Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

**C S A S**

**Canadian Science Advisory Secretariat**

**S C C S**

**Secrétariat canadien de consultation scientifique**

**Research Document 2008/077**

**Document de recherche 2008/077**

Not to be cited without
Permission of the authors *

Ne pas citer sans
autorisation des auteurs *

# Abundance of Northwest Atlantic harp seals (1960 – 2008)

# Abondance du phoque du Groenland du nord-ouest Atlantique (1960 - 2008)

M. O. Hammill[1] and Garry Stenson[2]

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

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

* This series documents the scientific basis for the evaluation of fisheries resources 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.

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

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

ISSN 1499-3848 (Printed / Imprimé)


Canada

## ABSTRACT

The impacts of different catch options on the Northwest Atlantic harp seal population were examined to provide science advice for the 2009 harp seal hunt, using the same model formulation reviewed by the National Marine Mammal Peer Review committee at the 2005 assessment. Catch data from the Canadian and Greenland harvests were updated, along with information on ice conditions encountered over the last 3 years. Reproductive rates were assumed not to have changed since the 2005 assessment. Pup production has increased from an estimated 609,900 (se=22,200) in 1960 to 982,300 (se=118,300) in 2005 then declined slightly to 955,900 (se=153,400) animals in 2009. The total population has increased from 2.74 million (se=100,000) in 1960 to a maximum of 5.71 million (se=796,200) in 2005 and then declined slightly to 5.61 million (se=1.06 million) in 2009. Catch options harvesting more than 270,000 animals in 2009 had a more than 20% probability that the population would fall below the Management objective level of $N_{70}$ or 4.1 million animals. Catch options taking 270,000 or 250,000 animals would have a greater than 20% probability of the population declining below $N_{70}$ after the 2010 hunt, while a catch option of 200,000 animals would fall below $N_{70}$ after the 2011 hunt. Although there is considerable uncertainty associated with the predicted impacts of different TAC levels on the population, five years after the last assessment, the cumulative impact of high harvests over the past decade is the main factor driving the current population trends.

## RÉSUMÉ

Les incidences des différentes possibilités de prise dans la population du phoque du Groenland de l'Atlantique Nord-Ouest ont été examinées afin de fournir des conseils scientifiques pour la chasse au phoque du Groenland en 2009 au moyen de la même formulation modèle examinée par le Comité national d'examen par des pairs sur les mammifères marins lors de l'évaluation de 2005. Les données sur les captures lors des récoltes au Canada et au Groenland ont été mises à jour, ainsi que l'information sur l'état des glaces au cours des trois dernières années. On présume que les taux de reproduction sont demeurés inchangés depuis l'évaluation de 2005. La production de nouveau-nés a augmenté d'un niveau estimé à 609 900 (erreur type = 22 200) en 1960 à 982 300 (erreur type = 118 300) en 2005, pour ensuite diminuer légèrement à 955 900 (erreur type = 153 400) animaux en 2009. La population totale a augmenté de 2,74 millions (erreur type = 100 000) en 1960 à un maximum de 5,71 millions (erreur type = 796 200) en 2005, pour ensuite baisser légèrement à 5,61 millions (erreur type = 1,06 million) en 2009. Les possibilités de prises pour capturer plus de 270 000 animaux en 2009 comportaient une probabilité de plus de 20 p. 100 que la population tombe en dessous du niveau de l'objectif de gestion de $N_{70}$ ou 4,1 millions d'animaux. Les possibilités de prises pour capturer 270 000 ou 250 000 animaux comporteraient une probabilité de plus de 20 p. 100 que la population chute en dessous de $N_{70}$ après la chasse de 2010, alors qu'une possibilité de prises de 200 000 animaux provoquerait une chute en dessous de $N_{70}$ après la chasse de 2011. Bien qu'il y ait une incertitude passablement considérable liée aux incidences prévues des différents niveaux de Total autorisé des captures (TAC) sur la population, cinq ans après la dernière évaluation, l'incidence cumulative des niveaux de captures élevés au cours de la dernière décennie constitue le principal facteur qui module les tendances de population actuelles.

# INTRODUCTION

Harp seals (*Pagophilus groenlandicus*) have been managed under an Objective Based Fisheries Management (OBFM) approach since 2003 (Anon. 2003a). This framework has two precautionary ($N_{70}$ and $N_{50}$) and a limit ($N_{30}$) reference levels which are established at 70%, 50% and 30% of the largest population size known (Hammill and Stenson 2007). Harvest levels are established that maintain at least an 80% probability that the population will remain above $N_{70}$ for the duration of the management plan. If the population falls below $N_{70}$, but is above $N_{50}$, then harvest levels are to be set that ensure an 80% probability that the population will move above $N_{70}$ within 10 years (Anon 2008). Under the 2003-2005 management plan, Total Allowable Catches (TAC) were set for a three year period i.e. the duration of the plan. In 2005, industry requested that the TAC be set annually in the 2006-2010 management plan.

Northwest Atlantic harp seals whelp on the pack ice off the northeast coast of Newfoundland (Front), in the southern Gulf of St. Lawrence, normally near the Magdalen Islands (SGulf), and in most years off the Lower North Shore of the northern Gulf of St. Lawrence (Mecatina patch). The SGulf patch normally forms in late February and peak pupping occurs around 1-3 March. Peak pupping in the northern Gulf and off Newfoundland occurs approximately 1 week later. Pups are weaned 12-14 days after birth. The pups require stable ice for nursing, as well as for resting during the post-weaning fast. Harp seals begin to enter the water about age 28 days. They develop foraging skills during the subsequent days/weeks, and continue to need access to some ice to haulout and rest on as animals begin to move north. A lack of unsuitable or insufficient ice during a period lasting into April appears to result in increased pup mortality. This is thought to have occurred with increasing frequency over the past decade, particularly in the southern Gulf (e.g. DFO 2007).

During March 2008, the harp seal herd was surveyed to obtain new estimates of pup production. Analyses of photographs are currently underway, and a complete update is not expected until the spring. However, scientific advice is required to ensure that the 2009 quota will be consistent with the management plan and the population will remain above the precautionary reference level. Here, we examine the impacts of different harvest and natural mortality scenarios on the NW Atlantic harp seal population based on the population model, reproductive rates, and survey estimates reviewed by the National Marine Mammal Peer Review Committee in 2005 (Hammill and Stenson 2005, DFO 2005a). In the current analysis, the catch data have been updated to include recent harvests in Canada (2008) and Greenland (2006) (Stenson 2008) and the proportion of young of the year (YOY) in the Canadian commercial harvest has been increased to reflect current hunting patterns (Stenson 2008). The reproductive rates used in 2005 were extended forward and assumed to remain constant.

