Fisheries and Oceans Canada — Pêches et Océans Canada
Science — Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2014/025

Quebec and Newfoundland and Labrador Regions

Changes in ice conditions and potential impact on harp seal pupping

M.O. Hammill[1] and G.B. Stenson[2]

[1] Science Branch
Fisheries and Oceans Canada
Institute Maurice Lamontagne
P.O. Box 1000
Mont-Joli, QC. G5H 3Z4

[2] Science Branch
Fisheries and Oceans Canada
Northwest Atlantic Fisheries Centre
PO Box 5667
St. John's, NL A1C 5X1

August 2014

Canada

Foreword

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

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

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Hammill, M. O and Stenson, G. B. 2014. Changes in ice conditions and potential impact on harp seal pupping. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/025. iv + 14 p.

ABSTRACT

Harp seals require stable ice as a platform for resting, pupping and rearing their young. Changes in ice cover in Atlantic Canada during the period of pupping and when the young animals or beaters are leaving the ice to forage on their own were examined between 1969 and 2013, using ice cover data from Environment Canada. The annual extent of ice cover has varied considerably, particularly in the Gulf of St Lawrence (Gulf). Overall, ice cover has declined during the pupping period, due to a decline in ice cover in the Gulf of St Lawrence. No significant trend in ice cover in southern Labrador, which includes the area known as the Front, was observed over the last 44 years. However, a decline in ice cover during April was observed at both the Front and in the Gulf. There is no direct measure of mortality in the harp seal assessment. Mortality of young of the year associated with very poor ice conditions has been identified and incorporated into the assessment since 2003. This mortality index is qualitative being based on expert opinion. An index was developed, based on the magnitude of the negative ice anomaly for the Gulf and the Front. This index suggests that ice related mortality may have been as high as 65% of the total number of pups born in 1969 and 2011.

Changements dans les conditions de glace et impact potentiel sur la mise bas du phoque du Groenland

RÉSUMÉ

Les phoques du Groenland ont besoin de glace stable sous forme de plate-forme pour se reposer, mettre bas et élever leurs petits. Les changements dans la couverture de glace dans l'Atlantique au cours de la période de mise bas et quand les jeunes phoques de l'année quittent la glace pour se nourrir de leur propre gré ont été examinés entre 1969 et 2013, en utilisant les données de la couverture de glace d'Environnement Canada. La superficie annuelle de la couverture de glace a varié considérablement, en particulier dans le golfe du Saint-Laurent (Golfe). Dans l'ensemble, la couverture de glace a diminué au cours de la période de mise bas, en raison d'une diminution de la couverture de glace dans le golfe du Saint-Laurent. Aucune tendance significative de la couverture de glace dans le sud du Labrador, qui comprend la zone connue sous le nom de Front, n'a été observée au cours des 44 dernières années. Cependant, une baisse de la couverture de glace pendant le mois d'avril a été observée à la fois au Front et dans le Golfe. Il n'existe pas de mesure directe de la mortalité dans l'évaluation du phoque du Groenland. La mortalité des jeunes de l'année associée à des conditions de glace très pauvres a été identifiée et incorporée dans l'évaluation depuis 2003. Cet indice de mortalité est qualitatif et est basé sur des avis d'experts. Un indice a été développé, basé sur l'ampleur de l'anomalie négative de glace pour le Golfe et le Front. Cet indice suggère que la mortalité liée à la glace peut-être aussi élevée que 65 % du nombre total de petits nés entre 1969 et 2011.

INTRODUCTION

Harp seals (*Pagophilus groenlandicus* (Erxleben 1777)) are medium-sized, highly migratory, phocids inhabiting continental shelf regions of the North Atlantic and adjacent Arctic oceans. They are separated into three distinct populations based on their whelping (pupping) sites: the Northwest Atlantic, the Greenland Sea, and the White Sea populations (Sergeant 1991). The Northwest Atlantic population is divided into two major intermixing herds: the “Front” herd that whelps off the coast of northern Newfoundland and/or southern Labrador, and the “Gulf” herd that whelps in the southern Gulf of St. Lawrence. Females have their young in late February in the Gulf and in early March at the Front (Sergeant 1991, Stenson et al. 2002). Harp seals rely on pack ice to haul out on, to give birth and nurse their young, and to moult. They rarely haul out on land. Field observations suggest that whelping normally occurs on ice pans that are extensive and thick enough to persist for some time and resist destruction from storm activity, but at the same time, not so extensive as to prevent adults from entering the water during the lactation period. The ice chosen by females at the beginning of the whelping season is crucial because mobility of the pup is severely restricted. Newborn animals need stable ice to allow them time to develop sufficient blubber for insulation and to rest.

After nursing for approximately12 days, the young of the year (YOY) are weaned, while the adults mate and disperse. Although the YOY spend an increasing amount of time in the water, they appear to need a solid surface to haul out on and rest after weaning, remaining with the ice for several weeks (Sergeant 1991). This extended association with ice appears to be related to additional physiological development as the YOY make the transition from a “terrestrial” animal to a marine mammal (Burns et al. 2010). Consequently, the presence of stable pack ice appears to be essential in the early development of the young seal (Bajzak et al. 2011).

Harp seals whelp on first year (i.e. ice of not more than one winter, 30 cm or greater, Canadian Ice Service) or grey white (i.e. young ice 15-30 cm thick) ice of 6/10 or more concentration, which is usually the thickest available in the areas where they traditionally pup (Sergeant 1991, Bajak et al. 2011). Given the importance of this ice to the life cycle of the harp seal, years when ice conditions are poor are expected to have a negative impact on pup production or pup survival through increased mortality among YOY during the nursing period, or after weaning, but prior to when the young begin to enter the water to forage on their own. Years where ice has been unsuitable for whelping have been observed and appear to have resulted in high mortality among YOY (Sergeant 1991, Stenson and Hammill 2012). Notable years include 1969, when there was almost no ice in the southern Gulf of St Lawrence and 1981, when ice cover was limited in both the Gulf and at the Front. Pup mortality was very high in 1981 and this cohort appears to have disappeared from the population, due in part, to high natural mortality in combination with high hunting mortality (Sergeant 1991).

