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A Discussion of the Precautionary Approach and its Application to Atlantic Seals

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Foreword

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

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ABSTRACT

The goal of the Precautionary Approach is to outline clear rules for management actions in response to changes of the resource with respect to different thresholds of management concern. The commercial harvest of Atlantic Seals is managed under a PA framework that was developed in collaboration with Fisheries Management, and implemented with the support of industry, in 2003. Science was requested by Fisheries Management to determine: 1) an appropriate Limit Reference Point that can be set at a fixed level (possibly reviewed periodically) and 2) the minimum harp seal population size that can maintain an ongoing (i.e. 15 years) sustainable harvest of 100K, 200K, 300K and 400K, while maintaining a probability of 85%, 90% and 95% of staying above the Limit Reference Point (LRP). Different methods of setting the limit reference point were reviewed. Some methods fixed the LRP at a specific number while others used relative values. Setting fixed values can be problematic if environmental conditions change, or if population estimates are updated as a result of new data or changes in the assessment methods. Changes in the estimates of harp seal abundance illustrate how our perception of a population can change as new data become available. This can result in a change in perceived status of the population with no change in the true abundance. Relative levels require an appropriate reference level for comparison.

Discussion sur l'approche de précaution et son application aux phoques de l'Atlantique

RÉSUMÉ

L'objectif de l'approche de précaution (AP) est de définir des règles claires pour les mesures de gestion en réaction aux changements liés à la ressource en ce qui concerne les différents seuils de préoccupation en matière de gestion. La chasse commerciale aux phoques de l'Atlantique est gérée selon un cadre d'AP qui a été élaboré en collaboration avec la Gestion des pêches, et mis en œuvre avec l'appui de l'industrie en 2003. La Gestion des pêches a demandé aux Sciences de déterminer : 1) un point de référence limite approprié pouvant être fixé à un niveau précis (et peut-être passé en revue périodiquement); 2) la taille minimale d'une population de phoques du Groenland pouvant soutenir une pêche durable continue (c.-à-d. 15 ans) à des taux de prise de 100 000, 200 000, 300 000 et 400 000, tout en maintenant une probabilité de 85 %, 90 % et 95 % de rester au-dessus du point de référence limite. Différentes méthodes d'établissement du point de référence limite ont été envisagées. Certaines méthodes prévoyaient fixer le point de référence limite à un nombre précis alors que d'autres proposaient des valeurs relatives. L'utilisation de valeurs fixes peut s'avérer problématique si les conditions environnementales viennent à changer ou si les estimations de la taille de la population sont mises à jour en raison de l'arrivée de nouvelles données ou de la modification des méthodes d'évaluation. Les changements aux estimations de l'abondance des phoques du Groenland illustrent comment notre perception d'une population peut changer lorsque de nouvelles données sont disponibles. Cela peut entraîner un changement de perception par rapport à l'état de la population sans que sa véritable abondance change nécessairement. L'emploi de niveaux relatifs nécessite l'utilisation d'un niveau de référence approprié à des fins de comparaison.

INTRODUCTION

The Precautionary Approach aims to outline clear rules for management actions in response to changes of the resource with respect to different thresholds. The main objective is to be more prudent in the face of uncertainty, and to minimize the risk of causing serious harm. To function properly, thresholds must be identified and stakeholders must agree on the framework. Opposing viewpoints must be balanced when setting up a PA framework and trade-offs are usually required. For example, adopting an extremely risk adverse approach incurs short-term economic loss while an excessively risky approach can cause significant damage to the population resulting in long-term economic loss, socio-economic hardship and often in increased costs due to the need for additional protection or actions (e.g. SARA listing). Failures (collapses) in Atlantic groundfish with little sign of recovery over the last 2 decades, underlines both failure in the management framework, as well the failure by individuals to consider the importance of uncertainty and to properly account for risk resulting in severe long-term consequences.

The commercial harvest of Atlantic Seals is managed under a PA framework that was developed at the request of Fisheries Management and implemented with the support of industry in 2003(Hammill and Stenson 2007; Stenson et al. 2012). Since then an almost identical approach has been adopted by ICES, Norway and Russia for the management of harp and hooded seals in the northeast Atlantic (ICES 2008). Within this framework, the current state of knowledge about a species or population is taken into account and management is adapted to changes in the quality and quantity of information. This is accomplished by establishing different frameworks for what are considered as Data-Rich populations or as Data-Poor populations, along with criteria for assigning populations (Stenson et al 2012). The framework identifies a limit (or critical) reference point (LRP or N_{lim}) which represents the (estimated) level at which continued removals would lead to serious and irreversible harm to the population, and a Precautionary Reference Point (also referred to as Upper Stock Reference Level (USRL), Upper Reference Point (URP) or N_{buf} which identifies a population range within which risk-adverse management control rules would apply to ensure that the population does not fall below the critical reference level. (Stenson et al. 2012). A third threshold, referred to as the Target Reference Point (TRP), represents the desired population size and is generally set above the USRL. The level of the TRP has not been identified for Atlantic seals, but will depend upon the management objectives of the harvest.

After nearly a decade, Fisheries Management and Industry have requested that the Atlantic seal PA framework be reviewed. Of particular concern is that because the thresholds are set as a proportion of some proxy of K, the thresholds have varied considerably across years. This variation is due, in part, to changes in population sizes as they have been recovering from lower levels but more importantly, as we have learned more about the resource, and improvements to the population models incorporated, significant changes have been made to our perception of both population abundance and trend (Table 1, Fig. 1, 2 & 3).

Science was requested by Fisheries Management to: 1) revisit the methodology/criteria to establish the Limit Reference Point (LRP or N_{lim}) and outline what are the biological/ecological reasons for using $B_{recover}$ (sometimes known as B_{loss}); 2) determine an appropriate Limit Reference Point (LRP) that can be set at a fixed level and identify when it should be reviewed; and 3) determine the minimum harp seal population size that can maintain an ongoing (i.e. 15 years) sustainable harvest of 100 thousand, 200 thousand, 300 thousand and 400 thousand, while maintaining a probability of 85%, 90% and 95% of staying above the Limit Reference Point.

Here, we review the PA for Atlantic seals by examining different options that may be considered in setting a N_{lim} that can be applied to a number of species with similar life histories We provide this within the context that the population size is known (with its estimated uncertainty). However, for a wild population, the true population size is not known. To highlight this, we outline how our perception of the Northwest Atlantic harp seal population has changed over the least two decades and the implications of such changes if we adopt a fixed approach or one that can be adjusted as new information becomes available. Finally, we also compare the current PA framework for seals to PA frameworks that have been proposed for other fisheries in the Department.

MATERIALS AND METHODS

To address the questions raised by FAM, two issues need to be considered. The first is how our understanding of the population has changed and what can we say about the true population size. The second is to estimate the minimum population sizes that can withstand certain harvest levels and respect the management objectives. We also outline how a PA framework has been developed for other fisheries within DFO in order to put the seal management strategy into a larger context. We include some international approaches, but this has also been discussed in Stenson et al. (2012).

The dynamics of the northwest Atlantic harp seal population (*Pagophilus groenlandicus*) are described using an age-structured model first developed in the early 1980's (Roff and Bowen 1983). Since then, it has undergone many revisions including the incorporation of struck and loss and unusual mortality related to poor ice conditions (Sjare and Stenson 2002; Hammill and Stenson 2003; Hammill et al 2011, 2012). Here we summarize the major changes in the models and how these have affected our understanding of the dynamics of the population over the last 2 decades.

It has been suggested by industry that having fixed reference levels is easier to understand and therefore preferable to levels that were established as a proportion of herd productivity (Maximum Sustainable Yield or MSY) or environmental carrying capacity (K). To examine this, we provide a simple example, using a fixed and a proportional framework to show how changes in our understanding of a population, such as changes in current population size, trajectory and environmental carrying capacity (K) could affect management decisions. This is done using the DFO framework, as well as using the approach developed in the Atlantic Seal Management Scheme. The DFO guidelines suggest setting the reference levels as proportions of Maximum Sustainable Yield (MSY), where N_{Buf}=80% of MSY and N_{lim}=40% of MSY. Assuming that MSY occurs at 60% of K, then N_{Buf} would be set at 48% of K, and N_{lim}=24% of K. Under the seal management framework, N_{Buf} is referred to as N70, which is set at 70% of the largest population estimated, and N_{lim} is referred to as N30, which is set at 30% of the largest population estimated.