## MATERIALS AND METHODS

There are 2 models associated with providing advice. The first is a fitting model**,** which is used to estimate the current and past population size. The second model is a projection model that takes the basic parameters estimated from the fitting model, and uses these parameters to project into the future under different harvest and environmental scenarios. The fitting model uses 1) total age specific human induced removals and 2) annual estimates of age specific pregnancy rates to estimate pup production. The resulting prediction of pup production is then compared to independent estimates of pup production. The model minimizes the difference between the predicted and survey estimates by adjusting the initial population size, which is the size of the population in 1960 and the 1+ (one year of age and older) mortality rate (M). The model draws from the uncertainty associated with the estimates of pup production and reproduction rates, minimizes the differences and then repeats the process to produce an estimate of mean Initial population size and M and a standard error associated with these estimates. These estimates are highly correlated.

The values for initial population size and M are used to estimate current population and are also used in the model to project forward to predict future population trends. The Projection model predicts the impact of future catch scenarios based upon estimates of current population (abundance at age) and natural mortality assuming:

- Reproductive rates remain constant
- Mortality from bycatch, the proportion of seals struck and loss, and catches in the Canadian Arctic remain constant
- Greenland catches may vary between 70,000 and 100,000 (uniform distribution)
- Ice related mortality will vary from 0 – 30% of pup production with an average of 12%
- Pup mortality is fixed at three times 1+ mortality and remains unchanged.

### ***Model structure***

The basic model has the form:

$$n_{a,t} = ((n_{a-1,t-1} * w) - c_{a-1,t-1})\, e^{-(\gamma)m} \qquad (1)$$

for a =1

$$n_{a,t} = (n_{a-1,t-1}e^{-m/2} - c_{a-1,t-1})e^{-m/2} \qquad (2)$$

for 1 < $a$ < $A$,

$$n_{A,t} = (n_{A-1,t-1}e^{-m/2} - c_{A-1,t-1})e^{-m/2} \qquad (3)$$

for $a$ = $A$, where $A$-1 is taken as ages $A$-1 and greater, and for $a$ = 0;

$$n_{0,t} = \sum_{a=1}^{A} n_{a,t}P_{a,t} \qquad (4)$$

where $n_{a,1}$ = population numbers-at-age $a$ in year $t$,
$c_{a,t}$ = the numbers caught at age $a$ in year $t$,
$P_{a,t}$ = per capita pregnancy rate of age a parents in year $t$,

assuming a 1:1 sex ratio. P is expressed as a Normally distributed variable, with mean and standard error taken from the reproductive data

*m* = the instantaneous rate of natural mortality.

$\gamma$ = a multiplier to allow for higher mortality of first year seals. Assumed to equal 3, for consistency with previous studies.

*w* = is the proportion of pups surviving an unusual mortality event arising from poor ice conditions or weather prior to the start of harvesting.

*A* = the 'plus' age class (i.e. older ages are lumped into this age class and accounted for separately, taken as age 25 in this analysis).

The model was adapted to function within an EXCEL spreadsheet and incorporated uncertainty in the parameters using an EXCEL add in called @Risk (@Risk , Palisade Corporation 2000). @Risk allows statistical distributions (*e.g.* Normal, Negative binomial, Triangle, Uniform) to be associated with parameters within the spreadsheet. The parameters can then be resampled repeatedly (Monte Carlo resampling) from within the distributions to estimate the impact of variability in input parameters.

To capture some of the variability in these parameters, single parameter values were replaced by statistical distribution functions with mean and standard error estimated from the available data. In the current fitting of the model, reproductive rates, initial population size and pup survey estimates were allowed to vary. For each set of pup production estimates the model was refitted by calculating new estimates of initial population size and adult mortality rates.

A total of 10,000 simulations were completed to fit the model to the aerial survey estimates. The resulting values for the mean initial population size (±SE) and M (±SE) were used in the projection model to examine the impacts of different harvest scenarios. The effects of different harvest scenarios were examined by adjusting different catch levels and running the model to complete 1000 simulations in order to estimate the uncertainty associated with each scenario.

## ***Data Input***

*Pup production estimates*

The model was fit to eight independent estimates of pup production (Appendix 1) obtained in 1978, 1979, 1980 and 1983 based on mark-recapture experiments (Bowen and Sergeant, 1983, 1985; revised in Roff and Bowen 1986) and aerial survey estimates for 1990, 1994, 1999 and 2004 (Stenson et al. 1993, 2002, 2003, 2005).

*Catches*

Recent catches were taken from Stenson (2008). Reported landings vary considerably between years owing to a combination of market conditions and ice conditions that affect access to the herd. Harvest levels from the Canadian commercial hunt, Greenland and Canadian subsistence harvests were corrected for unreported harvests (i.e. seals struck and killed but not landed or reported) and were incorporated into the model along with estimates of bycatch (Stenson 2005; Sjare et al. 2005). It was assumed that 95% of the

YOY and 50% of the animals aged 1+ years in the Canadian commercial hunt (Front and Gulf) were recovered. 50% of all animals killed in the Greenland and Canadian Arctic harvests were assumed to be recovered and reported (Stenson 2008).

The age structure of older seals and seals caught in Greenland and the Canadian Arctic was assumed to be the same as reported by Stenson (2008).

*Pregnancy rates*

The age specific pregnancy rates were based upon samples obtained between 1954 and 2001 (Sjare et al. 2004). All seals less than four year of age were considered immature, while seals eight years of age and older were considered fully recruited to the breeding population and grouped together. Pregnancy rates were smoothed using a nonparametric regression estimator to estimate the expected pregnancy rates to 1999 (Hammill and Stenson 2005). For 2000 to 2005, the mean and SE of reproductive rate data from 2000-2004 were incorporated into the model and were extrapolated forward (Appendix 2).

*Climate variability*

Variable environmental conditions have likely had an impact on mortality rates among years.

