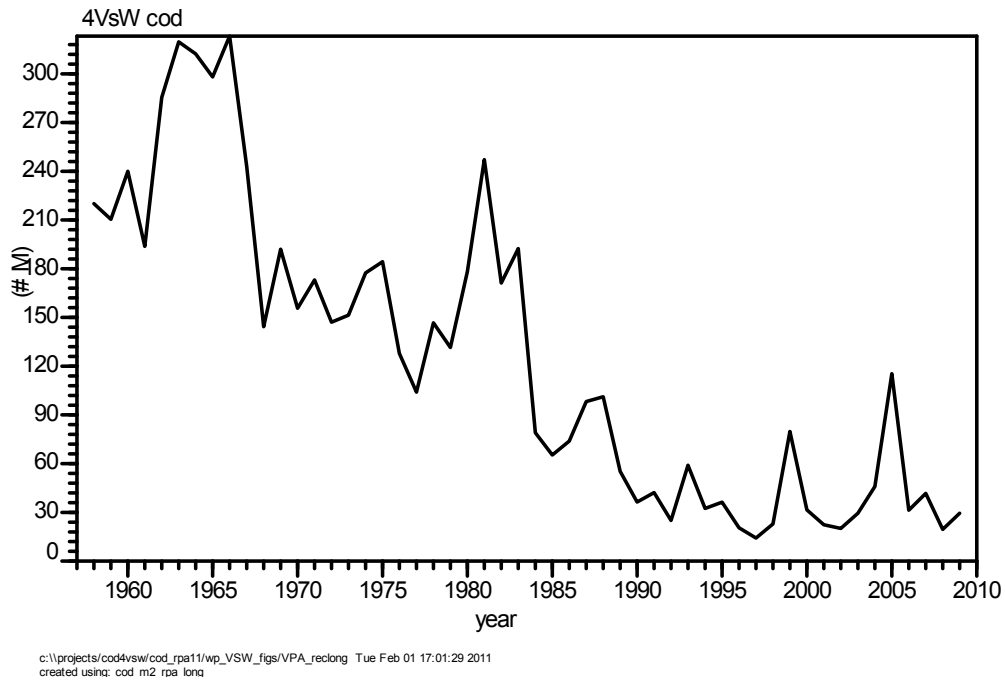


Figure 35. Recruitment index at age 1 from VPA using estimated M rather than 0.2.

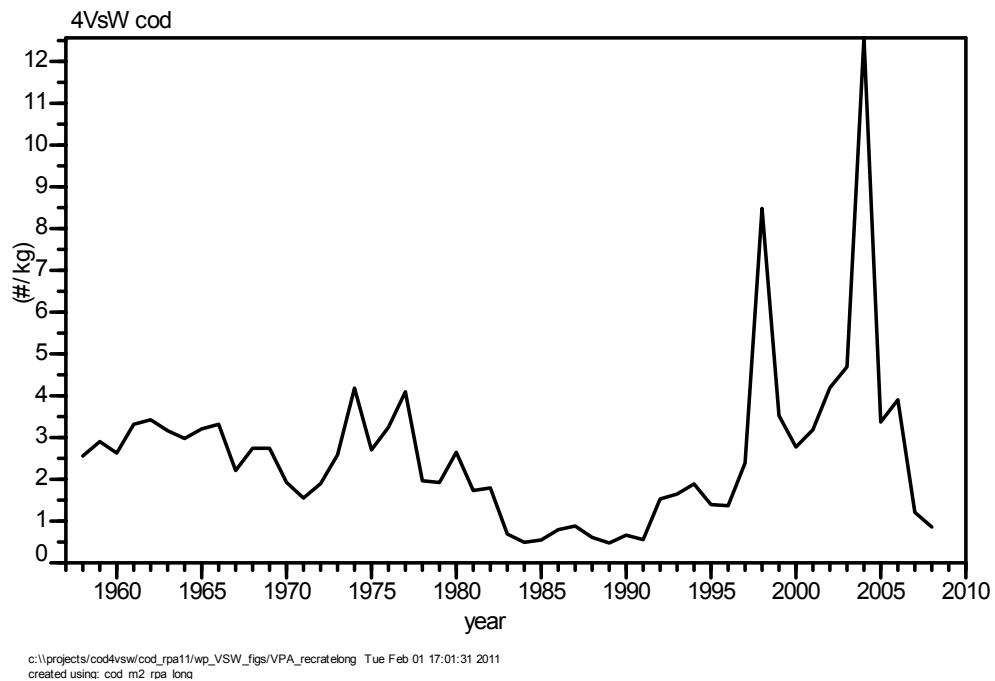
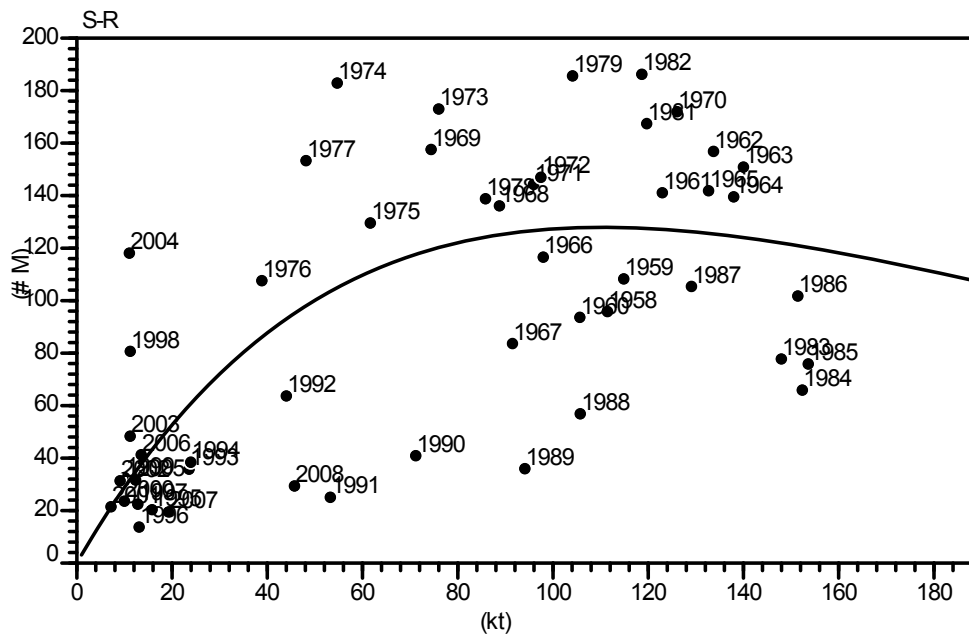
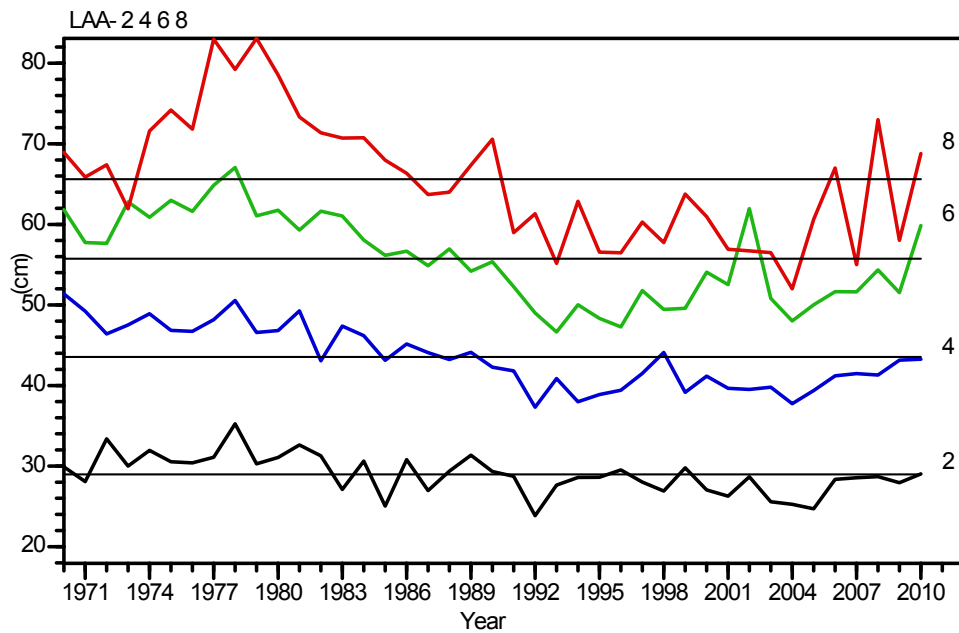


Figure 36. Recruitment rate index from VPA. The number of age 1 is divided by the 5+ biomass that produced the cohort. Recruitment index at age 1 from VPA using estimated M rather than 0.2.



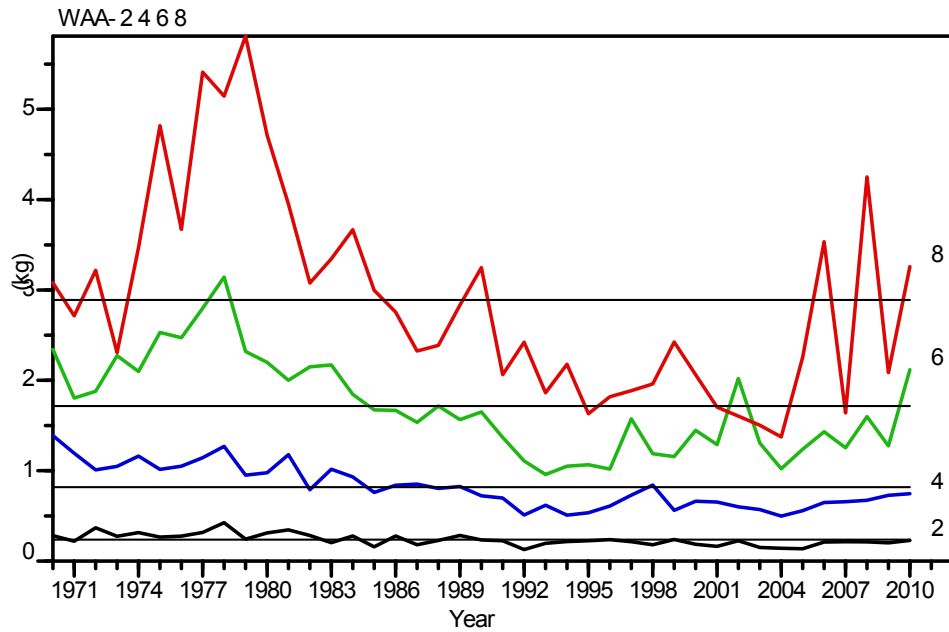
C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\VPA_SR Wed Feb 09 17:41:07 2011
 created using: cod m2 rpa lonq4

Figure 37. Stock recruit relationship from VPA estimates. The number of age 1 is shown as a function of the 5+ biomass that produced the cohort. A Ricker curve has been fit to the data.