During the period from the mid-1980s until the late 1990s, the Northwest Atlantic harp seal population underwent a period of rapid expansion, which coincided, among other things, with a period of above average ice cover, particularly in the Gulf of St Lawrence (Johnston et al. 2005, Friedlander et al. 2010, Bajzak et al. 2011). However, since the late 1990s the frequency of years with below average ice cover has increased and this may have an impact on YOY survival, particularly in the southern Gulf of St Lawrence which is at the southern limit of their range and the southern limit of seasonal pack-ice formation in North America. Climate change models suggest that ice conditions in the Gulf will continue to decline (McCarthy et al. 2001, IPCC 2007) and so, the impact of changes in ice on the population dynamics must be considered.

The possibility of mortality of YOY associated with poor ice conditions has been incorporated into the assessment model since 2003 (Hammill and Stenson 2003). This mortality is considered to be periodic and to represent a level of mortality that exceeds what might be considered the long-term level of natural mortality experienced by this population. Low ice extent reduces available habitat and ice that is extremely thin and breaks up easily forces YOY prematurely into the water which may result in drowning. This ice-related mortality acts on the YOY between birth, and the start of the harvest in late March (Gulf) or mid-April (Front). Currently, a mortality factor (which is actually incorporated into the model as a Survival term, S_{ice}=1-Mice) has been based on qualitative assessments based upon expert opinion, which involves a combination of personal observations, local environmental conditions and reports of neonate carcasses.

Here we examine changes in ice conditions encountered by Northwest Atlantic harp seals during the whelping seasons between March 1969 and March 2013 and present an approach that could be used to quantify mortality rates associated with poor ice conditions.

MATERIALS AND METHODS

Ice data were provided by the Canadian Ice Service (CIS) of Environment Canada in Ottawa. These data were derived from a combination of helicopter and shipboard observations, airborne radar imagery, and since 1990s from satellite imagery. Data were available for a specific day or on a weekly basis between the winters of 1968-69 and 2012-13 following the World Meteorological Organization sea-ice nomenclature. The data contain information on total area, the proportion of the area that is ice covered (i.e. total concentration), the proportion of cover of new ice (0 to 10 cm thick), young ice (10–30 cm thick), and first-year ice (30–120 cm thick).

Pupping is complete in the southern Gulf of St Lawrence (Gulf) by the first week of March, and by mid-March off the southeast Labrador coast (Front) (e.g. Stenson et al. 2002). Consequently, we examined ice conditions for the Gulf from ice charts from the Gulf for the week of 5 March, 1969 to 2013, and for the week of 12 March for the Front (referred to as 'Southeast Labrador' by the CIS. We also examined ice conditions during the week of 12 March for the Atlantic zone, which includes the southeastern Labrador coast, Newfoundland, Gulf of St Lawrence and Nova Scotia. After the YOY are weaned, they remain associated with the ice for 2-3 weeks while they moult their lanugo fur (to become what are called beaters) and undergo a post-weaning fast. At this stage they begin entering the water to begin learning how to forage. We selected April 23 as the date for the end of the post-weaning fast. In the Gulf all animals have left the southern portion of the Gulf by that time and moved to the northern Gulf and Front where the ice is quite loose.

The annual ice anomaly (A) was calculated using the formula: A_x= (ice cover $_x$ – ice cover $_{mean\ 1969\text{-}2013}$)/ ice cover $_{mean\ 1969\text{-}2013}$, where ice cover was in (km^2), and *x* represents the year of interest. Data were from the charts prepared for the Gulf of St Lawrence to examine the Gulf area, the southern Labrador Sea for the Front, and the 'Atlantic coast', when the whole region was examined as a single unit. Changes in ice-cover over time were also examined using linear regression (SAS Institute).

This index was compared with the more quantitative measure we develop here (see below).

Based upon the negative anomalies, we identified years when higher than normal mortality may have occurred. Seals do not use all of the ice in the areas and so minor anomalies were unlikely to have an impact. Therefore, it was necessary to determine the degree of anomaly that actually resulted in mortality. The southern Labrador area included a large area that was north of the traditional Front and so it was assumed that compared to the Gulf, a larger reduction in ice cover over the full area could occur before pups were impacted. Using years when we could confirm pup mortality, we identified a cutoff for the annual ice anomaly at 0.3 for the Gulf and 0.5 at the Front.

We assumed that given the ice anomaly was greater than the cutoff level, the increase in mortality (M_{ice}) of the YOY was directly related to the relative decline in ice cover, as expressed by the annual ice anomaly (A). Thus a 40% decline in ice cover was assumed to result in a 40% increase in mortality (or 40% decline in survival). Positive A values were assumed not to have any impact on survival. A separate M_{ice} was calculated for each zone following which the two indices were combined, weighted by the relative distribution of pupping assuming that 30% of the herd pups in the Gulf and 70% pups at the Front. These were converted to a survival index (S_{ice}). These estimates were compared to the qualitative estimate of ice related mortality used previously.

RESULTS

Ice cover has varied considerably over the last 4 decades, particularly in the Gulf (Fig. 1). Ice coverage was well below average at the beginning of the series in 1969. During the 1970s, ice cover was mixed with some years being up to 40-60% greater than normal, while others were 40-80% below normal, or near normal. The variable conditions continued during the 1980s while in the 1990s, ice was generally much heavier with the majority of years having ice cover that was ≥40 to 80% above normal. By the late 1990s, however, there was a major change in ice conditions with the virtually all of the years having ice that was below normal (Fig. 1).

In the Atlantic zone, between 1969 and 2013, there has been a decreasing trend in ice cover, with total ice cover declining at a rate of about 4,400 km^2 per year (SE=1 827, df=43, F=5.8, $p<0.02$). However, first year ice cover does not show any long-term trend ($p>0.5$) (Fig. 2). There is a slight decline in total ice cover at the Front, but the trend is not significant, nor is any significant trend observed in first-year ice cover at the Front. In the Gulf, total ice cover has been declining at an annual rate of 1,940 km^2 (SE=776, DF=43, F=6.2, $P<0.02$) (Fig. 2, 3). No trend was observed in the amount of first-year ice in the Gulf.

