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Improving the Management of Atlantic Seals under the Precautionary Approach

Améliorer la gestion du phoque de l'Atlantique dans le cadre de l'approche de précaution

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ABSTRACT

Adopted in 2003, the Atlantic Seal Management Strategy, formerly referred to as Objective Based Fisheries Management (OBFM), was the first plan to incorporate a precautionary approach in the management of marine species in Canada. It provides a framework that identifies precautionary and critical reference limits which define healthy, cautious and critical zones of abundance, along with management actions that are triggered when thresholds are exceeded to reduce potential damage to the resource. Currently, the precautionary and critical reference levels are defined as 70% and 30% of the maximum population size. To determine if the strategy meets the management objectives within the Precautionary Approach framework, a series of simulations were carried out to test the various components of the current approach.

The impact of any proposed management action can not be identified within the life of the management plan and therefore, management actions should be evaluated over a period of 15-20 years at a minimum. The current approach used estimates of total population to assess the status of the population with respect to the reference levels. While pup production estimates are a more direct measure of abundance, they are carried out periodically and respond slowly to environmental changes or harvest levels that affect young seals. Model estimates of total abundance provide a more responsive measure of current population status, recognizing that the estimates are uncertain and must be updated when new survey estimates are available. Although more simulations are required to determine the most appropriate precautionary level and precision requirement, the current approach (N_{70} and L_{20}) do not appear to be overly cautious. The current management plan allows for a carry over of 10% of the unused quota between years within a 5 year management plan. Increasing the amount of carry over to 20% is unlikely to have an impact on the population assuming the average removal remains the same over the life of the management plan.

Key words: Atlantic seals, precautionary approach, sustainable management, hunt, quota, reference levels

RÉSUMÉ

Adoptée en 2003, la Stratégie de gestion du phoque de l'Atlantique, nommée antérieurement Gestion des pêches par objectifs (GPO), a été le premier plan conçu pour intégrer une approche de précaution dans la gestion des espèces marines au Canada. Cette stratégie fournit un cadre qui précise les seuils de précaution et les seuils critiques de référence utilisés pour définir les zones d'abondance saines, de prudence et critiques ainsi que les mesures de gestion à déclencher, afin de réduire les risques possibles pour la ressource quand ces seuils sont dépassés. Actuellement, le seuil de prudence et le seuil critique de référence correspondent à 70 % et à 30 % de la taille maximale de la population. Pour déterminer si la stratégie répond aux objectifs de gestion prévus dans le cadre de l'approche de précaution, on a effectué une série de simulations en vue de vérifier les diverses composantes de l'approche actuelle.

Comme il est impossible de déterminer les effets des mesures de gestion proposées pendant la durée du plan de gestion, il convient d'évaluer ces mesures sur une période d'au moins 15 à 20 ans. L'approche actuelle utilise des estimations de la population totale de phoques de l'Atlantique pour évaluer l'état de celle-ci par rapport aux seuils de référence. Les estimations de la production de blanchons constituant une mesure plus directe de l'abondance, de telles estimations sont exécutées périodiquement et rendent compte lentement des changements environnementaux ou des niveaux de capture qui affectent les jeunes phoques. Les estimations de l'abondance totale fournies par le modèle permettent de mesurer plus exactement l'état de la population actuelle, puisque les estimations sont habituellement incertaines et doivent être mises à jour lorsque des relevés fournissent de nouvelles données. Même si un nombre plus grand de simulations est nécessaire pour déterminer les niveaux de précaution et de précision les plus adéquats, l'approche actuelle (N_{70} et L_{20}) ne paraît pas excessivement prudente. Le plan de gestion actuel permet de reporter d'une année à l'autre 10 % du quota non utilisé au cours d'un plan de gestion quinquennal. Il est peu probable que l'augmentation de ce report à 20 % ait des répercussions sur la population, si on suppose que la réduction moyenne reste inchangée pendant la durée du plan de gestion.

Mots clés : phoques de l'Atlantique, approche de précaution, gestion durable, chasse, quota, seuils de référence.