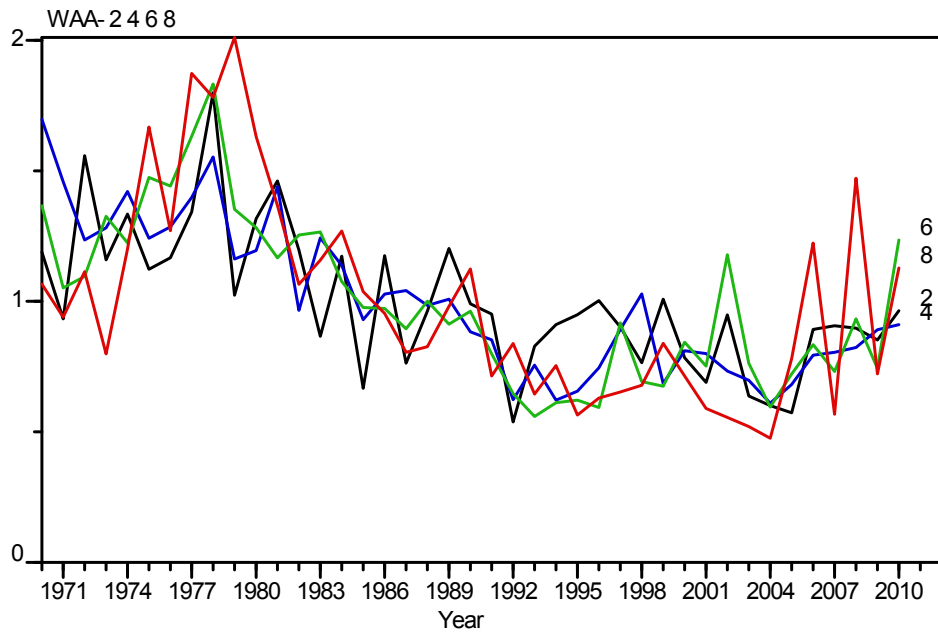
C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\co_laa2468 Tue Feb 08 17:12:29 2011
 created using: cod zap rv2

Figure 38. Length at age for ages 2, 4, 6, and 8 from the summer survey series. The horizontal black lines are the means for each age.



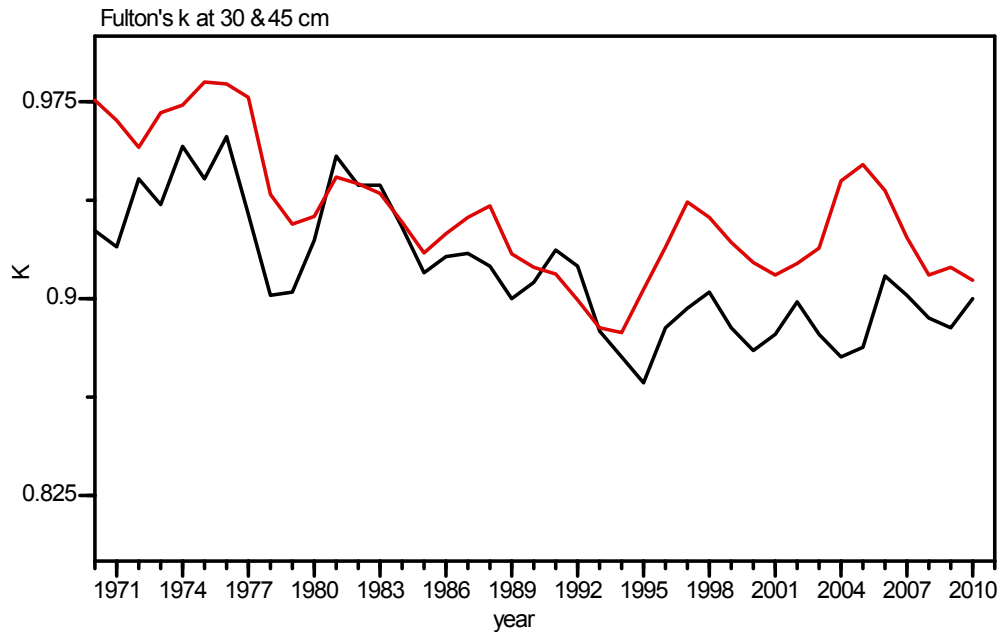
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created using: cod zap rv2

Figure 39. Weight at age for ages 2, 4, 6, and 8 from the summer survey series. The horizontal black lines are the means for each age.



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created using: cod zap rv2

Figure 40. Normalized weight at age for ages 2, 4, 6, and 8 from the summer survey series.



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 created using: cod zap rv2

Figure 41. Condition expressed as Fulton's K for 30 cm (black line) and 45 cm (red line) Atlantic cod in 4VsW. Data have been smoothed with a 3 year moving average.

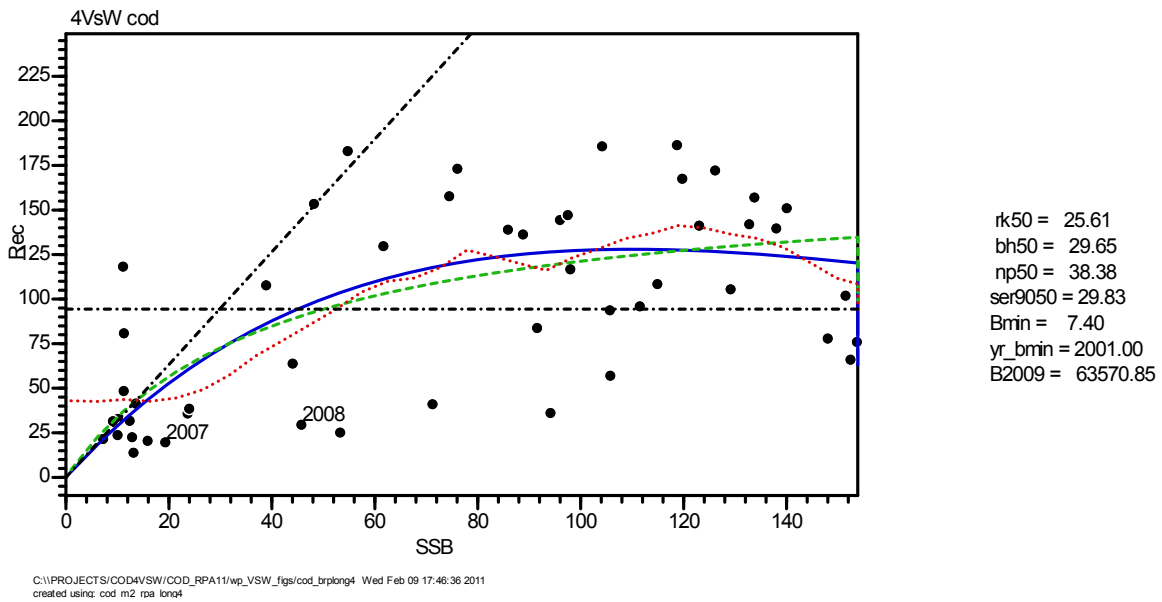
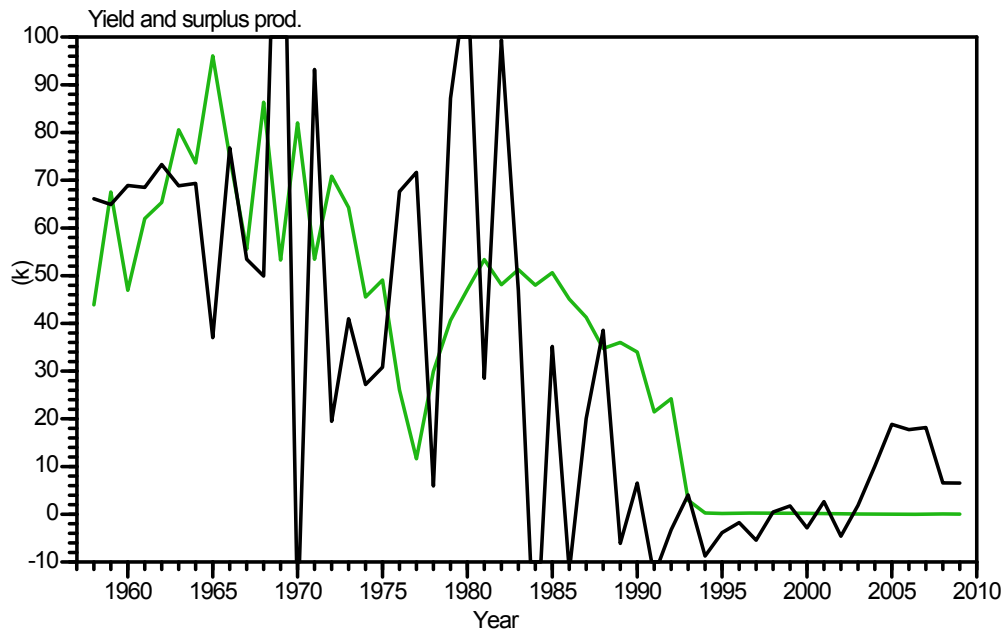
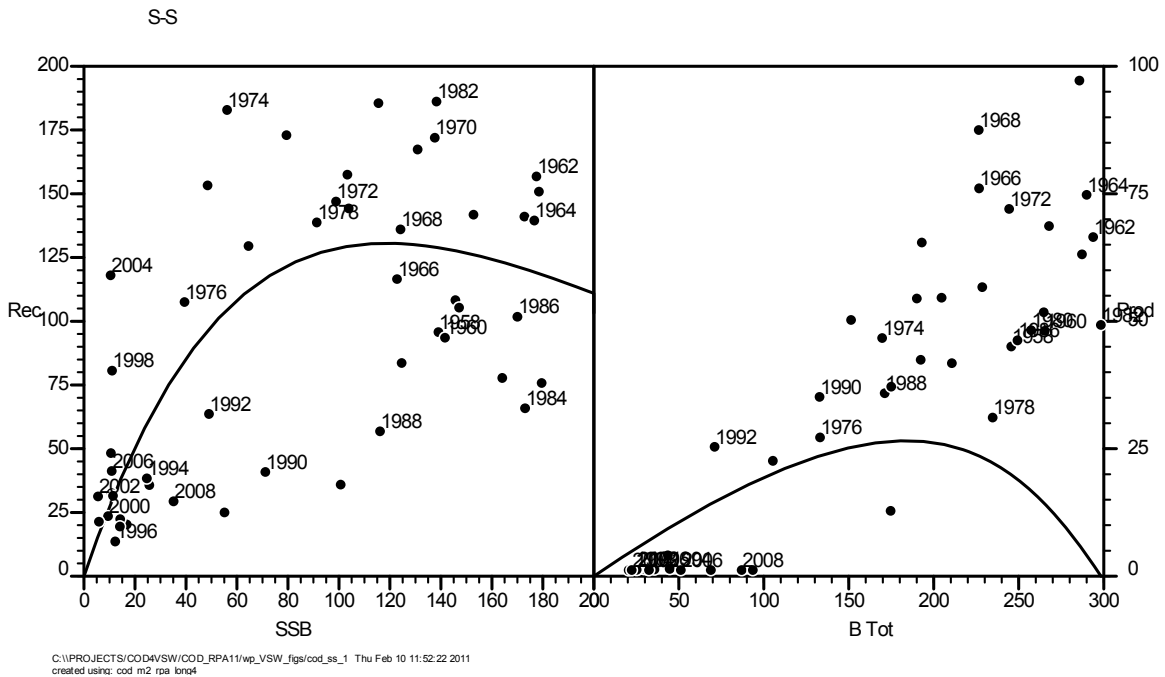


Figure 42. Candidate B_{lim} calculations from stock-recruit data. Blue line: Ricker model; green line: Beverton-Holt model; and red line: a non-parametric fit.



C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\cod_prodlong Thu Feb 10 11:47:21 2011
 created using: cod m2 rpa long4

Figure 43. Landings (green line) and surplus production (black line) for 4VsW cod from VPA estimates.



