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# Abundance of Northwest Atlantic harp seals (1960 – 2005)

# Abondance du phoque du Groenland dans l'Atlantique Nord-Ouest (1960 – 2005)

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## ABSTRACT

The Canadian and Greenland hunt for Northwest Atlantic harp seals is the largest marine mammal harvest in the world. Therefore, it is important to monitor abundance and population trends to ensure that these removals are sustainable. Since 1980 abundance has been estimated using a two-parameter population model that estimates unreported mortality (i.e., natural mortality plus unreported hunting mortality) and an initial abundance to fit to independent field estimates of pup production using data on removals and age specific reproductive rates.

A population model incorporating pup production estimates since the late 1970s, reproductive rates since 1960 and human induced mortality (catches, by-catch in fishing gear and struck and lost) since 1952 was used to estimate total abundance for the period 1960 - 2004. The harp seal population declined during the 1960s to a low of less than 2 million in the early 1970s, and then increased steadily to 1996. Since then the population has remained relatively stable at the highest values in the time series, and possibly its highest level since commercial exploitation began in the 1700s. The estimated total population size in 2005 is 5.82 million (95% CI= 4.1-7.6 million).

The current Canadian landed sustainable yield is estimated to be 250,000. Owing to the increasing uncertainty associated with future population changes, there is a 20% chance that the population will decline to N70 by 2013 under the current sustainable harvest. Harvests greater than 300,000 would result in the likelihood of the population reaching N70 prior to the end of a 5 year management plan being greater than 20%.

**RÉSUMÉ**

La chasse au phoque du Groenland effectuée par le Canada et le Groenland représente la plus importante récolte de mammifères marins au monde. En conséquence, il importe d'effectuer un suivi de l'abondance de la population et des tendances qu'elle affiche afin de s'assurer que ces prélèvements n'affectent pas la durabilité de la ressource. Depuis 1980, on estime l'abondance avec un modèle de la population à deux paramètres qui évalue les mortalités non déclarées (c.-à-d. la mortalité naturelle plus la mortalité non déclarée causée par la chasse) et un niveau d'abondance initiale ajusté en fonction d'estimations indépendantes de la production de petits réalisées sur place, à partir des données sur les prélèvements et des taux de reproduction à l'âge.

On a aussi utilisé un modèle de la population qui intègre les estimations de la production de petits depuis la fin des années 1970, les taux de reproduction depuis 1960 et la mortalité causée par l'homme (captures, captures accidentelles dans les engins de pêche et animaux blessés et perdus) depuis 1952 pour évaluer l'abondance totale de 1960 à 2004. La population de phoques du Groenland a décliné pendant les années 1960 pour atteindre un creux, à  2 millions d'individus, au début des années 1970 et, par la suite, a augmenté de façon constante jusqu'en 1996. Depuis, la population est demeurée relativement stable, aux niveaux les plus élevés de la série chronologique et, possiblement, à son plus haut niveau depuis le début de l'exploitation commerciale dans les années 1700. La taille de la population totale en 2005 est estimée à 5,82 millions d'animaux (IC de 95 % = 4,1 à 7,6 millions).

On estime que le niveau d'exploitation soutenu du Canada est de l'ordre de 250 000 phoques actuellement. En raison de l'incertitude croissante liée aux changements à venir dans la population, la probabilité que la population décroisse pour atteindre le niveau N70 d'ici 2013 est de l'ordre de 20 %, selon les présentes conditions d'exploitation soutenue. Avec des prélèvements excédant 300 000 phoques, la probabilité que la taille de la population atteigne N70 avant la fin d'un plan de gestion quinquennal serait supérieure à 20 %.

## INTRODUCTION

Stock assessments normally attempt to estimate the current status and predict future changes in the state of the resource by incorporating information on the age structure of past catches, estimates of recruitment and indices of abundance into an assessment model (Cooke 1999). Because the information is often incomplete, and model parameters are subject to natural variability, the resulting advice is also associated with considerable uncertainty. In the past, failure to recognize the importance of this uncertainty has lead managers to require proof that populations or resources were in difficulty before actions were taken (Taylor et al. 2000). Unfortunately, by the time serious damage to resources has been identified, they have often collapsed. Northwest Atlantic cod stocks and many large whale populations are examples of species for which traditional management approaches have resulted in fisheries collapse and, in many cases, limited recovery (Hammill and Stenson 2003a).

The harp seal is the most abundant pinniped in the Northwest Atlantic. It is harvested commercially and for subsistence purposes in Atlantic and Arctic Canada, and from waters around Greenland. Harps are also taken as bycatch in commercial fisheries. In Canada the commercial harvest is limited through a management plan that outlines management objectives, catch levels, methods of hunting, seasonal and regional closures. In 2003, the Minister adopted an Objective Based Fisheries Management (OBFM) approach to the management of the NW Atlantic harp seal fishery (Anon. 2003; Hammill and Stenson 2003a). The objective of this plan was to ensure that the population did not decline below a precautionary reference level, called N70, that was set at 70% of the largest population seen. At that time, modelling suggested that the population had increased to 5.5 million (SE=580,000) in 2002, then declined to 5.3 million (SE=608,000) in 2003 as a result of a combination of high harvests and pup mortality (Hammill and Stenson 2003b). N70 was set at 3.85 million. To recognize increasing uncertainty associated with predicting population trajectories into the future, the control rule was the point at which the probability that the population remained above the N70 precautionary level was ≥80%. If the probability that the population was above N70 was less than 80%, then increasingly restricted harvests were to be established to ensure that populations returned above N70 as soon as possible (Hammill and Stenson 2003a; Anon 2003). The most recent plan ended in May 2005 (Anon. 2003) and a new plan is being developed for release prior to the start of the 2006 harvest. This process involves a review of the status of the population, an examination of different harvest scenarios, and public consultations.

Northwest Atlantic harp seal population size has been estimated using a two-parameter population model that incorporates information on pup production, removals from the population (e.g.., reported catches in Canada and Greenland), and age-specific reproductive rates since 1980 (Roff and Bowen 1983, 1986). This model estimates unreported mortality (i.e., natural mortality plus unreported anthropogenic mortality) and an initial abundance to fit to independent field estimates of pup production. The model used by Shelton *et al*. (1996, described in Cadigan and Shelton, 1993) to estimate abundance following the 1994 pup production survey was very similar to that of Roff and Bowen (1983), although it differed slightly in the parameter estimation methods and how it extrapolated reproductive rates to periods for which there are no data. Warren *et al*. (1997) improved the methods used to determine the uncertainty associated with the parameter and total population estimates. Their study also showed that the model is most sensitive to the estimates of pup production and incorporating uncertainty in pregnancy rates within the model had very little impact on the estimates or precision.

Although no new estimates of pup production were available, Stenson *et al* 1999 updated the model by incorporating assumed levels of struck and lost (i.e. seals killed but not reported) explicitly in the removals. They also incorporated a step-wise approach (Sjare et al 1996) to estimating annual reproductive rates to provide an objective method of determining changes in annual reproductive rates. Using the same basic model, Healey and Stenson (2000) provided abundance estimates following the 1999 pup production survey. In addition to simplifying the coding, they explicitly incorporated bycatch in the removals. The most recent population estimates were provided by Hammill and Stenson (2003) who continued to improve the model by incorporating uncertainty in the estimates of age specific reproductive rates using a kernel smoothing approach and assuming increased pup mortality in the late 1990s due to poor ice conditions.

Thus, since the early 1980s, there has been a consistency in the underlying the models used to assess northwest Atlantic harp seals although there have been improvements in the methods used to incorporate reproductive data and to explicitly include more sources of mortality and uncertainly in estimates of total population size. However, the current assessment model does not include potential density-dependent changes in mortality (i.e mortality is assumed to be constant). It is not known if such changes have occurred because estimating density-dependent changes in mortality cannot be done with current information.

Here, we outline the general population model structure currently used by the Department for harp seal management and present current population estimates obtained from the model. We also describe the different harvest scenarios that Fisheries and Aquaculture Management (FAM) would like explored, and indicate the impact of these removals with respect to the biological reference points identified under OBFM.

## Materials and Methods

The current model is fitted to survey estimates of pup production by adjusting the initial population size and adult mortality rates to minimize the mean sum of square differences between pup production estimated by the model, and estimates obtained from survey data. Pup mortality is fixed at three times adult mortality, but can be changed if necessary, as in Healey and Stenson (2000).

***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*,

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

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

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

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.

A second feature called RiskOptimizer uses genetic algorithms to search for optimal answers to simulation models (Palisade Corporation 2000). For some model inputs (*e.g.* reproductive rates) information is available to describe sample variability in our estimates (mean and standard error). 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.

The model randomly selects values for the initial population size and mortality rates, then re-samples (Latin Hypercube) values from the defined functions for each parameter (*e.g.* values for reproductive rates). Sampling was repeated 200 times (replicates) and from the 200 replicates the mean sum of squares (MSS) was calculated. These constitute a simulation. The MSS for the simulation was stored, new values for the initial population size and mortality rate chosen at random and 200 samples from the defined functions drawn to complete another simulation. A total of 1000 simulations were completed. The model inputs that generated the smallest MSS out of the 1000 simulations were retained. This was repeated for 560 different pup production survey values randomly drawn using the mean and standard error of the pup survey estimates which generated 560 estimates of initial population size and adult mortality rates. We incorporated the mean and SE of these two parameters (initial population size and adult mortality rate) into the model as lognormal functions when testing the impact of different harvest scenarios. The effects of different harvest scenarios were examined by adjusting different catch levels and running the model to complete 5000 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 (Table 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*

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 and were incorporated into the model along with estimates of bycatch (Stenson 2005; Sjare et al. 2005). It was assumed that 95% of the pups killed in the Canadian hunt and that 50% of animals aged 1+ years and 50% of all animals killed in the Greenland and Canadian Arctic harvests were recovered (Stenson 2005).

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 (2005). Total removals taking into account corrections for non-reporting and adding in bycatch are listed in Table 2.

### *Pregnancy rates*

The age specific pregnancy rates were based upon samples obtained between 1954-1997. The raw data are presented in Sjare *et al.* (2000), adjusted for age at birth. 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 (Sjare *et al*. 2000). Samples were obtained between November and February and so provide late-term pregnancy rates. Age-specific sample sizes were highly variable with total annual sample sizes ranging from 11 to 258 seals. The vast majority of samples were collected in the Newfoundland area.

Previous analyses have attempted to provide annual pregnancy rates from the available sampling data. An analysis by Shelton *et al*. (1996) attempted multi-linear regression, analysis of covariance, analysis of variance, and auto-regression models, and discovered that all methods were inadequate to predict the unknown pregnancy rates. Healey *et al*. (In prep.) developed a nonparametric regression estimator to estimate the expected pregnancy rates. There are no data for many year-age combinations, thus these expectations have to be inferred from neighboring observations using a simple model. Assuming that for each age, the number of pregnant seals sampled in year $t$ (denoted as $Y_t$) from a total of $n_t$ is Binomially distributed, with mean $n_t p_t$ where $p_t$ is the probability that a seal was pregnant. With no further restrictions on $p_t$, the maximum likelihood estimate (mle) of $p_t$ is $y_t / n_t$ - the sample proportion of pregnant seals.

The sample proportion of pregnant seals may be quite dissimilar from year to year, but the population pregnancy rates are not expected to vary widely between years. Sample proportions may vary widely when the sample size is small, and this is compounded when there is considerable within-age population variability in sampled pregnancy rates. Another problem is estimating pregnancy rates in the years with no samples. These problems suggest that some reasonable model restrictions of the $p_t$'s are necessary, especially to infer $p_t$'s in years not sampled. Assuming that the $p_t$ must be a smooth function of $t$, the amount of smoothness will be determined by the available data. The statistical problem then is to estimate this function or, equivalently, to estimate $p_t$. Since it is not possible to estimate $p_t$ via maximum likelihood without specifying this function more exactly, a non-parametric approach is taken. Local averaging is a commonly used alternative to estimate $p_t$. The rationale for local averaging is as follows.