Under PA, if a population falls below the limit reference level, then it is considered to have suffered serious harm. We assume here that removals can be reduced to some minimal level, but that there would continue to be some minimal level of anthropomorphic removals. If the population were to fall below a level where this minimal number of removals would no longer be sustainable, then the population would be considered to have suffered serious harm. Using this definition of serious harm, we assume that subsistence hunts in Greenland and Arctic Canada would remove 26,000 seals per year, 10,000 would be caught in fishing gear (i.e. by-catch) and 40,000 seals (~ the number taken from 1983-1995 following collapse of the large vessel hunt) continued to be taken in southern Canadian waters for a variety of reasons. Reported harvests were adjusted for animals struck and loss rates of 50% for the Greenland/Arctic hunt and 5% for the southern Canadian hunt, resulting in a total catch of 106,000 animals (Sjare and Stenson 2002, Hammill et al. 2011). We constructed a surplus production model assuming exponential growth and estimated from the model the minimum population size that would persist with the level of removals outlined above and under different levels of productivity. The model identified a minimum population size which remains constant over the simulation period. This is done by minimizing the sum of square differences between the start and end population size. The model followed the form:

$$N_{t+1}=N_t+ N_t (\lambda_{max}-1)- H_t ,$$

where N is the population size at time t and t+1, Lambda (λ_{max}) is the maximum rate of increase, or the population productivity, and H_t is removals from the population at time t. The maximum rate of increase for pinnipeds, including harp seals is approximately 12% (Wade 1998; Harkonen et al 2002; Hammill and Stenson unpublished data), whereas a decline equal to lambda of 0.97 has been observed in this population (Hammill and Stenson unpublished). These provided minimum and maximum values for the simulation. The simulations, estimated the minimum population size over a projection period of 100 years, assuming a different lambda, selected in each year. Three general cases were examined assuming different levels of herd productivity (low, medium and high). The value for lambda was drawn from a triangular distribution ranging from 0.97 to 1.12, with modes at: 1) lambda low productivity=1.03; 2) lambda medium productivity=1.06; 3) lambda high productivity =1.10.

Finally, we estimated minimum population sizes that can maintain an ongoing (i.e. 15 years) sustainable harvest of 100,000, 200,000, 300,000 and 400,000 while maintaining a probability of 85%, 90% and 95% of staying above the limit reference point, assuming a harvest composition of 90% beaters. The stock assessment model developed during the 2011 assessment, with carrying capacity (K) fixed at 12 million, was used to evaluate these scenarios (Hammill et al. 2012). Two model formulations were used : the first assumed that reproductive rates were fixed, where the model selects randomly from a sample consisting of reproductive rates observed during the last five years; the second formulation assumed that reproductive rates changed in a density dependent manner, for a population with the same carrying capacity (K=12 million). For these simulations an environmental factor was included, where reproductive rates were multiplied by 1.5, 1.6, 1, 0.6, or 0.4 to simulate variable environmental conditions (Stenson and Buren, unpublished data) that act as random factors in addition to population density effects on pregnancy rates. The starting point for the model was the 2011 estimate of population size.

ESTIMATES OF ABUNDANCE

Until 1999 there were few changes to the basic population model that was originally developed in the mid 1980s. In the early 2000s, the model was modified to incorporate reproductive rates differently, account for struck and loss and include the impacts of ice-related mortality on the population (Table 1). During this period, a general decline in reproductive rates was recognized along with an apparent increase in inter-annual variability (Fig. 1). This inter-annual variability was assumed to be primarily due to sampling error and in particular the smaller-sample sizes available and so the reproductive rates were smoothed. The dynamics of the harp seal population were described assuming that the population was growing exponentially. During 2003-2005, when the PA framework was first implemented, the population was estimated to vary from 5.3 to 5.7 million animals (Table 1; Fig. 2, 3). At the time, the N_{Buf}, (or N70 as it is called) was set at around 3.7-4.0 million animals and N_{lim} (or N30 as it is referred to) was set at 1.6-1.7 million animals.

In 2008, the aerial survey resulted in a higher than predicted estimate of pup production. This resulted from unusually high reproductive rates in 2008 (Stenson and Wells 2011; Stenson et al. 2010). Following this survey, it was recognized that the inter-annual variation observed in the reproductive data reflected actual changes in pregnancy rates. As a consequence, the model formulation was changed during the 2010 assessment to incorporate the annual measured pregnancy rates. It also described the dynamics of the population assuming density-dependent changes in young of the year mortality, rather than a simple exponential growth model (Table 1) (Hammill and Stenson 2011; Hammill et al. 2011). This change altered our perception of the population from one that may have been as high as 9 million animals and still increasing under the assumption of exponential growth, to a population that had leveled off at a lower number (7.5 - 8.5 million in 2008, depending upon assumptions about carrying capacity) due to the impact of density dependence factors (Fig. 3). Recent model runs estimate the population during the period 2003-05 at approximately 7 million animals (Fig. 3), resulting in estimates of 30 and N70 of 2.1 and 4.9 million respectively. These levels are very similar to those estimated based upon the most recent model formulation (Hammill et al. 2012). The differences in population trajectory predicted between exponential and density-dependent models appear in the late 1990s. It also appears that the period of largest growth in the population (four-fold increase) occurred between 1972, when harvest quotas were first implemented, and 2003, when the current PA framework was first adopted. Since then reproductive rates continued to decline, ice related mortality and catches increased and the population appears to have levelled off (Fig. 3).

The greatest sources of uncertainty in a density-dependent model are the estimated carrying capacity (K) and the shape of the curve used to describe the density-dependent changes in the trajectory of the population. The shaping parameter and K are highly correlated and at the current time it is not possible to further refine these two parameters. The consequences of this uncertainty can be important with respect to our understanding of the dynamics of the population, and its response to environmental and harvesting conditions. Some of the effects of changing the way in which the dynamics of the population are described and how K and the shaping parameter interact are illustrated in Figures 4 and 5.

LOWER STOCK REFERENCE LEVEL OR N_{LIM}

N_{lim} separates the Critical/Cautious zones. It identifies a threshold, below which the population is considered to suffer serious harm. A number of different approaches have been proposed for setting the LRP or N_{lim}.

N_{loss} (B_{loss} for fisheries) is the lowest population size that has been observed in the past and from which recovery has occurred and has been used in some fisheries as a N_{lim} or B_{lim}. It is based on the concept that if a population has been reduced to this level in the past, and has recovered; it will be able to do so again under the current conditions. The use of B_{loss} has been considered in a number of situations, but has not been adopted in many. Generally, it has been applied in fisheries where there have been no changes in ecosystem conditions (e.g. scallop). If different ecosystem conditions have occurred within the assessment time series available (e.g. shrimp) and known to be due to a regime shift, the B_{loss} during different productivity/environmental regimes must be estimated and combined (Table 2).

For harp seals, all model runs completed since the 1990s indicate that the population probably reached a minimum in the early 1970s (Fig. 3). The population at this time, based on averaging all models estimates together was around 1.5 million animals (SE=99,000, 95% CL=1.2 to 1.8 million).

It is not always certain that a population that has been reduced to low levels will recover in a timely manner. 2J3KL and 4T cod stocks were reduced during the 1960s and 1970s, and were able to recover somewhat once fishing was reduced (but not eliminated). However, these stocks were reduced to similar low levels again during the late 1980s and have not recovered over the past two decades in spite of fishing activity that is even more limited than occurred during the previous decline. B_{loss} has also been used as a LRP for North Sea cod and has been set at 70,000 t, However, there have been signs of recruitment impairment well above that level resulting in some suggestion that the reference level should be set above 160,000 t (Hauge et al. 2007). These stocks illustrate that the simple fact that species has recovered from a given level in the past, does not ensure that it will do so again.

Current ecosystem conditions may be considerably different for harp seals. At the time of the previous low period for the population in 1970s, approximately 87% of mature females were pregnant. Pregnancy rates have declined considerably since then, with only 20-30% of females pregnant in the last few years (Fig. 1). Although much of this decline appears to be a response to changes in population size, environmental conditions, appear to have a significant influence on the abortion rate and overall fecundity (Stenson and Buren unpublished data). Climate change also has had an important negative impact on the population through increased mortality due to poor ice conditions, particularly in the Gulf of St Lawrence (Bajzak et al. 2011; Johnston et al. 2012; Stenson and Hammill 2012). These changes make it very unlikely that harp seals will have as high a level of recruitment as they did during the previous recovery period. The need to understand changes in the productivity regime and factors that can modify density dependent responses to changes in abundance underscores the major weakness of using N_{loss} as a LRP.

The use of N_{loss} as a lower limit is problematic for species that are recovering from historical lows. Grey seals (*Haliocherus grypus*) were almost extirpated from Atlantic Canada during the 18th century and the population showed little sign of recovery until the 1980s. The reasons for the lack of recovery prior to this are unknown although several factors have been proposed (Bowen 2011). The adoption of N_{loss} as a lower limit would have a very high likelihood of extirpation of the species.