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 created using: cod m2 rpa long4

Figure 44. Sissenwine-Shepherd production analysis. The left hand panel is the fit to the stock and recruitment data. The right shows the equilibrium production data (which were not fit but are shown for reference) as a function of the total biomass.

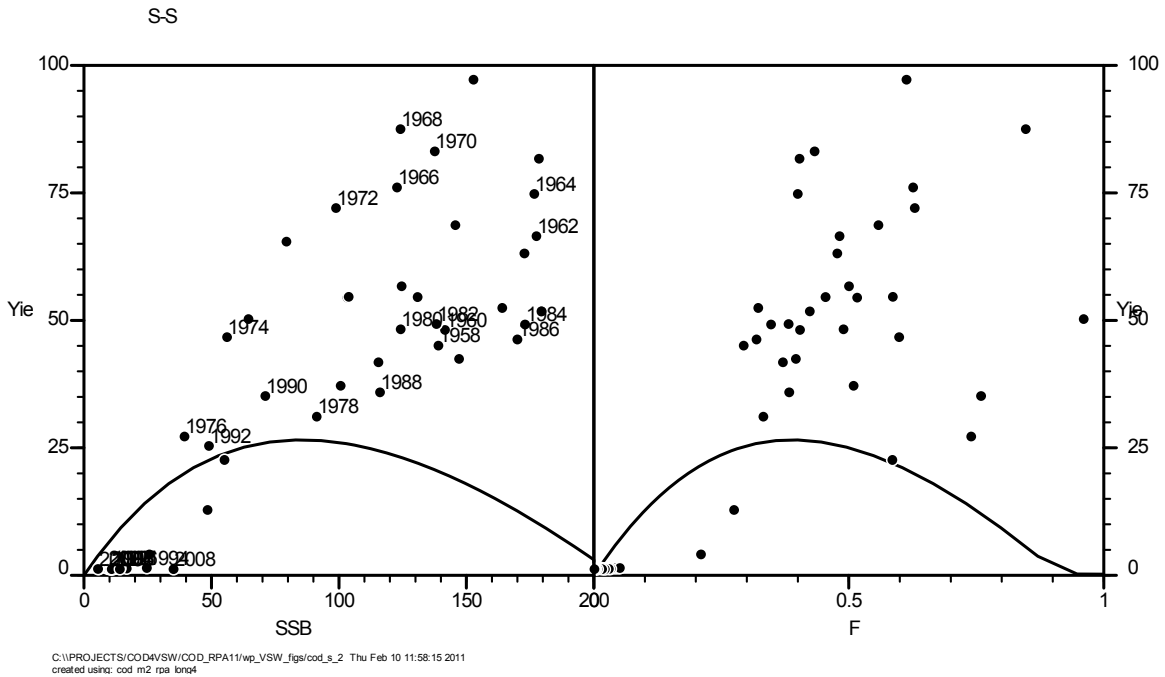


Figure 45. Sissenwine-Shepherd production analysis continued. The left hand panel shows the equilibrium production and yield as a function of the SSB. The right hand panel is the equilibrium yield as a function of fishing mortality. Again, the historical values are shown for reference.

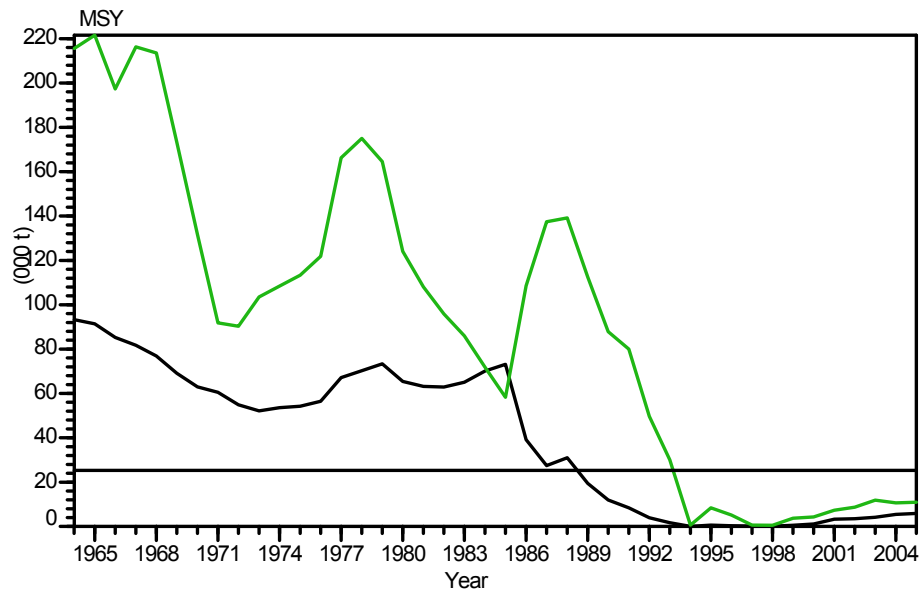
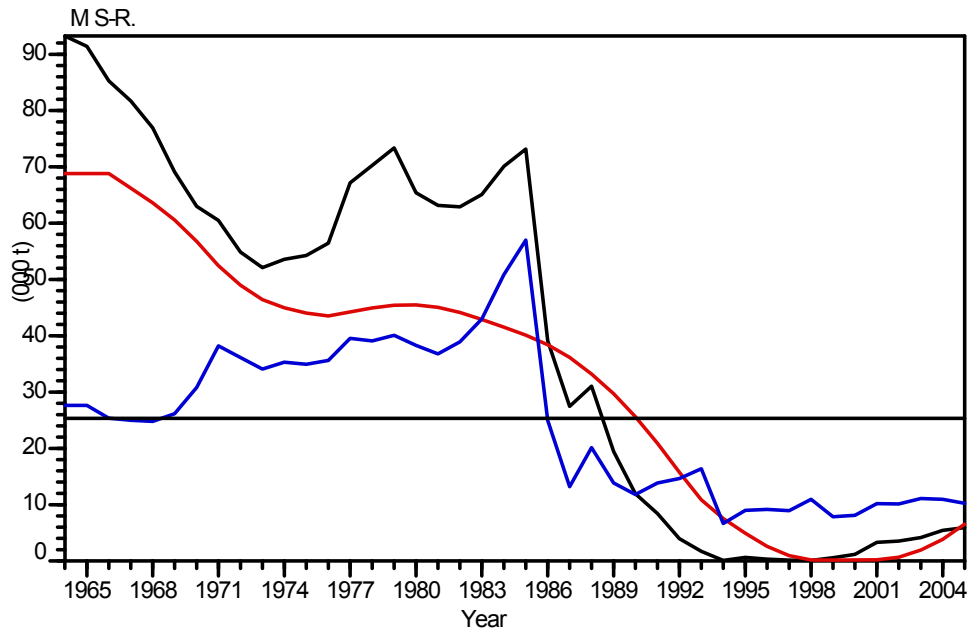
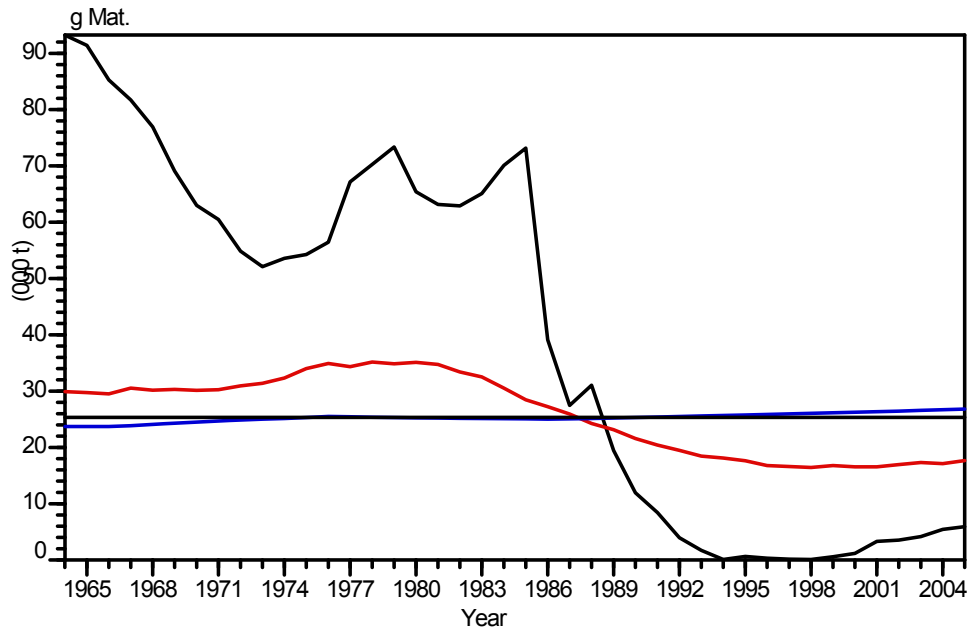


Figure 46. Moving window estimates of MSY (black line) and SSB_{MSY} (green line) from Sissenwine-Shepherd production analysis. All data are being sampled for the windows. The straight black line is the MSY when all data are set at long term means.



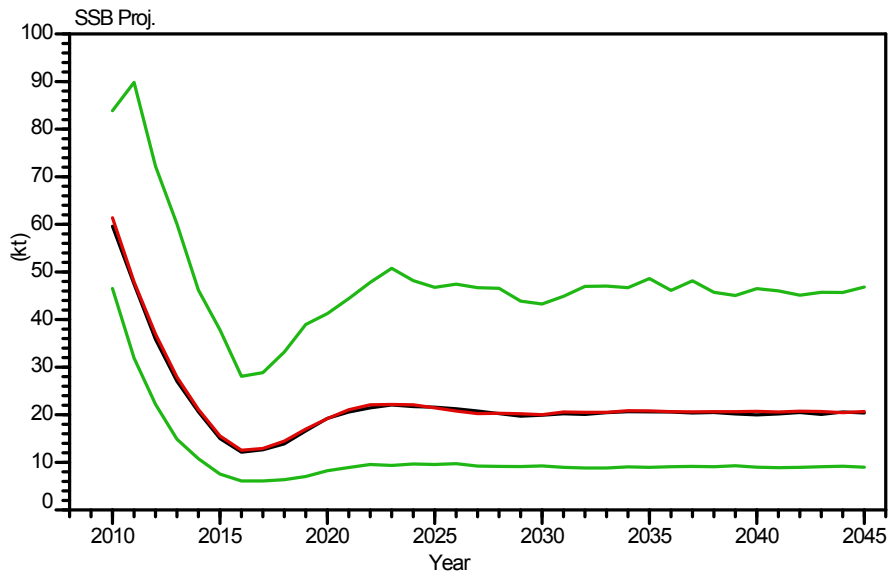
C:\PROJECTS\COD4VSW\COD_RPA11\wp_VSW_figs\mw_msy_comp1 Thu Feb 10 12:18:51 2011
 created using: cod m2 rpa long4

Figure 47. Moving window estimates of MSY from Sissenwine-Shepherd production analysis. The black line is as in Figure 46 with all data being sampled for the windows, the red line is when only natural mortality is windowed, and the blue line is when only stock-recruit data are windowed. The straight black line is the MSY when all data are set at long term means.



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 created using: cod m2 rpa long4

Figure 48. Moving window estimates of MSY from Sissenwine-Shepherd production analysis. The black line is as in Figure 46 with all data being sampled for the windows, the red line is when only growth data are windowed, and the blue line is when only maturity data are windowed. The straight black line is the MSY when all data are set at long term means.



