Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

NOAA FISHERIES
NATIONAL MARINE FISHERIES SERVICE

***CERT***

**Comité d'évaluation des ressources transfrontalières**

***TRAC***

**Transboundary Resources Assessment Committee**

**Document de référence 2013/09**

**Reference Document 2013/09**

Ne pas citer sans
autorisation des auteurs

Not to be cited without
permission of the authors

# Preliminary Examination of Ecological Information Relevant to Natural Mortality of Eastern Georges Bank Atlantic Cod (*Gadus morhua*)

Y. Wang

Fisheries and Oceans Canada
531 Brandy Cove Road
St. Andrews, New Brunswick  E5B 3L9
Canada

## TABLE OF CONTENTS

## ABSTRACT

For the 2013 Transboundary Resources Assessment Committee benchmark assessment review of Eastern Georges Bank Atlantic Cod, several relevant ecological factors, such as life history, environmental factors, competitors and predators were examined in order to understand the mechanisms that might cause elevated natural mortality for Eastern Georges Bank Cod since the mid-1990s. Factors that could contribute to elevated recent natural mortality were decreased fish size, poor condition, and competition for food with other fish species and marine mammals, as well as predation by seals.

## Examen préliminaire des renseignements écologiques pertinents au taux de mortalité naturelle de la morue franche (*Gadus morhua*) de l'est du banc de Georges

## RÉSUMÉ

Au cours de l'examen d'évaluation de la morue franche de l'est du banc de Georges pour 2013 du Comité d'évaluation des ressources transfrontalières, plusieurs facteurs écologiques pertinents, tels que le cycle biologique, les facteurs environnementaux, les concurrents et les prédateurs ont fait l'objet d'un examen afin de comprendre les mécanismes qui peuvent avoir entraîné des taux de mortalité naturelle élevée chez la morue de l'est du banc de Georges depuis le milieu des années 1990. Les facteurs qui pourraient contribuer au récent taux de mortalité naturelle élevé constituent la diminution de la taille des poissons, le mauvais état et la compétition pour la nourriture avec d'autres espèces de poissons et mammifères marins, ainsi que la prédation par les phoques.

## INTRODUCTION

For Atlatnic Cod (*Gadus morhua*) on Eastern Georges Bank (Fisheries & Oceans Canada [DFO] Statistical Unit Areas 5Zej and 5Zem; USA Statistical Areas 551, 552, 561 and 562), concerns about uncertainties in natural mortality for ages 6+ were raised at the 2009 benchmark assessment meeting. It was agreed that the models with higher natural mortality for ages 6+ during 1994-2007 were supported by fit diagnostics, but persistence of higher natural mortality was questionable. Documenting the fate of the 2003 year class, the only above average year class since the 1990 year class, would be informative about natural mortality at older ages, when it passed through the fishery and survey (O'Brien and Worcester 2009). Based on the catch curve analysis using fishery and survey data updated to 2012, the total mortality for ages 6+ of the 2003 year class ranged between 1.46 and 2.25 (Wang and O'Brien 2013). Therefore, in the terms of reference for the 2013 cod benchmark meeting, it was stated "Examine relevant ecological and biological data such as, but not limited to, growth, maturity, fecundity, recruitment, environmental factors, and trophic interactions to estimate natural mortality". This paper describes the preliminary results from the examination of ecological information relevant to natural mortality of the Eastern Georges Bank Atlantic Cod, which was presented at the 2013 Transboundary Resources Assessment Committee (TRAC) benchmark review stock assessment meeting.

## LIFE HISTORY

A long term perspective on variation in the growth of cod on Eastern Georges Bank is available from length and weight data collected during the annual bottom-trawl surveys; DFO conducted in February/March, National Marine Fisheries Service (NMFS) spring conducted in April, and NMFS fall conducted in October.

The average weight at age derived from the DFO and NMFS spring surveys shows a gradual declining trend (Figure 1). The length at age from the DFO survey (Figure 2) shows a decrease in length at age for cohorts after the mid-1990s. Also, results from fitting length at age data for each cohort to a von Bertalanffy growth function indicated that recent cohorts were dominated by relatively small fish with higher K and lower $L_{inf}$ compared to earlier cohorts (Table 1). Using the method of Myers and Doyle (1983), the longevity of Southern Gulf of St. Lawrence cod was estimated by calculating the age at which the fish would reach 95% of the estimated maximum size (Sinclair 2001). For Eastern Georges Bank cod, the estimated longevity decreased from 15 years in the 1970s to about 11 years in the 2000s. These results were consistent with the observed age structure in the fishery catch. Fish of ages 11-16 were seen consistently before 1994, but the age structure is more truncated in recent years. In 2011 and 2012, the observed maximum age in the fishery catch was age 11 and age 10, respectively. Changes in growth rate and the rate of occurrence of older fish support a possible change in natural mortality for cod on Eastern Georges Bank.

The trends in fish condition were examined to determine whether patterns in condition were congruent with temporal patterns in natural mortality. Considering all the weight data collected from the three surveys is in round weight, the indices of fish condition were calculated as Fulton's K (round weight/length$^3$). Because gonad has different maturity stage, seasonal and possibly different inter-annual patterns of changes, only post-spawning fish (based on maturity stage determination) were used for condition calculations to reduce the variability caused by changes in gonad weight. Condition of Eastern Georges Bank cod decreased substantially across all ages and stayed at low levels in recent years based on data from the DFO winter and NMFS spring surveys (Figure 3 and 4). Fulton's K calculated using gutted weight sampled during the 2013 DFO survey indicated that most fish >55cm had a condition factor below 0.8 (Figure 5), a value near that of fish from starvation experiments in the lab (<0.7, Lambert and Dutil 1997). The NMFS fall survey catches very few cod older than age 6, and there was no clear temporal trend for the Fulton's K calculated from these samples (Figure 6). It was important to note that condition varies seasonally, with the lowest value expected immediately after spawning (Link and Burnett 2001). The DFO winter survey (February) and NMFS spring survey (April) were conducted during pre-spawning and post-spawning seasons, respectively. The hypothesis is that cod on Eastern Georges Bank are most likely at risk of suffering high natural mortality after the overwintering period when little feeding occurs. Low condition might decrease the likelihood of fish survival due to costs of reproduction. Poor condition might have other consequences for this stock as well, such as the ability to avoid predation or the lack of energy to catch food. For adjacent stocks, Dutil and Lambert (2000) concluded that Northern Gulf of St. Lawrence cod condition was sufficiently low to increase their risk of mortality, and Rose and O'Driscoll (2002) stated that the high mortality experienced by Northern cod, since the collapse, was due to poor condition.