By late April the YOY seals have reached the beater stage and animals begin to take to the water. However, the ice is still important as a platform for resting while they increase their ability to dive. In Atlantic Canada, total ice cover has declined on average 2,194 km^2 (SE=790, df=43, F=7.7, $p<0.01$) per year since 1969, although there has been no trend in the amount of first-year ice cover (Fig. 4). At the Front, there is a significant declining trend in ice cover at a rate of 1,107 km^2 (SE=370, df=43, F=9, $p<0.004$) annually, but no decline in total first year ice cover. In the Gulf, total ice has been declining at a rate of 514 km^2 (SE=248, df=43, F=4.28, P=0.04) per year. First-year ice cover has also been declining but not quite significantly at a rate of 462 km^2 (SE=235, df=43, F=3.86, P=0.056).

Generally, there was good agreement between the qualitative index and the quantitative ice index in identifying years when ice conditions were much less than normal and therefore mortality was likely to be much higher than normal (Table 2, Fig. 5). The method we present here identified a few more years when mortality may have been higher (1970, 1978, 1996 and 1999), but in most of these years the differences in survival estimates were small. With few exception (e.g. 2010) the estimates survival was also similar.

DISCUSSION

Harp seals require stable pack ice for pupping and early development of the young. The period from 1969 until the early 1980’s was characterized by lighter ice conditions, followed by a decade of heavier than normal ice conditions, which would have favoured pup survival (Bajzak et al. 2011, Johnston et al. 2005). Since the late 1990s, the area has been characterized by a high frequency of winters with lighter than normal ice-conditions, with the winters of 2010, 2011 and 2013 being among the lightest ice cover years on record since 1969, when Environment Canada first began collecting data. These have likely resulted in conditions where YOY mortality during their first three months is likely to be above the long-term average.

Over the last decade, we have incorporated a level of ice-related mortality into the assessment, but this has been based on expert opinion, with little attempt to define more rigorous parameters (e.g. Hammill et al. 2011). In this study, we developed a quantitative ice index based on ice anomalies. Although we still do not have a direct measure of mortality, this approach results in a less subjective measure of possible mortality levels in each herd. In harp seals, the mother-pup bond is very strong, and females are often seen leading their pups to other locations, sometimes traversing leads a few 100 m wide (Hammill and Stenson, personal observation). Small fluctuations in ice cover around the mean are unlikely to have much impact on YOY survival. To adjust for this, in the Gulf we set a cutoff at an anomaly of -0.3. At the Front, the ice chart for what is called the South Labrador Sea includes a large area that lies outside of the traditional Front pupping area and therefore represents a significant area that is not used. Therefore, we set a higher threshold in this area considering that areas used by harp seals would not be seriously affected unless there was a larger reduction in ice cover anomaly of more than -0.5. In the Gulf, we used total ice cover in developing our index, whereas at the Front we used total cover of first year ice. In our own experience, the satellite imagery tends to do a poor job of evaluating ice thickness, with a tendency to determine that ice is thicker than it really is. This is appropriate when providing information relating to shipping, but is less appropriate when trying to identify solid ice for harp seals or landing a helicopter. Normally first-year ice is the preferred ice type of harp seals (Bajzak et al. 2011), but there appears to be little ice of this type early in the pupping season in the Gulf, hence we have used total ice cover. At the Front, the ice tends to be heavier, new ice and grey ice would be more susceptible to breaking up from swell and storm activity, whereas first year ice would be more resistant. Therefore, we feel that first year ice is a more appropriate measure for this area.

The levels of mortality estimated using the approach outlined here are similar to the qualitative estimates used previously. One exception is 1970 where the quantitative method suggests that there was considerable mortality associated with low ice cover (Table 2). Although there are reports of considerable mortality for 1969 which was another low ice year, there were no similar reports in 1970. Closer examination of the ice data, indicated that there is considerable missing data for this year in the Environment Canada database and that the values that are given are based largely on interpolation. As a result, the conclusions for this year should be considered to be unreliable.

The quantitative index is based solely on ice cover and does not take into account other potential factors. For example, in 2005, ice cover was considered to be normal, but there was considerable mortality of whitecoats in the northern Gulf. Examination of some of these pups indicated that they had been crush by shifting ice as a result of a storm (Stenson, personal observation). Stenson and Hammill (2012) also found that the response of harp seals to poor ice conditions is dependent on the timing of ice development and destruction, as well as the total ice available. In order to account for the potential impact of these dynamics on pup mortality, it may be necessary to develop an index of within season ice degradation.

We observed a decline in total ice cover in the Atlantic zone during the pupping season. The greatest decline in ice cover occurred in the Gulf, with a small declining trend in ice for the southern Labrador region, but this was not significant. This region includes southern Labrador along with much of central Labrador. The large extent of relatively consistent ice in the northern part of this region (through ice drift from the north) will dampen any statistical change in the ice cover obtained from CIS. It is possible that restricting an analysis to the southern portion where whelping occurs would provide a better understanding of the potential mortality of harp seals at the Front. A decline in ice cover was also observed throughout the Atlantic zone during April. At that time, a significant decline in ice cover was observed in both the Gulf and at the Front. If this pattern continues, then there will, over the long term, be a decline in suitable ice for pupping as well as a decline in the duration of the period of stable ice during YOY physiological development (Burns et al. 2010) and the transition to independent foraging.