INTRODUCTION

As a signatory to the United Nations *Agreement on Straddling and Highly Migratory Fish Stocks* (UNFA)[2], which came into force in 2001, the Government of Canada committed itself to incorporating the Precautionary Approach (PA) into the management of species under its jurisdiction. Within the context of fisheries management, the Precautionary Approach strives to be more cautious when information is less certain, does not accept the absence of information as a reason for the failure to implement conservation measures, and defines, in advance, decision rules for stock management when the resource reaches clearly-stated reference points (Punt and Smith, 2001). In 2003, the Privy Council Office, on behalf of the Government of Canada published a framework applicable to all federal government departments that set out guiding principles for the application of precaution to decision making about risks of serious or irreversible harm where there is a lack of full scientific certainty

The Atlantic Seal Management Strategy (ASMS), formerly referred to as Objective Based Fisheries Management (OBFM), was the first plan to incorporate a precautionary approach in the management of marine species in Canada (DFO 2003, 2006). It provides a framework that identifies precautionary and critical reference limits which define healthy, cautious and critical zones of abundance, along with management actions that are triggered when thresholds are exceeded to reduce potential damage to the resource. This management plan was based upon an approach outlined by Hammill and Stenson (2003, 2007). They suggested that the total population size be used as the metric for population health. They also proposed that the critical reference limit (referred to as 'N_{30}'), i.e. the level below which the population could be in serious and irreversible harm, be set at 30% of the highest population observed or inferred. In order to avoid the possibility of the population falling below this critical limit undetected, the population should be managed around a precautionary reference point. Based upon the biology of seals, previous work with other marine mammals and the frequency of surveys, Hammill and Stenson (2003, 2007) suggested that the precautionary reference level (referred to as 'N_{70}') be set at 70% until the appropriate simulation studies could be carried out. In order to account for the increased uncertainty in the estimates that occurs over time after a survey, the lower 20^{th} percentile of the confidence limits ('L_{20}') was used rather than the mean estimate.

Since initially adopted, the Canadian Atlantic Seal Management Strategy has been adopted by a number of other organizations including the ICES/NAFO Working Group on Harp and Hooded Seals (ICES 2004, 2006a,b, 2008) and the Russian/Norwegian Sealing Commission for managing seal populations in the northeast Atlantic. However, they have incorporated some modifications to address some gaps in the original design (Stenson and Hammill 2008).

The initial Canadian seal management framework was adopted in 2003 and renewed in 2006 for a 5-year period. A new Integrated Fisheries Management Plan (IFMP) for Atlantic seals is being developed. In order to ensure that the IFMP continues to meet the requirement for the Precautionary Approach, Science has been asked to provide input on a number of questions (see below). The objective of this paper is to provide relevant information on the questions being asked of Science in order to provide advice for the development of a new IFMP.

The questions Science has been asked to provide advice on are:

- Over what time period should the requirement to remain above the precautionary limit be, in order to meet the management plan objectives?

- What is the appropriate measure to use when comparing to the precautionary level?

- o At what level should the precautionary reference level (currently N_{70}) be set at to ensure a high (i.e. 95%) probability of avoiding falling below the N30?
- o How should uncertainty in annual estimate of the metric be taken into account (currently L_{20})?
- o If 'Carry forward' of uncaught quota is allowed, what would be the impact of an additional catch of up to 20% be on our ability to meet the management objectives?

MATERIALS AND METHODS

MODEL STRUCTURE

The basic model has been described in Hammill and Stenson (2009b, 2011) and has the form:

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

for 1 < *a* < *A*: $$n_{a,t} = (n_{a-1,t-1}e^{-m/2} - c_{a-1,t-1})e^{-m/2} \quad (2)$$

for *a* = *A*, where *A*-1 is taken as ages *A*-1 and greater:
$$n_{A,t} = [(n_{a-1,t-1} + n_{A,t-1})e^{-M/2} - c_{a-1,t-1}]e^{-M/2} \quad (3)$$

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.
γ = 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).
N_t= total population size,

The model is adjusted using the weighted sum-of-square difference between the estimated pup production from the model and the observed one from the surveys. The predicted values of pup production for the survey years are calculated using the equations presented above and their differences with the observed values is evaluated. The two parameters are optimized to minimize the weighted sum-of-square difference by iterative methods.