Specifically, poor ice conditions and extensive storm activity appear to have resulted in higher than normal mortality rates for pups (Sergeant 1991). This has most often occurred in the Gulf of St. Lawrence, where approximately 25-35% of the pups are born, but can also occur off Newfoundland. Sergeant (1991) identified 1981 as a particularly poor ice year that may have resulted in substantial pup mortality in all areas. Between 1981 and 1997, unusually stable ice conditions were observed, but since then there have been several winters of below normal ice cover, particularly in the southern Gulf of St. Lawrence (Appendix 4). Based on total ice extent, ice thickness, storms, reports of dead pups and on ice observations, we have assumed that increased mortality has occurred in 6 of the 11 years since 1998 (Appendix 4). Although it is difficult to quantify the amount of increased mortality during these years compared to ‘normal’ ice years, it was assumed that increased mortality affected between 6 and 25% of the total pup production. The majority of this mortality has occurred in the southern Gulf, accounting for 20% (1998) to 80% (2007) of pup production, additional mortality was also observed at the Front and in the northern Gulf occasionally (e.g. 2005).

***Projections:***

Fisheries and Aquaculture Management requested that four harvest scenarios be examined within the context of a five-year management plan that ends in 2010. Therefore, 3 years of harvest were investigated. These scenarios are:

| Scenario | 2009 | 2010 | 2011 |
|---|---|---|---|
| A | 270,000 | 270,000 | 270,000 |
| B | 300,000 | 250,000 | 170,000 |
| C | 200,000 | 200,000 | 200,000 |
| D | 300,000 | 300,000 | 300,000 |
| E | 250,000 | 250,000 | 250,000 |

A fifth scenario (E) was included with a harvest of 250,000 for 3 years starting in 2009.

Each of the projections was run assuming: that the level of subsistence catch in the Canadian Arctic, bycatch in fishing gear and the age structure of the harvest remained unchanged; and the age composition of the Canadian commercial catch was changed from 90% young of year (YOY) to 95% YOY to reflect the structure observed in the catch (Stenson 2008).

We assumed that extra mortality related to poor ice conditions in 2009 and future years could be described by a uniform distribution with a mean value of 12% but varies equally between 0 and 30% (0, 0.1, 0.30, 0.20, 0). The values in the uniform distribution were for additional mortality in each year of the projections and this mortality occurs before the hunt begins.

An additional source of uncertainty relates to reported harvest rates in Greenland. Greenland harvest has varied greatly in recent years with reported harvests ranging from as low as 70,000 in 2004 to as high as 106,000 in 2000. The Greenland harvest is not limited by quota; therefore we entered the Greenland harvest into the model as a uniform function with a range of 70,000 to 100,000 for a mean harvest of 85,000 animals.

## RESULTS

There was a strong correlation (r=0.996) between the estimated initial population size (mean=2.74 million, se=100,000) and the estimated 1+ mortality rate (mean=0.054, se=0.0037)(Fig. 1).

Pup production has increased from an estimated 609,900 (se=22,200) in 1960 to 982,300 (se=118,300) in 2005 then declined slightly to 955,900 (se=153,400) animals in 2009 (Fig. 2). The total population has increased from 2.74 million, (se=100,000) in 1960 to a maximum of 5.71 million (se=796,200) in 2005 and then declined slightly to 5.61 million (se=1.06 million) in 2009 (Fig. 2).

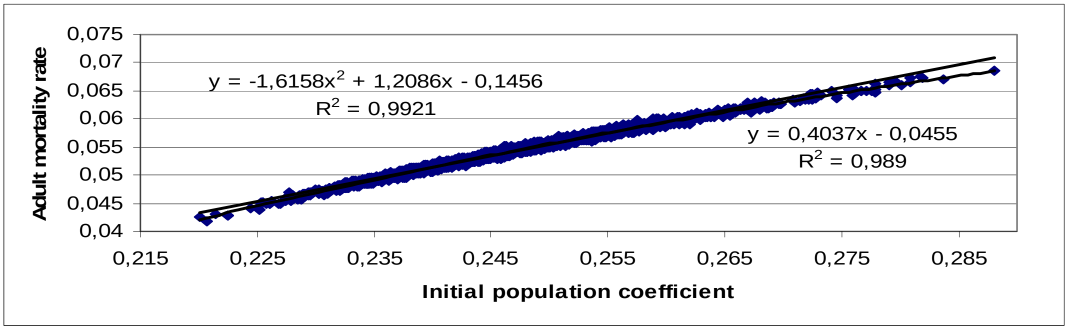
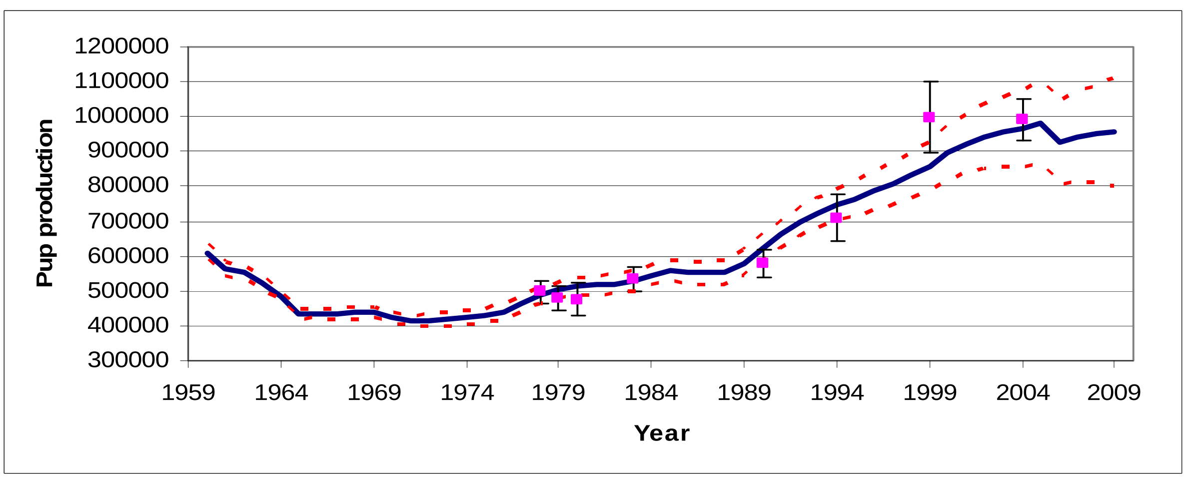



Figure 1. Relationship between adjustable parameters (Initial population size coefficient and 1+ mortality coefficient) used to fit the population model to the pup survey data.