The impact of changes in stable ice and the response of harp seals might be expected to vary, depending on whether apparently suitable ice forms early (e.g. 2011), providing animals with a pupping platform, or does not form at all (e.g. 2010 in the Gulf) (Stenson and Hammill 2012). Some short-term tactics that harp seals might adopt include changing the timing of birth or searching out areas with more suitable ice. In the Gulf, there is some evidence for a shift in the timing of births, with females giving birth earlier in the season. For example, in surveys flown between 7-10 March in 1994, it was estimated that 88 to 92% of the pups were born, whereas in 2012 it was estimated that 98% of the pups were born by 4 March (Stenson et al. 2002; Stenson et al. this meeting). Harp seals have not shown similar signs of adjusting the timing of births at the Front, but in years of very little ice cover they have responded by shifting their distribution to more suitable ice in areas further to the north as was observed in 2010 (Stenson and Hammill 2012).

The decline in ice cover in Atlantic Canada has been reported in other studies (e.g. Johnston et al. 2005, Friedlander et al. 2010, Soulen et al. 2012), but the rate of decline in ice cover that we have estimated is less than previously reported. This is primarily due to the fact that their time series began with the start of satellite telemetry datasets,1979, which was a period of higher than normal ice cover, whereas our dataset begins a decade earlier when ice conditions were lighter than those observed in the 1970s.

Other studies have reported identified a linkage between increased ice cover and a positive North Atlantic Oscillation (NAO) (Johnston et al. 2005; Friedlander et al. 2010). During positive NAO phases, a stronger than usual subtropical high pressure center and a deeper than normal polar low pressure system results in more and stronger westerly winter storms crossing the Atlantic Ocean on a more northerly track. This phase produces warmer and wetter winters in the eastern USA and Europe, and colder and drier winters in northern Canada and Greenland (Hurrell et al. 2003). We have not examined if this relationship between ice cover and NAO has been maintained.

It is important to account for changes in morality associated with changing ice conditions to capture the population dynamics of northwest Atlantic harp seals (Hammill and Stenson 2008). Unfortunately, it is not possible to measure natural mortality rates directly. In this study we developed a proxy based on anomalies in ice cover, associating very low ice cover with very high mortality. For example, ice cover during the winter of 1981 was among the lowest recorded in the time series, particularly in the Gulf. Although hunting mortality was high, natural mortality must have also been high to account for the apparent complete failure of this cohort (Sergeant 1991). Similar conditions may have occurred during the winters of 2010, 2011 and 2013, which were also among the winters with the lowest amount of ice cover. Although harvesting was not extensive, natural mortality related to poor ice conditions may have been high, particularly in 2011, when there was sufficient ice for pupping which subsequently disintegrated (Stenson and Hammill 2012). As a result, these cohorts may be under-represented in the population, which will have an impact on future productivity.

The Gulf is the southern limit of the seasonal pack ice, and there has been considerable inter annual fluctuation in ice cover. Since the early 1970s, there has been a general declining trend in ice cover. If this trend continues, then there will no longer be suitable ice available for harp seals to pup on in this area and as a consequence, the Gulf area will no longer comprise a significant component of the Northwest Atlantic harp seal population.

LITERATURE CITED

Bajzak, C.E., Hammill, M.O., Stenson G.B. and Prinsenberg. S. 2011. Drifting away: Implications of changes in ice conditions for a pack-ice breeding phocid, the harp seal (*Pagophilus groenlandicus*). Can. J. Zool. 89:1050-1062.

Burns, J.M., N. Skomp, N. Bishop, K. Lestyk, and M. Hammill. 2010. Development of aerobic and anaerobic metabolism in cardiac and skeletal muscles from harp and hooded seals. The Journal of Experimental Biology 213:740-748

Friedlaender, A.S., Johnston, D.W., and Halpin, P.N. 2010. Effects of the North Atlantic Oscillation on sea ice breeding habitats of harp seals (*Pagophilus groenlandicus*) across the North Atlantic. Prog. Oceanogr. 86(1–2): 261–266. doi:10.1016/j.pocean.2010.04.002.

Hammill, M.O. and G. B. Stenson. 2003. Harvest simulations for 2003-2006 harp seal management plan. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/068.

Hammill, M.O. and G. B. Stenson. 2008. Possible Impacts of Ice Related Mortality on Trends in the Northwest Atlantic harp seals population. ICES CM 2008/B:15

Hammill, M.O., Stenson, G.B., Doniol-Valcroze, T. and Mosnier, A. 2011. Northwest Atlantic Harp Seals Population Trends, 1952-2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/099. iv + 28 p.

Hurrell, J.W., Kushnir, Y., Ottersen, G., Visbeck, M., 2003. An overview of the North Atlantic Oscillation. In: Hurrell, J.W., Kushnir, Y., Ottersen, G., Visbeck, M. (Eds.). The North Atlantic Oscillation. Climatic significance and Environmental Impact, vol. 134. American Geophysical Union, Washington, DC, pp. 1–36.

IPCC. 2007. Fourth assessment report. International Panel on Climate Change (IPCC) Secretariat, c/o World Meteorological Organization, Geneva, Switzerland.

Johnston, D.W. Friedlaender, A.S. Torres, L.G. and Lavigne, D. M. 2005. Variation in sea ice cover on the east coast of Canada from 1969 to 2002: climate variability and implications for harp and hooded seals. Climate Research 29:209-222.

McCarthy, J. J., Canzani, O. F., Leary, N. A., Dokken, D. J., and White, K. S. (eds.). 2001. Climate change 2001: Impacts, Adaptation, and Vulnerability. Contribution of working group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Sergeant, D.E. 1991. Harp seals, man and ice. Can. Spec. Publ. Fish. Aquat. Sci. 114: 153 p.

Soulen, BK, Cammen, K., Schultz, T.F. and Johnston, D. W. 2012. Factors Affecting Harp Seal (*Pagophilus groenlandicus*) Strandings in the Northwest Atlantic. PLoS ONE 8(7): e68779. doi:10.1371/journal.pone.0068779 Editor: Gil Bohrer, The Ohio State University, United States

Stenson, G.B. and Hammill, M.O. 2012. Living on the edge: Observations of Northwest Atlantic harp seals in 2010 and 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/108 iv + 12p.