Define an ε-neighborhood of observations around some given year $t$ as $A_t = \{i : |t_i - t| \le \varepsilon\}$. If ε is chosen small enough then it can be assumed that $p(t_i)=p(t)$ for all $i$ in $A_t$. In this case the mle for $p(t)$ is:

$$\hat{p}(t) = \frac{\sum_{i \in A_t} y_i}{\sum_{i \in A_t} n_i}. \qquad (5)$$

Only $y_i$'s with $t_i$ values within the ε - distance of $t$ have a full contribution to the estimate of $p(t)$. Other $y_i$'s have no contribution to the estimate. Another approach is to use a weight function designed so that the contribution of $y_i$ changes gradually according to the distance between $t_i$ and $t$. The weight function $W$ measures the distance between $t$ and $t_i$. The size of the neighborhood is determined by a bandwidth, $b$. The maximum local likelihood estimate is:

$$\tilde{p}(t) = \frac{\sum_i W\left\{\frac{(t_i - t)}{b}\right\} y_i}{\sum_i W\left\{\frac{(t_i - t)}{b}\right\} n_i}. \qquad (6)$$

The Gaussian weight function, $W(x) \propto \exp(-x^2/2)$, is used here, although other functions are commonly used. The Gaussian weight function defines elliptical neighborhoods in $t$. As $b \rightarrow 0$, the neighborhood includes just $t_i$.

The choice of bandwidths is critical in smoothing. A bias-variance trade-off exists in determining the size of the bandwidths. A small bandwidth leads to an estimator with small bias, but large variance (i.e. erratic), while a large bandwidth leads to an estimator with large bias, but small variance (i.e. oversmooth). The data were used to choose a bandwidth, or the amount of smoothness, that minimizes a measure of prediction error. The measure used is Generalized Cross Validation. This is a common prediction error measure used in kernel smoothing and spline smoothing (Healey *et al.* In prep.), along with comparisons with other methods. The amount of smoothness that is useful will depend on age, so bandwidths were selected separately for each age. Reproductive rates were smoothed from 1960 to 1999. For 2000 to 2005, the 1999 smoothed rate was extrapolated forward (Table 4). Recognizing that there is some variability associated with the age specific pregnancy rates, the mean age specific reproductive rate ($P_{a,t}$ ; Equation 4) incorporated into the model was defined as a Normally distributed variable, with the mean and standard error defined by the annual age specific mean reproductive rate and standard error determined by the smoothing procedure (obtained from Healey *et al* in prep; Table 3).

*Climate variability*

Variable environmental conditions have likely had an impact on mortality rates among years. Specifically, poor ice conditions and extensive storm activity has probably 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. For example, Sergeant (1991) identified 1981 as a particularly poor ice year that may have resulted in substantial pup mortality in all areas. The 16 years from 1981 until 1997 represent a period of unusually stable ice conditions, but in 1998, 2000, and 2002 poor ice conditions were observed in the Gulf, while in 2005 severe storms were noted at the Front. Consequently, it is suspected that pup mortality was higher than normal. Although it is difficult to quantify the difference in mortality during these years compared to ‘normal’ ice years, it was assumed that during 1998 and 2000, 20% and 40% of the pups born in the Gulf respectively, died before harvesting began. Assuming that Gulf pups make up approximately 30% of the total pup production, this translated into an overall mortality of 6% and 12% prior to harvesting in 1998 and 2000 respectively. During 2002 we received reports of large numbers of whitecoats in the water and dead animals were found on beaches in Prince Edward Island, the Magdalen Islands and along the west coast of Newfoundland. Overall, ice conditions in 2002 were very similar to conditions observed in 1981. During that year pup mortality appeared to be extremely high and Sergeant (1991) noted that the 1981 year class was almost completely absent in subsequent age class samples collected during an early winter fishery at La Tabatiere. Assuming that the Gulf cohort in 2002 suffered extremely high mortality similar to what had been observed in 1981, we assumed that 75% of the Gulf pups died prior to harvesting which translates into an overall mortality of 25% for the population. Higher mortality than expected also appears to have occurred at the Front in 2005 as a result of high storm activity that crushed a large number of pups in the northern Gulf and along the NE coast of Newfoundland (Table 4).

***Projections:***

Fisheries and Aquaculture Management requested that harvest scenarios be examined within the context of a five-year management plan. These scenarios included removals at 250,000 (approximate Sustainable Yield), 275,000, 300,000, 325,000 and 350,000 animals per year. We also examined one year harvests of 400,000 and 500,000, and three year harvests of 325,000 and 500,000 animals per year. In all cases, the harvests returned to an appropriate sustainable yield level at the end of the specified management period. Sustainable yield was defined as a constant harvest that will result in the total population in year +10 to be the same as in year + 20.

In order to carry out these projections, a number of assumptions were required. The level of subsistence catch in the Canadian Arctic, bycatch in fishing gear and the age structure of the harvest was assumed to be the same as in recent years.

In three of the last five years, there have been indications of higher than normal pup mortality. This was incorporated into the future projections as higher than expected pup mortality of 10%, 20% and 20% in three out of five years. The model randomly chose one of five possible proportions (0, 0, 0.10, 0.20, 0.20) for additional mortality in each year of the projections.

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

The current model tracks the Healey and Stenson (2000) model very well up until 2000, the last period for which simulations from their model are available (Fig. 1). The model estimates during the early 1960s differ slightly, but this is likely due to the manner in which the initial populations are estimated.

The current model was repeatedly fitted to sampled values of the number of pups born, based on the mean and standard errors of the pup survey estimates. This provided estimates of initial population size and adult mortality rates. However, both parameters are highly correlated (r=0.99), with changes in initial population size having a direct impact on mortality rates that the model must estimate to fit to the survey estimates (Fig. 2). Failure to consider this correlation results in a coefficient of variation around the model estimates of population size for 2005 of 0.4. Although the correlation is quite strong, the relationship is not quite linear (Fig. 2). Assuming correlation coefficients of 0.9, 0.95 and 0.99 results in coefficients of variation for the model estimates of 0.2, 0.18 and 0.15 respectively in 2005, increasing to 1.24, 1.10 and 0.97 by 2030 (Fig. 3). These coefficients of variation are greater than the average coefficients of variation for the pup production surveys of 0.08. Our estimates of the trajectory for this population are based on only 8 pup production estimates conducted at intervals of at least five years and on small numbers of reproductive samples. For the purpose of providing a current estimate of population size we used a correlation coefficient of 0.99. However, this was reduced to 0.9 to examine the impacts of future harvest scenarios because of our uncertainty related to under-reporting, quota over-runs and other factors such as bycatch.

Fitting the model to the pup production data, incorporating uncertainties outlined above, resulted in an estimates of pup production that fit the data quite closely (Fig. 4). Pup production from the model was estimated to have decreased from 493,000 (95% CI= 480,000-506,000) in 1960 to a low of 393,000 (95% CI= 380,000-406,000) in 1971. It then increased to an estimate of 986,000 (95% CI=753,000-1,235,000) in 2004 and was predicted to be 1 million pups (95% CI.=785,000-1,272,000) in 2005.

The total population was estimated to have increased from an initial population size of 2.21 million (95% CI=2.16-2.27 million) in 1960 to 5.74 million (95% CI= 4.19-7.35 million) in 2004 and 5.82 million (95% CI= 4.1-7.6 million) in 2005 (Fig 5). The instantaneous mean mortality rate (m) of 1+ seals was estimated to be 0.057 (95% CI= 0.055-0.060).

In previous runs of this model only single estimates of initial population and m were obtained. In these runs however, the model was fit to 560 randomly chosen sets of pup production in order to estimate the variance associate with the parameters. The mean population trajectory obtained from these two methods is similar but incorporating the uncertainty associated with the parameters results in wider confidence limits (Fig. 6).

After removing Greenland and Canadian Arctic harvest, bycatch and accounting for struck and lost and periodic mortality from unfavourable environmental conditions (outlined in Table 5), the Sustainable Canadian reported yield (SY) was 250,000. This value is very sensitive to the assumed correlation between the initial population size and adult mortality estimates, Greenland harvest levels and the frequency of unusual mortality events.

The uncertainty associated with changes in the population increase as time since the last survey increases. Although the SY indicates a stable population there is a 50% probability that the population may be lower than predicted. Under OBFM, a population that has less than a 20% probability of being below N70 is considered to have exceeded the precautionary point. Under a sustainable yield of 250,000, there is a 20% probability that the population will decline to N70 by 2013, 2015 and 2017 assuming a correlation coefficient between the initial population and adult mortality coefficients of 0.9, 0.95 and 0.99 respectively (Fig 7).

*Harvest simulation projections*

A summary of the projected impacts of various harvest scenarios is presented in Table 6. As indicated above, SY was 250,000 animals. Owing to the increasing uncertainty associated with future population changes, there is a 20% chance that the population will decline to N70 by 2013 (Fig. 7; Table 6) under the current sustainable harvest. As annual harvest rates increase, the year by which the likelihood of reaching N70 is 20% is reduced and the rate of decline in SY increases (Table 6, Fig 8, 9). For example with a 5-year plan of 275,000, N70 is reached by 2012 and the SY declines by 6% from 250,000 to 235,000 animals. The median estimate of population size at the end of the management plan (2011) would be only slightly lower than the current (5.77 vs 5.82 million) but the lower 20% confidence limit would be 4.14 million. This is similar to a single harvest of 400,000 followed by replacements at SY (table 6) although the uncertainty in the estimates would be slightly less. A five year harvest of 300,000 animals results in a 12 % decline in SY to 220,000 animals, a 20% likelihood of reaching N70 in 2011 and slightly lower population estimates. Harvests greater than 300,000 would result in the likelihood of the population reaching N70 prior to the end of a 5 year management plan being greater than 20% although harvest of 325,000 and 350,000 could occur if there were severe reductions in the final year(s) of the management plan (Table 6).

The impact of allowing an average annual harvest of 300,000 to vary up to 20% in two of the five years is similar to that of maintaining a fixed catch in each year (Table 6). It appears that as long as the amount of transfer among years is not too large, the impact on the population will remain the same as long as the total removals over the life of the plan are the same.

## DISCUSSION

The most recent surveys resulted in a 2004 pup production estimate of 991,400 (SE = 58,200). Incorporating information on reproductive rates and estimates of removals from the population into a model and fitting this model to pup production survey data resulted in an estimate of pup production in 2004 of 990,000 (SE = 165,000). The total population declined through the 1960s to a low of 1.88 million (SE = 46,200) in 1971 after which it increased until the mid 1990s. Since then it has been relatively stable at 5.75 million (SE = 1.08 million) in 2004 and 5.82 million (SE=1.19 million) in 2005. This population trajectory is similar to that estimated by Healey and Stenson (2000) and Hammill and Stenson (2003b) although the estimates of total population in 2000 obtained from this study are slightly higher than those obtained by Healey and Stenson (5.5 million SE = 868,500 vs. 5.2 million SE = 612,200, Fig. 4). The estimates are also slightly higher than those obtained by Hammill and Stenson (2003b). For example, this study estimated a total 2002 population of 5.76 million (SE = 687,200) vs. an estimated 5.5 million (SE = 580,000). These differences are not significant and reflect a re-tuning of the model estimates to the new data available.

Preliminary runs of this model were presented at the 2005 meeting of the National Marine Mammal Peer Review Committee and is reported in the 2005 Stock Advisory Report on harp seals (DFO 2005a,b). The model provided the best fit to the data with a 1960 pup production of 488,000 (SE=4 000) and an instantaneous mortality rate ($m$)= 0.058. Total population was estimated to be 5.5 million in 2002 and 5.9 million (SE=747,000) seals in 2005. However, in harvest projections examined after the National Marine Mammal Peer Review Committee meeting, equation 1 has been modified, to allow increased natural mortality due to poor environmental conditions to occur prior to hunting instead of post-hunting, and variability associated with the initial population size and adult mortality coefficients has been incorporated into the model. When these additional sources of uncertainty are included in the model, the estimates change slightly; the 2002 estimate of population size increases to 5.76 million, while the 2005 estimate declines slightly to 5.82 million (SE = 878,100, 95% CI=4.13-7.59 million). By incorporating the new pup survey estimates, increased mortality due to environmental conditions and changes in the Greenland harvest, the model clearly indicates that the population has leveled off.