Scenarios with a 2009 harvest of 300,000 animals (300k) did not respect the management plan, resulting in the population falling below $N_{70}$ after the 2009 harvest had been completed (Fig. 3). Harvests of 270,000 and 250,000 could be carried out in 2009 and would allow the population to remain above $N_{70}$ after the 2009 hunt, but would result in L20 falling below the precautionary level (N70) after the 2010 hunt. A harvest of 270,000 animals in 2009, may require a substantial reduction to less than 175,000 animals in 2010 to respect the management plan. A harvest of 250,000 animals in 2009 would only require reducing the TAC to 225,000 animals in 2010 to respect the plan. An annual harvest of 200,000 could be carried out in 2009 and 2010 and still respect the management objective.



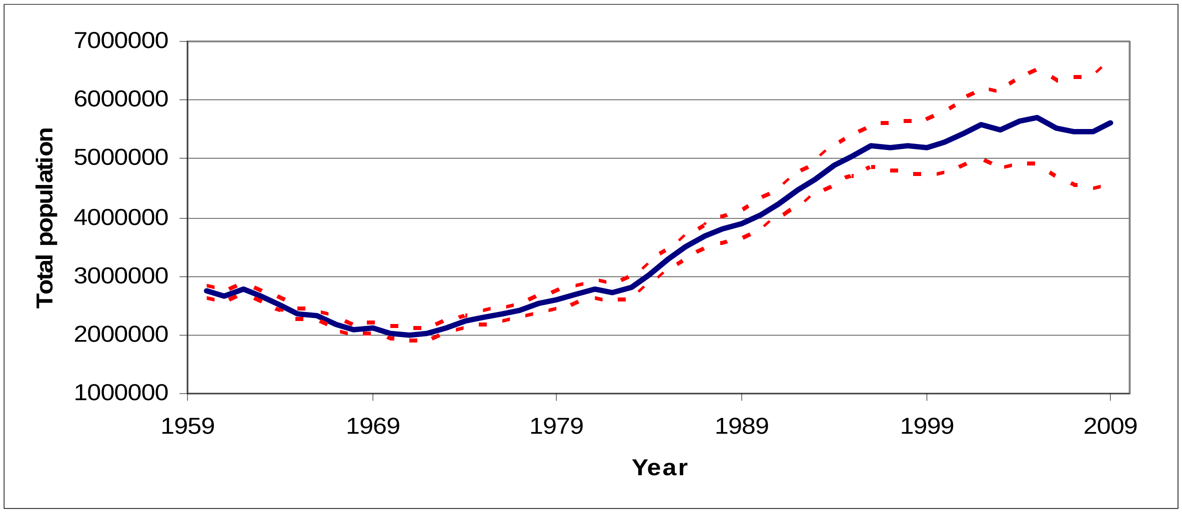
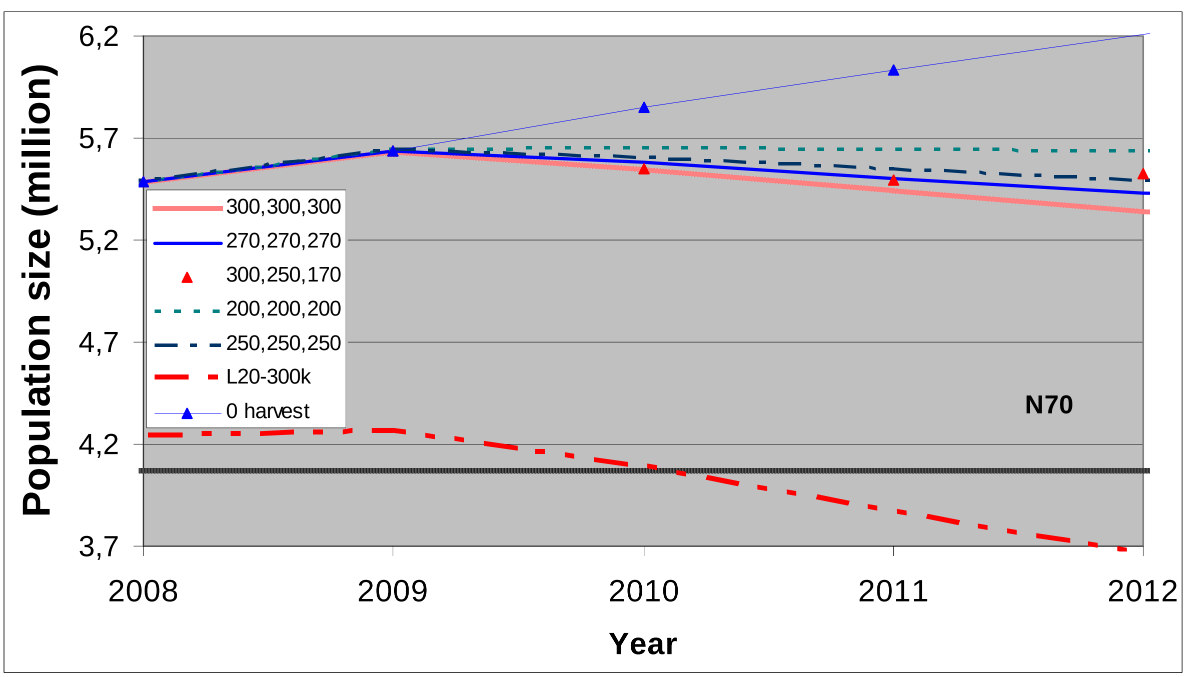



Figure 2. Estimated trends in pup production (top) and total abundance (bottom) of the Northwest Atlantic harp seal population between 1960 and 2009. Mean ±se

## DISCUSSION

For these runs, the population model examined at NMMPR in 2005 was updated by extrapolating forward reproductive rates examined in 2005, as well as including new catch data and environmental conditions experienced since then. New reproductive data will be presented at the next assessment along with the review of the 2008 survey data. Preliminary analyses suggest that reproductive rates have declined over the last decade and that this trend continues (Sjare and Stenson unpublished).