Maturity at age based on data collected from the DFO and NMFS spring surveys did not reveal a notable trend over time the series (Figure 7).

## ENVIRONMENTAL FACTORS

The annual stratum specific bottom temperature and salinity data collected from the three bottom trawl surveys was used for this analysis. Annual mean bottom temperatures (Figures 8-10) fluctuated above and below the long term mean without any apparent trend. Mean annual salinity by stratum from the DFO survey (Figure 11) also showed no apparent trend over the time series. Therefore, there was no obvious evidence to show that bottom temperature or salinity was an important factor influencing natural mortality.

## COMPETITORS AND PREDATORS

Natural mortality rates due to predation in an ecosystem can change year-to-year based on changes in the biomass of both the predator and prey. While cod are considered generalist predators, they do show preferences for particular prey items. Medium to extra-large cod on Georges Bank, prefer fish as prey (including herring, silver hake and sand lance) and invertebrates such as crabs and shrimp (Smith and Link 2010).

There are overlaps between the diet of cod and many species of fish and marine mammals. For example, pelagic fish and crustaceans were the major diet component of spiny dogfish (Smith and Link 2010); sand lance and silver hake were important prey species for swordfish (Stillwell and Kohler1985); herring were more often found in the diet of bluefin tuna (Chase 2001, Pleizier *et al.* 2012, Overholtz 2006); seals fed heavily on sand lance (Ampela 2009). Recent biomass of spiny dogfish (TRAC, 2010) and swordfish (Anon. 2009) have been high, and the dominant piscivore in the Georges Bank ecosystem has shifted from cod to spiny dogfish (Link and Garrison 2002). It is suspected that natural mortality of cod on Eastern Georges Bank might have elevated due to increased competition with cod for food from an increase in competitors.

Since cod is in a higher trophic level, predation mortality may not be a significant source of natural mortality compared with fishing mortality. However, cod is a major diet item of grey seals throughout the seals' distributional range. Although the importance of cod in the diet of Georges Bank grey seals is unknown, numerous studies have discussed the possibility that predation by grey seals was an important component of the high mortality of Atlantic Cod stocks in Newfoundland–Labrador, the Northern and Southern Gulf of St. Lawrence and the Eastern

Scotian Shelf (Lilly and Murphy 2004, Chouinard *et al.* 2005, Swain *et al.* 2011, O'Boyle and Sinclair 2012). The grey seal is a highly mobile species foraging in waters from Georges Bank to the Northern Gulf of St. Lawrence. The population of seals in Canadian waters was estimated to have increased from approximately 10,000 animals in 1960 to about 330,000-410,000 animals in 2010, and the current population size was estimated to be the largest measured in the past several hundred years (DFO 2011). In New England, the grey seal has increased from tens of animals in the early 1980s to thousands of animals in the late 2000s (Waring *et al.* 2010). A grey seal tagging analysis indicated that a high proportion of adult males from the Sable Island herd forage seasonally on Georges Bank and in neighboring waters in winter and early spring (February-April) (Breed *et al.* 2006). During February-April, Eastern Georges Bank cod are aggregating for spawning and fish condition is generally low at this time of year. It is suspected that this might be when higher natural mortality occurs on cod. Also, adult male seals have been found to consume a higher proportion of large groundfish than females in the Southern Gulf of St. Lawrence (Swain *et al.* 2011). Furthermore, the local harbour seal populations off New England have become more abundant during the last few decades (NEFSC 2013). The fishing industry has reported multiple observations of "belly biting" of larger cod (Rafferty *et al.* 2012) on Georges Bank. In conclusion, predation by seals may be another important contributor to the recent potentially higher natural mortality for Eastern Georges Bank cod.

## ADJACENT STOCKS

For adjacent cod stocks, Swain *et al.* (2011) stated that evidence strongly supports the hypothesis that predation on cod by grey seals in the Southern Gulf of St. Lawrence was a major cause of high natural mortality. O'Boyle and Sinclair (2012) concluded that grey seals have contributed to increases in natural mortality of cod on the Eastern Scotian Shelf since the late 1980s, and have contributed to the lack of recovery of the stock since 1993 when the fishery was closed, natural mortality increased to about 1.0 in the early 1990s (Swain and Mohn 2012). For 4X cod, natural mortality was assumed to be 0.7 for ages 4+ fish in a recent assessment (Clark and Emberley 2009). Due to the uncertainties in natural mortality, two assessment models have been adopted for Gulf of Maine cod, with one model assuming M=0.4 for the recent time period since 2000 (NEFSC 2013). The indication that natural mortality is elevated in adjacent stocks is noteworthy because it precludes the suggestion that the absence of older cod on Eastern Georges Bank is due to emigration to adjacent areas.

## SUMMARY

This paper provides preliminary results on the possible ecological and biological factors which could contribute to elevated natural mortality of Eastern Georges Bank cod. The hypothesis is that decreased fish size, poor condition, food competition with other fish species and marine mammals, and predation by seals could cause higher natural mortality of Eastern Georges Bank cod in recent years.

Currently, data for quantitative analysis is not available. Diet analysis of Eastern Georges Bank cod stomachs, especially samples from the overwintering and spawning seasons, could provide insight into the cause of poor cod condition. It is known that seal diet varies by sex, season, area, and other factors (DFO 2011). In the future, estimates of cod consumption from seal feeding studies on Eastern Georges Bank could provide an indication of the importance of cod in seal diets. Using tagging studies to estimate the population number of seals moving to Eastern Georges Bank, coupled with the average duration of seal occurrence in Eastern

Georges Bank and the average consumption of fish per day, would help quantify the impact of seal predation on Eastern Georges Bank cod.

## LITERATURE CITED

Ampela, K. 2009. The diet and foraging ecology of gray seals (*Halichoerus grypus*) in United States waters. Ph.D. thesis. The City University of New York, Staten Island, NY.