We included the uncertainty in the pregnancy rates and the pup production estimates in the fitting model by resampling them using Monte Carlo techniques. Both pregnancy rates and pup production data are resampled from a normal distribution of known mean and standard error. For each Monte Carlo simulation, a new *M* and α were estimated and stored. The model was run within the programming language R.

Data Input

Catches, reproductive rates and climate related mortality were incorporated as described in Hammill and Stenson (2009b). Estimates of pup productions since 1952 were incorporated, using the lower (i.e. visual) estimate for 2008 (Bowen and Sergeant 1983,1985; Roff and Bowen 1986, Stenson et al. 1993, 2002, 2003, 2005, 2009).

Projection model and simulations

The modelling consists of two main steps. The first one is the fitting model (explained earlier) where multiple population matrices are created using Monte Carlo and the parameters *M* and α are estimated. This is done from 1952 until the last year data are available (i.e. 2010). The second part of the model is the projection, where the population is projected into the future following different management plans. The projection model is based on the same equations as the fitting model, but in this case, the parameter α is not used as it is associated with the initial population vector. The projection is instead started from the last year of the population vector estimated by the fitting model. The mortality rates (*M*) used for the projection are selected from the set of *M's* created by the fitting model. Data on pregnancy rates, seal removals and ice conditions are then extrapolated to complete the projection.

The pregnancy rate data are modified according to the simulation being examined. They are permitted to vary around a normal distribution. Ice-related mortality is selected randomly from the vector [0, 0, 0.1, 0.2, 0.3] assuming a uniform distribution, which gives a mean mortality rate from environmental conditions of 12%.

Finally, harp seal removals for the projection years are generated by summing the Canadian quotas, the Greenland and Arctic catches and estimates of bycatch. From these four sources of mortality, only the Greenland catches are allowed to vary and follow a uniform distribution ranging from 70,000 to 100,000 catches per year. Canadian commercial catches are determined following the different management scenarios being tested. Bycatch and Arctic catches are believed stable at 12,500 and 1,000, respectively. In every case, the age structure is taken into account when calculating the amount of mortality within the population. It was assumed that the Canadian hunt consists of 90% of young of the year while the Greenland hunt is limited to 14% young of the year (Stenson 2009). The remaining seals (i.e. 10% of the Canadian and 86% of the Greenland catches) would be considered to be one year of age and older (1+) which would then be distributed uniformly within the 1+ age classes following the age structure of the population.

A struck and lost factor is added to the three different hunts to take into account the seal that are being killed but that are not recovered or reported. This struck and lost factor is calculated the same way it was to evaluate removals for the fitting model. A total of 95% of the YOY in Canada and 50% of every other animal (adult in Canada and all seal in Greenland and the Arctic) are considered to have been reported and the estimated morality adjusted accordingly.

Monitoring of the Canadian harvest occurs via a daily hail-in system, where fishermen report their catches on a daily basis. Dockside monitoring and comparison with hail-in tallies provides an incentive for hunters to provide accurate information on daily takes. Nonetheless, there is considerable capacity in the fleet, which might result in the Total Allowable Catch (TAC) being exceeded before the fishery can be closed (Table 2). In this simulation, we included this uncertainty, known as implementation error, in the model as a multiplier applied against the Canadian reported catch, before correcting for unreported harvests (struck and loss), as a Uniform distribution with a minimum of 1.0 and a maximum of 1.1, for a mean of 1.05.