During the last four years, Canadian commercial harvests were 312,367, 289,512, 365,971, and 329,829 during 2002, 2003, 2004 and 2005 respectively. In spite of the high Canadian harvests observed in recent years, the decline in the population predicted by Hammill and Stenson (2003b) has not occurred, due primarily to lower than expected harvests in the Canadian Arctic and Greenland. Recent harvest information from the Arctic shows a decline in harvesting from about 5,000 animals during the 1990s to about 1000 animals in the Canadian Arctic and a decline in Greenland harvests from approximately 100,000 animals to around 70,000 animals (Stenson 2005). Changes in harvest levels in these areas have an important impact on expected population trajectory because they consist of more mature animals than the Canadian commercial hunt, and because as open water hunts, they are associated with higher estimates of animals struck and lost.

While we have not observed a decline, the very high harvests that have been in place since the 1990s have resulted in stabilization of the overall population level and changes in the age structure as the impacts of the high harvests work their way through the population. Overall, it must be remembered that over the course of the last management plan, human induced mortality (i.e. directed harvests, struck and loss and bycatch from other fisheries) have accounted for the removal of an estimated 1.52 million animals from relatively few cohorts. The removal of these animals will affect the dynamics of this population for a number of years to come.

*Future Projections:*

The strategic plan for the Department of Fisheries and Oceans calls for the development and application of a Precautionary Approach framework to fisheries management. The Northwest Atlantic harp seal is the first species managed by the department where this framework has been developed and applied within a management context. This framework is referred to as the Objective Based Fisheries Management (OBFM) approach to the management of the NW Atlantic harp seal population and was adopted in 2003 (Anon. 2003; Hammill and Stenson 2003a). Under this scheme, a primary management objective is to ensure that the population will remain above a precautionary level of 70% (referred to as N70) of the maximum population size that has been observed (Hammill and Stenson 2003a). If the population falls below this level, then more restrictive harvest levels are to be implemented to allow the population to recover. To take into account the uncertainty associated with stock assessments and the fact that this uncertainty increases with projections into the future, a control rule was established that the probability the population was above N70 was ≥80% (or the corollary the probability that the population was less than N70 was ≤20%). If the likelihood that the population fell below N70 was >20%, then harvest levels were to decline to allow the population to recover above N70. Based on data obtained prior to 2003, Hammill and Stenson (2003b) estimated that a maximum population of 5.5 million seals was obtained in 2002. Recalibration of the population model as a result of including the 2004 pup production estimates, results in a maximum population size of 5.82 million animals, and an N70 of 4.08 animals. This re-calibration also changed the estimate of the 2002 population to 5.75 million. These slight differences indicate that the population has not grown but rather, the new data has improved our understanding of the true population size.

The simulations completed for this study were designed to examine the impacts of different management strategies. For these simulations we reduced the strength of the correlation between the estimates of initial population size and the estimates of adult mortality rates, from 0.99 to 0.9. This had the effect of increasing the apparent uncertainty associated with model projections. Generally, this results in the population declining to N70 about three years earlier than if the correlation had been maintained at 0.99. We feel that this approach provides some additional level of caution, given our lack of understanding of current trends in reproductive rates (see below), quota over-runs or changes in bycatch levels.

The evaluation of different scenarios indicated that assuming harvest levels of 275,000 animals per year for 5 years followed by a decline in catches to the estimated replacement yield of 235,000 animals per year beginning in 2011, the population is not expected to decline below N70 until 2013. At that point harvests would have to decline to 165,000 animals per year to remain above N70 (Table 6). At harvest levels of 300,000 animals per year the population would fall to N70 prior to the 2011 harvest season. Beginning in 2011, harvests would have to decline to 140,000 animals to remain above N70. It is evident the higher the harvest, the greater the reduction in catches required to allow the population to remain or recover above N70 at the end of the subsequent five year period. Harvest levels of 325,000 or higher would likely result in the population declining below N70 before the start of harvesting in 2010, which is similar to predictions from simulations conducted prior to the last management plan (Hammill and Stenson 2003b). In the previous management plan, an annual harvest of 325,000 animals was expected to result in a 20% probability of the population declining to N70 by 2011 (Fig. 10). Re-calibrating the population model with the new survey estimates, results in similar predictions.

The model predictions are affected by the uncertainty associated with the size of future harvests in Greenland, and variability in environmental conditions, as well as uncertainty associated with the reproductive rate and pup survey data. Over the last five years we have seen the reported Greenland harvest vary between 70,000 and 100,000 animals. Currently this large subsistence hunt in not managed with a TAC or quota. The reasons for the recent decline in harvest levels have not been identified and for the moment it is not possible to predict what future harvests might be. Similarly, we have observed an increase in the frequency of poor ice years since 1996, along with indications of greater than normal mortality among pups (Johnston et al. 2005; Hammill and Stenson unpublished data). If warmer climate conditions continue, the frequency of poor ice years may increase.

In addition to the pup survey data, the population model requires catch data and estimates of female reproductive rates. However, in most years less than 200 reproductive samples were examined, which is a small sample when the age structure of the population is taken into consideration. In our simulations, we extended the smoothed rates of Healey and Stenson

(2000) from 2000 onwards. If reproductive rates have actually declined since the period of high Canadian harvests began in 1996, then the population will decline more rapidly over the short term than predicted. However, it would not be until 2013 that the probability of the population falling below N70 would be greater than 20% (Fig. 11). The model is extremely sensitive to small changes in estimates of adult mortality rates, yet we do not have any independent information on mortality rates in this species. Animals as old as 40 years of age are sometimes taken, suggesting an adult mortality rate as low as 0.025, while the majority of 1+ animals obtained from sampling programs are 10-15 years old suggesting a higher mortality rate of 0.067.

A further source of uncertainty results from the combination of harp seal life-history characteristics, and properties of the harvest, as well as survey effort. Harp seal females have their first pup when they are five years old. Since the Canadian harvest is directed towards young of the year animals, it takes at least five years before the impacts of the harvest are reflected in the breeding population. Current model predictions are based on only 8 estimates of pup production since 1978. Because surveys are only conducted at five year intervals, the result is that only two estimates of pup production are available since 1996, when the current period of large harvests from this population began. Depending upon the timing of surveys, it could be 10 years before changes in pup production would be detected by the survey program. By that time, significant changes in the population could have occurred. However, even with significant reductions in harvest levels, further declines in the population would continue to occur for several years (demographic momentum) until the new (protected) cohorts enter into the reproductive component of the population. An increase in survey frequency would help to reduce some of the uncertainty associated with the model fitting process, and would also improve our ability to track changes in the population resulting from changes in environmental conditions and Greenland harvests.

As the population declines it might be expected that density dependent changes in mortality and reproductive rates could occur, which would enable faster recovery rates than predicted. Unfortunately, density-dependent relationships are difficult to predict. Also, the expected changes in reproductive parameters for this species are not as convincing as has been suggested (McLaren 2001). Since 1990 there has been little change in age specific reproductive rates (Sjare et al 2004) although they have become more variable. Model simulations for this study assumed no change in the relatively low reproductive rates (compared to the 1970s) currently experienced by this population. Although this population has recovered from heavy exploitation in the past, examples such as Northern cod, northern fur seal and many large cetaceans have shown that density dependent responses are difficult to predict and cannot be counted on to aid in recovery of over-exploited populations (Anon 2003b; Lilly and Murphy 2004; Baker and Clapham 2004).

Experience from other fisheries has shown that although it is easy to increase harvests, attempts to limit harvests are often met with resistance. A higher harvest in the short term will have to yield to much lower harvests in the future in order to conserve the resource. These reductions will be greater if environmental deterioration (*e.g.* poor ice conditions) continues. Also, major changes in the Greenland harvest will also have an impact on the status of the stock. We have incorporated lower estimates for the Greenland harvests since the previous plan, but have also increased the uncertainty associated with future trends in this large subsistence hunt. Unfortunately, harvest statistics from Greenland are generally not available for at least two years and therefore, management decisions based on current estimates of natural mortality and the Greenland harvest can change drastically, as the most recent updates have shown. A reduction in the uncertainty associated with model predictions could be achieved through increased survey frequency and incorporating the Greenland harvest into a more formal management framework.

## Literature cited


Anonymous. 2003a. Atlantic seal hunt 2003-2005 management plan. 34 pp. 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.

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. http://www.dfo-mpo.gc.ca/csas/Csas/Proceedings/2005/PRO2005_001_B.pdf

DFO, 2005b. Stock Assessment of Northwest Atlantic Harp Seals (*Pagophilus groenlandicus*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/037. http://www.dfo-mpo.gc.ca/csas/Csas/status/2005/SAR-AS2005_037_E.pdf

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/publications/ResDocs-DocRech/2003/2003_067_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/publications/ResDocs-DocRech/2003/2003_068_e.htm

Healey, B. P. and G. B. Stenson. 2000. Estimating pup production and population size of the northwest Atlantic harp seal (*Phoca groenlandica*). Can. Stock. Ass. Sec. Res. Doc. 2000/081. 27p. http://www.dfo-mpo.gc.ca/csas/Csas/publications/ResDocs-DocRech/2000/2000_081_e.htm

Healey, B. P., G. B. Stenson and N.G. Cadigan. In prep. Modelling the Population Dynamics of the Northwest Atlantic Harp Seal (*Phoca groenlandica*).

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.

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. Res. Doc 2004/102. http://www.dfo-mpo.gc.ca/csas/Csas/publications/ResDocs-DocRech/2004/2004_102_e.htm

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/publications/ResDocs-DocRech/2004/2004_107_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.

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. http://www.dfo-mpo.gc.ca/csas/Csas/publications/ResDocs-DocRech/2005/2005_037_e.htm

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.

Table 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 |

Table 2. Total removals from Northwest Atlantic harp seal stock, including reported harvests, struck and lost and bycatch.