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 created using: cod mm2 rpa spro2

Figure 49. SSB projections with $F = 0$ (red line) and 0.01 (black). The green lines are the 2.5 and 97.5 percentiles for the $F = 0.01$ run.

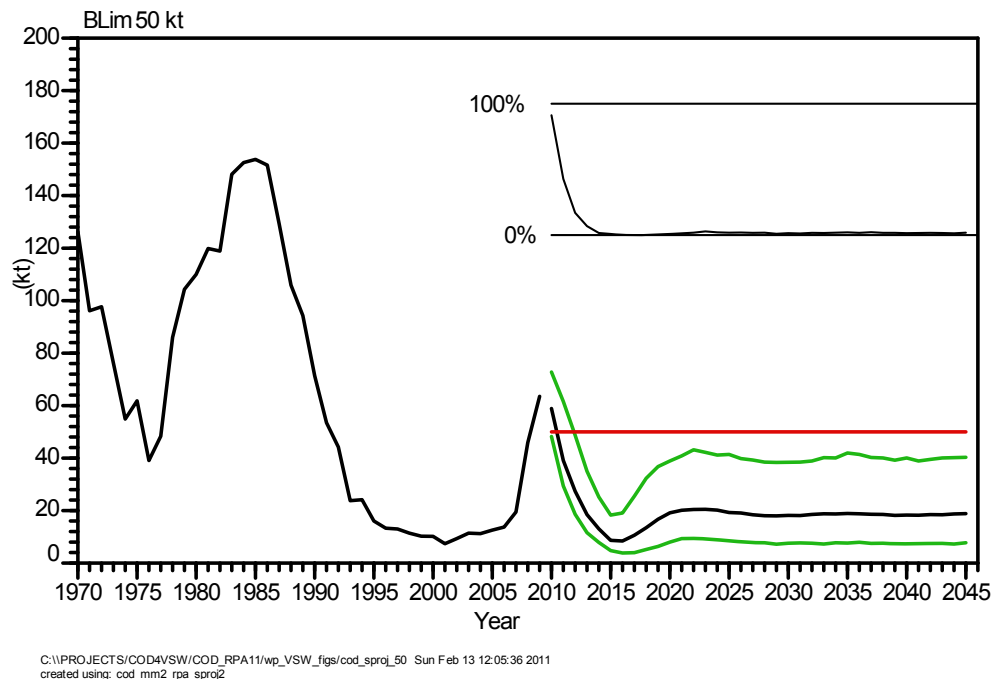


Figure 50. SSB projections with $F = 0.01$ (black line). The green lines are the 2.5 and 97.5 percentiles for the $F = 0.01$ run. The 50 kt B_{lim} is shown as the horizontal red line. The inset graph is the probability of exceeding the limit.

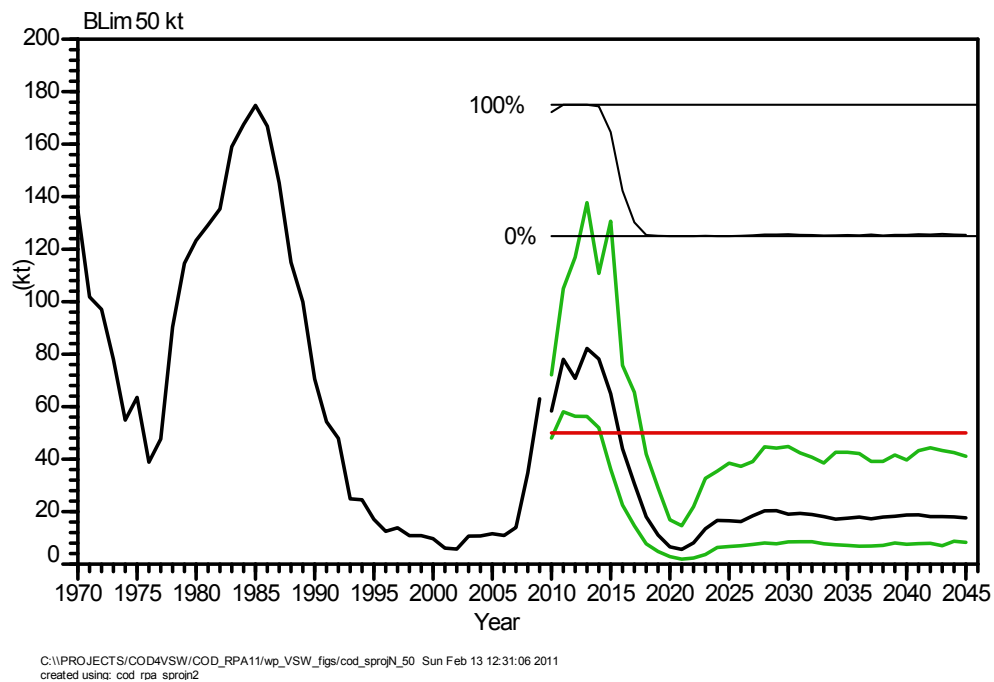
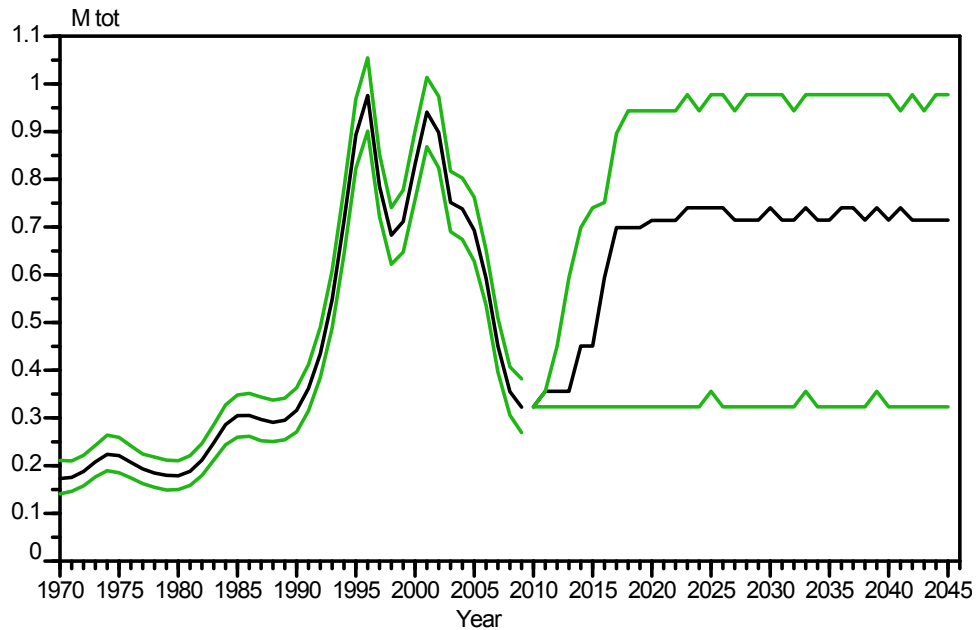
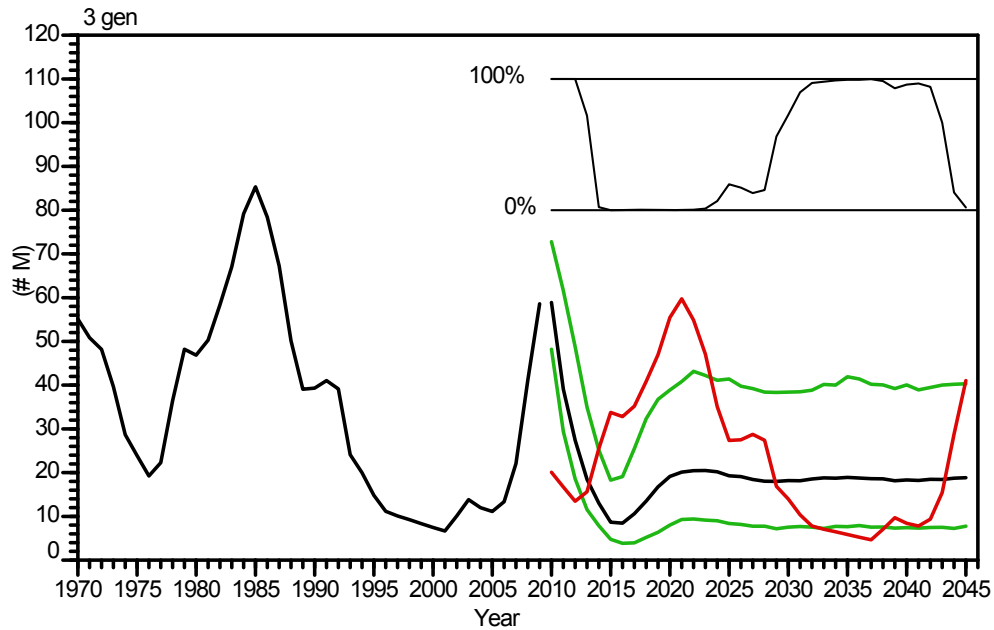


Figure 51. SSB projections with $F = 0.01$ (black line) and scenario proposed by Newfoundland Region (DFO 2011b) in which the values used in the projection are sampled with increasing windows backwards in time until 1994. The green lines are the 2.5 and 97.5 percentiles for the $F = 0.01$ run. The 50 kt B_{lim} is shown as the horizontal red line. The inset graph is the probability of exceeding the limit.



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 created using: cod_rpa_sproj2

Figure 52. Average *M* trajectory and projection using the scenario proposed by Newfoundland Region (DFO 2011b) in which the values used in the projection are sampled with increasing windows backwards in time until 1994. The green lines are the 2.5 and 97.5 percentiles for the $F = 0.01$ run.



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 created using: cod_mm2_rpa_sproj2

Figure 53. Spawning abundance projections with $F = 0.01$ (black line). Green lines are the 2.5 and 97.5 percentiles for the $F = 0.01$ run. Red line is a 30% reduction in abundance from 36 years earlier. The inset graph is the probability of exceeding the limit.

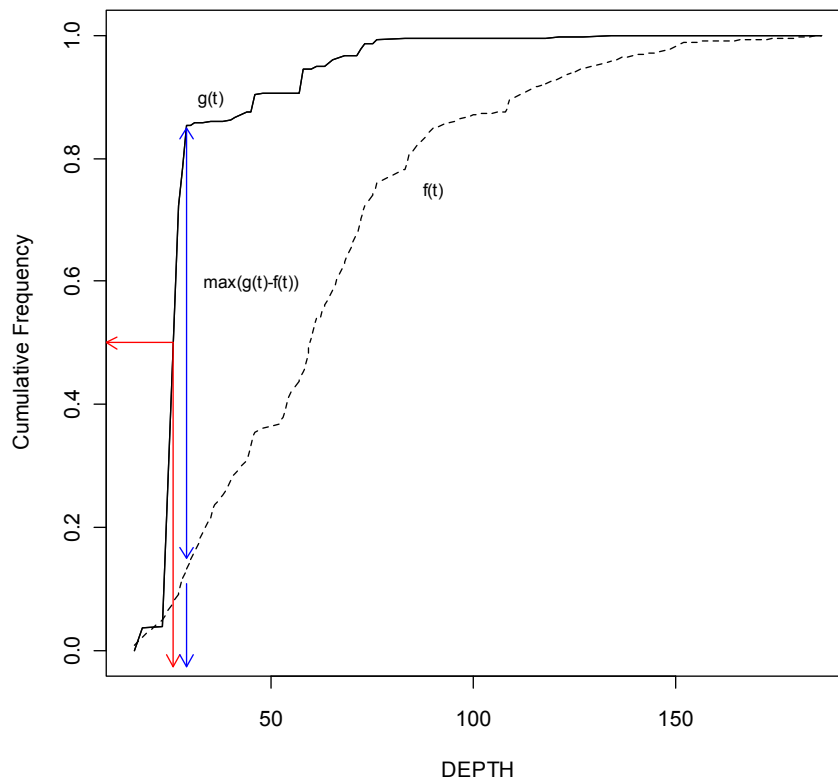


Figure 54. Cumulative distribution functions of effort and catch for Atlantic cod <38 cm in NAFO 4VsW from the 2007 Summer RV Survey. Red arrow indicates median depth of Atlantic cod; blue arrows indicate the location of the maximum difference between the distribution of effort and catch curves.