Two different approaches were used to assess the performance of the harp seal management framework. The first examined, over what time period should the requirement to remain above the precautionary limit be in order to meet the management plan objectives. This was done by adjusting harvest levels to respect a plan for a 5 year, 10 year, 15 year period etc. In the second set of model runs the objective was to determine how likely it was for the management plan to be respected if certain model assumptions were incorrect. This is to determine if it would be possible to detect negative changes in the population before harvesting resulted in serious harm to the resource (i.e. falling below the limit reference level, N_{30}). For this component, two models were run in parallel. One model, mimicked the conditions that would be used during an assessment to provide advice to management. Referred to as the 'Error model', this model incorporated observed information, in the same manner that data are used in an assessment and used to estimate TAC levels that would respect the management plan. The second model, called the 'Reference model', represents the 'reality' of the scenario and was modified to incorporate of failures of certain assumptions. The overall objective was to determine if the precautionary threshold (N_{70}) and the harvest control rule (80% probability that the population remains above N_{70}) are sufficiently robust to prevent the population declining to seriously low levels (i.e. below the critical reference level of N_{30}), or if a decline does occur, can this decline be detected before serious harm occurs.

The testing algorithm was as follows. Both the Error and Reference models used the same inputs up to and including 2010. The Error model was projected forward to estimate the TAC in the absence of any problems with the inputs. This TAC was then inserted into the Reference model which was also modified according to the scenario being tested (e.g., assume that YOY were subjected to an unknown mortality of 20% that occurred prior to the opening of the hunt). Using the presumed 'sustainable' catch obtained from the error model, the Reference model (modified to include an additional YOY mortality of 20%) was run to obtain a new estimate of pup production (and population) at the time of the next survey. The interval for a new survey was set at five years, (i.e. 2008, 2013, 2018, etc) and it was assumed that the average CV around the pup production estimate was 0.08 (the average of eight estimates completed between 1979 and 2004). This new estimate of pup production was then introduced into the Error model to extend the data set of abundance estimates. The Error model was then fitted to this new survey series and a new TAC was determined. The process was repeated for the next five year 'management plan'.

The estimated TAC had to respect the management plan over the timeframe being examined, i.e., the TAC was a constant level of harvest (assumed to be taken in full) during a five year block that maintained an 80% probability of the population being above N_{70}. Only a single parameter was adjusted in each simulation. The simulations were allowed to proceed for 50 years (2009-59).

To determine the impact of carrying over unused quota from one year to another year within the same management plan, we explored scenarios that allowed for carry over among years of 10%

and 20%. The maximum catch level that met the management objective (i.e. 80% likelihood of being above N_{70}) for a period of 15 years was estimated. Catches were modified to be equal to this amount in the first year and then modified to allow for a 10 or 20% carry over in the 2nd and 4 years. This amount was subtracted from the quotas in year 3 and 5 so that the total catch over the 5 years was the same as would occur with a constant catch.

RESULTS

TIME FRAME FOR MEETING MANAGEMENT OBJECTIVES

To determine the time frame over which the requirement to remain above the precautionary limit should be required to meet the management plan objectives, the model was fitted to the pup production and harvest data up to 2010. Future TACs were estimated by projecting the population into the future and a new TAC was set in blocks of 5 years. Different scenarios examined the impact of altering the time-frame into the future that the TAC must continue to respect the management plan (Table 1). For example, the first scenario estimated a TAC that would respect the management plan for the next five years; the second scenario estimated a TAC that respected the management plan for the subsequent 10 years, etc.

The simulations indicate that if the object is only to meet the management objectives for 5 years, initial catches are high (700,000). However, they cannot be sustained and drop quickly. As the time frame is extended, initial catches are lower, but can be sustained over the life of the simulations. Longer time frames result in less variability in annual catches and result in higher average annual and overall total catches.

Table 1. Total allowable catch (000's) per year, in 5 year blocks, total harvest over 30 years and the coefficient of variability in harvest levels. The TAC is estimated under conditions that it must respect the management plan for 5, 10, 15, or 20 years.