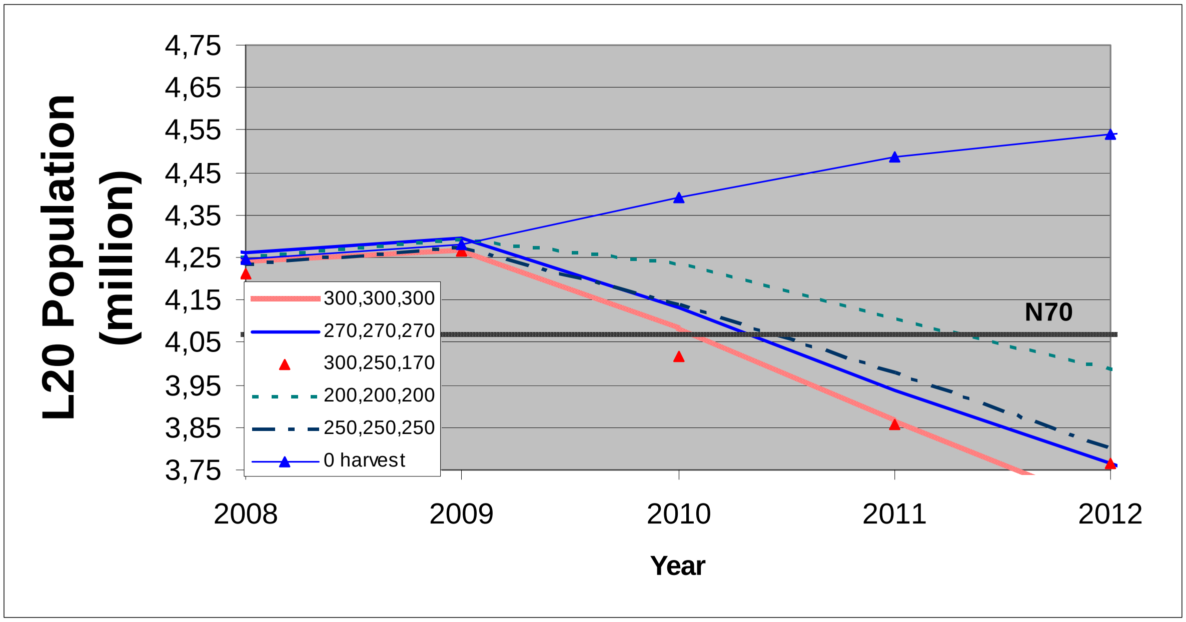



Figure 3. Estimated population trajectories under different harvest scenarios ('000s). The top graph presents changes in the mean population size, with the L20 line for a harvest of 300,000 for 3 years. The bottom graph presents the L20 trajectories for the same harvest levels, where there is an 80% probability that the population is greater than L20. A 2009 TAC greater than 270,000 leaves the 2010 population at a less than an 80% probability of remaining above N70 (4.1 million) which is required under the current management plan in 2010.

Five harvest scenarios were examined. Only scenarios with a TAC of 270,000 animals or less in the first year would respect the management plan in 2009. A TAC of 250,000 animals would have to be reduced to 225,000 in 2010 to respect the management plan while a TAC of 200,000 or fewer animals would respect the management plan until the end of the 2010 season.

This population was last surveyed in 2004, and assessed in 2005. A new survey was completed in 2008, and it will be reviewed in 2009. The assessment of this population is somewhat unique in the department in that surveys are only conducted every 4-5 years, not annually as in most groundfish stocks. Consequently, there is considerable uncertainty associated with the population projections which increases with projections that occur up to 5 years into the future. This is due to uncertainties in the aerial survey estimates, the reported Canadian catches, Greenland catches, ice conditions and reproductive rates. For example the coefficient of variation around the estimate (100 *se/mean) increases from 24% in 2004 to 32% in 2009 and this is reflected in the widening of the 80% percentiles as we project from the last survey in 2004. Failure to consider the importance of uncertainty in management decisions has been recognized as contributing to the failure of North Atlantic cod stocks and some have argued that our current treatment of the uncertainty related to harp seal management is not sufficiently risk adverse (Leaper and Mathews 2008). The recent financial crisis is an excellent example of not properly evaluating risk and the uncertainty surrounding risk, in an area where considerable more resources are deployed than in harp seals.

Table 2. Quota, and reported harvest levels of Northwest Atlantic harp seals over the last 5 years.

| | Canada | | | Greenland |
|---|---|---|---|---|
| | Quota | Catch | % | |
| 2003 | 325,000 | 289,512 | 89.1 | 68,499 |
| 2004 | 350,000 | 365,971 | 104.6 | 70,585 |
| 2005 | 319,517 | 329,829 | 103.2 | 91,361 |
| 2006 | 335,000 | 354,867 | 105.9 | N/A |
| 2007 | 270,000 | 224,745 | 83.2 | N/A |
| 2008 | 275,000 | 217,636 | 79 | N/A |
| Av. | 320,000 | 312,985 | 97 | 76,815 |

Including new (2008) survey estimates in the analysis will reduce the uncertainty around the current population size and will create some flexibility with respect to the evaluations of TAC scenarios for the 2010 season. However, much of the change in the trajectory of the northwest Atlantic harp seal population is being driven by the inertia associated with harvests experienced over the last 5-10 years. During the 12 year period from 1984 to 1995, the reported Canadian harvest removed on average 52,000 animals per year. Between 1996 and 2008 an average of 265,000 animals were removed annually for a total of about 3.4 million seals (table 2). The commercial harvest is directed towards YOY and therefore, the impacts of the harvest in any particular year will not be detected in the population until at least 5 years later, when the harvested cohorts reach maturity and begin contributing to the breeding population of animals. As a result there is considerable inertia in the population trajectory as past TAC decisions and catches work themselves through the population. This can be illustrated in a simulation using a control population subject to an annual harvest of 200,000 animals beginning in 2009 and continuing into the future. If we apply a harvest of 500,000 animals to a single year (2009), and then return to an annual harvest of 200,000 animals, we see that there is absolutely no difference in the pup production trajectories during a period of 5 years. After 5 years, the two simulated pup productions diverge markedly as the cohort that was subjected to a very high harvest matures and enters into the breeding component (Fig. 4). Over the last five years, the Canadian reported harvest has removed an average of 313,000 animals per year. The population has not been exposed to such high harvests since the 1970's, and their effects are currently working themselves through the population (Table 2).