Stenson, G. B., M. O. Hammill, M. C. S. Kingsley, B. Sjare, W. G. Warren and R. A. Myers. 2002. Is there evidence of increased pup production in northwest Atlantic harp seals, Pagophilus groenlandicus? ICES J. Mar. Sci. 59:81-92.

Table 1. Qualitative Survival $_{ice}$(1-M_{ice}) index that has been incorporated into the harp seal assessment model since 2003. Years where no unusual mortality has been considered to have occurred are assigned a value of Survival $_{ice}$=1.

Year	$Survival_{ice}$
1969	0.6
1981	0.43
1998	0.94
2000	0.91
2002	0.88
2005	0.83
2006	0.99
2007	0.94
2010	0.59
2011	0.3
2012	0.83
2013	0.9

Table 2. Qualitative and quantitative indices for ice related survival. 1970 is an anomalous year with considerable missing data for the Front. This resulted in an index of 0 (i.e. 100% mortality), which is highly unlikely.

Year	Qualitative Survival	Quantitative index:Front	Quantitative index:Gulf	Quantitative index:combined
1969	0.43	0.34	0.37	0.35
1970	1.00	-	1.00	0.30
1978	1.00	1.00	0.73	0.92
1981	0.19	0.32	0.32	0.32
1996	1.00	1.00	0.78	0.93
1998	0.91	1.00	0.42	0.83
1999	1.00	1.00	0.79	0.94
2000	0.87	1.00	0.33	0.80
2002	0.83	1.00	0.59	0.88
2005	0.76	1.00	1.00	1.00
2006	0.99	1.00	0.52	0.86
2007	0.91	1.00	0.49	0.85
2010	0.41	1.00	0.05	0.71
2011	0.3	0.35	0.36	0.35
2012	0.83	1.00	0.22	0.77
2013	0.9	1.00	0.24	0.77

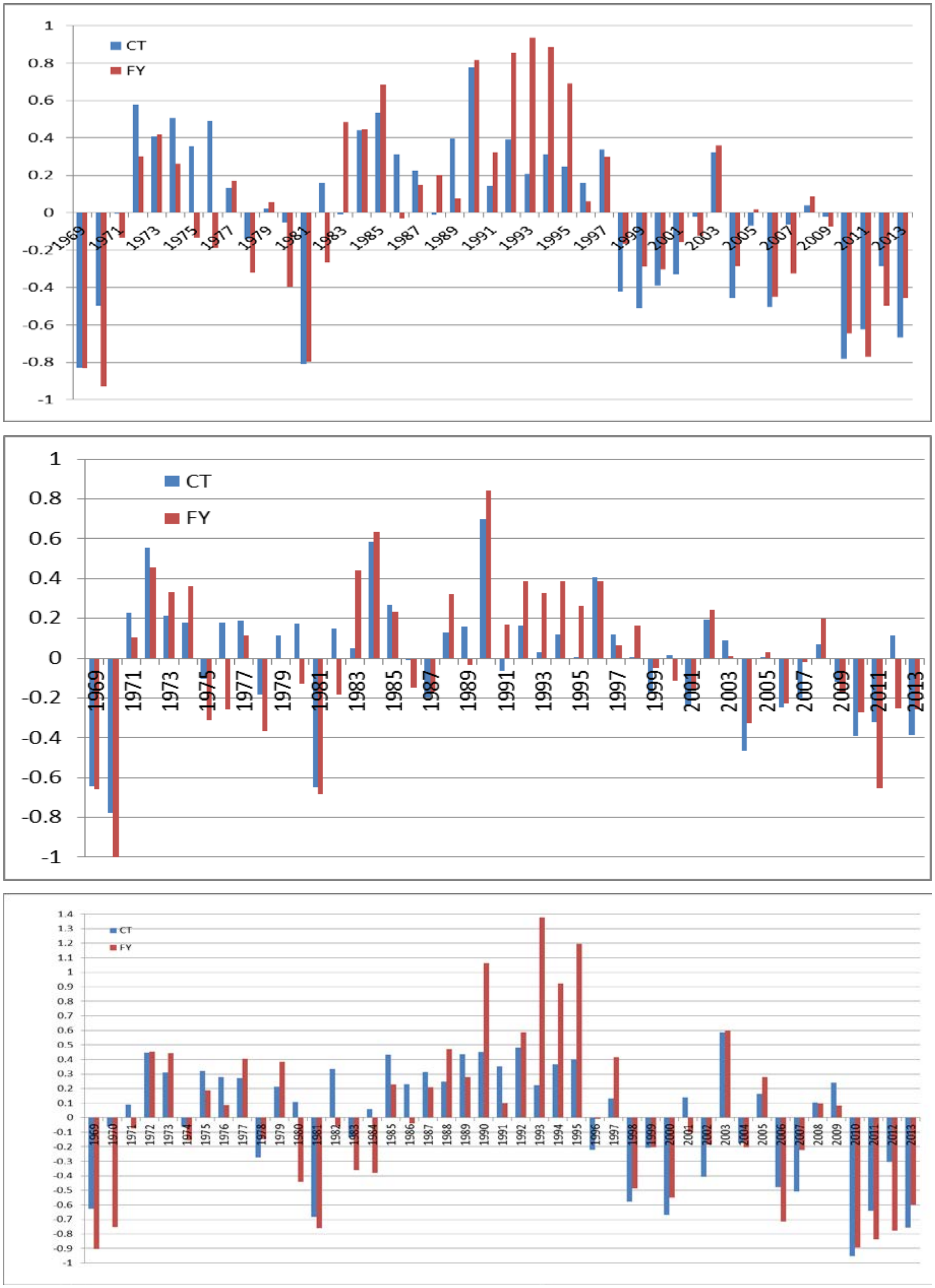
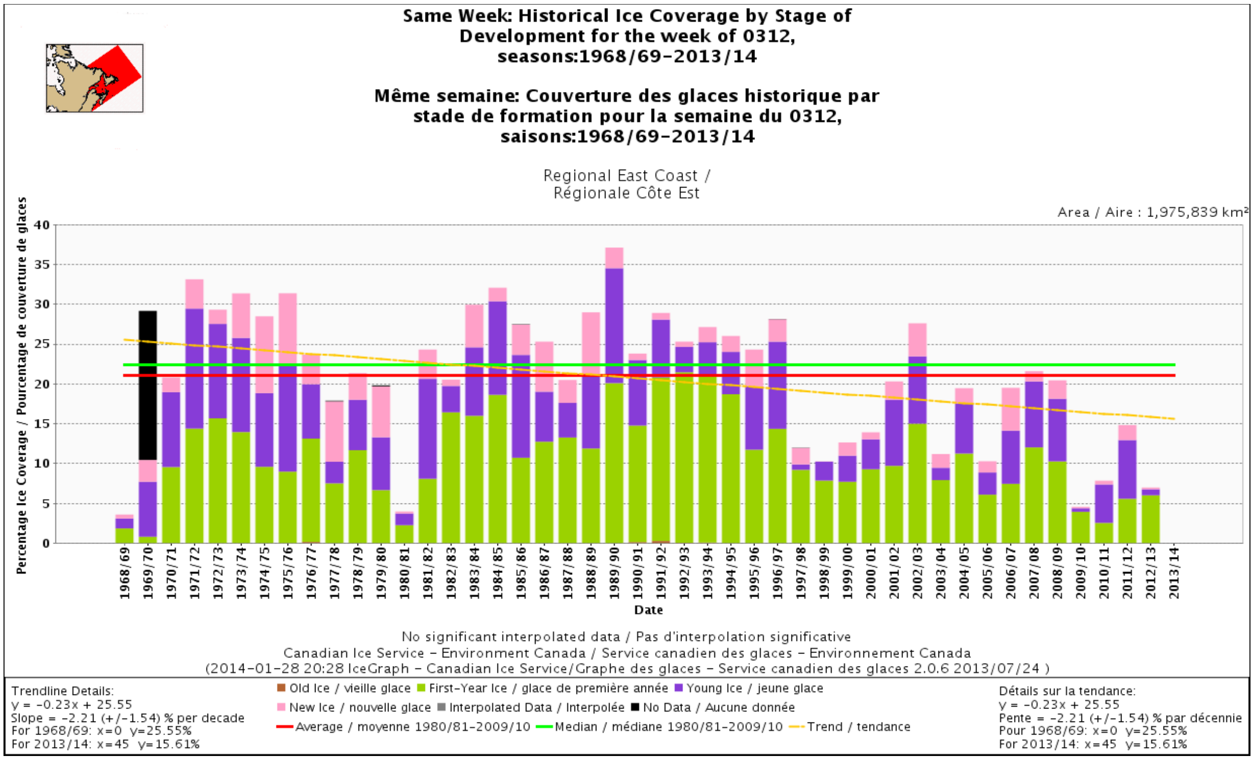