Anon. 2009. Report of the 2009 Atlantic swordfish Stock Assessment Session. Col. Vol. Sci. Pap., ICCAT SCRS/2009/016.

Breed, G.A., W.D. Bowen, J.I. McMillan, and M.L. Leonard. 2006. Sexual segregation of seasonal foraging habitats in a non-migratory marine mammal. Proceedings of the Royal Society B: Biological series, 273: 2319–2326.

Chase, B.C. 2001. Differences in diet of Atlantic Bluefin Tuna (*Thunnus thynnus*) at five seasonal feeding grounds on the New England continental shelf. Fish. B-NOAA., 100(2): 168-180.

Chouinard, G.A., D.P., Swain, M.O. Hammill, and G.A. Poirier. 2005. Covariation between grey seal (*Halichoerus grypus*) abundance and natural mortality of cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 62: 1991-2000.

Clark, D.S., and J. Emberley. 2009. Assessment of cod in Division 4X in 2008. DFO Can. Sci. Advis. Sec. Sci. Res. Doc. 2009/018.

DFO. 2011. Impacts of grey seals on fish populations in eastern Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/071.

Dutil, J.-D., and Y. Lambert. 2000. Natural mortality from poor condition in Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. 57 : 826-836.

Lambert, Y., and J.-D. Dutil. 1997. Condition and energy reserves of Atlantic cod (*Gadus morhua*) during the collapse of the northern Gulf of St. Lawrence stock. Can. J. Fish. Aquat. Sci. 54: 2388–2400.

Link, J.S., and J. Burnett. 2001. The relationship between stomach contents and maturity state for major northwest Atlantic fishes: New paradigms? J. Fish Biol. (2001)59: 783–794.

Link, J.S., and L.P. Garrison. 2002. Changes in piscivory associated with fishing induced changes to the finfish community on Georges Bank. Fish. Res. 55: 71–86.

Lilly, G.R., and E.F. Murphy. 2004. Biology, fishery and status of the 2GH and 2J3KL (northern) cod stocks: information supporting an assessment of allowable harm under the *Species at Risk Act* for the COSEWIC-defined Newfoundland and Labrador population of Atlantic cod (*Gadus morhua*). DFO Can. Sci. Advis. Sec. Sci. Advis. Res. Doc. 2004/102.

Myers, R.A., and R.W. Doyle. 1983. Predicting natural mortality rates and reproduction-mortality trade-offs from life history data. Can. J. Fish. Aquat. Sci. 40: 612-620.

NEFSC 2013. 55th Northeast Regional Stock Assessment Workshop (55th SAW) Assessment Report. US Department of Commerce, NEFSC Ref. Doc. 13-11: 845 pp.

O'Boyle, R., and M. Sinclair. 2012. Seal–cod interactions on the Eastern Scotian Shelf: reconsideration of modelling assumptions. Fish. Res. 115–116: 1– 13.

O'Brien, L., and T. Worcester. 2009. Transboundary Resources Assessment Committee eastern Georges Bank cod benchmark assessment. TRAC Proceed. 2009/02.

Overholtz, W.J. 2006. Estimates of consumption of Atlantic Herring (*Clupea harengus*) by Bluefin Tuna (*Thunnus thynnus*) during 1970–2002: An approach incorporating uncertainty. J. Northw. Atl. Fish. Sci. 36: 55–63.

Pleizier, N.K., S.E. Campana, R.J. Schaller, S.G. Wilson, and B.A. Block. 2012. Atlantic Bluefin Tuna (*Thunnus thynnus*) diet in the Gulf of St. Lawrence and on the Eastern Scotia Shelf. J. Northw. Atl. Fish. Sci. 44: 67–76.

Rafferty, A.R., Jr. E.O. Brazer, and R.D. Reina. 2012. Depredation by Harbor Deal and Spiny Dogfish in a Georges Bank gillnet fishery. Fisher. Manag. Ecol. 19: 264–272.

Sinclair, A.F. 2001. Natural mortality of cod (*Gadus morhua*) in the Southern Gulf of St. Lawrence. ICES J. Mar. Sci, 58: 1–10.

Smith, B.E , and J.S. Link. 2010. The trophic dynamics of 50 finfish and two squid species on the Northeast U.S. Continental Shelf. NOAA Tech. Memo. NMFS-NE-216: 640 pp.

Swain, D.P., and R.K. Mohn. 2012. Forage fish and the factors governing recovery of Atlantic Cod (*Gadus morhua*) on the eastern Scotian Shelf. Can. J. Fish. Aquat. Sci. 69: 997-1001.

Swain, D.P., H.P. Benoît, M.O. Hammill, G. McClelland, and É. Aubry. 2011. Alternative hypotheses for causes of the elevated natural mortality of cod in the southern Gulf of St. Lawrence: The weight of evidence. DFO Can. Sci. Advis. Sec. Sci. Res. Doc. 2011/036.

Stillwell, C.E., and N.E. Kohler. 1985. Food and feeding ecology of the swordfish *Xiphias gladius* in the western North Atlantic Ocean with estimates of daily ration. Mar. Ecol. Prog. Ser. 22: 239-247.

Rose, G.A., and R.L. O'Driscoll. 2002. Capelin are good for cod: Can the northern stocks recover without them? ICES J. Mar. Sci. 59: 1018-1026.

TRAC 2010. Northwest Atlantic Spiny Dogfish. TRAC Status Report 2010/02.

Wang, Y., and L. O'Brien. 2013. Benchmark assessment of eastern Georges Bank Atlantic Cod (*Gadus morhua*). TRAC Ref. Doc. 2009/07.

Waring, G., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2010. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments-- 2010, NOAA Tech. Memo., NMFS NE 219: 595 pp.