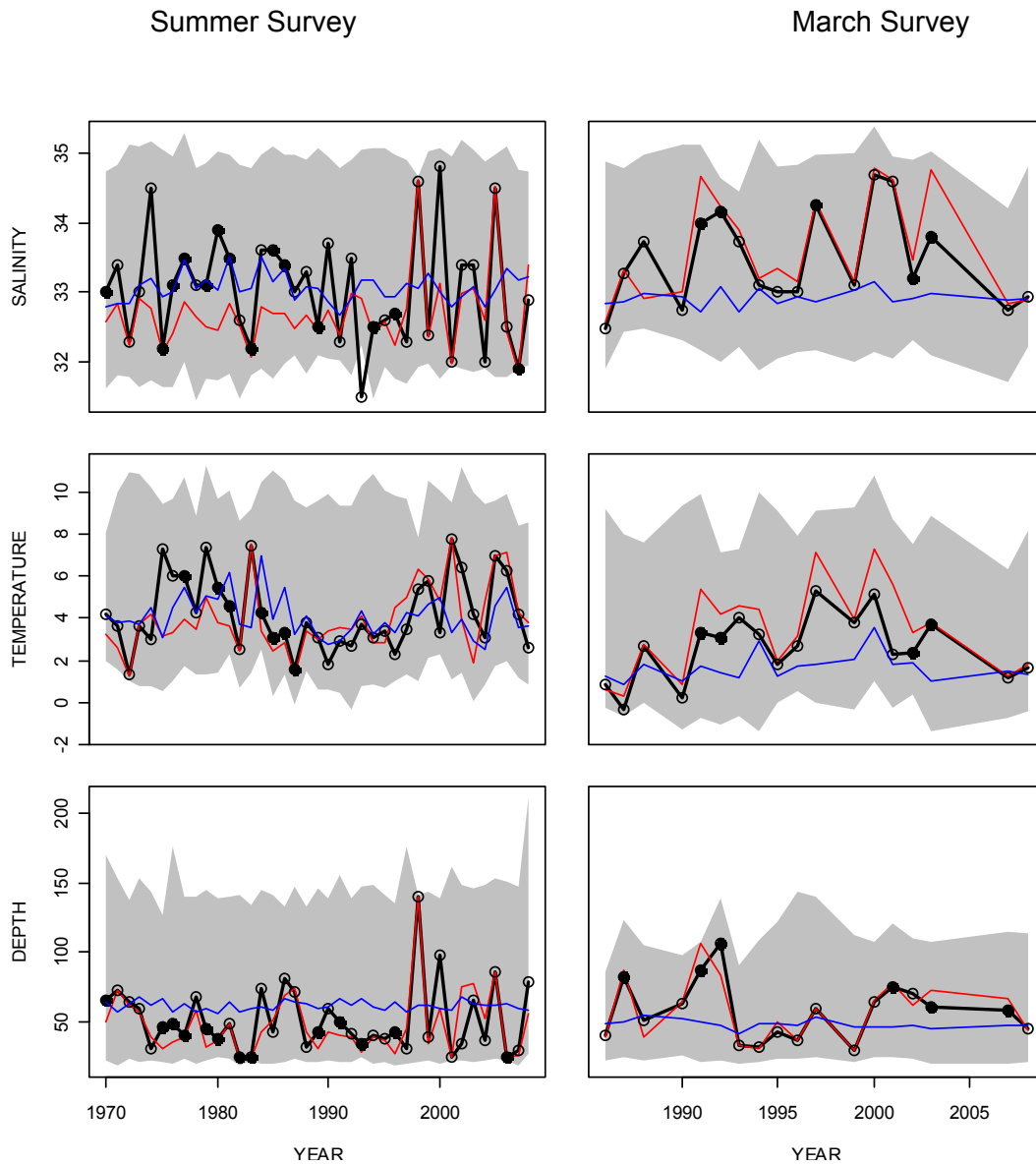
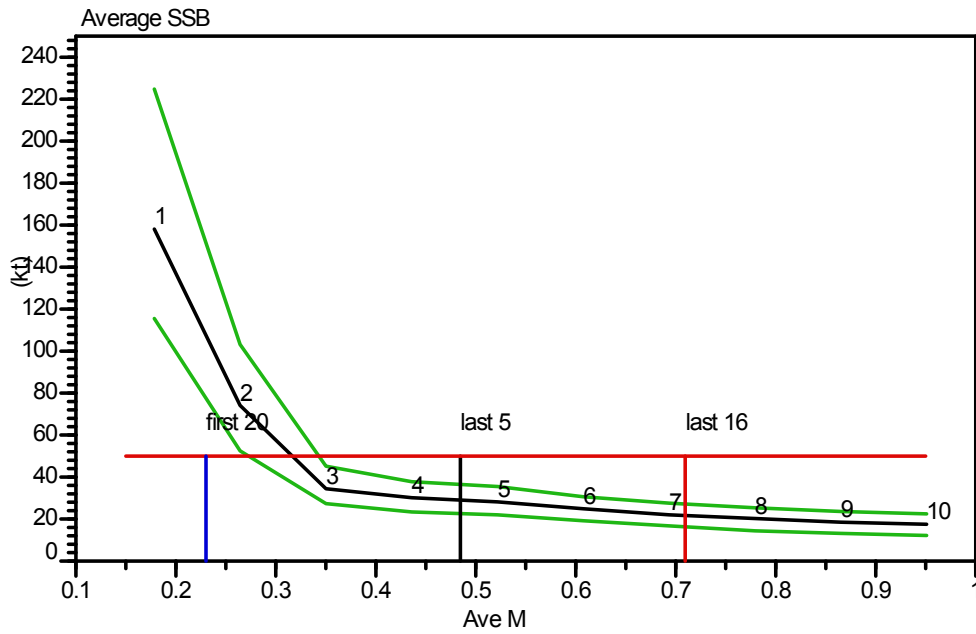


Figure 55. Time series of habitat preferences of Atlantic cod in NAFO 4VsW as obtained from the RV Summer and March Survey series, 1970-2008. Circles represent the location of maximum deviation of cumulative distributions from catch and effort. Filled circles represent statistically significant habitat associations and open circles represent non-significant associations. Red line indicates the median habitat occupied by Atlantic cod. Blue line is median of sampled habitat. Shaded polygon in background is the 95th percentile for range of sampling habitat.



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 created using: cod mm2 rpa spro2

Figure 56. Projections at ten levels of age 5+ M while the age 1-4 M and other projection parameters are set at the recent average. The Y-axis is the average SSB over the last 10 years of the 36 year projection with the black line being the mean estimate and the green lines are the 2.5 and 97.5 percentiles. The horizontal red line is the 50 kt SSB B_{lim} . The average M for the first 20 years (1970-1989), the most recent 5 years, and the period 1994-2009 are included for reference.

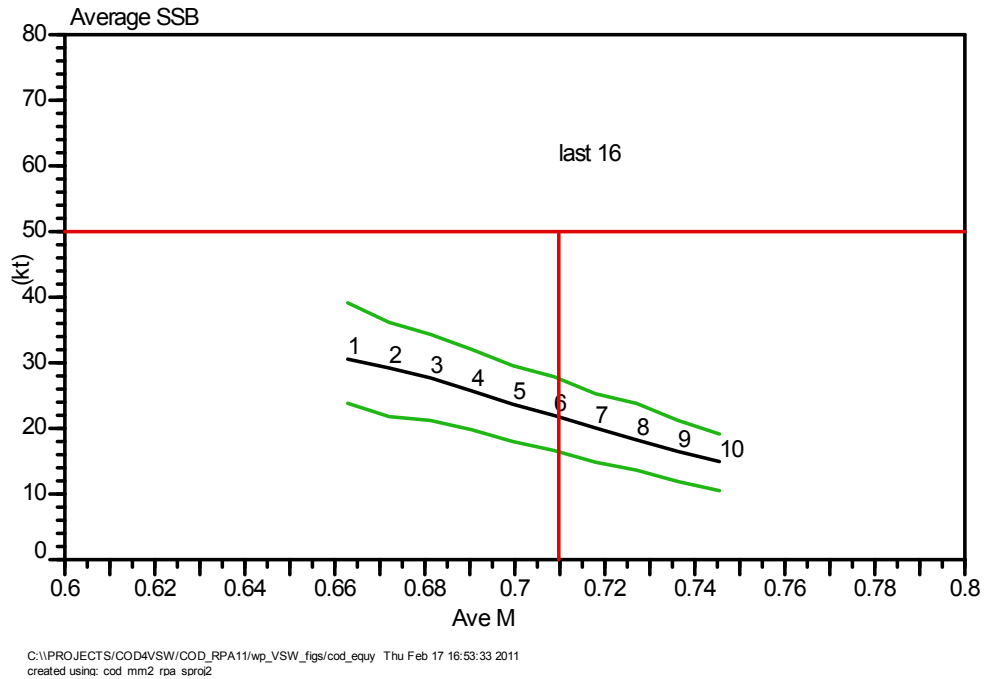


Figure 57. Projections at ten levels of age 1-4 M while the age 5+ M is set at the recent average. The Y-axis is the average SSB over the last 10 years with the black line being the mean estimate and the green lines are the 2.5 and 97.5 percentiles. The horizontal red line is the 50 kt SSB B_{lim} .