| YEAR | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25+ | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1952 | 219536 | 16162 | 25580 | 17342 | 13292 | 14558 | 24120 | 16690 | 16290 | 11934 | 13642 | 11517 | 3861 | 3129 | 4568 | 8554 | 3015 | 4660 | 3739 | 2121 | 11017 | 1858 | 94 | 952 | 2704 | 3588 | 454522 |
| 1953 | 219447 | 46686 | 14724 | 290 | 8792 | 8920 | 7276 | 6164 | 6226 | 5980 | 5146 | 5983 | 3777 | 2913 | 2248 | 4018 | 4151 | 3010 | 1955 | 1499 | 5317 | 3440 | 1966 | 1330 | 998 | 910 | 386165 |
| 1954 | 199519 | 69652 | 27513 | 9902 | 12719 | 6824 | 8358 | 7227 | 6589 | 4503 | 6357 | 2809 | 5566 | 5257 | 2857 | 4074 | 4583 | 2248 | 831 | 2411 | 1921 | 738 | 669 | 1526 | 385 | 2396 | 397434 |
| 1955 | 273296 | 48805 | 18973 | 13717 | 9894 | 8789 | 8099 | 6723 | 6987 | 5605 | 6353 | 5508 | 4351 | 3278 | 2523 | 4804 | 4328 | 2916 | 1616 | 1684 | 4975 | 2715 | 1647 | 1311 | 1119 | 1611 | 451625 |
| 1956 | 357914 | 27881 | 11111 | 7948 | 6236 | 5017 | 4867 | 4223 | 4435 | 3813 | 4053 | 3398 | 2862 | 2135 | 1859 | 2959 | 2781 | 1895 | 1270 | 1264 | 3197 | 1568 | 991 | 843 | 765 | 1097 | 466385 |
| 1957 | 182432 | 47669 | 17676 | 12163 | 9643 | 7877 | 7617 | 6580 | 6648 | 5724 | 6396 | 5768 | 4413 | 3577 | 2809 | 4942 | 4493 | 3013 | 1684 | 1785 | 5040 | 2698 | 1670 | 1293 | 1150 | 1771 | 356529 |
| 1958 | 162465 | 54293 | 21747 | 24445 | 25043 | 21049 | 14027 | 12650 | 10656 | 10062 | 19836 | 11776 | 14472 | 8515 | 6504 | 18005 | 11869 | 6171 | 1265 | 3152 | 10987 | 5912 | 4945 | 2097 | 4025 | 7372 | 493338 |
| 1959 | 251899 | 46855 | 17687 | 12102 | 9334 | 8123 | 8013 | 6829 | 6807 | 5937 | 6557 | 5593 | 4318 | 3431 | 2708 | 4963 | 4423 | 2984 | 1585 | 1749 | 4992 | 2679 | 1612 | 1325 | 1118 | 1650 | 425272 |
| 1960 | 176927 | 70511 | 27383 | 20804 | 14367 | 11958 | 11962 | 9771 | 9467 | 8141 | 9289 | 8070 | 6298 | 4962 | 3770 | 7047 | 6500 | 4284 | 2310 | 2442 | 7368 | 3959 | 2401 | 1913 | 1649 | 2431 | 435985 |
| 1961 | 184800 | 14143 | 5578 | 5334 | 5838 | 2290 | 2682 | 2444 | 1608 | 1510 | 2216 | 1319 | 863 | 771 | 783 | 620 | 641 | 540 | 317 | 368 | 488 | 94 | 237 | 186 | 95 | 415 | 236178 |
| 1962 | 219330 | 61960 | 69026 | 19974 | 18278 | 12876 | 5868 | 5332 | 5440 | 5336 | 2494 | 2682 | 3950 | 2055 | 2842 | 4085 | 1443 | 3463 | 1627 | 1264 | 2748 | 397 | 1273 | 116 | 369 | 1322 | 455550 |
| 1963 | 284999 | 20494 | 18044 | 14511 | 8611 | 6825 | 7460 | 7410 | 7056 | 6492 | 7534 | 7157 | 5359 | 5661 | 5727 | 4631 | 5409 | 3766 | 2483 | 1988 | 2103 | 1799 | 1340 | 1061 | 908 | 1358 | 440187 |
| 1964 | 279868 | 13629 | 12218 | 12606 | 13994 | 9408 | 13564 | 7304 | 5896 | 5552 | 8554 | 4528 | 4517 | 3437 | 3435 | 5306 | 4179 | 5173 | 7838 | 4153 | 328 | 4004 | 2054 | 2037 | 2956 | 5071 | 441609 |
| 1965 | 195499 | 25698 | 12488 | 10457 | 10679 | 12683 | 11620 | 4746 | 2258 | 1568 | 2806 | 1023 | 3542 | 678 | 2568 | 2383 | 1244 | 789 | 1467 | 1564 | 697 | 1026 | 536 | 111 | 138 | 1471 | 309740 |
| 1966 | 261978 | 28843 | 22716 | 10839 | 10325 | 10587 | 10496 | 9596 | 6457 | 3499 | 3711 | 4661 | 3432 | 3041 | 3417 | 3022 | 2883 | 2081 | 3130 | 1982 | 2178 | 1533 | 668 | 1324 | 772 | 2189 | 415362 |
| 1967 | 285596 | 29407 | 13714 | 5915 | 4983 | 6679 | 8256 | 7200 | 5031 | 3317 | 3045 | 3752 | 2668 | 2074 | 3069 | 3202 | 2036 | 2579 | 2775 | 2864 | 1940 | 1237 | 908 | 1014 | 638 | 1922 | 405820 |
| 1968 | 166413 | 13294 | 9808 | 6641 | 4053 | 3559 | 3467 | 4731 | 4738 | 3288 | 3358 | 2512 | 2047 | 1840 | 2385 | 2183 | 1902 | 1660 | 2309 | 2016 | 1533 | 919 | 1216 | 660 | 508 | 1274 | 248314 |
| 1969 | 243285 | 43884 | 6955 | 6705 | 5412 | 5896 | 4358 | 4966 | 5895 | 4339 | 3751 | 3268 | 2237 | 2450 | 2514 | 2728 | 1694 | 2671 | 1722 | 1937 | 1684 | 1177 | 739 | 881 | 449 | 1488 | 363085 |
| 1970 | 226420 | 18572 | 15700 | 6335 | 5580 | 5418 | 3201 | 3240 | 3537 | 3273 | 4086 | 2777 | 2473 | 1929 | 1627 | 1878 | 1942 | 1158 | 1132 | 1158 | 1261 | 844 | 662 | 536 | 402 | 785 | 315929 |
| 1971 | 220222 | 16738 | 6082 | 5430 | 2690 | 2416 | 1592 | 1282 | 1092 | 1636 | 1681 | 1231 | 1226 | 820 | 608 | 663 | 465 | 418 | 422 | 337 | 272 | 228 | 248 | 124 | 54 | 703 | 268682 |
| 1972 | 125453 | 9950 | 5944 | 3585 | 3489 | 1682 | 1455 | 1192 | 809 | 418 | 646 | 644 | 707 | 371 | 522 | 545 | 305 | 337 | 406 | 242 | 520 | 297 | 216 | 158 | 138 | 283 | 160313 |
| 1973 | 109989 | 14063 | 9738 | 6701 | 5103 | 6887 | 2395 | 2097 | 2321 | 1395 | 1458 | 1632 | 1395 | 1313 | 957 | 1026 | 900 | 590 | 443 | 479 | 544 | 170 | 372 | 114 | 118 | 580 | 172779 |
| 1974 | 125441 | 23773 | 12998 | 4843 | 4009 | 3863 | 5662 | 1828 | 2011 | 2217 | 1571 | 1166 | 1488 | 1398 | 1065 | 960 | 994 | 866 | 564 | 527 | 346 | 294 | 340 | 208 | 288 | 926 | 199645 |
| 1975 | 150727 | 28924 | 13741 | 6997 | 3864 | 3385 | 3051 | 2991 | 1753 | 1333 | 1811 | 1165 | 1221 | 1041 | 817 | 692 | 663 | 506 | 484 | 440 | 308 | 298 | 162 | 168 | 178 | 144 | 226865 |
| 1976 | 148881 | 34799 | 16824 | 9228 | 5945 | 2030 | 1363 | 1249 | 1284 | 553 | 867 | 742 | 691 | 412 | 498 | 644 | 373 | 346 | 190 | 178 | 220 | 139 | 86 | 114 | 82 | 86 | 227825 |
| 1977 | 149464 | 18238 | 12900 | 11273 | 8194 | 4136 | 2338 | 1762 | 1106 | 513 | 655 | 636 | 509 | 470 | 804 | 920 | 459 | 187 | 132 | 84 | 152 | 103 | 105 | 106 | 80 | 137 | 215464 |
| 1978 | 133850 | 42054 | 24317 | 14908 | 10059 | 6787 | 4839 | 1598 | 2150 | 907 | 1464 | 642 | 700 | 640 | 483 | 662 | 375 | 337 | 344 | 212 | 333 | 273 | 239 | 142 | 85 | 481 | 248883 |
| 1979 | 154521 | 35164 | 16921 | 8444 | 4871 | 3380 | 2423 | 1537 | 990 | 813 | 569 | 421 | 466 | 340 | 562 | 655 | 332 | 393 | 275 | 303 | 305 | 257 | 234 | 186 | 171 | 1069 | 235601 |
| 1980 | 144684 | 39709 | 19333 | 13351 | 7553 | 5351 | 4209 | 3102 | 2351 | 1623 | 1198 | 1419 | 1331 | 938 | 1079 | 1308 | 950 | 796 | 286 | 504 | 719 | 383 | 339 | 210 | 212 | 955 | 253896 |

| YEAR | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25+ | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | 196163 | 27800 | 14312 | 11439 | 8254 | 6392 | 4462 | 2897 | 2209 | 1093 | 1421 | 1416 | 1068 | 783 | 697 | 973 | 690 | 747 | 564 | 598 | 489 | 546 | 532 | 307 | 249 | 856 | 286958 |
| **1982** | 167072 | 31240 | 18303 | 10835 | 5755 | 4610 | 2546 | 2729 | 1636 | 2096 | 1460 | 1303 | 668 | 765 | 418 | 844 | 454 | 607 | 399 | 542 | 630 | 565 | 277 | 377 | 187 | 753 | 257071 |
| **1983** | 71044 | 20788 | 10383 | 7673 | 5414 | 2898 | 2632 | 2184 | 1106 | 1136 | 1153 | 802 | 749 | 401 | 408 | 754 | 507 | 504 | 369 | 394 | 395 | 221 | 104 | 139 | 127 | 363 | 132648 |
| **1984** | 36565 | 12339 | 13910 | 11179 | 6729 | 4342 | 3290 | 2702 | 2043 | 1025 | 1159 | 1166 | 753 | 642 | 617 | 1063 | 740 | 701 | 606 | 551 | 769 | 719 | 452 | 619 | 496 | 775 | 105952 |
| **1985** | 24522 | 11027 | 10753 | 9542 | 5342 | 3455 | 2674 | 2148 | 1816 | 879 | 1059 | 770 | 497 | 591 | 619 | 935 | 613 | 548 | 556 | 552 | 689 | 432 | 383 | 345 | 305 | 573 | 81627 |
| **1986** | 37954 | 12326 | 10972 | 10739 | 5929 | 3855 | 3006 | 2386 | 1956 | 1013 | 1085 | 1000 | 642 | 683 | 551 | 1000 | 736 | 647 | 709 | 604 | 789 | 584 | 505 | 472 | 419 | 705 | 101269 |
| **1987** | 60516 | 18198 | 16341 | 16410 | 9904 | 6217 | 4814 | 3595 | 3083 | 1667 | 1687 | 1601 | 772 | 1028 | 819 | 1437 | 1093 | 976 | 941 | 905 | 1131 | 811 | 667 | 731 | 624 | 1763 | 157731 |
| **1988** | 89515 | 28401 | 26513 | 22512 | 13333 | 7993 | 5689 | 4107 | 3691 | 1704 | 1632 | 1402 | 1048 | 1466 | 904 | 1783 | 1414 | 1247 | 1240 | 1335 | 1606 | 725 | 652 | 683 | 972 | 2214 | 223781 |
| **1989** | 81362 | 18919 | 17477 | 16613 | 10775 | 7364 | 5216 | 3636 | 3003 | 1593 | 1506 | 1370 | 793 | 1244 | 796 | 1469 | 1190 | 1061 | 1156 | 907 | 1245 | 964 | 1036 | 821 | 675 | 997 | 183187 |
| **1990** | 52236 | 26401 | 23476 | 25552 | 15622 | 10287 | 6706 | 4449 | 3137 | 1920 | 2031 | 2083 | 1283 | 1745 | 860 | 1509 | 1415 | 1142 | 1518 | 846 | 1795 | 802 | 1099 | 1218 | 551 | 2485 | 192168 |
| **1991** | 67740 | 21462 | 16681 | 17508 | 12227 | 9231 | 6295 | 4275 | 3436 | 1758 | 1866 | 2074 | 1340 | 1636 | 953 | 1801 | 1172 | 1251 | 1253 | 1056 | 1170 | 840 | 843 | 684 | 663 | 1425 | 180640 |
| **1992** | 79926 | 33592 | 26274 | 21504 | 14530 | 10228 | 8427 | 6535 | 4248 | 3328 | 2423 | 2117 | 1098 | 1417 | 1059 | 1592 | 1807 | 1879 | 1546 | 1932 | 1297 | 1047 | 791 | 1052 | 770 | 1872 | 232292 |
| **1993** | 51652 | 27749 | 22023 | 20186 | 11963 | 8623 | 6751 | 5104 | 4100 | 2294 | 2019 | 1882 | 1038 | 1589 | 874 | 1559 | 1308 | 1246 | 1213 | 1127 | 1173 | 1210 | 953 | 831 | 754 | 1867 | 181089 |
| **1994** | 80462 | 35068 | 28207 | 29703 | 21615 | 14641 | 11279 | 7858 | 7305 | 4158 | 3430 | 3566 | 1797 | 2610 | 2182 | 3109 | 1984 | 2414 | 2296 | 1738 | 1559 | 1695 | 1463 | 1234 | 1373 | 2499 | 275248 |
| **1995** | 69275 | 38983 | 31789 | 29576 | 18497 | 15051 | 10538 | 9160 | 5901 | 3102 | 2667 | 2841 | 1632 | 1774 | 1922 | 2784 | 1949 | 1920 | 2151 | 1574 | 2026 | 1739 | 1110 | 1327 | 862 | 1825 | 261975 |
| **1996** | 227914 | 63092 | 49762 | 33632 | 21115 | 15865 | 12268 | 10416 | 7965 | 4397 | 5384 | 5015 | 2832 | 3388 | 3265 | 4246 | 5058 | 4897 | 3575 | 2700 | 2970 | 2657 | 2992 | 2195 | 2244 | 5367 | 505214 |
| **1997** | 266574 | 63439 | 39408 | 27559 | 16522 | 11859 | 9184 | 7351 | 5843 | 2951 | 4672 | 3819 | 1893 | 3091 | 1459 | 2441 | 2538 | 2537 | 2279 | 1794 | 2470 | 1771 | 1510 | 1254 | 1240 | 2220 | 487679 |
| **1998** | 292721 | 42735 | 29688 | 29321 | 16825 | 15579 | 12388 | 9791 | 9707 | 5435 | 3929 | 4812 | 2859 | 2859 | 2270 | 2792 | 3279 | 2290 | 2576 | 1838 | 2317 | 2026 | 1582 | 1337 | 1262 | 2274 | 504491 |
| **1999** | 287839 | 45336 | 34604 | 29392 | 16511 | 11640 | 8898 | 6650 | 5921 | 2530 | 2608 | 2233 | 899 | 2267 | 993 | 2365 | 1845 | 1969 | 1727 | 1478 | 1715 | 1473 | 1345 | 1394 | 1155 | 1461 | 476245 |
| **2000** | 128371 | 39806 | 33180 | 30317 | 17546 | 12409 | 9735 | 7725 | 6565 | 3208 | 2976 | 2860 | 1371 | 2318 | 1409 | 2346 | 2394 | 1906 | 2052 | 1665 | 2100 | 1630 | 1403 | 1303 | 1147 | 1838 | 319579 |
| **2001** | 266306 | 41488 | 31737 | 27700 | 15898 | 11672 | 9102 | 7096 | 6245 | 3030 | 2921 | 2772 | 1344 | 2295 | 1290 | 2268 | 2180 | 1906 | 1893 | 1526 | 1896 | 1528 | 1318 | 1251 | 1102 | 1680 | 449444 |
| **2002** | 338946 | 36154 | 26714 | 22253 | 12832 | 9658 | 7629 | 6029 | 5344 | 2725 | 2648 | 2470 | 1280 | 2078 | 1174 | 1969 | 1906 | 1669 | 1610 | 1271 | 1627 | 1271 | 1070 | 1035 | 947 | 1452 | 493761 |
| **2003** | 318026 | 31410 | 24204 | 21265 | 12216 | 8929 | 6962 | 5437 | 4771 | 2313 | 2248 | 2125 | 1043 | 1749 | 996 | 1762 | 1668 | 1464 | 1452 | 1178 | 1465 | 1175 | 1016 | 961 | 845 | 1284 | 457962 |
| **2004** | 399893 | 33654 | 25129 | 21220 | 12225 | 9132 | 7190 | 5666 | 5009 | 2524 | 2454 | 2296 | 1175 | 1920 | 1088 | 1849 | 1779 | 1558 | 1513 | 1203 | 1530 | 1202 | 1019 | 980 | 888 | 1358 | 545455 |