Time Frame (Years)	5 yr	10 yr	15 yr	20 yr	25 yr	30 yr	Total Catch	Average Catch	SD
5	700	210	120	115	40	40	1,225	204	251
10	500	350	270	200	250	180	1,750	292	118
15	425	350	300	270	230	230	1,805	301	76
20	400	320	320	300	270	270	1,880	313	48

PRECAUTIONARY LEVELS

To determine the significance of setting the precautionary level and incorporating the uncertainty in the population estimated, we explored the impact of an unrecognized mortality by incorporating an additional annual mortality on YOY of 20% into the reference model. This mortality occurs prior to the hunt. Therefore, the Error model assumed that there was no unidentified mortality when setting the TAC in 5-year blocks. When estimating the TAC, it was assumed that the TAC estimate would respect the management plan over a 15 year period. This catch was then incorporated into the Reference model and the model was projected forward to obtain a new survey estimate of pup production at the end of the 5-year block. Simulations examined the effects of using the current level of uncertainty L_{20} (i.e. an 80%

probability that the population would remain above the precautionary level of N_{70}) as well as reducing the level of uncertainty by using likelihoods of 70% (L_{30}) and 60% (L_{40}).

All simulations including increased mortality resulted in the closure of the hunt after 15-20 years. The error model predicted that the population would continue to decline even after the closure and all scenarios were characterized by marked increases in estimates of adult mortality rates (M) after 15-20 years, with an extremely high standard error. Since the TAC was set using the error model, all simulations respected N_{70} under different probability levels, depending on the particular scenario being tested.

Using a harvest control rule (HCR) with an 80% probability that the population remained above N_{70} (i.e. L_{20}), the Error model estimated that the population would have at least a 96% likelihood of remaining above the critical reference level (N_{30}) over the 35 year period examined, even under a model scenario where the model inputs were incorrect (Table 2). During this period, the total population declined by a little more than 50%. Similar results were seen when the probability of the population remaining above the precautionary reference level was reduced to 70% (L_{30}) although the model runs were inconsistent and may be affected by the relatively low number of runs included. Further reduction of the likelihood to a 60% probability (i.e. L_{40}) appeared to maintain the population above N_{30} for 20 years, but then declined quickly and were estimated to be extinct in less than 30 years.

Table 2 Results from model simulations where a model that did include an unrecognized mortality was used to estimate a Total Allowable Catch. This TAC was incorporated into a Reference model (i.e 'true') that did include ice-related mortality and the change in the population as perceived by the Error model under different harvest levels over 30+ years was compared to changes in the Reference population. N_{30} was estimated to be 2.0 million and N_{70} was 4.79 million for the model runs.

L_{20}	2	5	10	15	20	25	30	35
Error model								
TAC ('000)	645	655	570	400	0	0	0	0
Population(M)	7.24	7.37	6.75	4.74	4.14	4.00	3.75	2.40
SE ('000)	619)	528	989	933	801	104	140	215
M	0.051	0.051	0.054	0.179	0.274	0.934	1.967	7.47
(SE)	(0.003)	(0.003)	(0.005)	(1.747)	(2.185)	(4.115)	(5.823)	(9.05)
Reference model ('True')								
Population (M)	7.30	7.01	6.03	4.68	3.47	3.55	3.58	3.71
SE ('000)	*544*	*493*	*604*	*6224*	*643*	*496*	*980*	*419*
M	0.051	0.051	0.051	0.052	0.189	0.052	0.151	0.055
SE	*0.003*	*0.003*	*0.003*	*0.003*	*1.92*	*0.005*	*1.383*	*0.005*
Prob respect N30	1	1	0.975	0.975	0.96	0.975	0.96	0.97