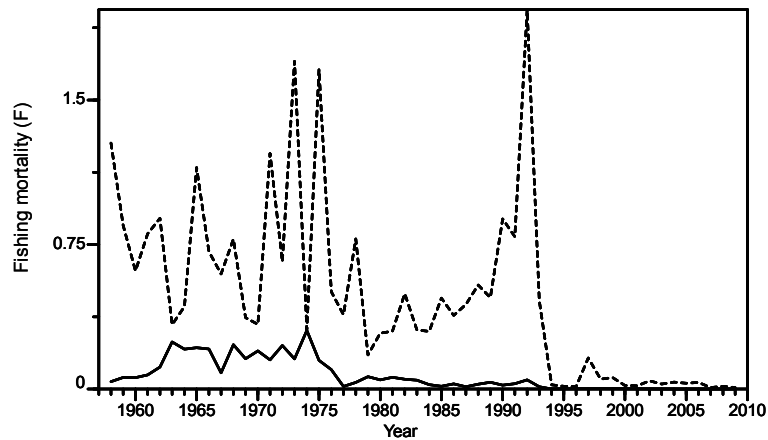
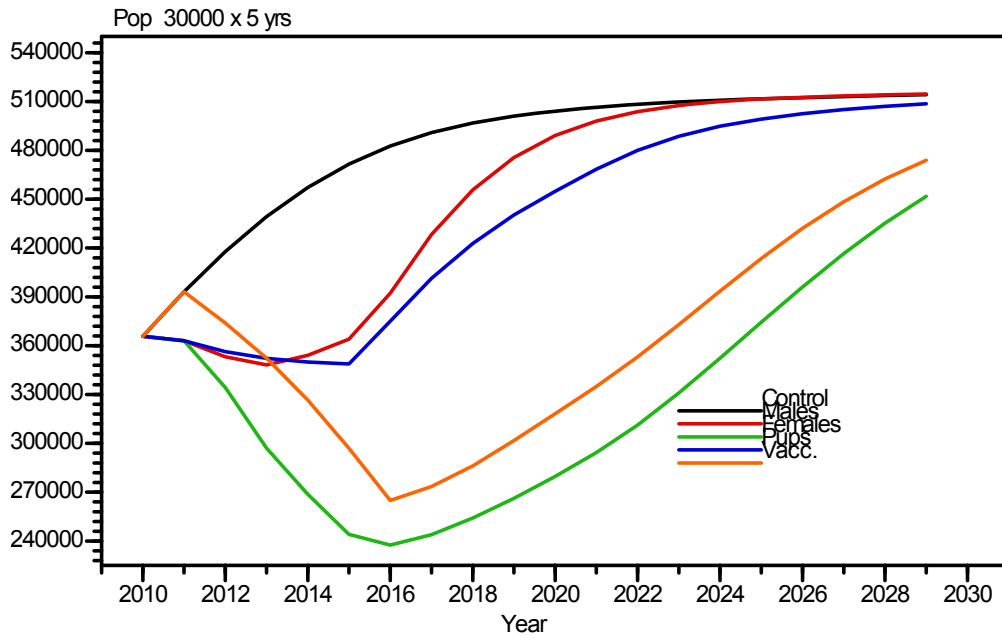


Figure 58. Estimated fishing mortality (F) for two age groups 1-4 (solid line) and 5-15 (dashed line) of 4VsW cod.



C:\PROJECTS\SEALS00\SEAL_COD10\wp_figs\pop_int30 Sat Oct 02 18:58:45 2010
 created using: seal trials5

Figure 59. Projections of age 1+ Sable Island seal population from control and four intervention projections (male cull, female cull, pup cull, sterilization) of 30,000 animals per year for five years. The model assumes all density dependence occurs before the pup census.

APPENDIX 1. TERMS OF REFERENCE***Recovery Potential Assessment (RPA) for Atlantic Cod
(Newfoundland and Labrador, Laurentian North, Laurentian South, Southern
Designatable Units)*****Zonal Advisory Process – Newfoundland & Labrador, Gulf, Quebec, and Maritimes
Regions*****February 21-25, 2011
St. John's, Newfoundland***

Co-Chairs: Denis Rivard and Nadine Templeman

Context:

When the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designates aquatic species as threatened or endangered, Fisheries and Oceans Canada (DFO), as the responsible jurisdiction under the Species at Risk Act (SARA), is required to undertake a number of actions. Many of these actions require scientific information on the current status of the species, population or designatable unit (DU), threats to its survival and recovery, and the feasibility of its recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) that is conducted shortly after the COSEWIC assessment. This timing allows for the consideration of peer-reviewed scientific analyses into SARA processes including recovery planning.

Atlantic Cod has been an economic and dietary mainstay for Atlantic communities since the late 15th century. Three of Canada's Cod populations have declined by 90% or more since the 1960s. Atlantic Cod was reassessed by COSEWIC in 2010, earlier than the 10-year reassessment, due to evidence of further declines in some stocks, most notably the Southern Gulf stocks. Atlantic Cod was previously assessed as four designatable units: Maritimes stock (Special Concern), Laurentian North (Threatened), Newfoundland and Labrador (Endangered) and Arctic (Special Concern). Atlantic Cod is now considered as six designated units of which four have been designated Endangered by COSEWIC: Arctic Lakes (Special Concern), Arctic Marine (Data Deficient), Newfoundland and Labrador (Endangered), Laurentian North (Endangered), Laurentian South (Endangered), and Southern (Endangered). The four populations assessed as Endangered by COSEWIC have diminished to the extent that they are predicted to experience serious or irreparable harm.

To support a decision regarding listing recommendations for Atlantic Cod by the Minister, DFO Science has been asked to undertake an RPA, based on the National Frameworks (DFO 2007a and b). The advice in the RPA may be used to inform both scientific and socio-economic elements of the listing decision, as well as development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits, agreements and related conditions, as per section 73, 74, 75, 77 and 78 of SARA. The advice generated via this process will also update and/or consolidate any existing advice regarding the four Atlantic Cod DUs that have been assessed as Endangered by COSEWIC: Newfoundland and Labrador, Laurentian North, Laurentian South, and Southern.

Objectives

- To assess the recovery potential of four Atlantic Cod DUs: Newfoundland and Labrador, Laurentian North, Laurentian South, Southern.

Assess current/recent species/Atlantic Cod status

1. Evaluate present Atlantic Cod status for abundance (i.e., numbers and biomass focusing on matures) and range and number of populations for each DU.
2. Evaluate recent species trajectory for abundance (i.e., numbers and biomass focusing on matures) and range and number of populations for each DU.
3. Estimate, to the extent that information allows, the current or recent life-history parameters for Atlantic Cod (total mortality, natural mortality, fecundity, maturity, recruitment, etc.) or reasonable surrogates; and associated uncertainties for all parameters.
4. Estimate expected population and distribution targets for recovery, according to DFO guidelines (DFO 2005) and based on the limit reference points developed under the Precautionary Approach Framework.
5. Project expected Atlantic Cod population trajectories over 33 years, which represents at least three generations for all populations, and trajectories over time to the recovery target (if possible to achieve), given current Atlantic Cod population dynamics parameters and associated uncertainties using DFO guidelines on long-term projections (Shelton et al. 2007). See Annex 1 for details.
6. Evaluate **residence requirements** for the species, if any.

Assess the Habitat Use of Atlantic Cod

7. Provide functional descriptions (as defined in DFO 2007b) of the properties of the aquatic habitat that Atlantic Cod needs for successful completion of all life-history stages.
8. Provide information on the spatial extent of the areas in Atlantic Cod's range that are likely to have these habitat properties.
9. Identify the activities most likely to threaten the habitat properties that give the sites their value, and provide information on the extent and consequences of these activities.
10. Quantify how the biological function(s) that specific habitat feature(s) provide to the species varies with the state or amount of the habitat, including carrying capacity limits, if any.
11. Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.
12. Provide advice on how much habitat of various qualities / properties exists at present.
13. Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present, and when the species reaches biologically based recovery targets for abundance and range and number of populations.

14. Provide advice on feasibility of restoring habitat to higher values, if supply may not meet demand by the time recovery targets would be reached, in the context of all available options for achieving recovery targets for population size and range.
15. Provide advice on risks associated with habitat “allocation” decisions, if any options would be available at the time when specific areas are designated as Critical Habitat.
16. Provide advice on the extent to which various threats can alter the quality and/or quantity of habitat that is available.

Scope for Management to Facilitate Recovery of Atlantic Cod

17. Assess the probability that the recovery targets (see Annex A) can be achieved under current rates of Atlantic Cod population dynamics parameters, and how that probability would vary with different mortality (especially lower) parameters.
18. Quantify to the extent possible the magnitude of each major potential source of mortality identified in the pre-COSEWIC assessment, the COSEWIC Status Report, information from DFO sectors, and other sources.
19. Quantify to the extent possible the likelihood that the current quantity and quality of habitat is sufficient to allow population increase, and would be sufficient to support a population that has reached its recovery targets.
20. Assess to the extent possible the magnitude by which current threats to habitats have reduced habitat quantity and quality.

Scenarios for Mitigation and Alternative to Activities

21. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all feasible measures to minimize/mitigate the impacts of activities that are threats to the species and its habitat (Steps 18 and 20).
22. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable alternatives to the activities that are threats to the species and its habitat (Steps 18 and 20).
23. Using input from all DFO sectors and other sources as appropriate, develop an inventory of activities that could increase the survivorship parameters (Steps 3 and 17).
24. Estimate, to the extent possible, the reduction in mortality rate expected by each of the mitigation measures in step 21 or alternatives in step 22 and the increase in survivorship associated with each measure in step 23.
25. Project expected population trajectory (and uncertainties) over 33 years, which represents at least three generations for all stocks, and to the time of reaching recovery targets when recovery is feasible; given mortality rates associated with specific scenarios identified for exploration (see Annex A). Include scenarios which provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.
26. Recommend parameter values for starting mortality rates, and where necessary, specialized features of population models that would be required to allow exploration of additional

scenarios as part of the assessment of economic, social, and cultural impacts of listing the species.

Allowable Harm Assessment

27. Evaluate maximum human-induced mortality which the species can sustain and not jeopardize survival or recovery of the species.

Expected Publications

- Four CSAS Science Advisory Reports (one per designatable unit)
- CSAS Proceedings of meeting
- CSAS Research Document(s)

Participation

DFO Science, Ecosystems and Fisheries Management, Oceans, Habitat and Species at Risk, Policy and Economics, Aboriginal Communities, Parks Canada, Provinces, External Reviewers, Industry, Non-governmental organizations and Other Stakeholders will be invited to participate in this meeting.

References:

- COSEWIC. 2010. COSEWIC assessment and update status report on the Atlantic Cod *Gadus morhua* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 105 pp.
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Annex A. Elements of Discussion for Projection Scenarios

The following elements will be considered to draft recovery target scenarios in order that enough details are provided so that it removes uncertainty on what has to be done.

1. To model population trajectory, we need to specify population conditions (recruitment, growth, maturation, natural mortality). We need to define only one set of conditions that would have reasonable chances to represent current and future realities. It is proposed to use conditions prevailing since the early 1990s up to now because it starts with the middle point of the best datasets (last 30 years) and covers a period that is long enough to capture a variety of environmental and species conditions that have prevailed over the recent past, without counting on series of exceptional years that have occurred between the 60's and mid-80's. This period would also be long enough so the absence of data for some years for some stocks should not have a strong impact on the range and average of parameter values. As much as possible, the time period should be the same across stocks within a given DU.

If a different time period is to be used for a given stock, a strong rationale should be provided.

2. Projection horizon
 - Given that the COSEWIC/IUCN decline "A" criterion make reference to 10 years or 3 generations whichever is longer, projections should expand over at least 3 cod generations.¹ As generation time is defined as the average age of parents in a population, the length of this time period may vary among stocks from 7.5 to 11 years. So projections horizons may vary from 23 to 33 years. Cod generation time (Table 1) is meant to be estimated in such a way that it reflects pre-fished states by adding the 'typical' age at first maturity (age at 50% maturity) observed as long ago as we have data for (for each stock of cod) and then adding to that age the value of $(1/M)$, where M is the instantaneous rate of natural mortality ($M=0.2$).
 - Projections could all go to 2043 (33 years from now) so that there is enough of a time span to evaluate progress against wide range of possible targets for all stocks/DUs (see below), but see first bullet under #3 below. Each DUs could adapt and present the information in a way that shows the end of 33 year timeline horizon as well as the timeline horizon for their particular stock generation time series (3 generations)
3. Possible population targets to measure progress against it and likelihood of success using projections according to the scenarios regarding fishing mortality (see #4 below)

SARA Targets:

To satisfy COSEWIC's assessment criteria to declare that a species is not threatened (or of it becomes special concern), i.e. that it does not require a SARA recovery strategy. This can be done using Criterion "A" rate of decline in total number of mature individuals thresholds (see Table 2 below). By default, this is normally what should be done at a minimum.