Table 3. 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 |

Table 3 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 |

Table 4. The assumed proportion of pups surviving in poor ice, high storm years, prior to harvesting.

| Year | Pup survival after storms |
|---|---|
| 1981 | 0.75 |
| 1998 | 0.94 |
| 2000 | 0.88 |
| 2002 | 0.75 |
| 2005 | 0.75 |

Table 5. Inputs into harp seal population model.

| Inputs | Parameter or sources |
|---|---|
| Pup production estimates | Table 1 |
| Removals | Table 2 |
| Reproductive rates | Table 3 |
| Unusual mortality | Table 4 |
| Initial population coefficient | 0.2, SD=0.0026 |
| Adult mortality coefficient | 0.955, SD=0.0232 |
| Greenland harvests 2006 and later | Uniform distribution. Range 70000-100000 animals |
| Increased mortality over 5 year period | (0%,10%, 20%, 20%, 0%) |

Table 6. Catch scenarios, duration of harvest plan, sustainable yield (SY) at the end of the harvest plan, the population at the end of the harvest, year that there is a 20% chance that the population is less than N70. N70 is 4.08 million, which is 70% of the largest population observed of 5.82 million. The last column indicates the year that the population reaches N70.

| Annual Catch (thousands) | Duration of plan (years, TAC per year) | Total Catch (million) | SY at end of plan (thousand) | 50% Probability Population ≥ (million)[1] | 80% Probability Population ≥ (million)[2] | Population below N70 prior to harvesting in year. | Harvest to ensure remain above N70[4] (thousand) |
|---|---|---|---|---|---|---|---|
| 400 | 1@400, 4@236 | 1.344 | 236 | 5.67 | 4.28 | 2012 | 160 |
| 500 | 1@500, 4@230 | 1.420 | 230 | 5.56 | 4.11 | 2012 | 155 |
| 250 | 5 | 1.250 | 250 | 5.72 | 4.42 | 2013 | 175 |
| 275 | 5 | 1.375 | 235 | 5.77 | 4.14 | 2012 | 165 |
| 300 | 5 | 1.500 | 220 | 5.65 | 4.05 | 2011 | 140 |
| 325 | 5 | 1.625 | 210 | 5.52 | 3.88 | 2010 | 110 |
| 350 | 5 | 1.750 | 200 | 5.40 | 3.75 | 2010 | 93 |
| 300 variable[3] | 5 | 1.500 | 220 | 5.65 | 4.05 | 2011 | 140 |
| 325 | 4@325 1@160 | 1.46 | 220 | 5.70 | 4.08 | 2011 | 148 |
| 350 | 3@350 2@211 | 1.47 | 220 | 5.68 | 4.08 | 2011 | 142 |

1. there is a 50% likelihood that the population is lower than the specified level.
2. there is an 20% likelihood that the population is lower than specified and a 80% chance that it will be higher than indicated.
3. The harvest plan allows for a total of 1.5 million animals to be taken over a 5 year period. Harvests are 360,000, 360,000, 300,000, 240,000 and 240,000 animals per year.
4. Harvest levels beginning in 2011 that will ensure an 80% probability that the population remains above N70 for at least 10 years.

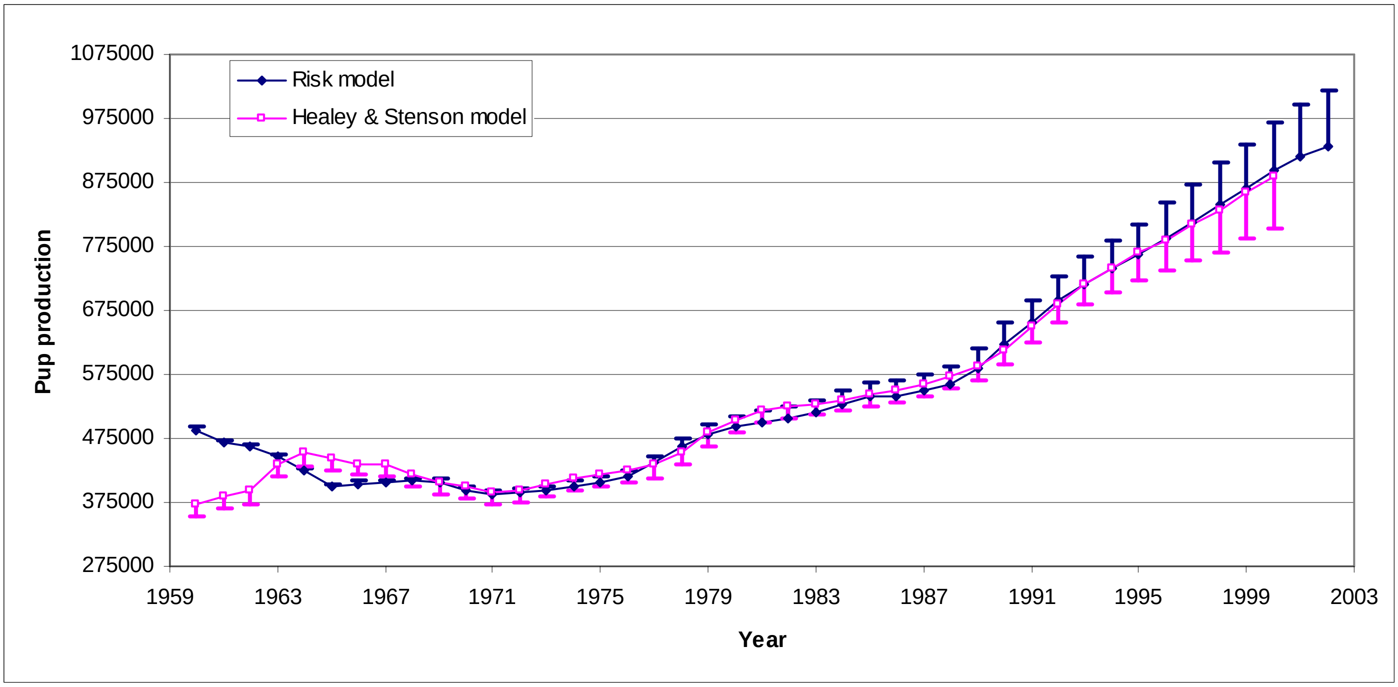



Figure 1. Pup production and total population trajectories of Northwest Atlantic harp seals from 1960 to 2002. A comparison between Healey and Stenson (2000) and the current model (Hammill and Stenson 2003b).