# TABLES

*Table 1. Estimates of von Bertalanffy growth parameters with corresponding coefficient variations (CV) using length at age data from the DFO survey for the 1984 to 2006 cohorts. The highlighted cohorts have greater uncertainties in the estimate of the growth parameters as indicated by the higher CV values (in red).*

| Cohort | value | | | CV | | |
|---|---|---|---|---|---|---|
| | $L_{inf}$ | K | t0 | $L_{inf}$ | K | t0 |
| 1984 | 108 | 0.26 | 0.21 | 0.07 | 0.20 | -1.19 |
| 1985 | 118 | 0.18 | -0.39 | 0.06 | 0.15 | -0.56 |
| 1986 | 133 | 0.16 | -0.37 | 0.10 | 0.22 | -0.76 |
| 1987 | 114 | 0.21 | -0.21 | 0.05 | 0.12 | -0.79 |
| 1988 | 143 | 0.14 | -0.49 | 0.11 | 0.21 | -0.46 |
| 1989 | 99 | 0.28 | 0.02 | 0.06 | 0.17 | 12.12 |
| 1990 | 151 | 0.12 | -0.85 | 0.14 | 0.25 | -0.34 |
| 1991 | 186 | 0.09 | -0.75 | 0.29 | 0.45 | -0.53 |
| 1992 | 154 | 0.10 | -1.08 | 0.14 | 0.25 | -0.29 |
| 1993 | 177 | 0.08 | -1.50 | 0.29 | 0.46 | -0.40 |
| 1994 | 220 | 0.06 | -1.67 | 0.41 | 0.60 | -0.37 |
| 1995 | 124 | 0.14 | -0.73 | 0.11 | 0.22 | -0.43 |
| 1996 | 100 | 0.24 | -0.08 | 0.05 | 0.12 | -2.31 |
| 1997 | 95 | 0.21 | -0.82 | 0.11 | 0.32 | -0.72 |
| 1998 | 97 | 0.21 | -0.65 | 0.06 | 0.18 | -0.54 |
| 1999 | 144 | 0.10 | -0.89 | 0.23 | 0.42 | -0.67 |
| 2000 | 107 | 0.20 | 0.04 | 0.10 | 0.24 | 9.70 |
| 2001 | 150 | 0.09 | -1.30 | 0.38 | 0.68 | -0.78 |
| 2002 | 342 | 0.03 | -1.14 | 1.10 | 2.20 | -0.94 |
| 2003 | 92 | 0.27 | 0.25 | 0.04 | 0.10 | 0.53 |
| 2004 | 88 | 0.36 | 0.87 | 0.05 | 0.17 | 0.26 |
| 2005 | 84 | 0.41 | 0.60 | 0.04 | 0.15 | 0.32 |
| 2006 | 101 | 0.20 | -0.62 | 0.15 | 0.37 | -0.89 |

# FIGURES

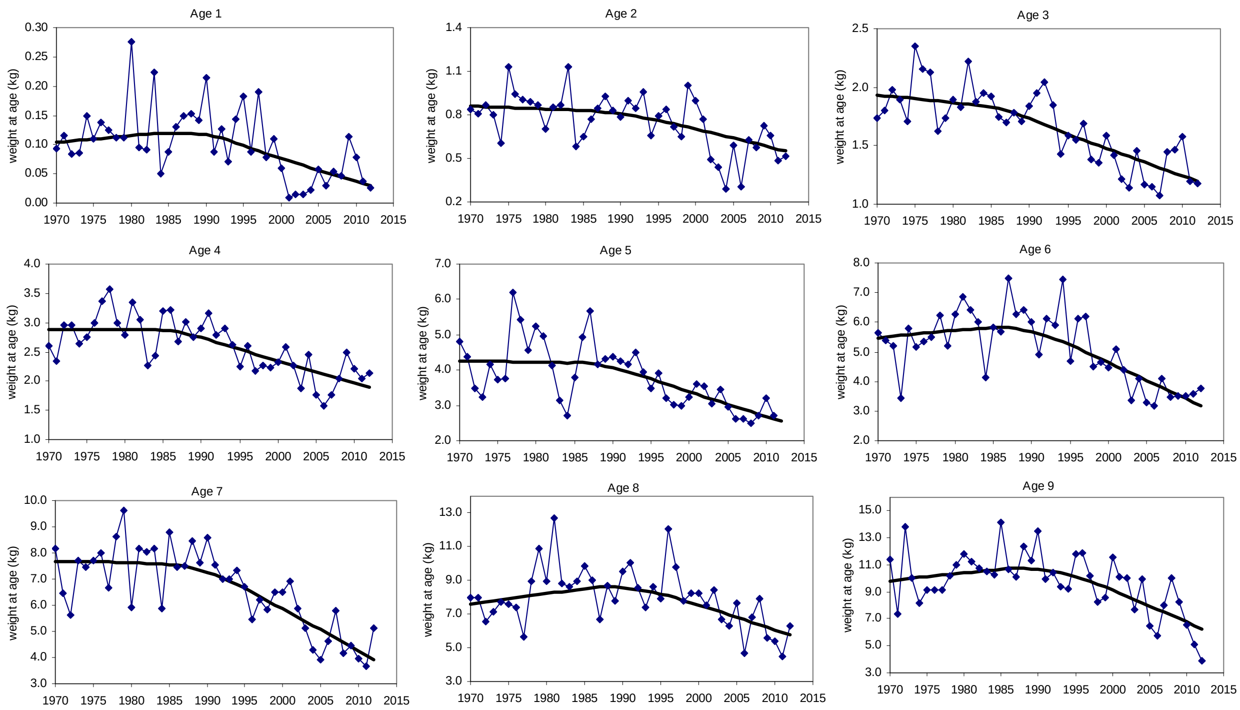



*Figure 1. DFO and NMFS spring survey weights at age of Eastern Georges Bank cod. The lines showed the smoothed values using the LOESS method.*