L_{30}	2	5	10	15	20	25	30	35
Error model								
TAC ('000)	680	650	470	0	220	0	0	0
Population (M)	7.01	7.31	6.31	4.60	4.82	4.22	4.06	2.73
SE ('000)	*118*	*798*	*1,1578*	*1,254*	*1,507*	*947*	*1,374*	*2,060*
M		0.052	0.053	0.057	0.421	0.339	0.717	6.625
SE		*0.005*	*0.006*	*0.009*	*2.733*	*2.802*	*3.332*	*9.473*
Reference model								
Population	7.13	6.63	5.28	4.10	4.10	3.54	3.60	3.69
SE	*484*	*517*	*549*	*389*	*586*	*809*	*483*	*394*
M	0.05	0.051	0.053	0.051	0.052	0.052	0.053	0.054
SE	*0.003*	*0.003*	*0.006*	*0.002*	*0.004*	*0.005*	*0.005*	*0.003*
Prob respect N30	1	1	0.975	1	0.98	0.97	0.98	0.98

L_{40}	2	5	10	15	20	25	30
Error model							
TAC (000)	685	660	510	180	0	0	0
Population (M)	7.14	7.25	6.24	4.71	3.27	2.10	1.24
SE (000)	*566*	*545*	*995*	*1,065*	*1,182*	*2,279*	*1,025*
M	0.051	0.051	0.061	0.962	1.801	4.649	7.385
SE	*0.0036*	*0.0038*	*0.0659*	*4.557*	*6.525*	*8.182*	*9.300*
Reference model							
Population (M)	7.16	6.69	5.34	3.81	3.00	2.17	0
SE (000)	*712*	*666*	*404*	*646*	*591*	*296*	
M	0.0503	0.0509	0.0512	0.0517	0.2057	0.0546	
SE	*0.00268*	*0.00232*	*0.00323*	*0.00469*	*1.53271*	*0.00569*	
Prob respect N30	1	1	1	0.96	0.96	0.4	

TAC CARRY OVER

A 10% or 20% carry over did not appear to have an impact on the population estimates or the likelihood of meeting the management objective (Table 3). Under either scenario, the likelihood of the population remaining above the precautionary reference level (N_{70}) was the same as that estimated assuming a constant catch.

Table 3. Probability of the population remaining above N_{70} under TACs that allow no (0%), 10% or 20% carry over within 5 year management blocks. Total catches within each 5 year period are the same in each scenario.

Carry over	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0%	1	1	1	1	1	1	1	1	0.985	0.975
10%	1	1	1	1	1	1	0.995	0.99	0.98	0.97
20%	1	1	1	1	1	1	0.995	0.995	0.985	0.98
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0%	0.97	0.94	0.92	0.89	0.87	0.85	0.825	0.82	0.8	0.755
10%	0.96	0.95	0.915	0.9	0.875	0.855	0.825	0.79	0.78	0.75
20%	0.96	0.955	0.915	0.915	0.865	0.84	0.81	0.79	0.78	0.765

ADVICE

1) Over what time period should the requirement to remain above the precautionary limit be in order to meet the management plan objectives?

The time frame over which the results of proposed management actions should be compared to the precautionary limit was not specified in either Hammill and Stenson (2003, 2007), or in the initial Management Plan (DFO 2003). As a result, there has been some confusion with the default time frame being the end of the individual plan itself. As the plan continues, the time frame becomes shortened to where it will be only a single year. Given that the Canadian hunt focuses almost exclusively on YOY (Stenson 2009), the impact of any removals will have very little impact in the short term. Therefore, it is important that the time frame be long enough for the impact of the action to affect the population and that it can be recognized in the assessments given the current frequency of pup production surveys (4-5 years for harp seals) and precision of the estimates.

While exploring the impact of ice mortality on the population dynamics of northwest Atlantic harp seals Hammill and Stenson (2008) found that a single year of high pup mortality would significantly affect the population, but that these changes would not be noticed as detectable changes in pup production for at least 20 years. Repeated low level (10%) mortality of pups would also result in changes in the population and pup production that could not be detected until 15 or more years have passed, given the current survey frequency.

Hammill and Stenson (2009) came to a similar conclusion during simulation studies designed to explore the robustness of the current management approach for harp seals. They found that because commercial harvest consist of 90-97% young and assessments are based upon pup production surveys carried out only every 4-5 years, the impact of overharvesting beginning in 2010 would not be observed until at least 2019 even though the population would decline much earlier. Additional surveys would likely have to be carried out before the decline could be confirmed, suggesting that a projection period of at least 15 years is required.