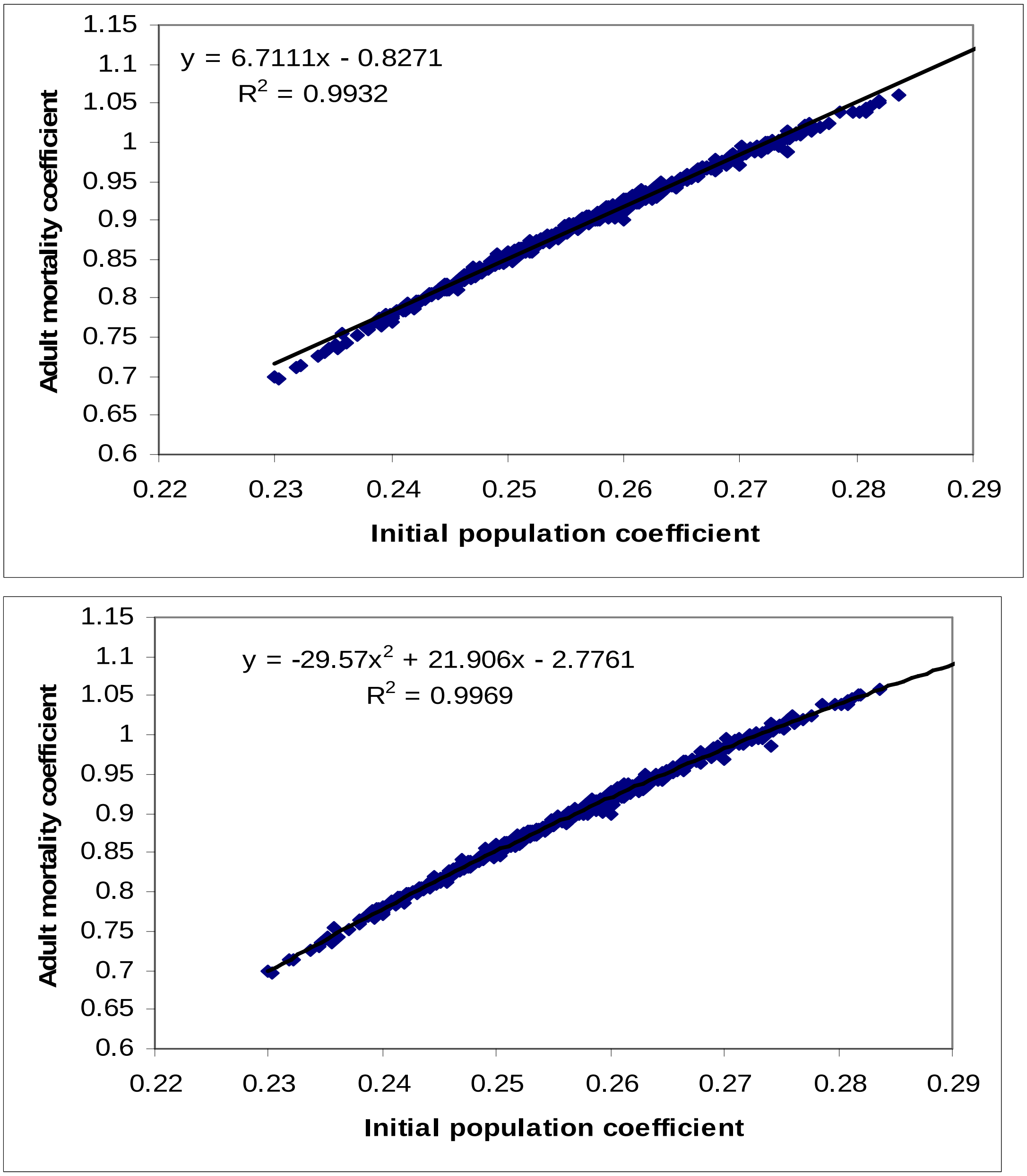



Figure 2. Relationship between adjustable parameters (Initial population size coefficient and Adult mortality coefficient) used to fit the population model to the pup survey data. The top panel shows that a linear relationship provides a good fit except at the extremities, while the bottom panel shows an improved fit using a second degree polynomial to describe the relationship. The parameters are strongly correlated.

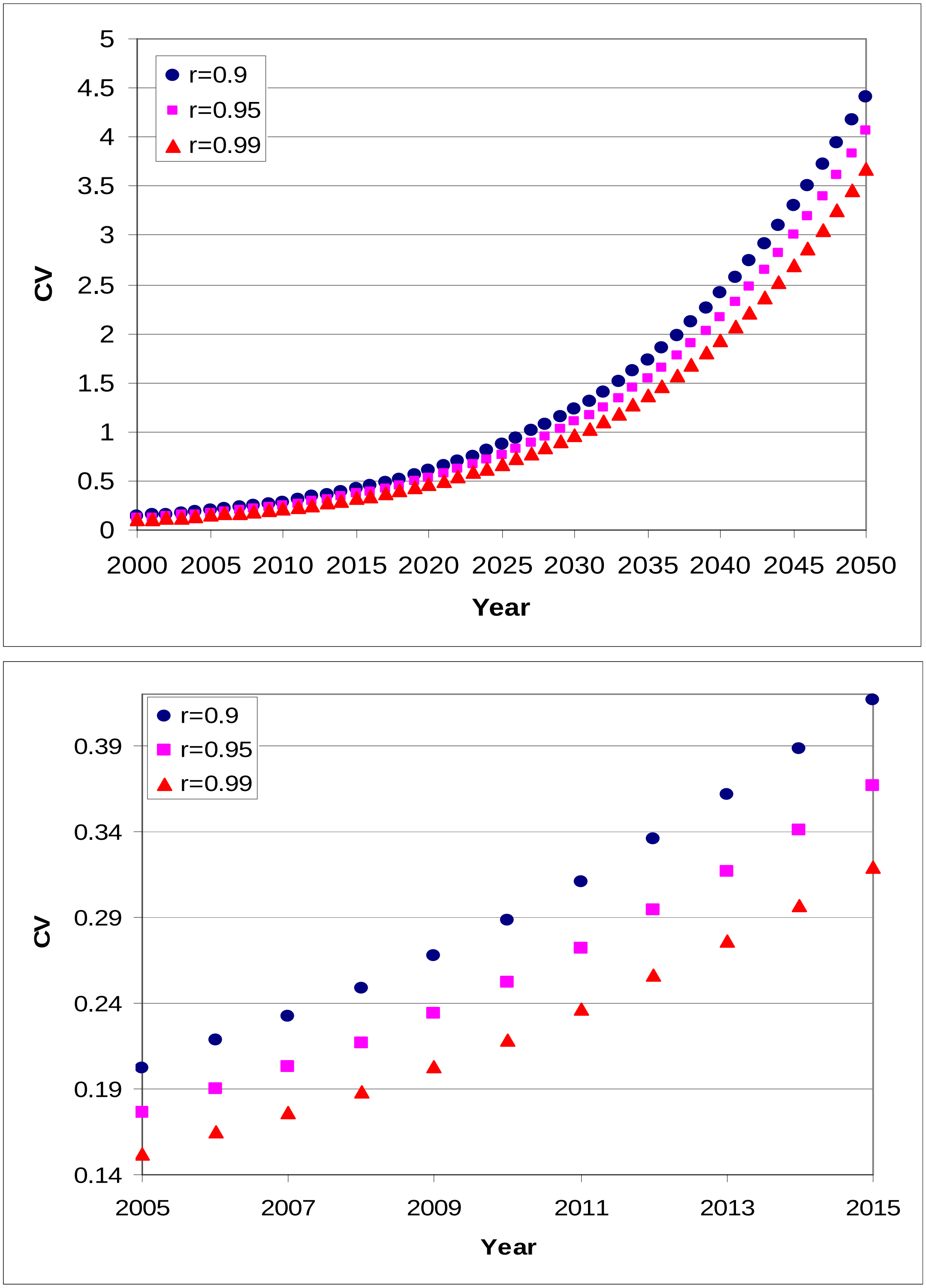



Figure 3. Changes in the coefficient of variation around the mean estimate of harp seal population size as the correlation between estimated initial population size and estimated adult mortality rates are varied. Top figure shows effects from 2005 to 2050, bottom figure focuses on 2005-2015.

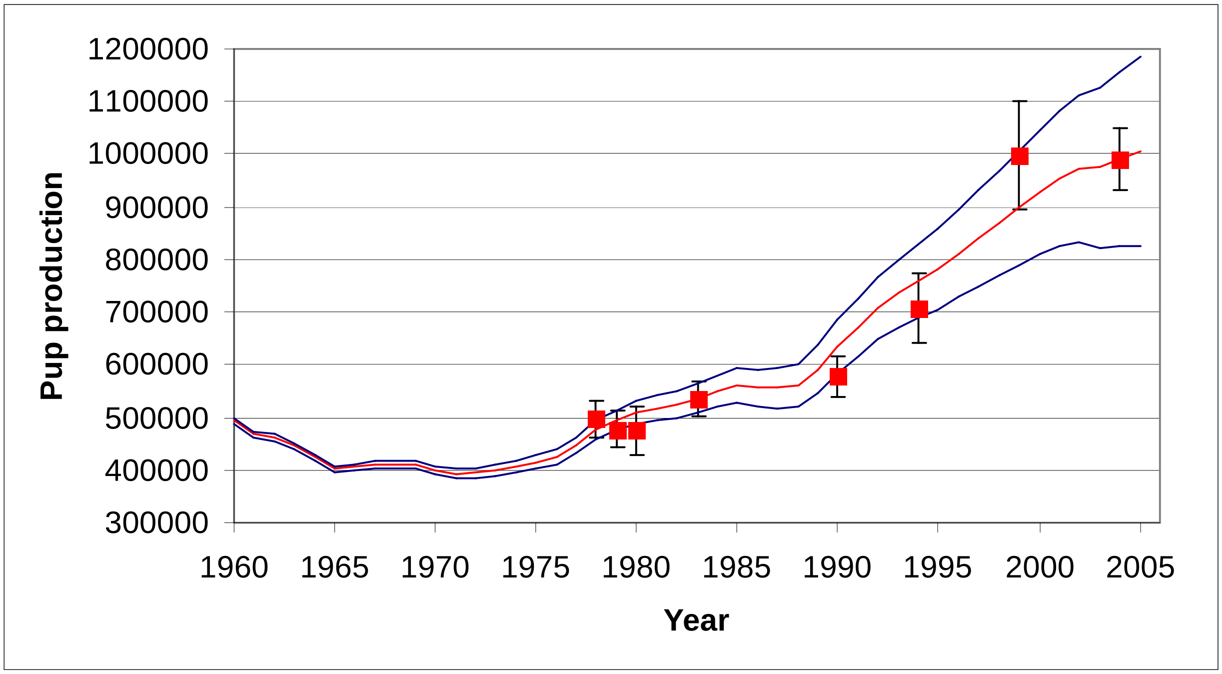



Figure 4. Estimates (± 95% CI) of pup production of Northwest Atlantic harp seals from 1960 to 2005 obtained from independent surveys and the population model .

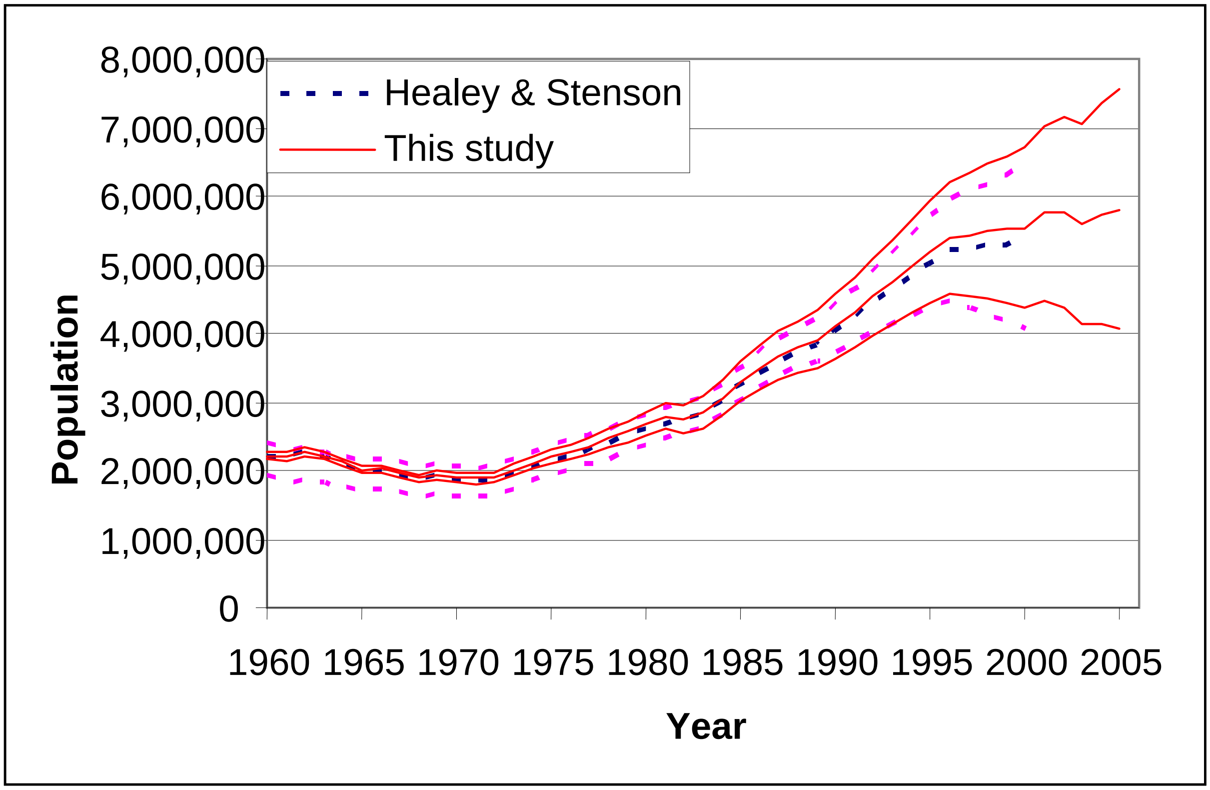



Figure 5. Estimated total population of Northwest Atlantic harp seals from 1960 to 2005 from this study (solid ± 95% CI) and that of Healey and Stenson 2000 (dashed).