N_{loss} does not work well in situations where there is little change in abundance over the time period for which data are available. Abundance of hooded seals (*Cystophora cristata*) has been estimated for the period 1965-2005 (Hammill and Stenson 2006). There has been very little change in this population over the time series with the lowest level (i.e N_{loss}) being estimated to be approximately 478,000 seals, which is 80% of the maximum (593,000) observed. Such a level is unlikely to be associated with serious harm.

$N_{\%}$ is the population where a threshold set as a proportion of a reference level such as carrying capacity (K) or the biomass at Maximum Sustainable Yield (MSY). The latter may be estimated using a theoretical relationship to K or if not available, based on a spawning stock size-stock recruitment relationship. This concept has been used extensively among fish populations and marine mammal populations where it is usually set as a proportion of K or a pre-exploitation level. A modification of this is used in the current Atlantic Seal PA framework that uses maximum population size as a proxy for K.

The general DFO guidelines recommend setting N_{lim} at 40% of MSY. In New Zealand, the standard is to set N_{lim} at 10% of the environmental carrying capacity (K) or 25% of MSY whichever is higher (Minister of Fisheries 2008). Examples of where this approach has been used for finfish within DFO include: American eel, Pollock, plaice, 4X5Y, and 4RS cod (Table 2). Estimating MSY for marine mammals depends upon the assumed level of K and the shape of the density dependent relationship (Fig. 5). Generally, it is between 60 and 80% of K. for harp and grey seals we are assuming that MSY occurs at 60% of K. if, for example, we assume that MSY occurs at approximately 60% of K, for marine mammals, then under our current understanding of the population, where K=10 million, N_{lim} would occur at 2.4 million animals. The current Atlantic seal management approach is consistent with the DFO approach, but was developed before estimates of K could be obtained. The Atlantic seal framework, uses the largest population observed as a proxy for K, and the N_{lim} is set at 30% of this proxy (Hammill and Stenson 2007; Stenson et al. 2012). Under the current harp seal population model (Hammill et al 2012) , the maximum population observed is approximately 7.0 million (reduced from 8.3 million in Hammill and Stenson 2011) which results in an estimate of N_{lim} being 2.1 million animals, which is similar to what N_{lim} should have been when the framework was established in 2003.

The advantage of the N or $B_{\%}$ approach is that it is self-adjusting to changes in knowledge and new information on the reference level (e.g. K or B_{msy}) and therefore incorporating new data does not require a change in the framework itself. As our understanding of the population changes or as our modelling approaches change, the N_{lim} may change in absolute terms, but the limits remain constant with respect to the other reference levels. The disadvantage of this approach is that the value of N_{lim} shifts when there are new data or model developments that result in changes to the estimated reference level. However, the relative value of the N_{lim} does not change and so the status of the population will not change (cf. B_{number} below). One way to reduce the apparent variability in the reference levels is to agree to only re-examine the reference level at specific intervals, for example after a major assessment. Changes in the reference levels also occur in other fisheries. For example, northern gulf cod was rescaled in 2011, after being set in 2009, owing to changes in weight at age estimates (Table 2).

$N_{conservation}$ is a variant of $N_{\%}$, in that the LRP is set at a proportion of some index of abundance, but in this case the population threshold is set based on the magnitude of decline from a reference population size. The reference population could be K (if known), the largest population estimated, or the population before decline. This approach is used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the International Union for the Conservation of Nature (IUCN). They consider a population to be endangered if there is a 70% (cause known and stopped) or 50% (cause unknown and decline not stopped) decline in the population within 10 years or 3 generations, whichever is longest. This approach has many of the same advantages and disadvantages as the $N_{\%}$ approach.

N_{number} where the lower stock reference level (LSRL) is set at a fixed number. Currently, no known framework uses this approach. This approach would establish a minimum population size that could continue to withstand some low level of harvesting. The advantage of this approach is that the number remains fixed which is generally easier to understand, particularly by industry. The two major disadvantages of this approach is that firstly, it is difficult to decide on an acceptable number, and secondly, because with few exceptions, we do not know the true population size, it is possible for the population to change status (e.g. fall into the cautious zone) due to changes in our perception of the abundance (e.g. model changes) without any actual biological change. If our understanding of the population trends change, then B_{number} may no longer be valid.

In the development of the Precautionary Approach, Nl_{im} is set at a level below which the resource would suffer serious harm. For fish and marine populations this could refer to the population level where a resource has declined to such a low level that mortality exceeds recruitment, and it is not possible to reduce mortality without extreme effort. If we use such an approach for seals and a minimum (i.e. non-discretionary) harvest level of 106,000 animals, the minimum population could be estimated assuming the rate of increase or productivity (Lambda) of the herd (Fig. 7). As expected, productivity has a major impact on estimates of the minimum population size needed, with the minimum population size ranging from 2.7 million (95% CI=2.2-3.3), 2.2 million (95% CI=1.8 to 2.6 million) and 1.7 (95% CI=1.4 to 2.1 million) assuming low, medium or high productivity respectively and a minimum harvest of 106,000 animals (Fig. 7).

The example of using a fixed N_{lim} instead of one based on a proportion was examined using a simulated population with an environmental carrying capacity (K) of 12 million animals, a maximum 'observed' population of 8 million animals and a current population size of 7 million animals (Table 3). If we follow the DFO guidelines, the N_{Buf} would be 5.8 million, and N_{lim}=2.9 million animals. Under the Atlantic Seal Management Strategy, N_{70}=5.6 million, and N_{30}=2.4 million animals. When new surveys are completed there are often changes in our perception of the population which result in changes in our estimates of K, maximum population size and the current population size. If such a survey resulted in a 25% reduction in these parameters, then the N_{Buf}, and N_{lim}, N70 and N30 would all shift downwards by 25% as they shift with our perceptions of the population. However, if these limits were fixed, and were unchanging, then as our perceptions of the population changed, this could result in one or more thresholds being exceeded, which would trigger management actions to reduce the harvest even though the true population had not changed (Table 3).

The fact that seal surveys are only completed approximately every 5 years, we are fitting data to, at best, 11 surveys over a 60 year period (compare this to a cod survey with 60 surveys over a 60 year period), then it is easy to understand why there is considerable uncertainty, associated with abundance and trend. Therefore the combination of limited data and uncertainty on the abundance and trend of the population indicate that considerable uncertainty will remain with our understanding of resource abundance. For example moving from an exponential model to a density dependent model resulted in a shift from an estimate of almost 9 million animals in 2008, to less than 8 million. These changes reflect changes in model structure, not actual changes in the population size. Using a system with fixed reference levels (see options #1,4,5 discussed above) would suggest that the population had been reduced closer to the precautionary reference level while remaining with a proportional system (see options #2, 3 discussed above), the relative health of the resource has remained unchanged.

MINIMUM POPULATIONS REQUIRED FOR COMMERCIAL HARVESTS

We were also asked to estimate populations that will provide for long-term, sustainable harvests of 100,000, 200,000, 300,000 and 400,000 while maintaining a probability of 85%, 90% and 95% of staying above the limit reference point, assuming a harvest composition of

90% beaters. In order to do this, we used the 2011 assessment model with a fixed K=12 million animals and assumed the current limit reference point (N_{30}) of 2.5 million based upon the current estimated maximum population (8.3 million). For this simulation, the population was reduced as quickly as possible to a minimum size by imposing extremely high harvests on the population over 3-5 years, then maintaining a constant harvest of 100,000, or 200,000 up to 400,000 animals, depending on the scenario over the next 15 years. The manner in which this reduction in the population occurred, in terms of the age structure of the removals and the time frame for the reduction, will have an impact on the minimum population size that can support the tested harvest levels. However, we did not explore different time periods for the reduction removals or different age structures during this reduction phase. Generally, a larger minimum population size was needed to support a larger harvest; a larger population size was also needed to have a higher probability of respecting the management objective (Table 4, Fig.6). The minimum population size was also affected by the type of model formulation during the future projections. Given the current low pregnancy rates, the populations required to sustain catches assuming that reproductive rates were fixed, are higher than those that assume that reproductive rates will increase as the population declines (i.e. a density dependent function). A population of approximately 5.3 million seals is required to sustain an annual catch of 100,000 with a 95% likelihood of remaining above the limit reference point if reproductive rates do not change while 4.7 million are required if we assume that they will increase as the population declines. Increasing the average harvest to 400,000 requires 7.7 or 6.7 million seals assuming constant or density dependent fecundity, respectively. Increasing the risk by accepting a lower probability of remaining above the limit reference point (80% vs 95%) reduced the required population by approximately 500,000 – 600,000 seals (Table 4, Fig. 6).