Figure 1. Ice anomalies of total ice concentration (CT) and First Year (FY) ice from Environment Canada ice data for the Atlantic zone (top), Labrador Sea (Front)(middle) and Gulf of St Lawrence (bottom)



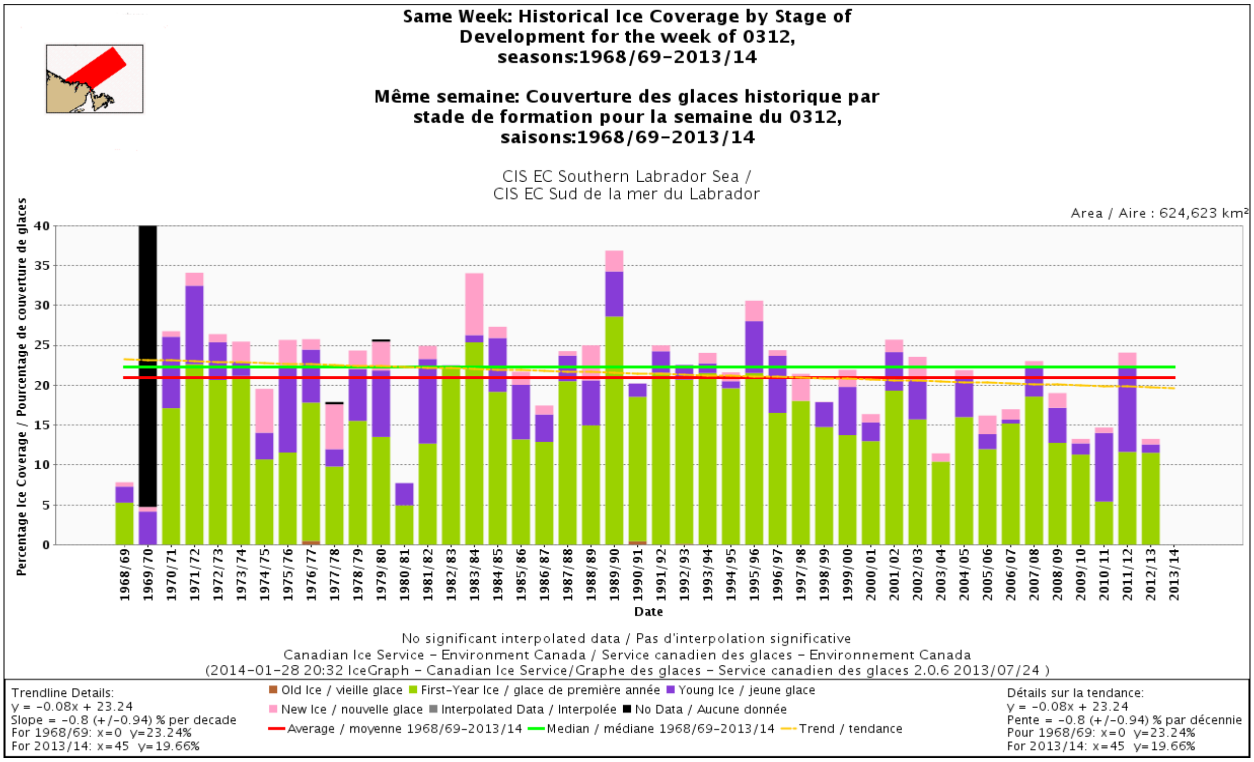


Figure 2. Changes in the amount of first year, young, new ice and total cover during the week of 12 March for Atlantic Canada and the Front.