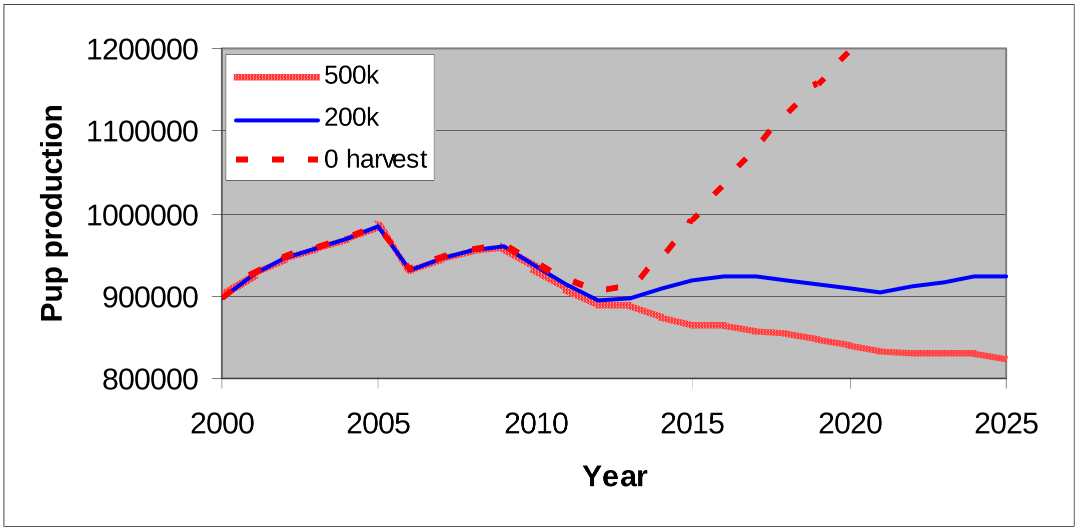



Figure 4. Changes in pup production trajectories when there is no Canadian commercial harvest, an annual harvest of 200,000, and if a harvest of 500,000 animals is applied in a single year, followed by annual harvests of 200,000 animals.

In addition to the Canadian catch over the past 5-10 years, large numbers of harp seals have also been taken in Greenland (Table 2). An average of 81,500 seals, mainly greater than one year of age, have been taken annually over the past decade (Stenson 2008). Given the age structure of the catch and the proportion of seals struck but not recovered, this level of catch has an important impact on the trajectory of the population.

The Northwest Atlantic harp seal population is currently estimated at 5.61 million (se=1.06 million), based upon an aerial survey to estimate pup production in 2004, assuming no change in reproductive rates since the last assessment and taking into account changes in reported harvests since 2005. As a result there is considerable uncertainty associated with this estimate. To respect the management objective of maintaining an 80% probability that the population remains above N70, the TAC must be set at 270,000 animals or lower. A TAC greater than this would necessitate a substantial reduction in the TAC for 2010 if the management plan was to be respected. Actual quotas in 2010, however, will depend upon the results of the new assessment expected in 2009, as well as recent Greenland catches and the 2009 catches in the Canadian hunt. At the same time, if the management plan is to be respected, it is unlikely that the TAC can be increased substantially owing to the high harvests that have occurred over the last decade and the inertia associated with these harvests.

## LITERATURE CITED


Anonymous. 2003a. Atlantic seal hunt 2003-2005 management plan. 34 pp. Available at: http://www.dfo-mpo.gc.ca/seal-phoque/report-rapport_e.htm

Anonymous. 2003b. Report of the workshop to develop improved methods for providing harp and hooded seal harvest advice. ICES2003/ACFM:13.

Anonymous. 2008. Atlantic seal hunt 2006-2010 management plan. 34 pp. Available at: http://www.dfo-mpo.gc.ca/seal-phoque/report-rapport_e.htm

Baker, C. S. and P. J. Clapham. 2004. Modelling the past and future of whales and whaling. TRENDS Ecol. Evol. 19:365-371.

Bowen, W. D. and Sergeant, D. E. 1983. Mark-recapture estimates of harp seal pup (*Phoca groenlandica*) production in the northwest Atlantic. Can. J. Fish. Aquat. Sci. 40(6):728-742.

Bowen, W. D. and Sergeant, D. E. 1985. A mark-recapture estimate of 1983 harp seal pup production in the northwest Atlantic. Northwest Atl. Fish. Organ. SCR Doc. 85/I/1, Ser., N935. 14p.

DFO. 2005a. Proceedings of the meetings conducted by the National Marine Mammal Peer Review Committee from February to May 2005. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2005/001.

DFO. 2005b. Stock Assessment of Northwest Atlantic Harp Seals (*Pagophilus groenlandicus*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/037.

DFO. 2007. A Review of Ice Conditions and Potential Impact on Harp Seal Neonatal Mortality in March 2007. DFO Can. Sci. Advis. Sec. Sci. Resp. 2007/008.

Hammill, M.O. and G.B. Stenson. 2003a. Application of the Precautionary Approach and Conservation Reference Points to the management of Atlantic seals: A Discussion Paper. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/067. 23 p. http://www.dfo-mpo.gc.ca/csas/Csas/Home-Accueil_e.htm

Hammill, M.O. and G.B. Stenson. 2003b. Harvest Simulations for 2003-2006 Harp Seal Management Plan. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/068. 29 p. http://www.dfo-mpo.gc.ca/csas/Csas/Home-Accueil_e.htm

Hammill, M.O. 2005. Abundance of Northwest Atlantic grey seals in the Gulf of St. Lawrence and along the Nova Scotia Eastern Shore. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/036.

Johnston, D.W. A. S. Friedlaender, L. G. Torres, D. M. Lavigne. 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.

Leaper, R. and J. Mathews. 2008. Implications of uncertainty for Canada's commercial hunt of harp seals (*Pagophilus groenlandicus*). Nature Precedings : hdl:10101/npre.2008.1798.1

Palisade Corporation. 2000. Risk Optimizer: Optimization with simulation for Microsoft EXCEL. 303 pp. Palisade Corporation. Newfield, NY USA.

Roff, D. A. and Bowen, W. D. 1986. Further analysis of population trends in the northwest Atlantic harp seal (*Phoca groenlandica*) from 1967 to 1985. Can. J. Fish. Aquat. Sci. 43:553-564.

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

Shelton, P. A., G. B. Stenson, B. Sjare, and W. G. Warren. 1996. Model estimates of harp seal numbers-at-age for the Northwest Atlantic. NAFO Sci. Coun. Studies. 26: 1-14.