Currently, the Precautionary level (N_{buf}) is set to minimize the risk that the population would fall into the critical zone, i.e. fall below the Limit reference point, before the actual population size can be recognized. The level at which the Precautionary level is set will include consideration of the degree of risk that is acceptable in ensuring that the Limit Reference point is not reached and will be affected by such factors as the type of harvest, assessment frequency and degree of uncertainty of the estimates variation in reproductive rates, accuracy of reporting of catches, etc. Internationally, the harvest control rules that have been developed maintain a 95-97% probability that the population will remain above the Limit Reference Point (Stenson et al 2012).

DISCUSSION

In this exercise we examined various options for setting a Limit Reference Point and the populations required to maintain harvests of a given level. The latter is an example of an approach to identifying the Target Reference Point (TRP) based upon a desired harvest level for a commercial species. The TRP is the preferred level for the population and is based upon the objectives of the harvest. In the case of commercial species, this is usually identified by the stakeholders and management and is intended to be above the Precautionary Reference Level. Setting the TRP requires discussions among the various stakeholders to outline what the overall objective is for the population. Table 5 illustrates some of the possible management objectives associated with setting a ‘preferred’ abundance of seals in Atlantic Canada. The level of population to maintain will depend on the management objectives. For example, if the hunt is carried out as an economic activity, is the objective to maximize harvests in years when prices are high, or have a constant economic return (constant harvest). As hunt levels increase, protest activity generally increases as well. Will a given level of hunt result in a backlash that will impact potential markets? Alternatively, under a larger ecosystem approach is the harvest of seals considered to be part of a diverse basket of income sources or is the objective to manage seals to protect other fisheries or to contribute to marine mammal observation activities? Each objective must be evaluated to determine if it can be supported by the available data, is it feasible to accomplish, what are the management, enforcement or monitoring requirements, etc. The importance of achieving different objectives will influence the degree of risk associated with maintaining a population above the limit reference point.

This study has shown that identifying a value for N_{number} or N_{loss} is affected by the productivity regime that the population is exposed to. It also underlines the uncertainty associated with the ability of a population reduced to a certain level under one set of ecosystem conditions, being able to recover under another set of ecosystem conditions that may prevail in the future. Another weakness in this approach is that it assumes that the model represents the true population size. However, as we have seen, modifications to the population model used in the assessment can result in shifts of 15-30% in our estimates of the total population size.

Setting fixed rates is an approach that has not been followed in other fisheries. The scenarios examined here showed that a fixed reference level could lead to conditions where the population could easily move from a healthy zone into the cautious zone, due simply to changes in modelling approaches.

In contrast, a system that relies upon proportional changes in abundance (e.g. the current framework, or the DFO general framework) provides an approach that is self-adjusting. If the reference levels are allowed to shift as our understanding of the population changes, then the relative position of the reference levels does not change as shown by the model scenarios. There are several frameworks that have now been established since the original version of the Atlantic seal plan was implemented. All approaches that have been accepted and implemented in commercial fisheries set limits within a similar range, with the exception of the IWC limits for commercial harvesting, although limits for subsistence harvests fall within the range applied in other approaches (Table 6). Stenson et al (2012) have outlined other examples of where reference levels have been allowed to change as our understanding of the population also changes. Establishing thresholds is only one aspect of the PA framework. Other factors that need to be considered when setting limits include the risk tolerance for falling below identified reference levels and time allowed for rebuilding.

One difficulty with the current approach has been the annual change in reference levels as data are added and our understanding of the population has changed. In other jurisdictions these levels are re-examined every 3-5 years (Anon 2007). We suggest that reference levels only change when a major assessment is undertaken, currently every 5 years or so for harps. This will provide some stability and allow for multi-year management.

One of the greatest difficulties with any PA is to explain what the approach is trying to accomplish. The general impression is that the Atlantic Seal Management Strategy is too conservative and arbitrary. This and other studies have shown that the current approach is consistent with DFO policy and that the current reference levels are similar to other possible alternatives. The implementation of the ASMS has allowed industry to harvest more seals than it would have using the previous replacement yield strategy while ensuring that the population has remained healthy. However, it has suffered from changing too rapidly, without proper discussion of why these changes have occurred. These concerns can be reduced by committing to fixing the levels between major assessments.

ACKNOWLEDGEMENTS

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Table 1. Summary of changes to harp seal population model since 2000. Exponential model=exp, density dependent model=dd, carrying capacity in millions=K, mortality due to poor ice conditions=M_{ice}.

Year	Population Model form	Reproductive rates	Population (million)	Significant changes
2000	Exp	Contingency table harmonized rates		90% beater
2003	Exp	Healey smoother non-parametric , Extended 1997 rates to 2003 and future	2002 = 5.5 2003 = 5.3	92% beater, M_{ice}. 15% EXCEL model ,
2005	Exp	Healey smoother non-parametric , Extended 1997 rates to 2005 and future	2004=5.7 2005=5.8	95% beater, M_{ice}.=0.1 in projections
2008	Exp	Healey smoother non-parametric ,to 1999, averaged 2000-2005 and extrapolated forward	2005=5.7 2008=5.6 2009=5.6	95% beater, Model reprogrammed from EXCEL to R, projected M_{ice}.=average 12%
2009	Exp	Healey smoother non-parametric , Rpd rates updated to 2007, projected	2008 (lo)=6.9 2008 (hi)=8.2	Uncertainty in pup survey estimate (low count accepted), smoothed rates until 2007. poor fit to data in 2008 using high pup count
2010	DD K=12 set, EXP examined	Annual reproductive rates for 8+ ages, average last 5 years used in projections,	2004=7.4 2008 (exp)=8.7 2010 (exp) =9.6 2008 (dd)=8.1 2010 (dd)=8.6	M_{ice}. updated to average 30%, transition from exponential growth to density-dependent growth of population. K was set
2011	DD, K=12, estimated	updated to 2010, new binomial smoother, annual rpd rates for 8+, projection used uniform distribution for reproduction from last 5 years in projections	2008=8.4 2010=7.8	
current	DD, K=10, estimated	updated to 2011, binomial smoother, annual rpd rates for 8+, projection can be DD prediction for rpd rates or some other function eg uniform distribution using observed rates last 5 years	2008=7.5 2010=7.1	

Table 2. Some PA frameworks used in other fisheries managed by DFO. LSRL is lower stock reference level, USRL is a precautionary Upper Stock Reference Level, and TRP is target Reference Point. Italics in table represent additions by authors (MOH&GBS)

Fishery	Approach	LSRL	USRL	TRP
American Eel, Chaput & Cairns CSAS Res Doc 2011/053	Fishing mortality rate as proportion of spawning biomass per recruit model (SPR) *ie MSY philosophy*	F resulting in <5% chance of falling below 30% SPR		F resulting in <50% chance of falling below 50% SPR
Pollock Stone CSAS Res Doc 2012/027	Mean Biomass for 1984-1993, set as proxy for MSY	40% BMSY	80% BMSY	
Plaice SAR 2012/018	Average of estimates from Beverton-Holt and Ricker spawning stock-recruitment models-*ie MSY philosophy*	SSB set at 50% of maximum recruitment		
Scallop Smith & Hubley CSAS Res Doc 2012/018	*hybrid*	30% of mean biomass over period 1991-2010, represents B loss	80% mean Biomass 1991-2010	
Snow crab SAR 2010/014	*Hybrid* Based on BMSY of males, where MSY =50% of largest biomass largest biomass determined	B recovery	80% of BMSY ie 40% of maximum biomass observed	
Gulf shrimp CSAS SAR 2011/062 Need to be revisited if groundfish recovery	Based on relative indicators	Average of 2 minimum indicators taken from 2 different environmental periods	80% of MSY, where MSY represents a period of productive and stable catches	Average indicator observed during period of productive stable catches
N. Gulf Cod Duplisea and Frechet CSAS Res Doc 2009/097 Needed to rescale in 2011 due to changing weights at age	spawning stock-recruitment models-*ie MSY philosophy*	SSB where recruitment is 50% of maximum as defined by SSB-recruitment models	On plateau of SSB/R curve	
4X5Y cod Clark et al. CSAS Res Doc 2011/085.	spawning stock-recruitment models-*ie MSY philosophy*	SSB where recruitment is 50% of maximum as defined by SSB-recruitment models, different curve than N gulf		

Table 3. Reference levels and the size of the healthy or cautious zone (population size-reference level) obtained using the DFO guidelines (DFO_NBuf or upper stock reference level (USRL) and DFO_Nlim or lower stock reference level (LSRL)) or the current seal management approach (N70, N30). The table shows what often happens when changes occur in our perception of the population. In this case, the scenario assumed that we perceived a 25% reduction in the population, carrying capacity and largest population seen, due to model changes. The table compares the outcome of using a framework based on proportions vs a framework that uses fixed reference levels.