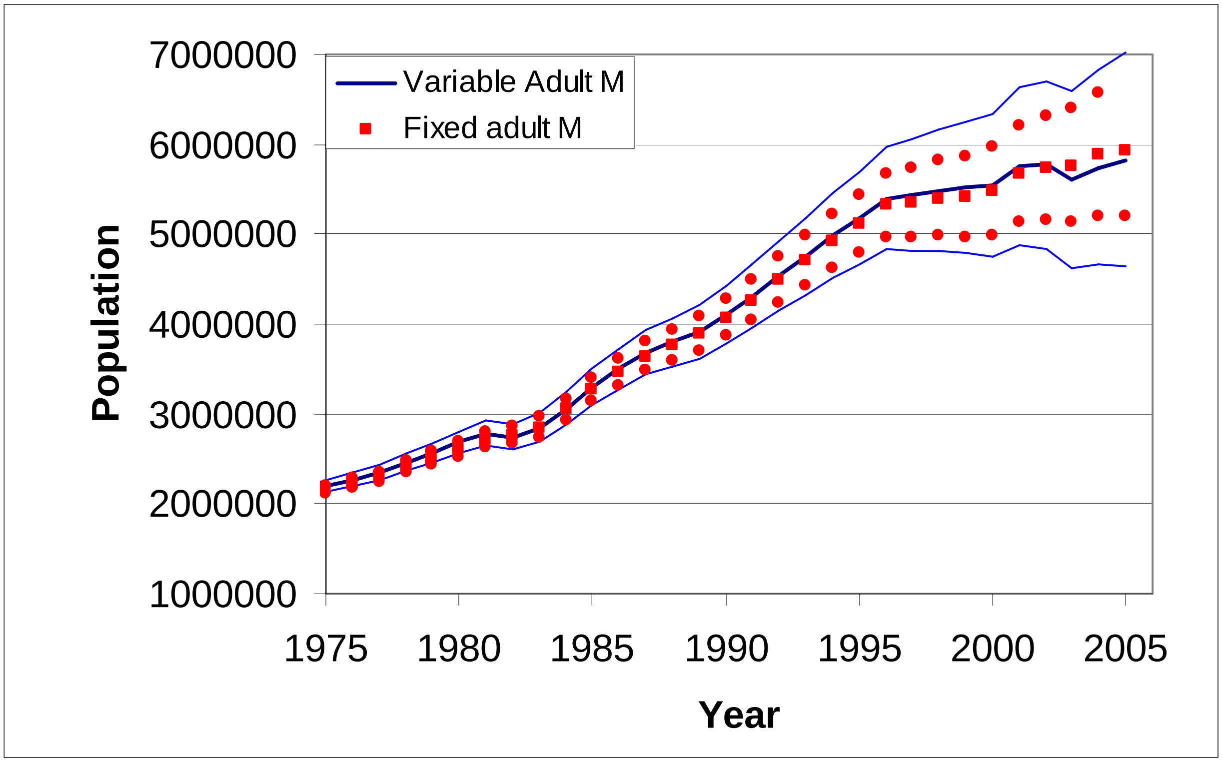



Figure 6. Estimates (± SE) of total population size, based on model runs incorporating variability in initial population and adult mortality coefficients (mean ± 1SE; solid lines) and runs (mean ± 1SE; dotted lines) using constant initial population and constant adult mortality coefficients as presented at May assessment.

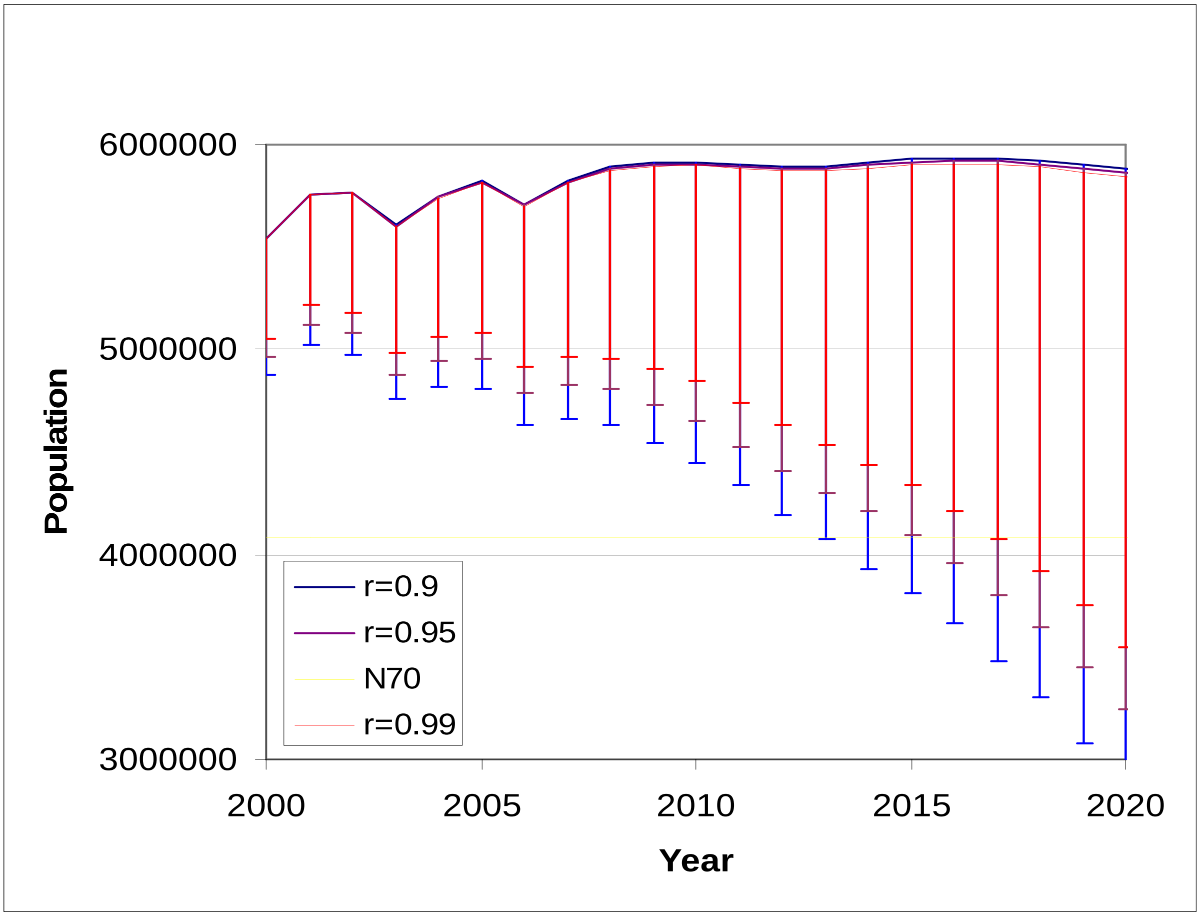
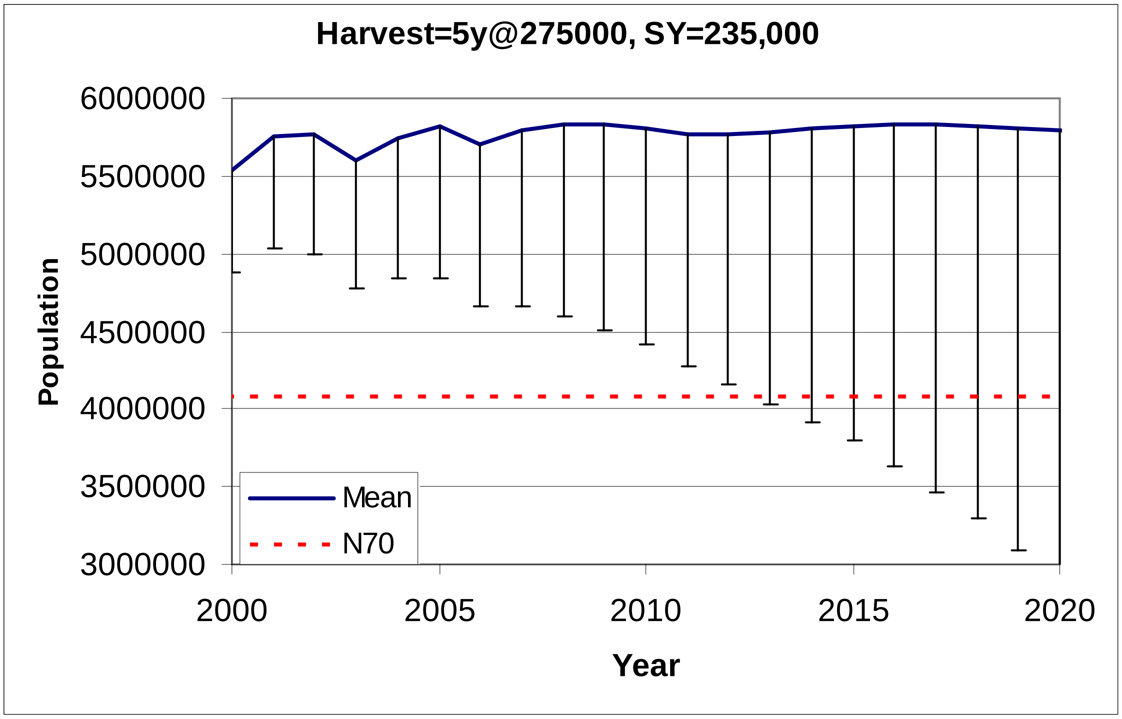



Figure 7. Predicted mean population size and lower 20% population size if model is run and we assume a harvest of 250,000 animals (which is sustainable yield) from 2006 onwards. The different scenarios represent correlation coefficients between estimated initial population size and adult mortality of r=0.9, 0.95 and 0.99.