Sjare, B. and G.B. Stenson. 2002. Estimating struck and loss rates for harp seals (*Pagophilus groenlandicus*) in the Northwest Atlantic. Mar. Mamm. Sci. 18: 710-720.

Sjare, B. G.B. Stenson and B. Healey. 2004. Changes in the Reproductive Parameters of Female Harp Seals (*Pagophilus groenlandicus)* in the Northwest Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/107. 40pp. http://www.dfo-mpo.gc.ca/csas/Csas/Home-Accueil_e.htm

Sjare, B., D. Walsh, S. Benjamins and G. B. Stenson. 2005. An Update on Harp Seal By-catch Estimates in the Newfoundland Lumpfish Fishery: 1999-2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/049.

Stenson, G. B. 2005. Estimates of human induced mortality in Northwest Atlantic harp seals, 1952-2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/050. 33p.

Stenson, G. B. 2008. Recent catches of harp seals in the Northwest Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/080.

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.

Stenson, G.B., M.O. Hammill, J. Lawson, J.-F. Gosselin, and T. Haug. 2005. 2004 pup production of harp seals (*Pagophilus groenlandicus*) in the Northwest Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/037.

Stenson, G.B., R.A. Myers, M.O. Hammill, I-H. Ni, W.G. Warren and M.C.S. Kingsley. 1993. Pup production of harp seals, *Phoca groenlandica*, in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 50:2429-2439.

Stenson, G. B., L.-P. Rivest, M. O. Hammill, J. F. Gosselin and B. Sjare. 2003. Estimating Pup Production of Harp Seals, *Pagophilus groenlandicus*, in the Northwest Atlantic. Mar. Mammal. Sci.. 19:141-160.

Appendix 1: Pup production surveys used to estimate pup production.

| Year | Estimate | Standard Error | Reference |
|---|---|---|---|
| 1978 | 497,000 | 34,000 | Roff and Bowen 1986 |
| 1979 | 478,000 | 35,000 | Roff and Bowen 1986 |
| 1980 | 475,000 | 47,000 | Roff and Bowen 1986 |
| 1983 | 534,000 | 33,000 | Bowen and Sergeant 1985 |
| 1990 | 577,900 | 38,800 | Stenson *et al*. 1993 |
| 1994 | 702,900 | 63,600 | Stenson *et al*. 2002 |
| 1999 | 997,900 | 102,100 | Stenson *et al*. 2003 |
| 2004 | 991,400 | 58,200 | Stenson *et al*. 2005 |

Appendix 2. Smoothed age specific reproductive rates (mean and standard error) from 1960 to 2005. Smoothing was carried out on the 1960-1999 data. 1999 rates were extrapolated forward to 2005.

| Year | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean age | | | | | | | | | | |
| 4 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 |
| 5 | 0.178 | 0.177 | 0.177 | 0.179 | 0.180 | 0.182 | 0.184 | 0.187 | 0.191 | 0.198 |
| 6 | 0.544 | 0.543 | 0.542 | 0.542 | 0.542 | 0.543 | 0.543 | 0.544 | 0.545 | 0.547 |
| 7 | 0.817 | 0.817 | 0.817 | 0.817 | 0.817 | 0.817 | 0.816 | 0.816 | 0.815 | 0.815 |
| 8+ | 0.873 | 0.873 | 0.873 | 0.873 | 0.872 | 0.872 | 0.871 | 0.870 | 0.870 | 0.869 |
| SE | | | | | | | | | | |
| 4 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| 5 | 0.040 | 0.039 | 0.038 | 0.037 | 0.036 | 0.035 | 0.034 | 0.034 | 0.034 | 0.035 |
| 6 | 0.050 | 0.048 | 0.047 | 0.045 | 0.044 | 0.043 | 0.042 | 0.042 | 0.042 | 0.042 |
| 7 | 0.032 | 0.032 | 0.032 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 |
| 8+ | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.012 | 0.012 |

| Year | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean age | | | | | | | | | | |
| 4 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 |
| 5 | 0.209 | 0.227 | 0.258 | 0.304 | 0.361 | 0.418 | 0.465 | 0.495 | 0.512 | 0.516 |
| 6 | 0.551 | 0.558 | 0.573 | 0.601 | 0.645 | 0.699 | 0.751 | 0.786 | 0.803 | 0.804 |
| 7 | 0.814 | 0.812 | 0.811 | 0.809 | 0.806 | 0.804 | 0.800 | 0.796 | 0.791 | 0.786 |
| 8+ | 0.867 | 0.866 | 0.864 | 0.861 | 0.858 | 0.855 | 0.850 | 0.844 | 0.838 | 0.830 |
| SE | | | | | | | | | | |
| 4 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| 5 | 0.035 | 0.035 | 0.035 | 0.036 | 0.039 | 0.046 | 0.053 | 0.058 | 0.060 | 0.061 |
| 6 | 0.043 | 0.044 | 0.044 | 0.043 | 0.043 | 0.047 | 0.053 | 0.059 | 0.063 | 0.063 |
| 7 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 | 0.032 | 0.033 |
| 8+ | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 | 0.013 | 0.013 |

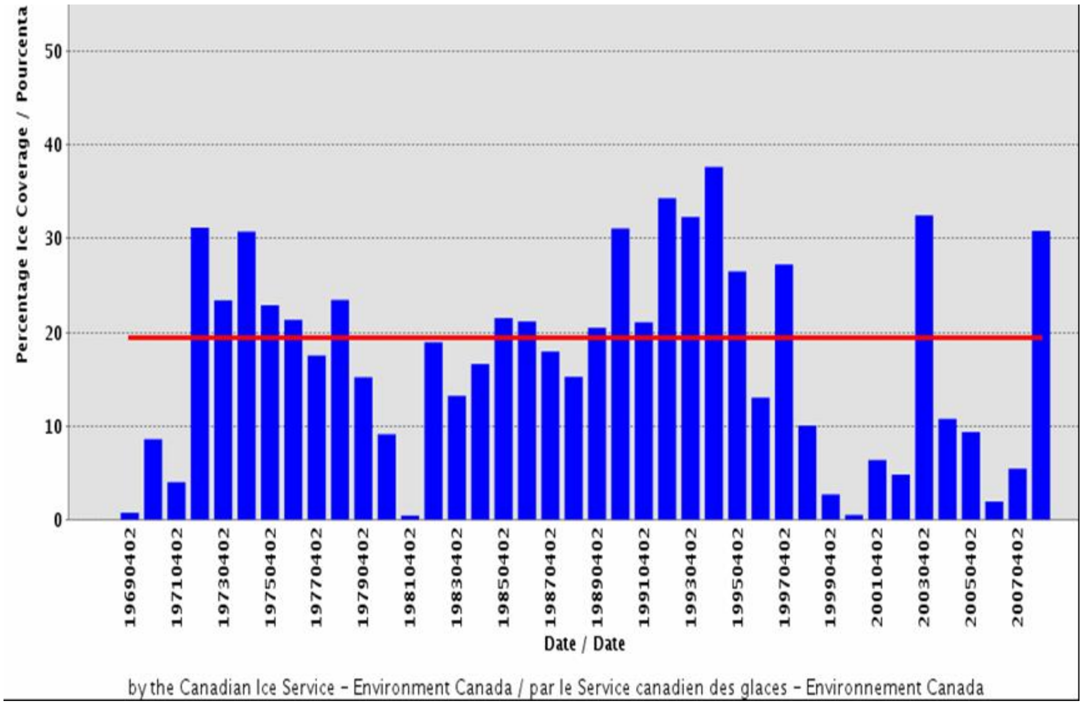
Appendix 2 continued.