The results of the simulations presented here support these earlier conclusions. In addition, we found that using a 15 year window improves catch stability, which is important for markets, and that overall, more seals can be harvested over time. We also found that increasing the time frame for projections to 20 years had only a slight improvement.

Given the simulation studies presented above, it is clear that the impact of any proposed management action can not be identified within the life of the management plan. This applies to other seal species in Atlantic Canada as they are also assessed in a similar manner. Although there are significant assumptions required for models that predict populations more than a few years in the future, it is important that, with the appropriate caveats, management actions should be evaluated over a period of 15-20 years at a minimum.

2) What is the appropriate measure to use when comparing to the precautionary level?

Currently, a measure of total abundance (see #4) is compared to the precautionary reference level to evaluate the health of the population and to determine if the proposed actions are consistent with the management objectives. Total abundance is estimated using a population model that incorporates annual estimates of human induced mortality, age-specific reproductive rates and periodic independent estimates of pup production. In principle, it is best to use a metric for population status that is measured directly which in the case of Atlantic seals, is pup production. However, pup production of harp seals is estimated every 4 to 5 years, grey seals every 3 years and hooded seals approximately every 10 years. Survey results are often difficult to interpret due to the time lag associated with the impact of environmental changes or harvest levels. Hammill and Stenson (2008, 2009) have shown that a population can be significantly reduced before changes in pup production are recognized. In contrast, estimates of total population can provide indications of impacts much more quickly. By monitoring annual reproductive rates and removals (e.g. Stenson 2009, Stenson et al 2009), changes in the resource can be identified by modelling the total population (Hammill and Stenson 2010). Therefore, it seems prudent to use the model estimates of total abundance as the measurement of current population status, recognizing that the estimates are uncertain and will be updated when new survey estimates are available.

3) At what level should the precautionary reference level (currently N_{70}) be set at to ensure a high (i.e. 95%) probability of avoiding falling below the critical limit (N_{30})?

Although simulations to determine the impact of changing the precautionary reference level have not yet been carried out, results of simulations exploring the impact of changing the precision of the population estimate (see below) suggest that lowering the current precautionary level (70% of the maximum estimated population) would increase the likelihood of the population falling below the critical reference level under conditions of higher than expected YOY mortality.

4) How should uncertainty in annual estimate of the metric be taken into account (currently L_{20})?

The simulations presented here indicated that the current harvest control rules (HCR) requiring an 80% probability that the population remained above N_{70} (i.e. L_{20}), ensured that the population has a greater than 95% likelihood of remaining above the critical reference level for the 35 years of the simulation. Runs using a less cautious level of 70% also maintained the population above the critical level when mortality is underestimated by 20% per year but reducing the uncertainty to a 60% likelihood requirement resulted in the population being reduced to 0 (i.e. a 100% likelihood of being below N_{30}) in a little more than 25 years.

Hammill and Stenson (2009a) also explored the impact of changing the degree of uncertainty acceptable using a similar situation of a 20% increase in YOY mortality and assuming the management objective was met for 10 years. Their scenario accepted a 70% probability that the population remains above N_{70}. The pattern of fit to the data was similar to that we observed here. Catches were initially high, but declined and the hunt was closed after approximately 20 years. However, in spite of the closure of the commercial hunt, the mean, L_{30} and lower 95% of the confidence limits of the population estimate fell below the critical reference limit (N_{30}) within 35 years.

We were able to explore a simple scenario where mortality was higher than normal. Other scenarios that assume errors in other components of the model inputs should be explored. However, using this simple scenario indicates that the current HCR requiring an 80% likelihood of being above the precautionary reference level provides a reasonable probability of the population remaining above the critical reference level. The likelihood of the population falling below the critical reference level without us recognizing it when the HCR is reduce to a 70% probability is less certain. In one simulation the HCR maintained the population, while in a second it did not. The difference between these simulations and the one presented in this paper may be due to the longer time period over which the management criteria had to be met in the current projections. This may improve the stability of the simulations. A lower requirement (N_{40}) can clearly result in an unpredicted decline in the population to a level where it is considered to be in serious and irreversible harm. Therefore, we feel that the current requirement to have an 80% likelihood of being above the precautionary level provides a reasonable level of certainty that the population will not be below the critical limit.