¹ The A1 and A2 subcriteria apply to decline within last 3 generations. It may be that for a given stock/DU, the population has been stable for 2 generations already, and stability for another generation would be sufficient for the stock/DU to surpass the threatened category threshold as it pertains to decline in number of mature individuals. Nevertheless, it is suggested that projections for all stocks and DUs cover at least the next 3 generations.

Management Targets:

Use the limit reference point from the PA framework as a target for rebuilding. This corresponds to B_{lim} .

4. Possible Scenarios for Fishing Mortality (natural and human induced):

The fishing mortality scenarios will be different depending on the DUs. It should also be noted that Economics will need to provide input as they will need to determine specific activities on specific fleets for each DU. Economics would determine the most cost-effective way to find reductions in mortality. Therefore, there needs to be a back and forth between biologists and economics. It was determined that Science could start modelling scenarios for option a, b, and c below, but will also model “d”, a pre-specified reduction from current level of fishing mortality from all sources, that will be determined at the DU level by managers in each region:

- a. Natural mortality only (100% reduction in human induced mortality)
- b. Natural mortality and recent level of human induced mortality (0% reduction in human induced mortality) through fishing operations (bycatch from other directed fishing, discards, directed). Need to define “recent”: e.g. last 3 years (depends on stock and availability of data)
- c. Natural mortality and only fishing mortality from by-catch and discards. This implies no directed fishing and would be useful to model for stocks under moratorium or for stocks where there is a possibility of a closure on directed fishing (depends on stock and data availability)
- d. Pre-specified reduction from current level of fishing mortality from all sources (e.g. 50% reduction in human induced mortality). Science will, by default, model projection scenarios based on 100% reduction rate in human induced mortality (no fishing). This will be covered under “a.” above, but for each DUs, Management will also need to determine other reduction rate(s) that are in line what they think is achievable from a management perspective. This(ese) reduction rate(s) will need to be identified in each of the Regions in advance of the RPA meeting so that Science is able to run the this through the projection trajectory model for each DU.

5. Displaying results

- a. Projections should be made based on number of mature individuals as well as biomass of spawners, over appropriate time periods as specified above.
- and
- b. Results should be displayed in terms of probability of achieving the set targets and describing uncertainties.

Table 1: Age at maturity and Generation Time by stock as Calculated by COSEWIC

Stock	Age at Maturity	Generation time
1. 2GH	5.25	11
2. 2J3KL	6	11
3. 3NO	6	11
4. 3Ps	6	11
5. 3Pn4RS	4	9
6. 4T	4.5	9.5
7. 4Vn	4.5	9.5
8. 4VSw	4	9
9. 4X	2.5	7.5
10. 5Z _{jm}	2.5	7.5

Note: It appears (Swain, D. 2010. Life-history evolution and elevated natural mortality in a population of Atlantic cod (*Gadus morhua*). Evolutionary Applications. 13 pp.) that age at 50% maturation of 4T cod in the 50's and 60's, was 6.7 years for females and 5.6 years for males. Using $M=0.2$, this translates into a generation time of 11.7 yr based on maturation of females and 10.6 yr based on maturation of males, for an overall average of about 11 years.

Table 2: COSEWIC Quantitative Criterion A

Indicator	Endangered	Threatened
A. Decline in Total Number of Mature Individuals		
A1. An observed, estimated, inferred or suspected reduction in total number of mature individuals over the last 10 years or 3 generations, whichever is the longer, where the causes of the reduction are: clearly reversible and understood and ceased, based on (and specifying) any of the following: (a) direct observation (b) an index of abundance appropriate to the taxon (c) a decline in index of area of occupancy, extent of occurrence and/or quality of habitat (d) actual or potential levels of exploitation (e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.	Reduction of \geq 70%	Reduction of \geq 50%
A2. An observed, estimated, inferred or suspected reduction in total number of mature individuals over the last 10 years or 3 generations, whichever is the longer, where the reduction or its causes may not have ceased or may not be understood or may not be reversible, based on (and specifying) any of (a) to (e) under A1.	Reduction of \geq 50%	Reduction of \geq 30%
A3. A reduction in total number of mature individuals, projected or suspected to be met within the next 10 years or 3 generations, whichever is the longer (up to a maximum of 100 years), based on (and specifying) any of (b) to (e) under A1.	Reduction of \geq 50%	Reduction of \geq 30%
A4. An observed, estimated, inferred, projected or suspected reduction in total number of mature individuals over any 10 year or 3 generation period, whichever is longer (up to a maximum of 100 years in the future), where the time period must include both the past and the future, and where the reduction or its causes may not have ceased or may not be understood or may not be reversible, based on (and specifying) any of (a) to (e) under A1.	Reduction of \geq 50%	Reduction of \geq 30%

APPENDIX 2. VPA MODEL

The model used to assess 4VsW cod is a virtual population model which uses survey and catch data as inputs. Instead of assuming a natural mortality, as was often done in the past because of the difficulty in estimating it, a time-varying natural mortality is estimated for two blocks of ages. This approach is quite similar to the manner in which this stock was estimated in Fu et al. (2001) except that there is no explicit seal contribution included. Fu et al. (2001) used a random walk M specified for two age groups (1-4 and 5+). This model is also very similar to the model used in the 4TVn stock (Swain 2011). The principle difference is the way in which the variance of the M random walks is parameterized.

Abundance and biomass of the 4VsW cod stock was estimated using this population model calibrated using the summer survey relative abundance expanded for the area surveyed. Data from 1970 up to and including 2009 were used to fit the model. The population was reconstructed for ages 1-15 with no plus group. Aged survey information was available for 2010 but it was not used in the model.

The population model used here differs from models used in previous assessments of this stock in a number of respects. The first is dropping the March survey as a tuning index. The March survey does not track cohorts well and has very strong “year” effects making it of little use in fitting the model. The second difference relates to the treatment of the instantaneous rate of natural mortality (M). Previous assessments of this stock have used a predetermined M which began at 0.2 for all ages in the early years, increased to 0.4 in the late 1980s (Mohn et al. 1998), and to 0.8 in 1994 (Fanning et al. 2003). In the present model, M is estimated using a random walk for two age categories: 1-4 and 5-15. For each age group, j , the M is modeled as the previous year plus a deviate ($Mdev$):

$$M_{j,y} = M_{j,y-1} * \exp(Mdev_{j,y}) \text{ if } y > 1971$$

The random walk is constrained by user supplied variances which control the inter-annual movement of each M . If it is too tight, the result can be little more than a constant M . If they are too loose, the signal is dominated by noise.

The current model is specified as follows:

Assumptions

- error in catch-at-age is negligible
- F on oldest age group is average of ages 10 and 11 (before 2009)
- M random walk ages 1-4 and 5-15
- abundance indices are proportional to population abundance at age
- $F(1) = F(2)$, $F(11-15) = F(10)$ in 2009

Parameters

- abundance at age in 2009 (ages 2-10)
- 2+ M in 2 age blocks for all years – random walks
- catchability coefficients at age (1-10)

Inputs

- $C_{i,k}$, $i = 1$ to 15, $k = 1970$ to 2009
- $RV_{i,k}$, $i = 1$ to 10, $k = 1970$ to 2009
- $C_{i,k}$, $i = 1$ to 15, $k = 1958$ to 1969 (untuned but iterated VPA)

Objective function

$$\log_norm(N - q RV)/sd + \text{norm2}(Mdev1-4, mvar1) + \text{norm2}(Mdev5+, mvar2) + Mpriors + \text{norm2}(Mdev1-4 - Mdev5+, mvar3)$$

where RV is an abundance index, N is estimated population abundance, q is catchability, cv is the coefficient of variation for index i , a indexes age, y indexes year, and i indexes abundance indices. A constant value of 0.3 was set for cv which applies to the survey data fit.

This model is over parameterized in the number of controls on the random walk ($mvar1, 2$ and 3). This was done to aid in exploring the role of various initializations and weightings. These values affect the degree to which the random walk is constrained. If it is too large, estimated M will tend to fluctuate erratically in response to year-effects. For the analyses presented here, $Mvar1$ and 2 was set at 0.1 and $Mvar3$ at 0.15.

Information on an appropriate starting value for the younger age class was lacking. The value of 0.65 was chosen based on the formula given by Gislason et al. (2010) for estimating M from length and growth characteristics. A limited sensitivity analysis indicated that the initial fixed value chosen for age 1-4 M (ranging from 0.21 to 0.81) had no noticeable effect on estimates of 5+ M or on estimates of spawning stock biomass (SSB). See Figure A2.1.

Models were extended back to 1958 using the catch at age for 1958-1969 and assuming that M in 1958-1969 was 0.2 for all ages. This is the version that was presented at the framework meeting (DFO 2011a). Since then, a more consistent model was tried in which the M for 1958-69 was set at the average M from 1970-1974 but not adopted for this analysis.

The retrospective performance of this model is shown in Figures A2.2-A2.5. As well as the usual retrospective plots for SSB and fishing mortality, Figures A2.2 and A2.3, the patterns for both age classes are presented. These patterns are tighter than often seen in fisheries models and at least part of the reason for this is the increased flexibility.

References:

- DFO. 2011. Proceedings of Gulf and Maritimes Zonal Science Advisory Process Framework Meeting for Atlantic Cod Assessment Models, Medium-term Projections, and Reference Points; 6-8 December 2010. DFO Canadian Science Advisory Secretariat Proceedings Series 2011/051.
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- Mohn, R.K., L.P. Fanning, and W.J. MacEachern. 1998. Assessment of 4VsW cod in 1997 incorporating additional sources of mortality. DFO Canadian Science Advisory Secretariat Research Document 1998/078.