	Variable reference limits (%)		Fixed reference limits
	Base (million)	25% reduction (million)	25% reduction (million)
K	12	9	9
Max_pop	8	6	6
Current pop	7	5.2	5.2
DFO_NBuf	5.8	4.3	5.8
N70	5.6	4.2	5.6
DFO_Nlim	2.9	2.2	2.9
N30	2.4	1.8	2.4
The difference between population size and reference levels (ie buffer thickness)			
DFO_NBuf	1.2	0.9	-0.6
N70	1.4	1.0	-0.4
DFO_Nlim	4.1	3.1	2.3
N30	4.6	3.4	2.8

Table 4. Harvest levels (thousands) and minimum population sizes (million) that would respect the management objective of remaining above N30 at different levels of probability. Density dependent changes in reproduction also include an environmental impact factor ranging from 0.6-1.5

Harvest	**Population**		
	85% probability	90% Probability	95% Probability
	Density dependent changes in reproduction		
400	5.7	6.5	6.7
300	5.1	5.5	5.7
200	4.8	4.9	5.3
100	4.1	4.2	4.7
	Constant reproductive rates (last 5 years)		
400	7.05	7.4	7.7
300	6.6	6.8	7.1
200	5.9	6.1	6.5
100	4.8	4.9	5.3

Table 5. Possible management objectives to be considered when setting the target reference point. Some considerations could include factors outlined in the table.

Objective	Pro	Con
Economic hunt: Maximize profits	High quota when prices high, low quota when prices low, adds to diversity of income sources Environmentally friendly, Renewable resource	Could lead to fluctuating harvests, fluctuating income Some limiting of harvests when prices high
Economic hunt: Consistent harvests	Predictable harvest levels, adds to diversity of income sources Environmentally friendly, Renewable resource	Not able to link harvests to prices
Economic hunt: Ecosystem approach	Adds to diversity of fishing income Environmentally friendly, Renewable resource	PA not fully implemented in other fisheries, difficult to implement
Protect fisheries	Reduce gear damage, may reduce processing costs in some areas. May favour fish recovery (4T only)	Wasteful, limited science support. Expensive, who pays?

Table 6. Comparison of reference levels from different management frameworks and applied to the Northwest Atlantic harp seal population, assuming a carry capacity (K) of 10 million, maximum population of 7 million and current population of 7 million. MSY is assumed to be 60% of K.

.Variable	Atlantic Seal Managemen t Strategy	DFO policy	New [a,b] Zealand	Australia[c]	IWC
Target Reference Point or TRP			6[1]	7.2[2]	
Precautionary Reference Point or N_{buf}	4.9[3]	4.8[4]	5.8 [5] (3[6])	6[7]	7.4[8]
Limit Reference Point or N_{lim}	2.1[9]	2.4[10]	1.5[11]	3.0[12]	5.4 (2.3)[13]

[1] MSY [2] MSY*1.2; [3] N_{70} – 70% of maximum population; [4] 80% MSY; [5] a threshold value equal to (1-Mortality)*MSY, where Mortality =0.04; [6] 'Soft Limit' = 50% MSY; [7] MSY; [8] 'tuning' level for Revised Management Plan Catch Limit Algorithm

[9] N_{30} – 30% of maximum population; [10] 40% MSY;[11] 'Hard Limit' - 25% MSY; [12] 50% MSY; [13]The IWC sets N_{lim} at 23% of the pristine population size for aboriginal whaling.

[a] Anonymous 2008,2011, [b] Minister of Fisheries 2008, [c] Anonymous 2007

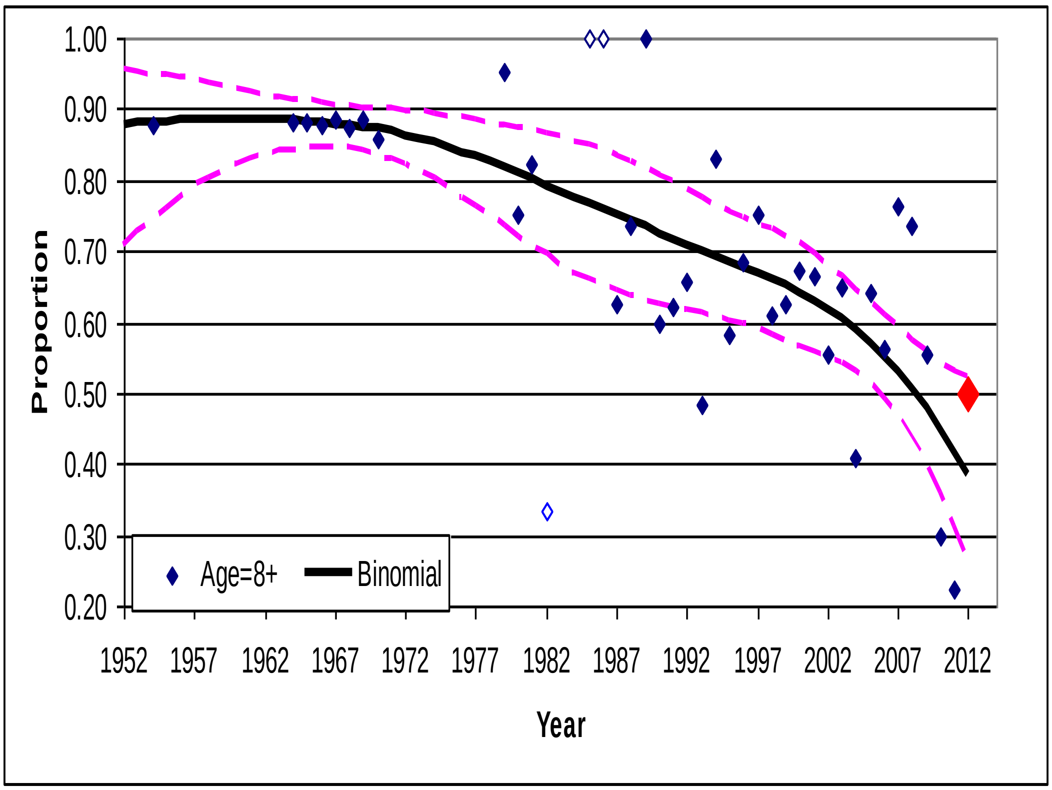


Figure 1. Age specific reproductive rates and non-parametric smoothed rates for harp seals 8 years of age and older (Hammill et al. 2012). An overall decline in productivity over the last 40 years is evident.