5) If 'Carry forward' of uncaught quota is allowed, what would be the impact of an additional catch of up to 20% (currently 10%) be on our ability to meet the management objectives?

Increasing the amount of carry over in quota from the current 10% to 20% is unlikely to have an impact on the population over a period of 20 years. This would indicate that catches can be varied as long as the total remains similar over the life of the management plan.

DISCUSSION

Since being adopted in 2003, the management framework used for Atlantic seals has been reviewed and suggestions made to improve it (e.g. ICES 2004, 2006a, b, 2008; Stenson and Hammill 2008; Leaper et al. 2010). Some suggestions such as carrying out additional simulation studies to determine the robustness of the approach have already begun (e.g. Hammill and Stenson 2009) while others are included in this study. However, some other refinements have yet to be addressed. For example, ICES (2004) identified a minimum precision (CV < 30%) for surveys. Although we have not identified this criteria, all the estimates available do meet this criterion (e.g. Stenson et al. 2010, Hammill and Stenson 2011).

The current management approach identifies populations for which our data are considered to be uncertain (i.e. data poor) and uses the PBR approach developed in the United States (Wade and Angliss 1997, Wade 1998) to identify an allowable quota. This calculation includes a recovery factor (F) that can be adjusted (0.1 – 1.0) to account for uncertainty in the available data. ICES (2006b) also suggested that if a data poor population is considered to be above N_{lim}, a recovery factor (F) of 0.5 should be used if the population is considered to be decreasing or have an unknown status while F=0.75 for populations thought to be increasing. To date, Canada has used a factor of 1 since the use of PBR for data poor species is already considered to be conservative. Choice of this recovery factor can have serious implications in setting TAC levels and therefore, it is important that we identify criteria for choosing appropriate levels.

Leaper et al. (2010) point out that ,the current strategy states that any population below the precautionary level (N_{70}), but above a management reference level at 50% of the maximum (N_{50}), must be allowed to increase to above N_{70} within 10 years, and that hunting should be stopped for populations below the critical level (N_{30}). However, it does not provide a control rule for a population below N_{50} but above the critical limit. In response to this problem, ICES (2008) clarified their approach by proposing that for species above N_{70}, a given harvest should have an 0.8 probability that stock size will remain above N_{70} 10 years in the future. For populations initially above N_{50} but below N_{70}, there should be an 0.8 probability that stock size will be above N_{70} 10 years in the future and for populations below N_{50} but above N_{lim}, there should be an 0.8 probability that the population size will be above N_{50} 10 years in the future. Canadian managers should consider how to address this apparent gap in our management strategy and decide upon a pre-agreed management action for a population that is below N_{50} but above $N_{lim.}$

In many of the simulations presented here we examined the impacts of an increase in mortality affecting young of the year seals. This could represent any source of mortality including events such as the high level of mortality that appeared to have occurred in 2010 due to the almost total lack of ice in the Gulf (Hammill and Stenson 2010) or an underestimate in catches. Given the decline in reproductive rates and condition observed in harp seals over the past three decades (Stenson et al 2009) it could also reflect an increase in juvenile mortality that may very well be occurring as a result of density-dependent processes.

The Atlantic Seal Management Strategy was the first attempt in Canada to incorporate the Precautionary Approach into the management of commercially exploited marine populations. Over the past seven years it has been successful in managing Atlantic seals during a period of intense exploitation and has provided an example that has been applied to marine mammals and fish species in Canada, and elsewhere. However, as in all new plans, it is time to review the strategy and modify it as required in order to meet management objectives. It is hoped that the information provided here will assist in this review and provide guidance for the continued improvement of management of marine species.

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