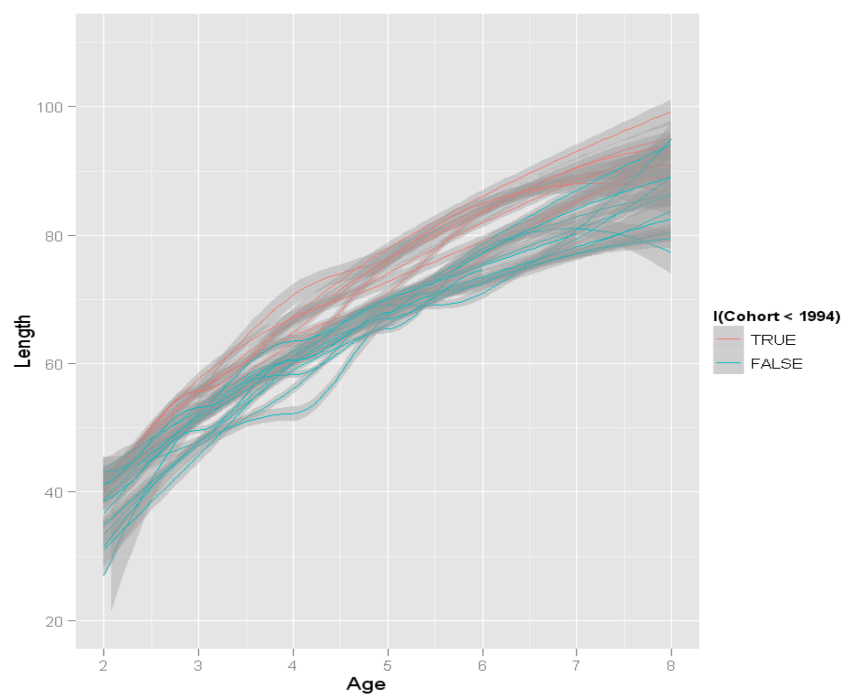



*Figure 2. Mean length at age for pre-1994 (red) and post-1994 (green) cohorts of Eastern Georges Bank cod from the DFO survey.*

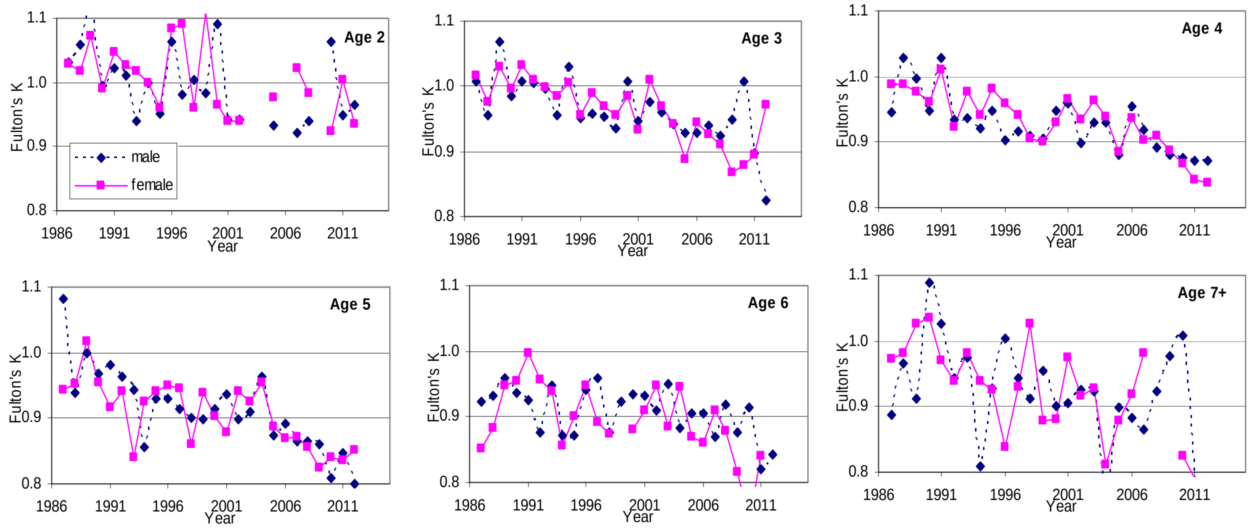



*Figure 3. Age- and sex-specific Fulton's K for post-spawning Eastern Georges Bank cod using data collected from the DFO survey.*

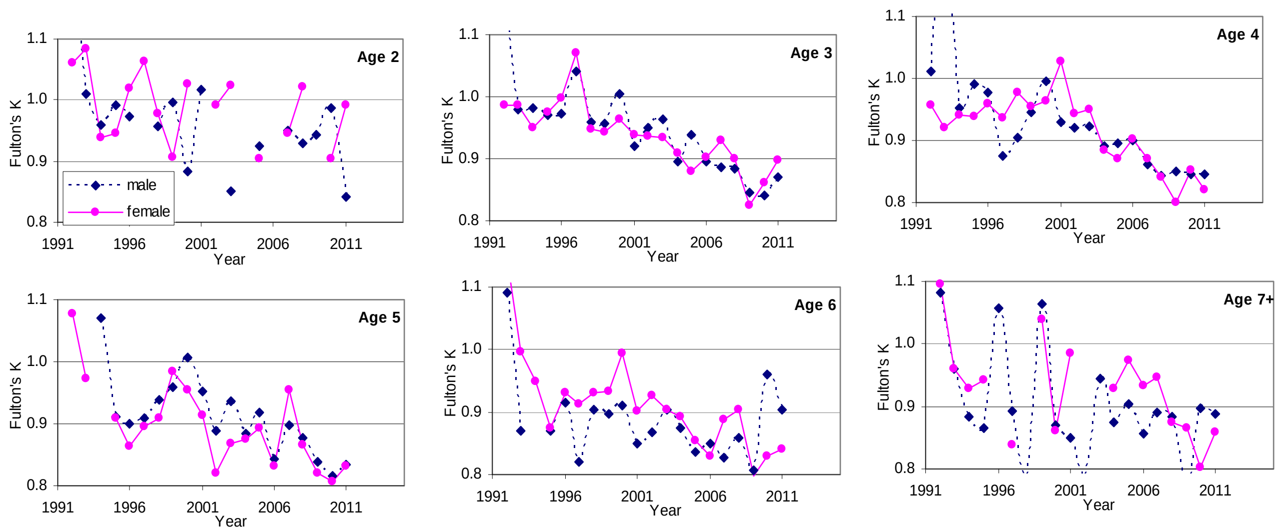



*Figure 4. Age- and sex-specific Fulton's K for post-spawning Eastern Georges Bank cod using data collected from the NMFS spring survey.*