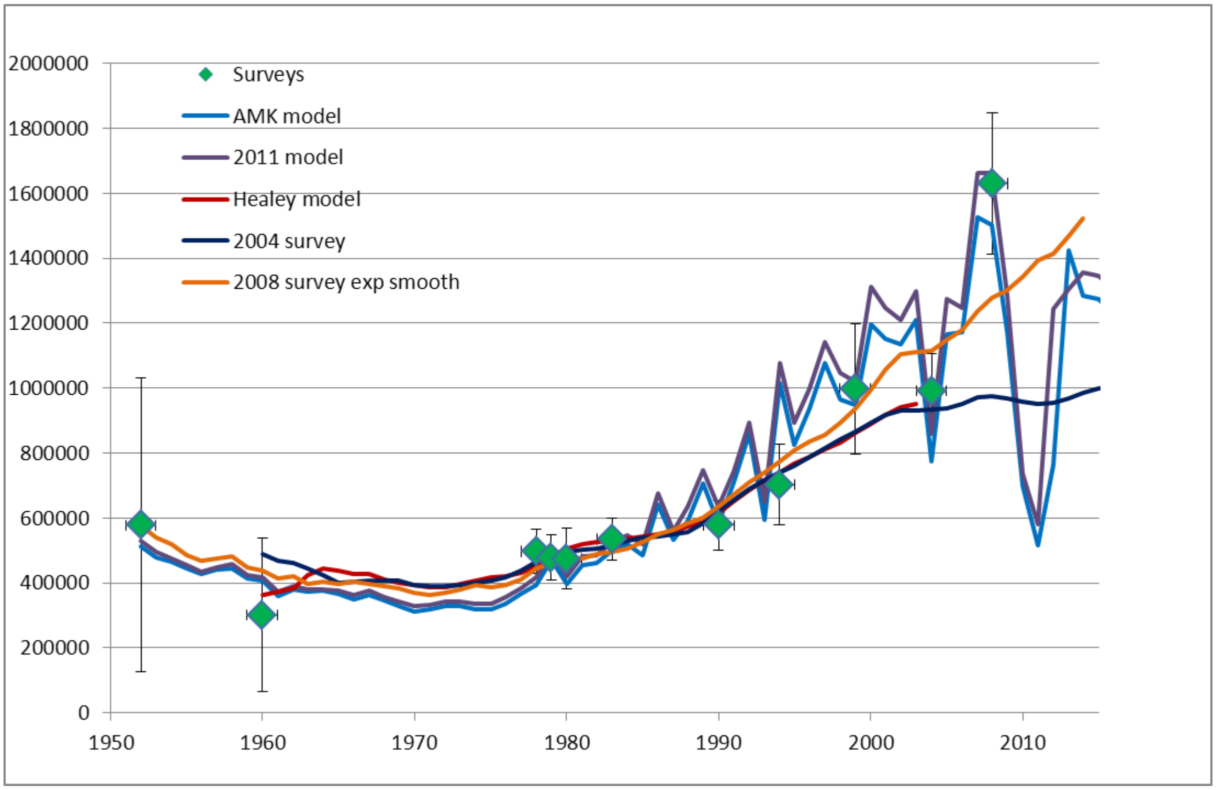


Figure 2. Estimates of northwest Atlantic harp seal pup production from a combination of aerial surveys and mark-recapture studies (symbols with 95% CI)(Hammill and Stenson 2011). Lines represent model fits to the pup production surveys based on DFO assessments completed between 2000 and 2011. The Healey and 2004 estimates are based on smoothed reproductive rates, an exponential model and are from runs completed at the time. The 2008 estimate assumes exponential growth and used smoothed reproductive rates. The 2011 model used annual values for the reproductive rate data and assumed a K=12 million. The AMK model (this meeting) fits the model to the survey data, the reproductive data and estimates K=10 million.

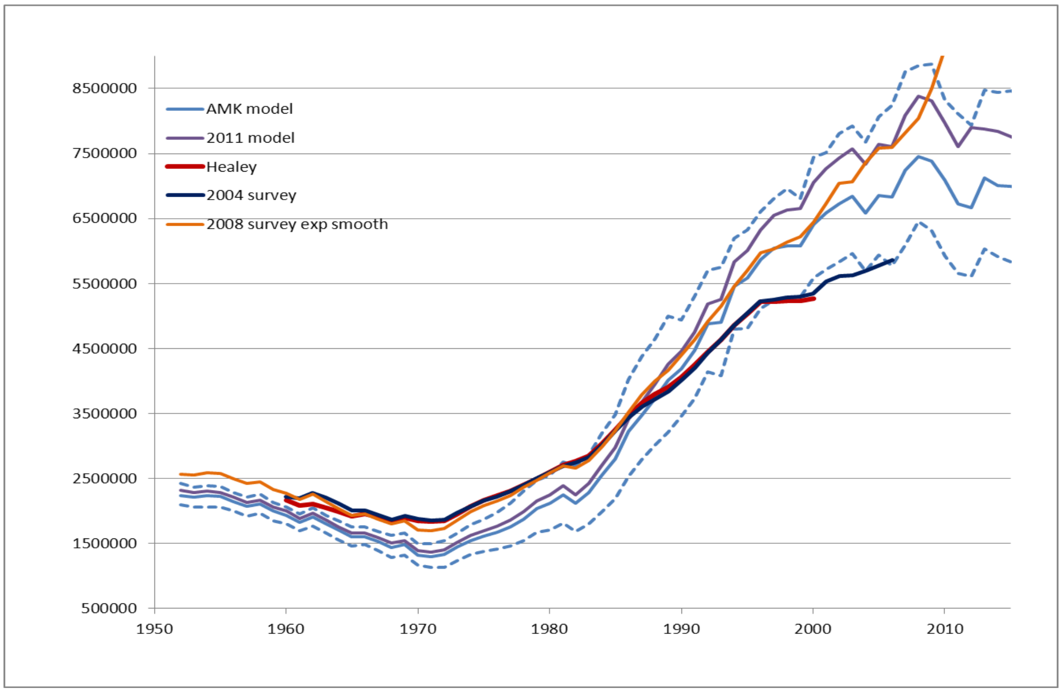


Figure 3. Estimated total population size of the Northwest Atlantic harp seal population as determined from different assessments from 2000 to 2011. The Healey model and 2004 estimates reflect an exponential growth model using smoothed reproductive data up to 1998 and 2004 respectively. The 2008 estimates were obtained using smoothed reproductive rates updated to 2008 and an exponential growth model. The 2011 model used annual values for the reproductive rate data updated to 2010 and assumed a K=12 million. The AMK model (this meeting) fits the model to the survey data, the reproductive data and estimates K=10 million.

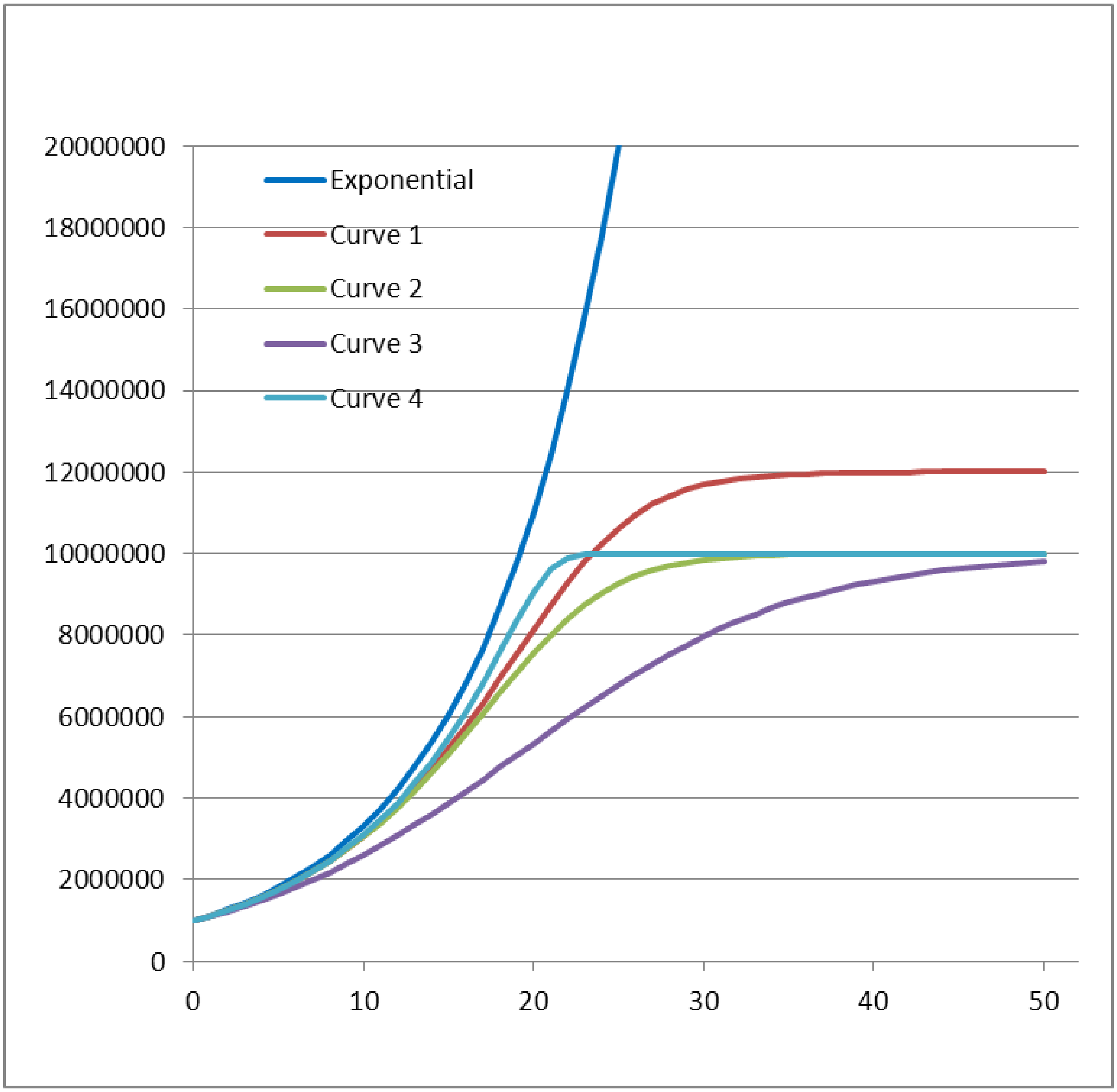


*Figure 4. Changes in abundance of a theoretical harp seal population using different models to describe this growth. A population that grows exponentially assumes that resources are unlimited. Growth is described by the model Population (P_{t+1})=P_{Nt} + (P_t*r_{max}-1), where the maximum rate of growth (r_{max}) is 12%. Curves 1-4 describe density dependent growth using the model formulation : (P_{t+1})=P_t + P_t*(r_{max}-1)*(1-(P_t/K)$^{\theta}$), K is the environmental carrying capacity and θ is a parameter to define the shape of the curve. For curve 1, K=12 million, theta=2.4, Curve 2, K=10 million, theta=2.4, curve 3, K=10 million, theta=1 and Curve 4, K=10 million and theta=7.*