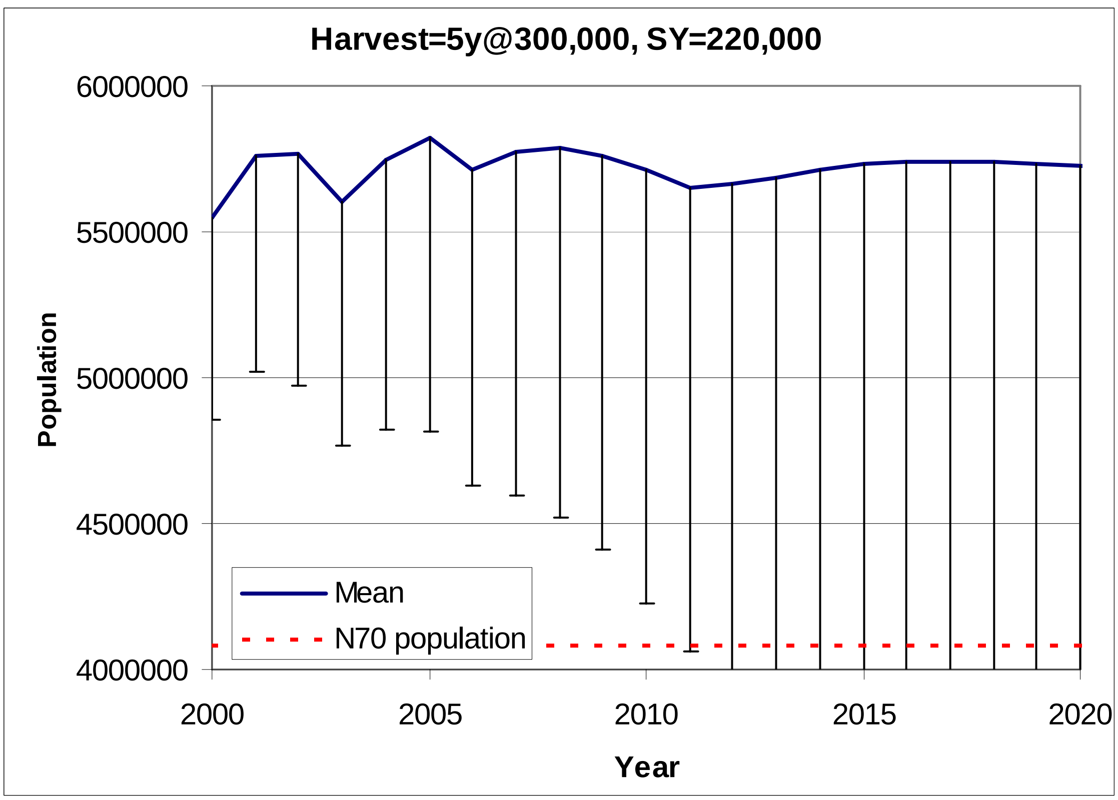
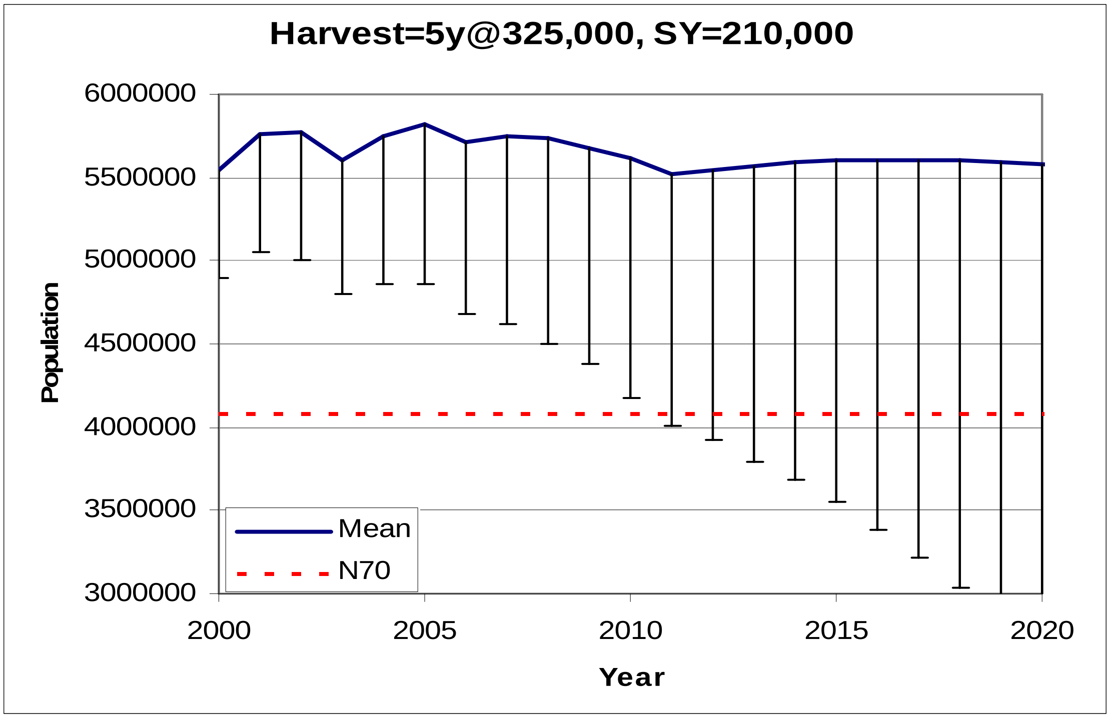




Figure 8. Predicted mean population size and lower 20% population size if model is run and we assume annual harvests of 275,000 and 300,000 animals for five years, followed by the sustainable yield from 2011 onwards.



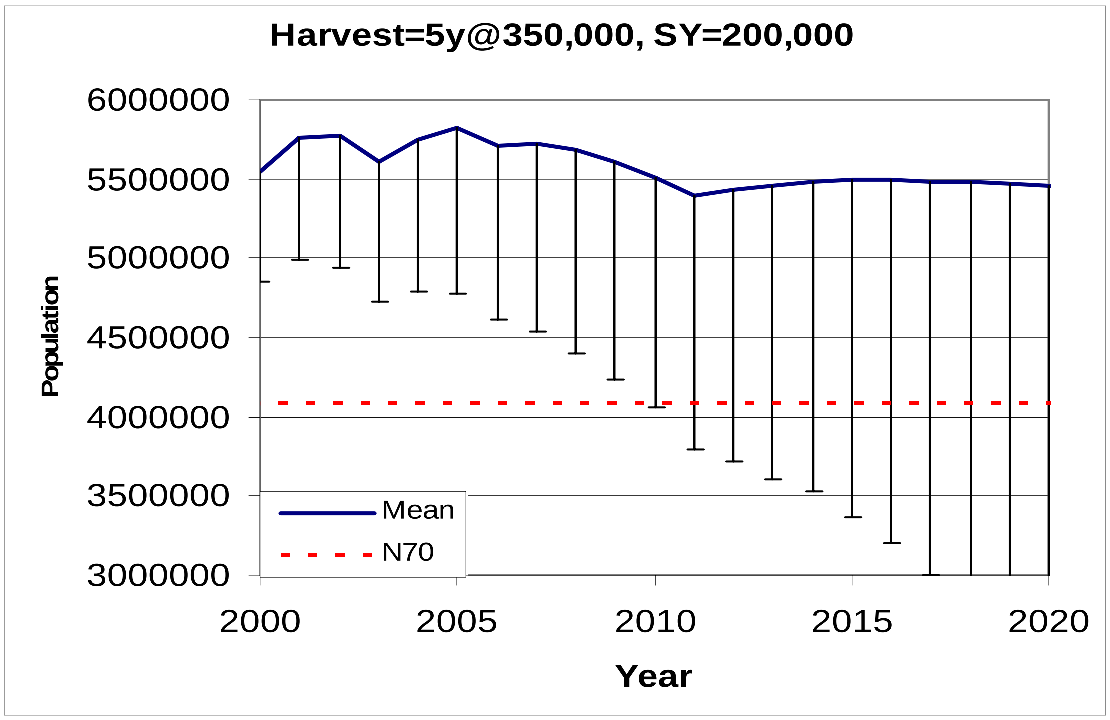




Figure 9. Predicted mean population size and lower 20% population size if model is run and we assume annual harvests of 325,000 and 350,000 animals for five years, followed by the sustainable yield from 2011 onwards.

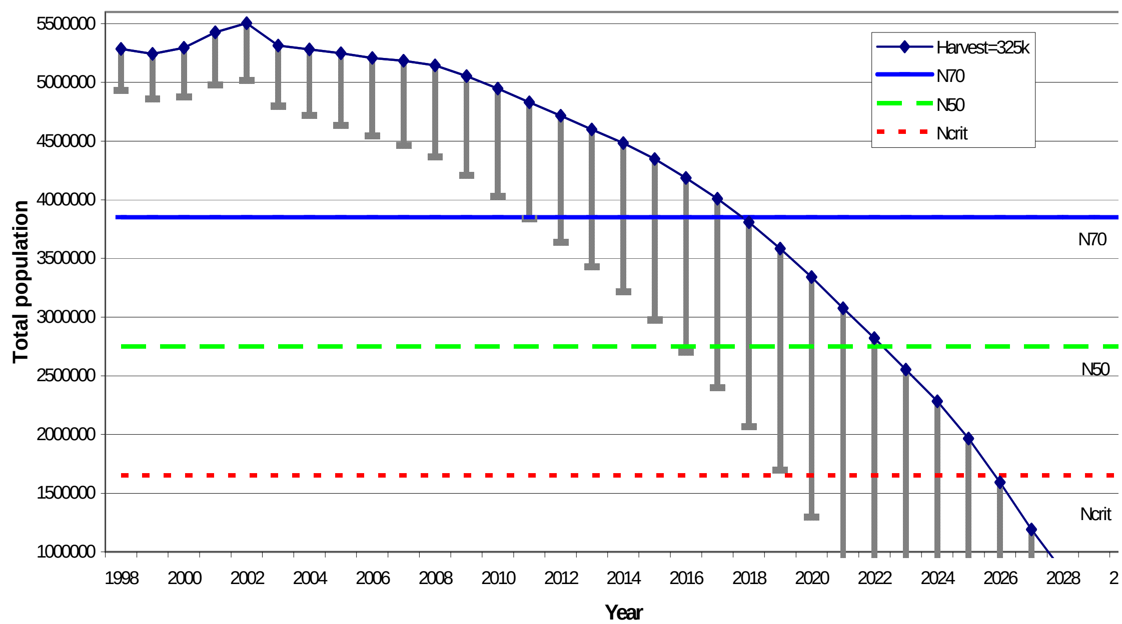



Figure 10. Predicted changes in the NW Atlantic harp seal population from model runs conducted prior to the 2003-05 management plan. Harvest levels were assumed to be 325,000 animals per year. The population was expected to reach N70 by 2011 as shown by the lower 20% population size (Hammill and Stenson 2003b). Note: N70 was calculated at 3.85 M in the 2003-2005 management plan.

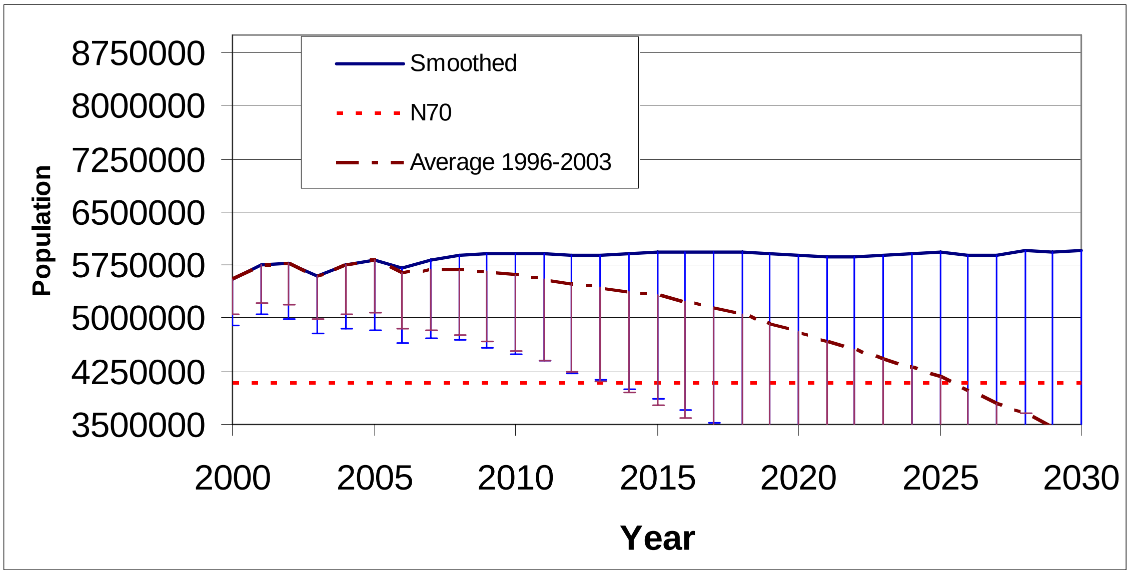



Figure 11. Estimated mean population size and lower 20% population size assuming an annual Canadian harvest of 250,000 animals and the smoothed reproduction rates from Healey and Stenson (2000) from 2000 onwards. If the average of the 1996-2003 reproductive rates is used instead, then an annual Canadian harvest of 250,000 animals will cause the population to decline. This decline falls within the lower 60% confidence limit identified by the smoothed line.