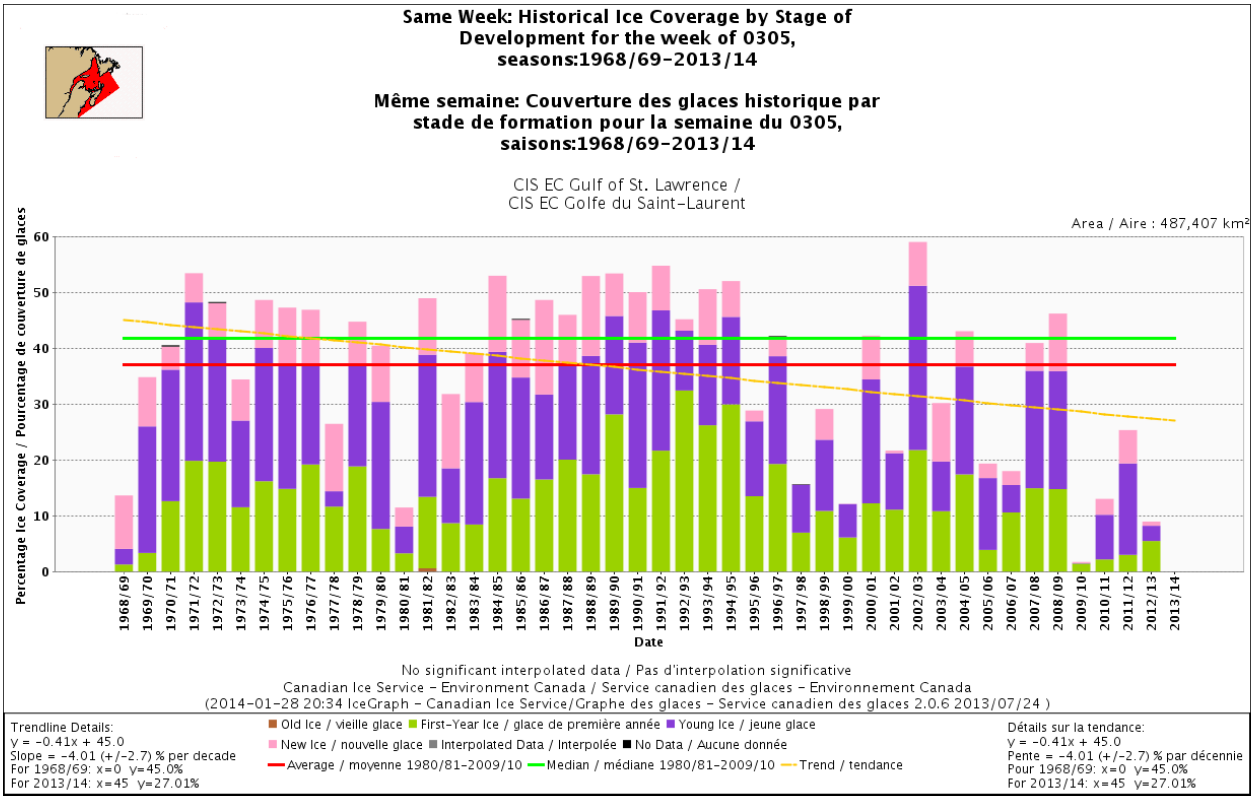


Figure 3. Changes in the amount of first year, young, new ice and total cover during the week of 5 March in the Gulf of St Lawrence.