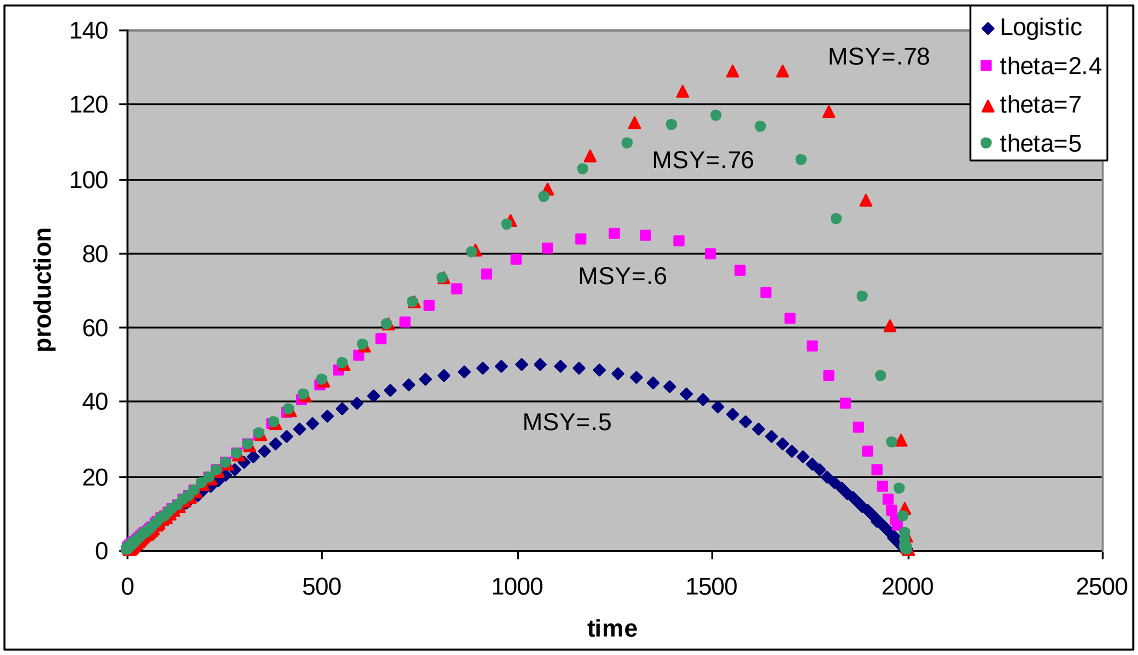


Figure 5. Changes in where MSY occurs as the theta for the logistic curve is changed. The base case, where maximum productivity occurs at 50% of the maximum occurs for theta=1.

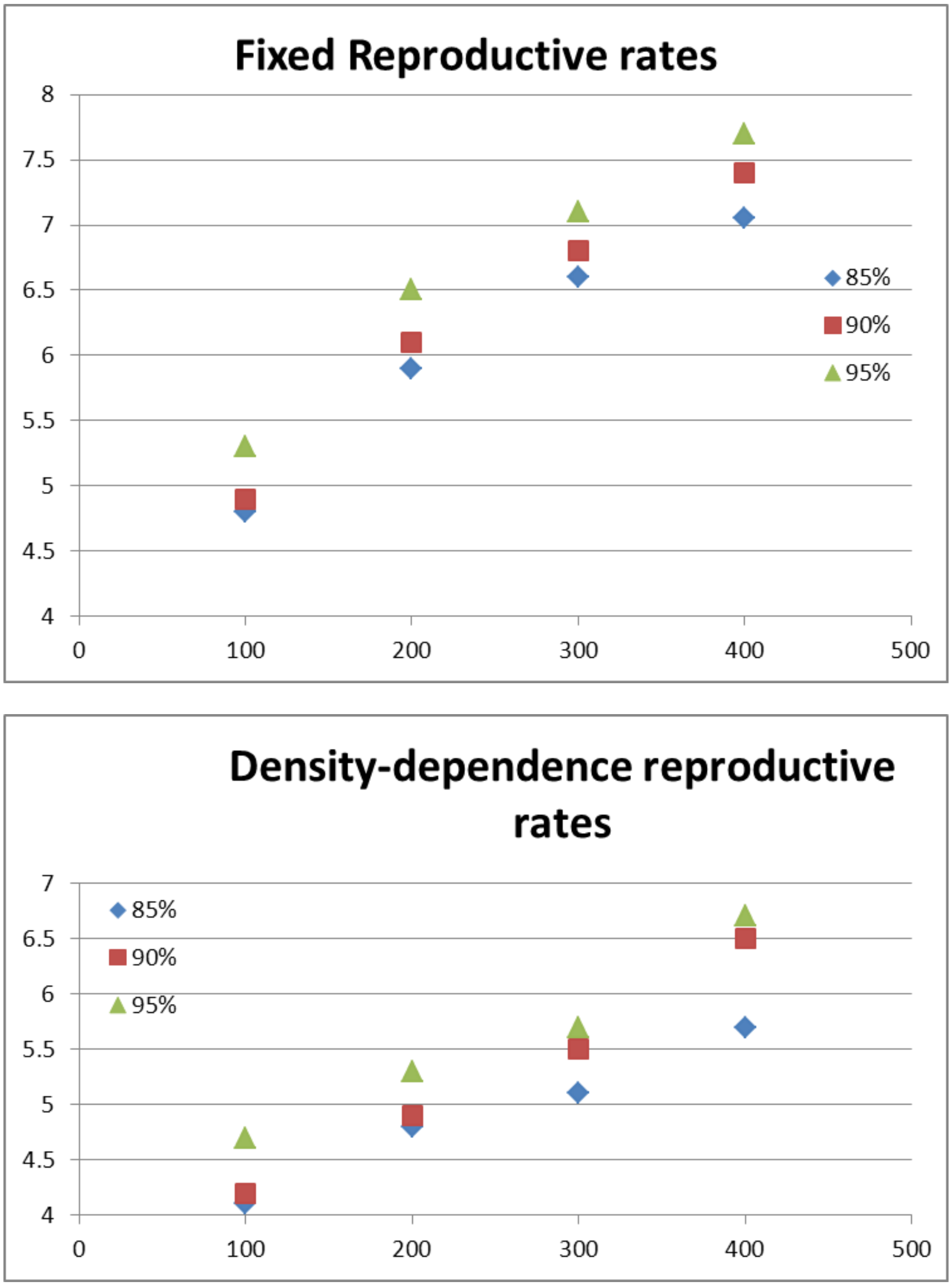
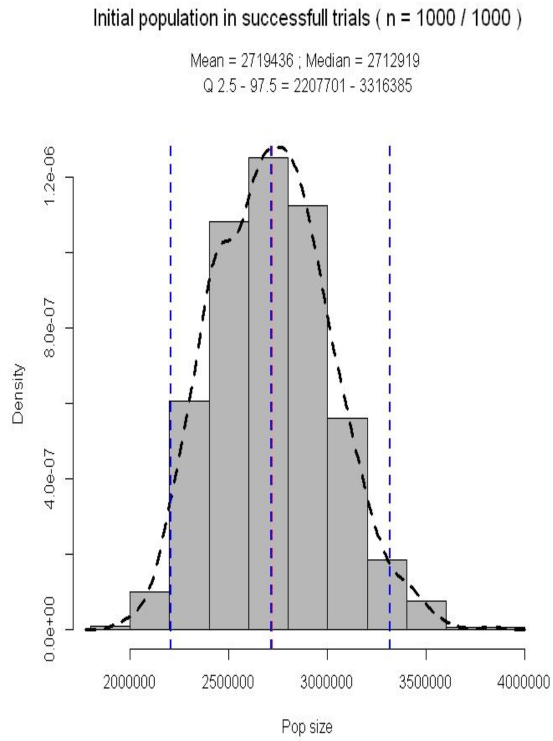
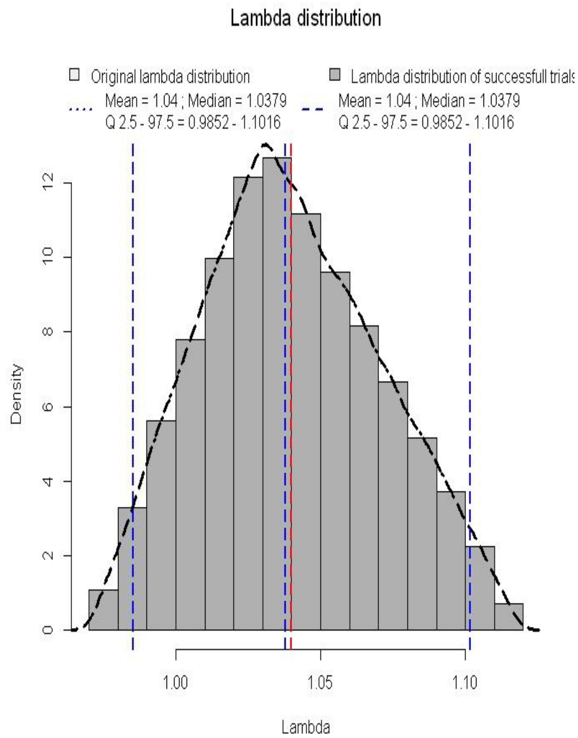
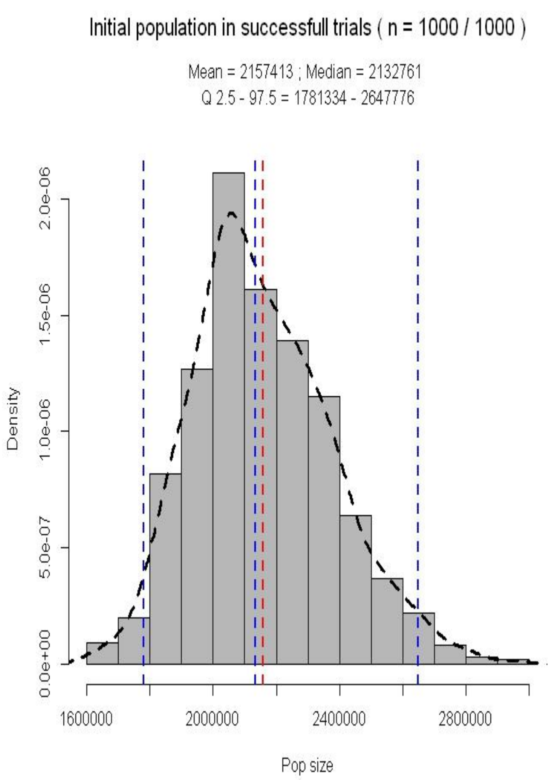
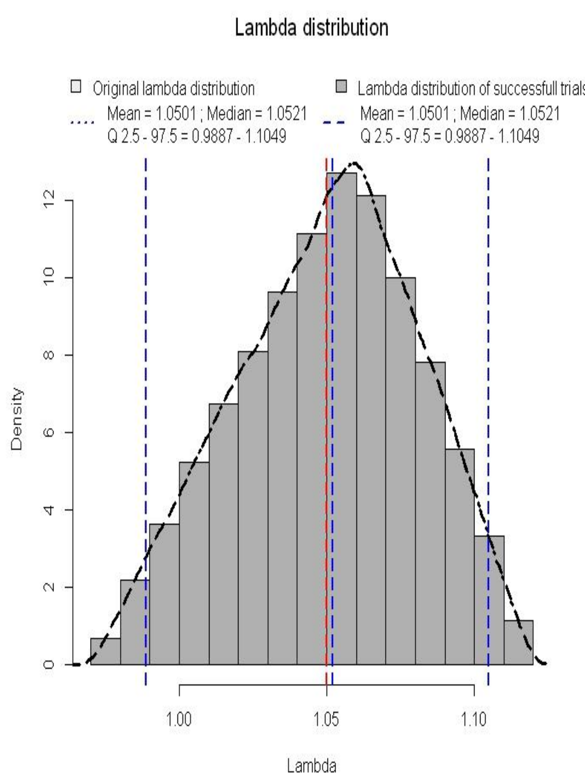