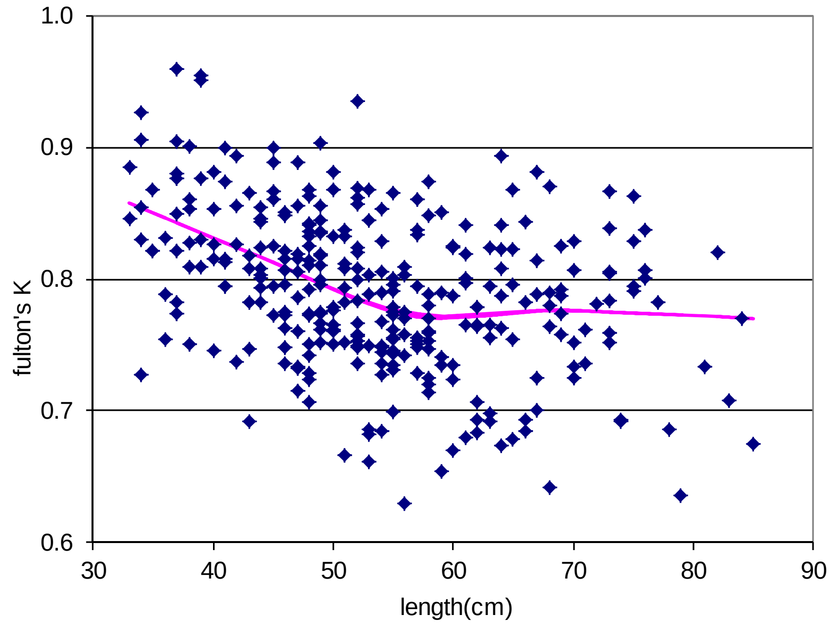



*Figure 5. Fulton's K for Eastern Georges Bank cod from gutted weight and length data collected from the 2013 DFO survey with a LOESS fitted line to show the main trend.*

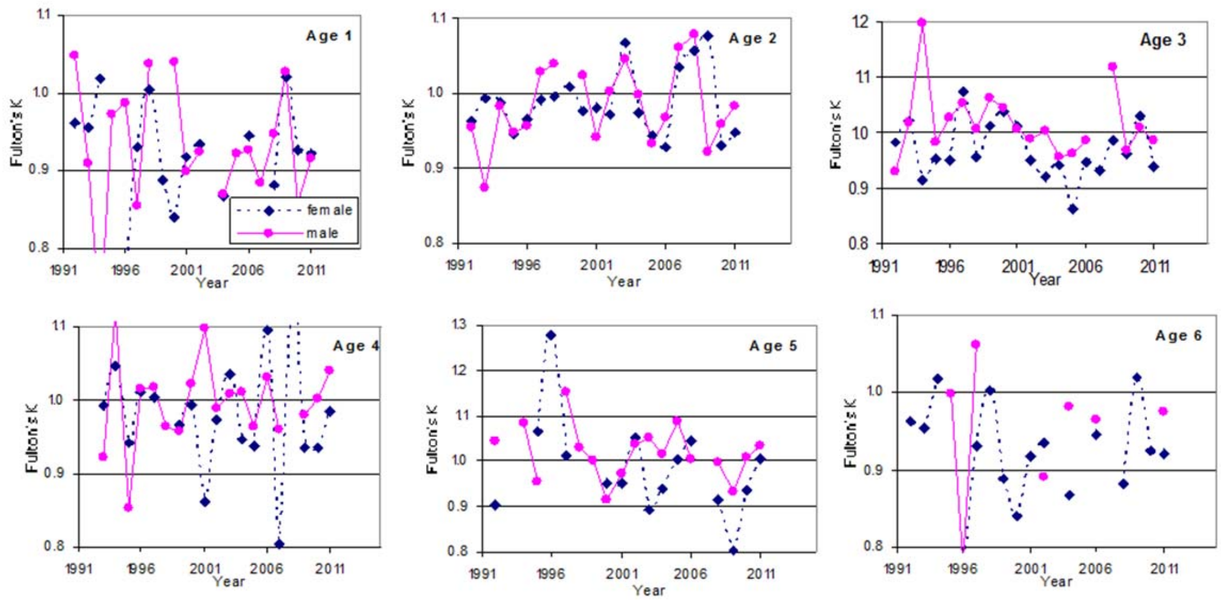
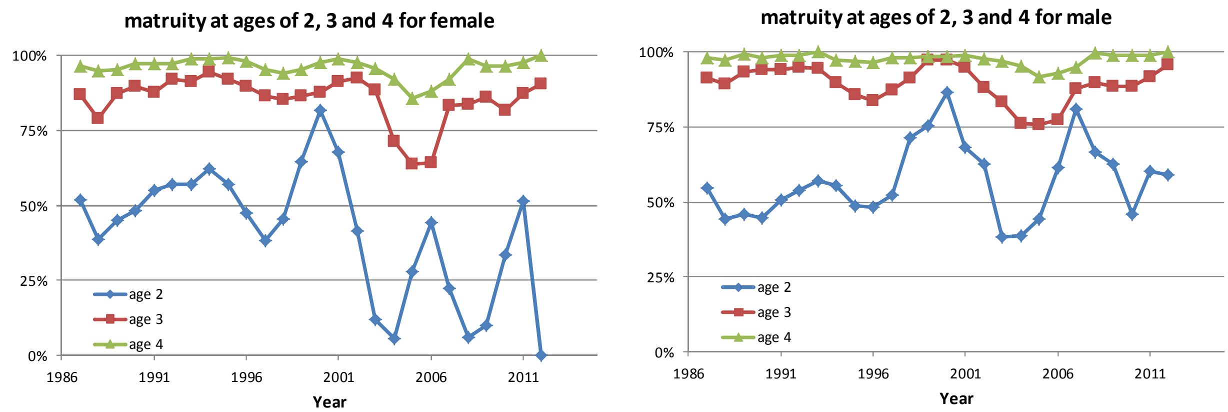



*Figure 6. Age- and sex-specific Fulton's K for post-spawning Eastern Georges Bank cod using data collected from the NMFS fall survey.*