| Year | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean age | | | | | | | | | | |
| 4 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 |
| 5 | 0.511 | 0.496 | 0.468 | 0.428 | 0.377 | 0.324 | 0.278 | 0.244 | 0.221 | 0.207 |
| 6 | 0.791 | 0.765 | 0.725 | 0.677 | 0.626 | 0.581 | 0.544 | 0.514 | 0.490 | 0.469 |
| 7 | 0.780 | 0.773 | 0.766 | 0.759 | 0.751 | 0.743 | 0.735 | 0.727 | 0.720 | 0.713 |
| 8+ | 0.821 | 0.811 | 0.801 | 0.791 | 0.780 | 0.770 | 0.760 | 0.752 | 0.744 | 0.737 |
| SE | | | | | | | | | | |
| 4 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| 5 | 0.060 | 0.058 | 0.055 | 0.051 | 0.048 | 0.045 | 0.044 | 0.042 | 0.041 | 0.039 |
| 6 | 0.062 | 0.061 | 0.060 | 0.062 | 0.066 | 0.068 | 0.068 | 0.066 | 0.063 | 0.060 |
| 7 | 0.034 | 0.035 | 0.037 | 0.039 | 0.041 | 0.043 | 0.045 | 0.047 | 0.049 | 0.052 |
| 8+ | 0.014 | 0.015 | 0.015 | 0.016 | 0.017 | 0.018 | 0.019 | 0.020 | 0.021 | 0.022 |

| Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean age | | | | | | | | | | |
| 4 | 0.086 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 |
| 5 | 0.199 | 0.195 | 0.192 | 0.190 | 0.190 | 0.189 | 0.189 | 0.189 | 0.189 | 0.189 |
| 6 | 0.450 | 0.434 | 0.420 | 0.409 | 0.399 | 0.390 | 0.383 | 0.377 | 0.372 | 0.367 |
| 7 | 0.707 | 0.701 | 0.695 | 0.691 | 0.686 | 0.683 | 0.679 | 0.676 | 0.673 | 0.671 |
| 8+ | 0.732 | 0.727 | 0.723 | 0.719 | 0.717 | 0.714 | 0.712 | 0.710 | 0.709 | 0.707 |
| SE | | | | | | | | | | |
| 4 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| 5 | 0.038 | 0.038 | 0.038 | 0.038 | 0.039 | 0.041 | 0.042 | 0.044 | 0.046 | 0.049 |
| 6 | 0.058 | 0.056 | 0.056 | 0.057 | 0.058 | 0.060 | 0.063 | 0.066 | 0.071 | 0.075 |
| 7 | 0.054 | 0.056 | 0.058 | 0.059 | 0.061 | 0.063 | 0.064 | 0.066 | 0.067 | 0.069 |
| 8+ | 0.022 | 0.023 | 0.024 | 0.024 | 0.024 | 0.025 | 0.025 | 0.026 | 0.026 | 0.026 |

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009+ |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean age | | | | | | | | | | |
| 4 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 | 0.020 | 0.020 | 0.020 | 0.020 |
| 5 | 0.189 | 0.189 | 0.189 | 0.189 | 0.189 | 0.189 | 0.265 | 0.265 | 0.265 | 0.265 |
| 6 | 0.367 | 0.367 | 0.367 | 0.367 | 0.367 | 0.367 | 0.456 | 0.456 | 0.456 | 0.456 |
| 7 | 0.671 | 0.671 | 0.671 | 0.671 | 0.671 | 0.671 | 0.549 | 0.549 | 0.549 | 0.549 |
| 8+ | 0.707 | 0.707 | 0.707 | 0.707 | 0.707 | 0.707 | 0.640 | 0.640 | 0.640 | 0.640 |
| SE | | | | | | | | | | |
| 4 | 0.0158 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.0043 | 0.004 | 0.004 | 0.004 |
| 5 | 0.0485 | 0.048 | 0.048 | 0.048 | 0.048 | 0.048 | 0.0314 | 0.031 | 0.031 | 0.031 |
| 6 | 0.0754 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.0215 | 0.021 | 0.021 | 0.021 |
| 7 | 0.0688 | 0.068 | 0.068 | 0.068 | 0.068 | 0.068 | 0.0494 | 0.049 | 0.049 | 0.049 |
| 8+ | 0.0264 | 0.0265 | 0.0265 | 0.0265 | 0.0265 | 0.0265 | 0.0594 | 0.059 | 0.059 | 0.059 |

Appendix 3. Percent ice cover in the Gulf of St. Lawrence on 2 April from 1969 until 2008. Ice is needed by the young of the year as a platform for nursing (1-14 March) and as a resting platform (mid-March –end April).




Appendix 4. The assumed proportion of pups surviving prior to harvesting in poor ice, high storm years. Unless stated below. it was assumed that there was no unusual ice related mortality.

| Year | Pup survival after storms |
|---|---|
| 1981 | 0.75 |
| 1998 | 0.94 |
| 2000 | 0.88 |
| 2002 | 0.75 |
| 2005 | 0.75 |
| 2006 | 0.90 |
| 2007 | 0.78 |