Figure 6. Minimum population sizes (million) required under different levels of harvest (thousand)(x-axis), different probabilities that the harvest would respect the management objective (y-axis), and under different assumptions about future production. For the density dependent reproductive rates, rates varied with population size, assuming K=12 million and environmental conditions that could vary from 0.6 to 1.5 times the expected reproductive rate. The fixed reproductive rate scenario assumed that reproductive rates were similar to those observed over the last five years.


Initial population in successfull trials (n = 1000 / 1000)
Mean = 2719436 ; Median = 2712919
Q 2.5 - 97.5 = 2207701 - 3316385
Density
0.0e+00
4.0e-07
8.0e-07
1.2e-06
2000000
2500000
3000000
3500000
4000000
Pop size


Lambda distribution
Original lambda distribution
Mean = 1.04 ; Median = 1.0379
Q 2.5 - 97.5 = 0.9852 - 1.1016
Lambda distribution of successfull trials
Mean = 1.04 ; Median = 1.0379
Q 2.5 - 97.5 = 0.9852 - 1.1016
Density
0
2
4
6
8
10
12
1.00
1.05
1.10
Lambda


Initial population in successfull trials (n = 1000 / 1000)
Mean = 2157413 ; Median = 2132761
Q 2.5 - 97.5 = 1781334 - 2647776
Density
0.0e+00
5.0e-07
1.0e-06
1.5e-06
2.0e-06
1600000
2000000
2400000
2800000
Pop size


Lambda distribution
Original lambda distribution
Mean = 1.0501 ; Median = 1.0521
Q 2.5 - 97.5 = 0.9887 - 1.1049
Lambda distribution of successfull trials
Mean = 1.0501 ; Median = 1.0521
Q 2.5 - 97.5 = 0.9887 - 1.1049
Density
0
2
4
6
8
10
12
1.00
1.05
1.10
Lambda

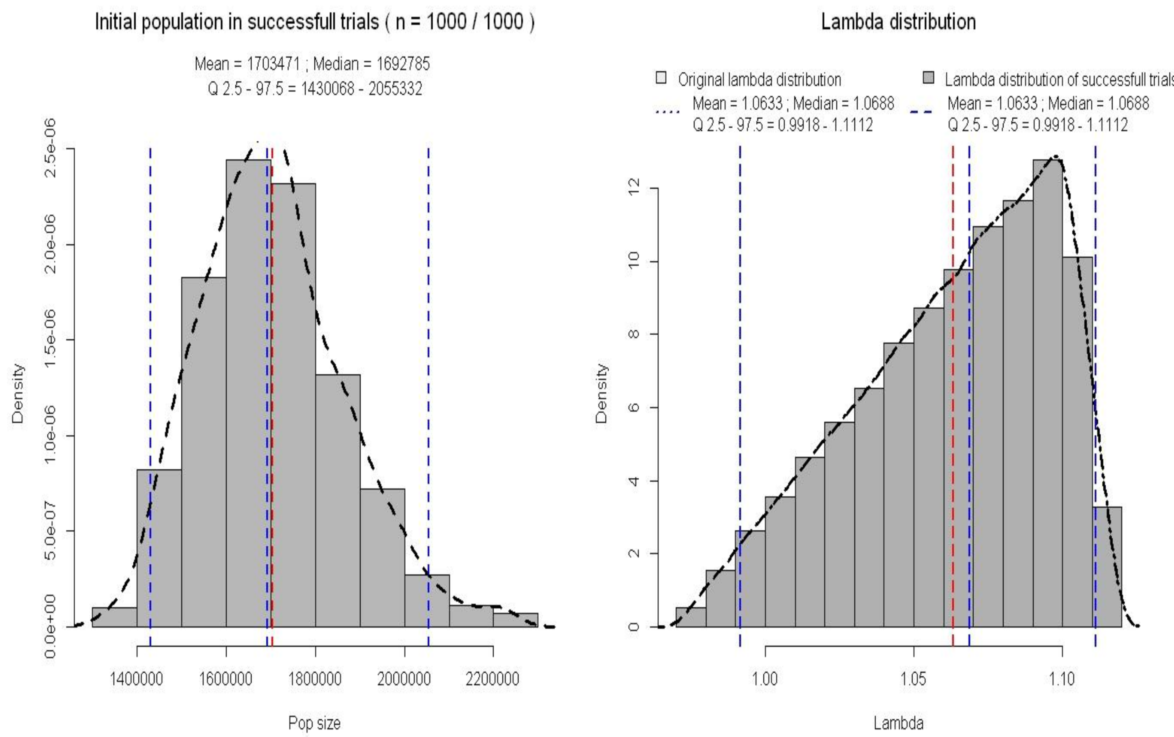


Figure 7. Mean (95% confidence limits) and median estimates of minimum population size that could support harvests of 106,000 seals under different productivity regimes using a surplus production model and assuming exponential growth. The simulation ran for 100 years and a new Lambda was selected for each year from a triangle distribution (range=0.97 to 1.12, mode=1.03, 1.06 or 1.10). The black dotted line around the columns is the original distribution, the columns represent the distribution of successful trials.