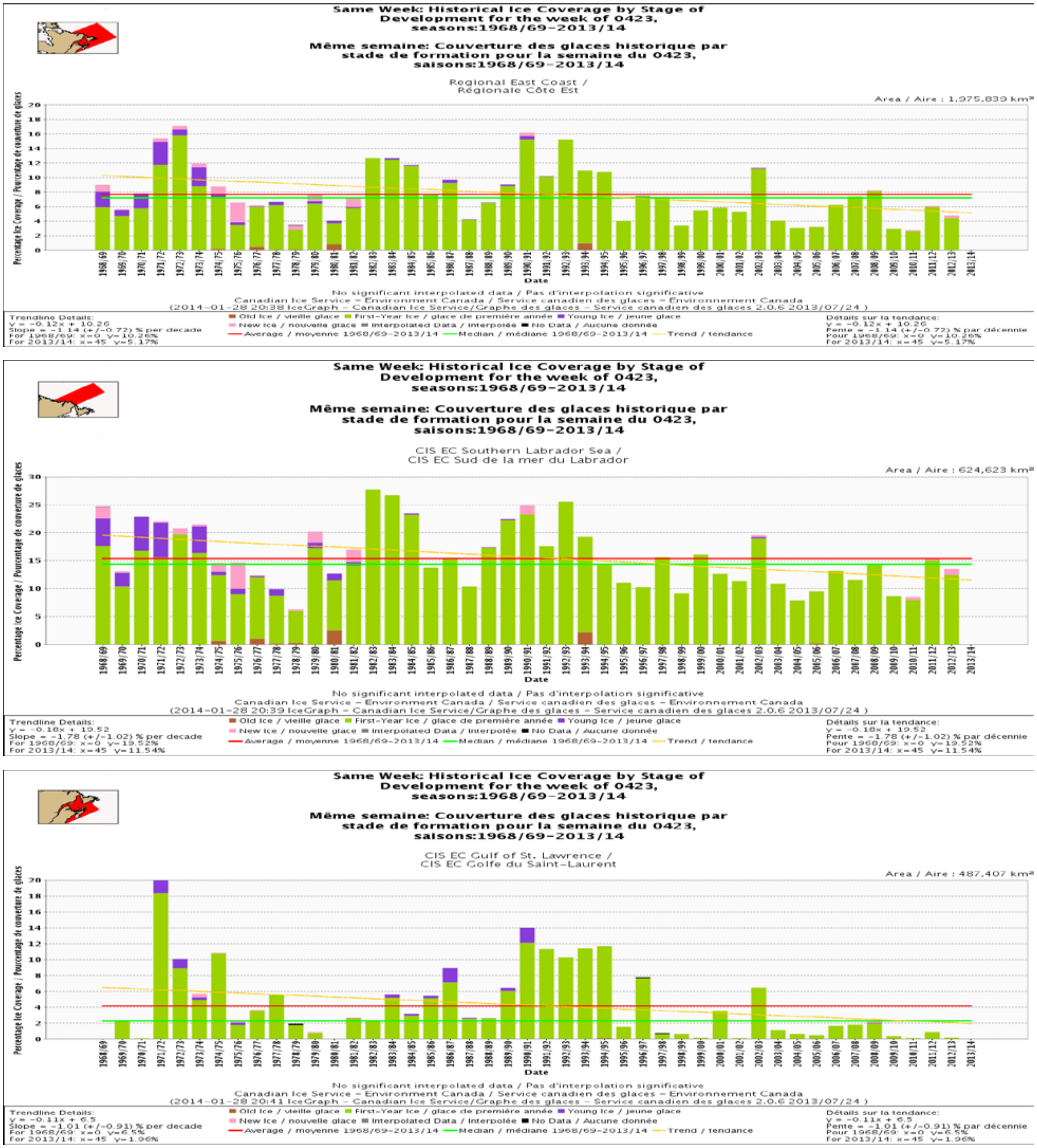


Figure 4. Changes in the amount of first year, young, new ice and total cover during the week of 23 April in the Atlantic zone, at the Front and in the Gulf.

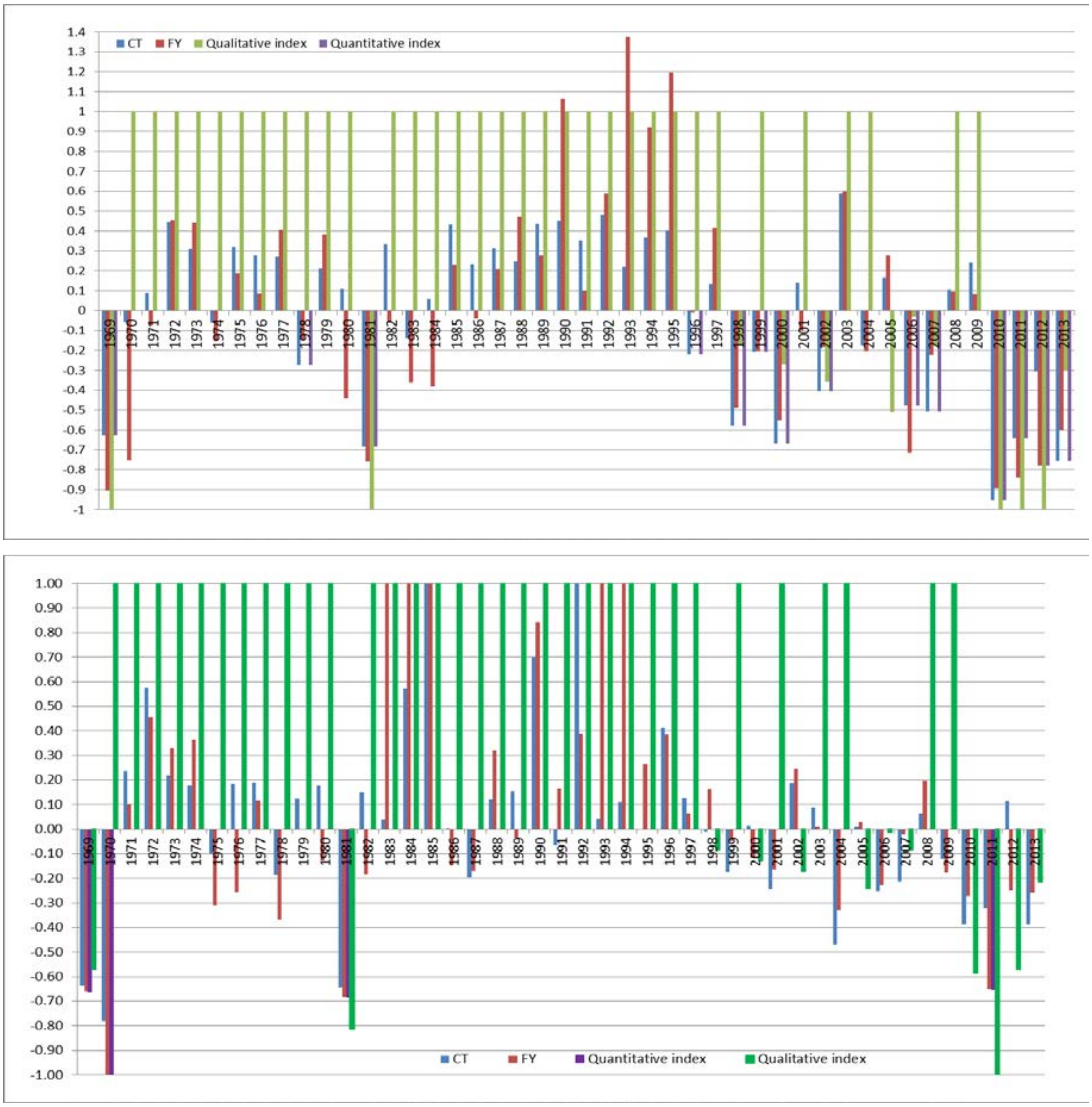


Figure 5 Total ice-cover and first-year ice anomalies for the week 5 March 1969-2013 in the Gulf of St Lawrence (top) and for the week of 12 March, 1969-2013 at the Front (bottom) and the qualitative ice survival index (Table 1), expressed as mortality (1-S_{ice}). The index, which was assigned as mortality for the entire herd has been, partitioned into Gulf and Front mortality assuming that the first 30% of the mortality occurs in the Gulf.