## DFO Survey




## NMFS Spring Survey

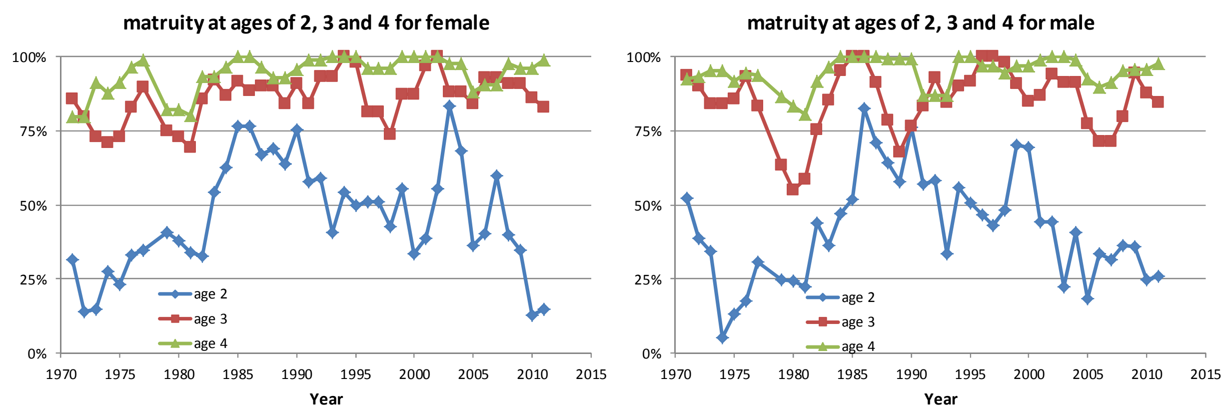



*Figure 7. Three-year moving window percent mature for Eastern Georges Bank cod ages 2, 3 and 4 using data collected from the DFO and NMFS spring surveys.*

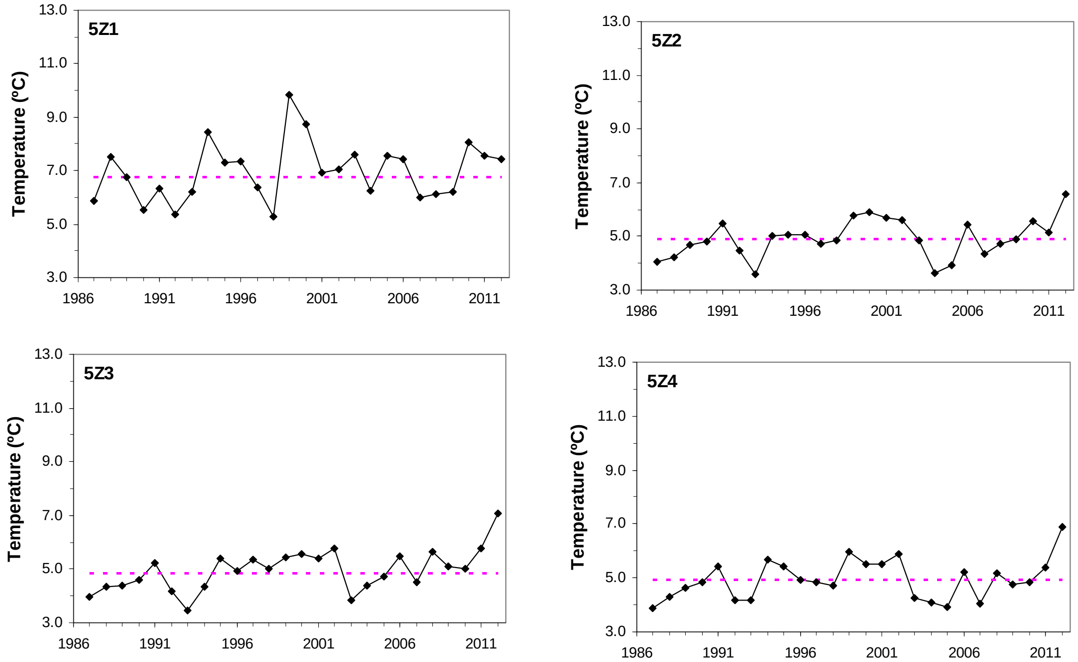



*Figure 8. Eastern Georges Bank DFO survey mean bottom temperature by stratum. The dashed line is the time series mean.*

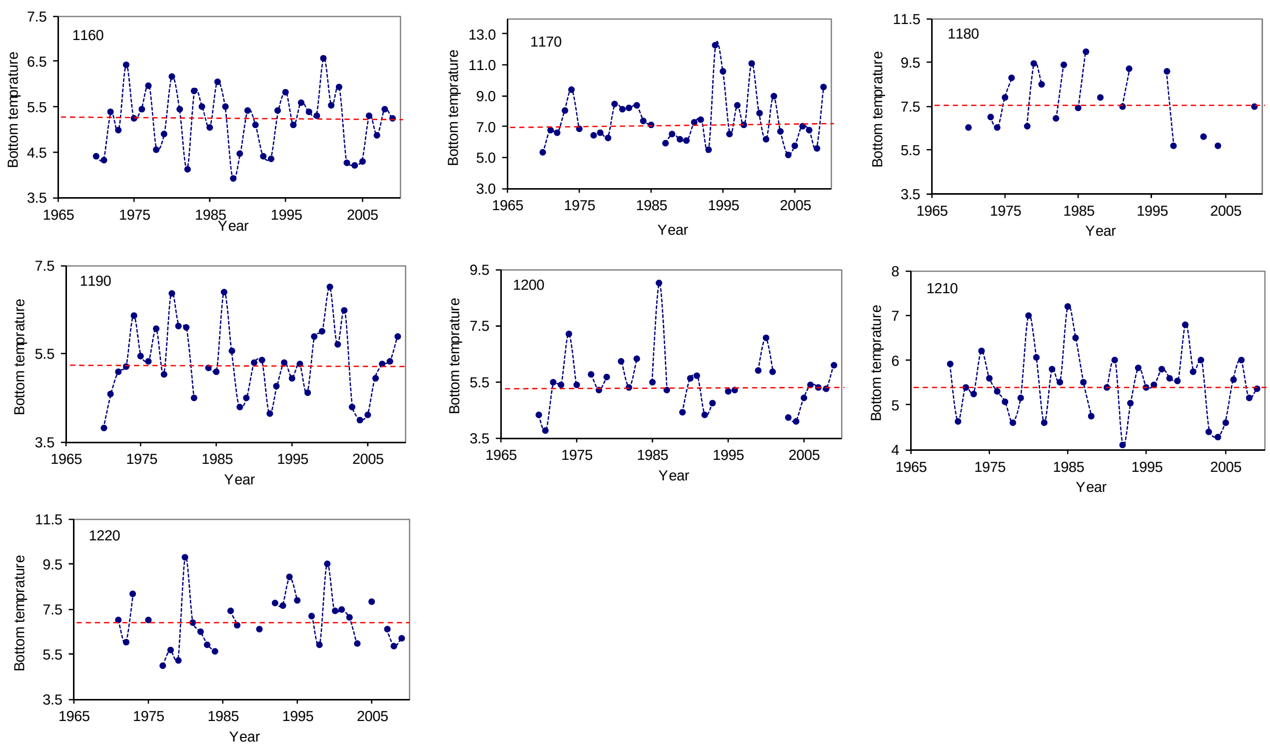



*Figure 9. Eastern Georges Bank NMFS spring survey mean bottom temperature by stratum. The dashed line is the time series mean.*