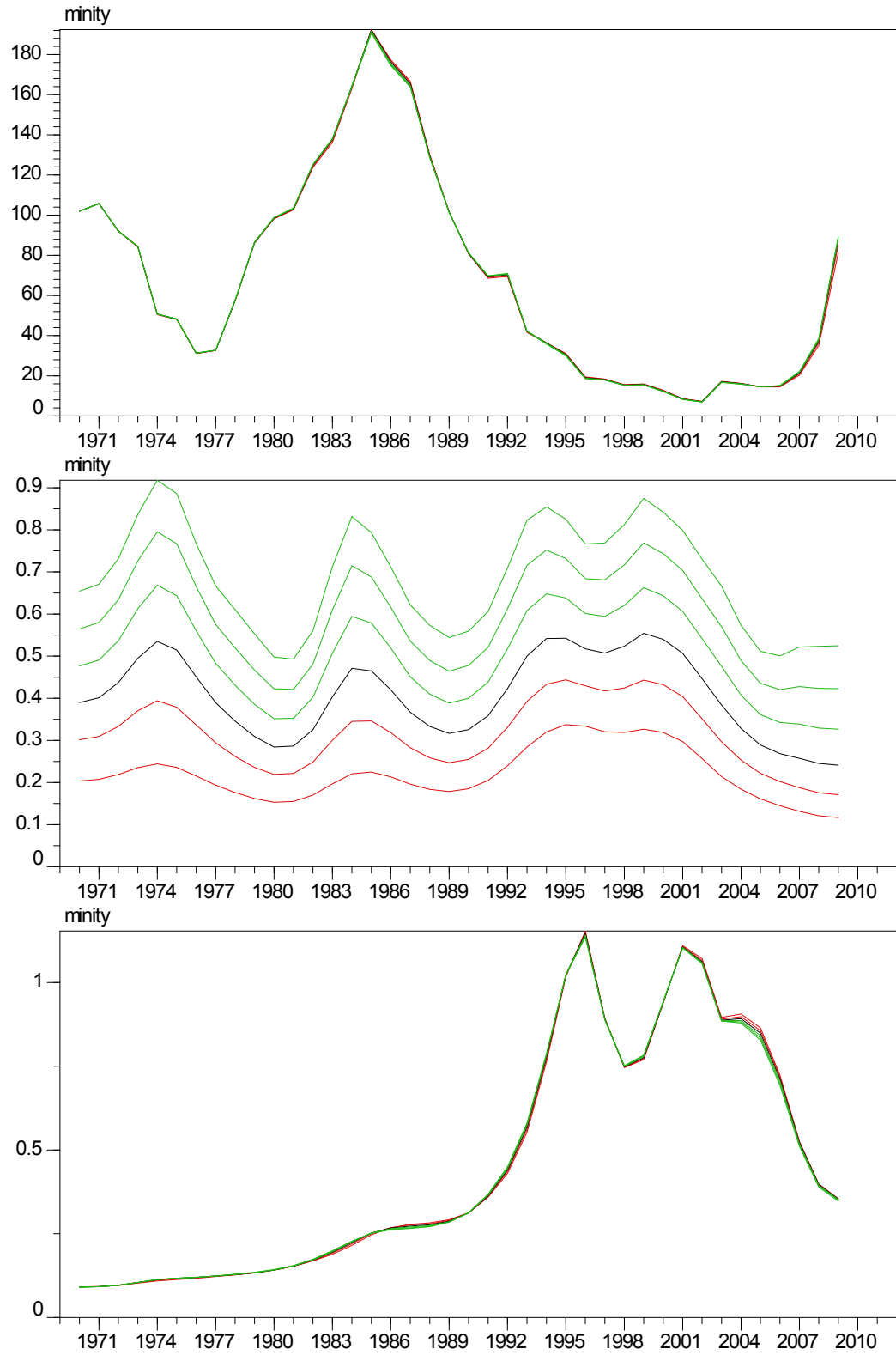
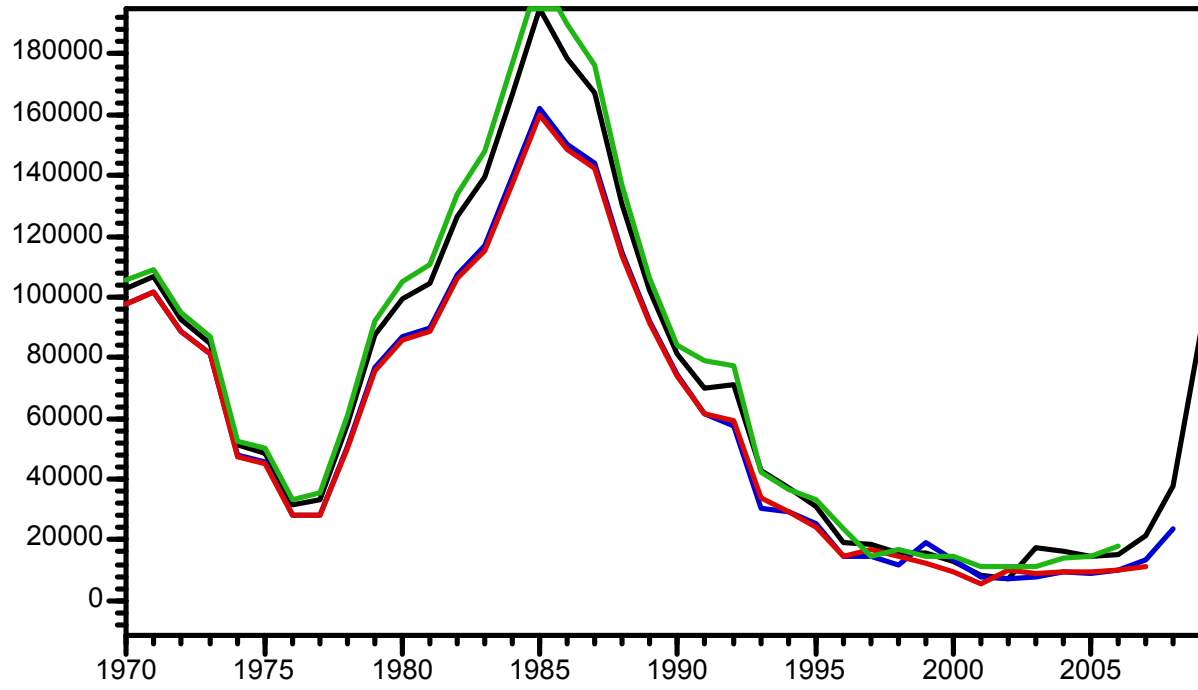
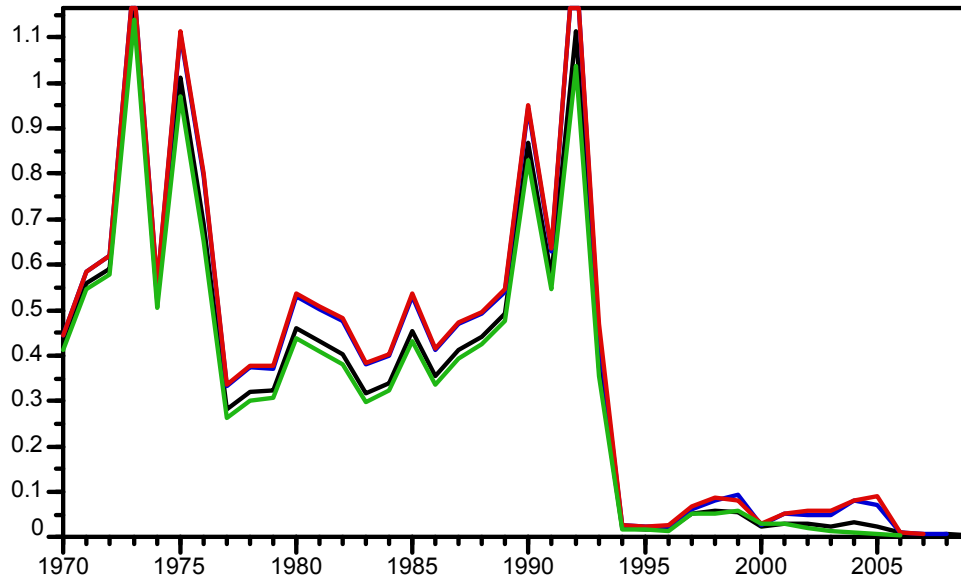


Figure A2.1. Plots of SSB (upper panel), M1-4 (middle), and M5+ (lower) when an initial M1-4 ranges from 0.21 to 0.81.



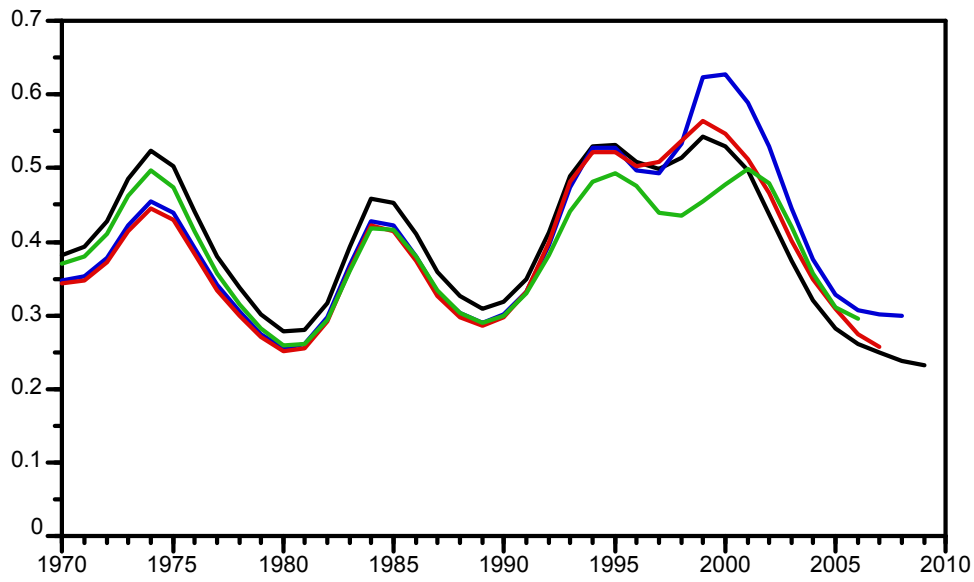
C:\PROJECTS\COD4VSW\COD_MODELS_10\rpa_figs\cod_retrob Tue Dec 07 10:51:55 2010
created using: cod m3 retro

Figure A2.2. Retrospective analysis on SSB for random walk M model.



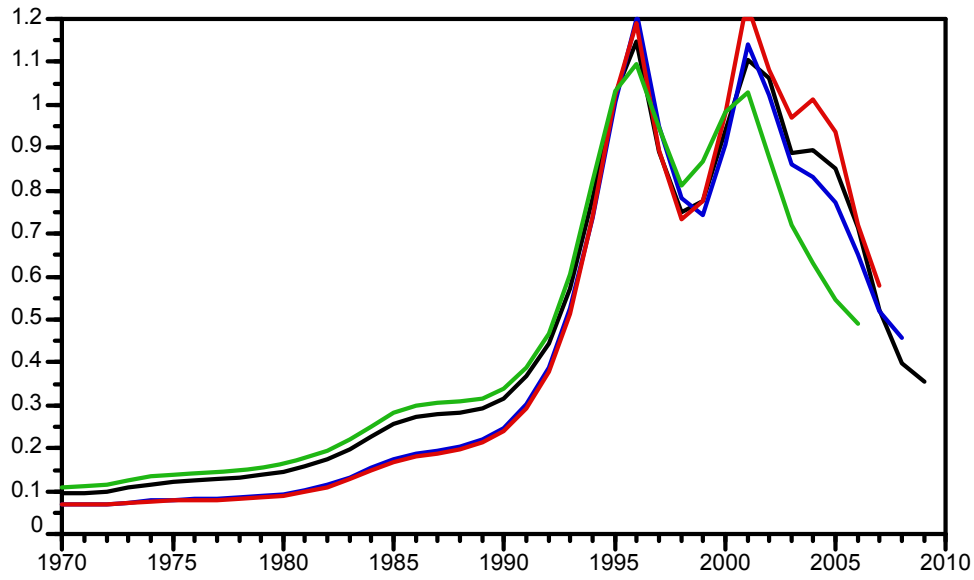
C:\PROJECTS\COD4VSW\COD_MODELS_10\rapa_figs\cod_retrof Tue Dec 07 10:52:53 2010
created using: cod m3 retro

Figure A2.3. Retrospective analysis on F5-9 for random walk M model.



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Figure A2.4. Retrospective analysis on M1-4 for random walk M model.



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Figure A2.5. Retrospective analysis on M5+ for random walk M model.