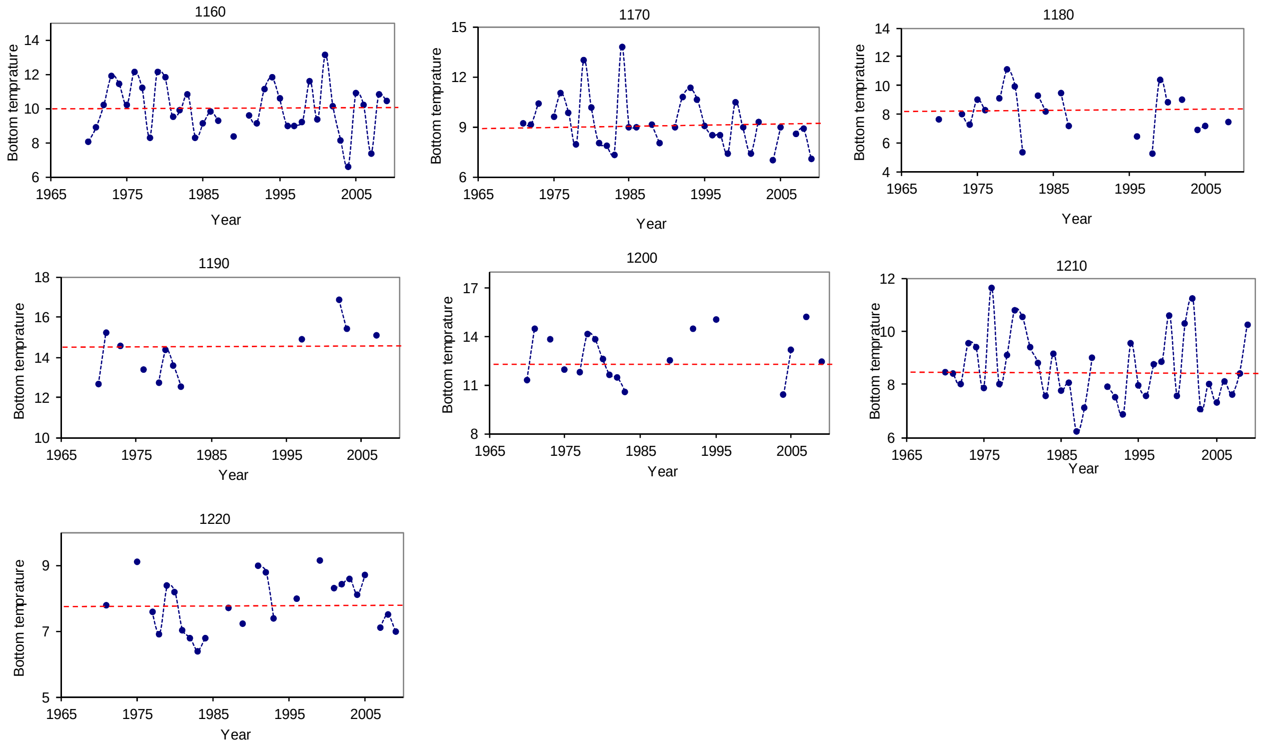



*Figure 10. Eastern Georges Bank NMFS fall survey mean bottom temperature by stratum. The dashed line is the time series mean.*

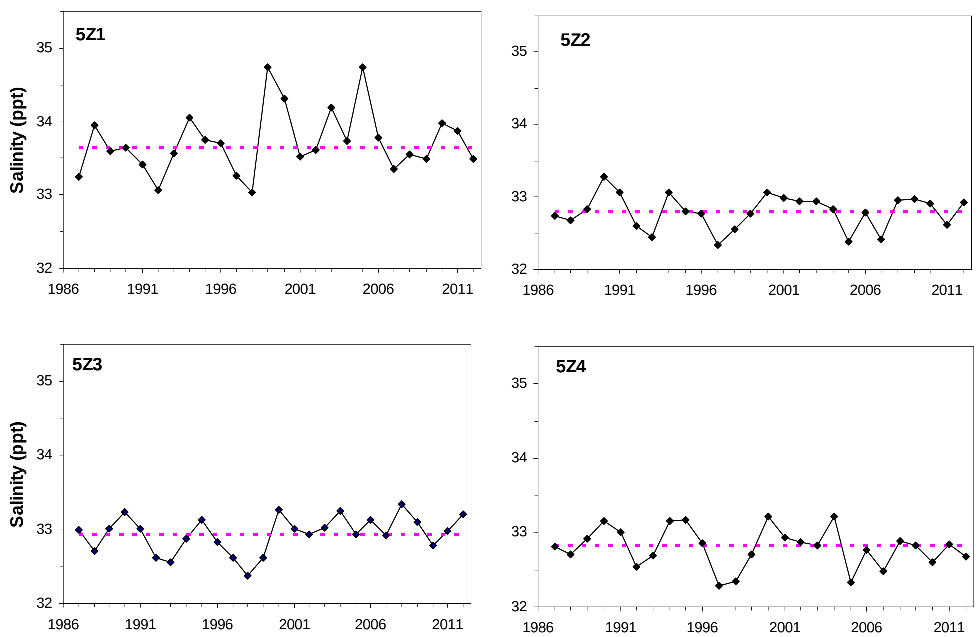



*Figure 11. Eastern Georges Bank DFO survey mean bottom salinity by stratum. The dashed line is the time series mean.*