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Grey seal reduction scenarios to restore the southern Gulf of St. Lawrence cod population

Scénarios de réduction des populations de phoques gris dans le but de rétablir les stocks de morue dans le sud du golfe du Saint-Laurent

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ABSTRACT

Natural mortality (*M*) of older (ages 5+ yr) cod in the southern Gulf of St. Lawrence has been unusually high throughout the 1990s and 2000s. Examination of the evidence for a suite of hypotheses for the causes of this elevated *M* leads to the conclusion that predation by grey seals is the most likely cause of a major component of this high *M*. However, due to data gaps, it is not possible to specify the probability that a given level of grey seal removals will result in a given level of reduction in cod *M*. Here we describe the effect of grey seal reduction on cod recovery given two alternate approaches for filling data gaps. Because many other approaches are possible, these results should be interpreted as 'what-if' scenarios regarding the impacts of seal removals on cod productivity given a range of estimates for the contribution of predation by seals to cod *M*. Based on one approach, predation by grey seals is estimated to account for only about 10% of the current *M* of 5+ cod. Given this estimate, seal removal cannot reduce *M* to a level that would permit cod recovery because *M* due to other unknown causes is too high to allow recovery. A second approach yields results more consistent with the weight of evidence that seal predation is an important component of cod *M*. This approach attributes about 50% of the current *M* of 5+ cod to predation by grey seals. In this case, seal removal can reduce *M* to a level that would permit cod recovery, though the necessary seal removals would be substantial. A lower seal reduction would be sufficient if grey seals show diet specialization and it is possible to target cod specialists. Based on a qualitative analysis of risk, grey seal reduction would appear to reduce ecological risk to the southern Gulf cod population without jeopardizing the security of the grey seal population.

RÉSUMÉ

La mortalité naturelle (*M*) chez les morues plus âgées (5 ans ou +) dans le sud du golfe du Saint-Laurent était inhabituellement élevée dans les années 1990 et 2000. L'examen des preuves d'un ensemble d'hypothèses quant aux causes de cette *M* élevée chez la morue mène à la conclusion que la prédation par les phoques gris est un important facteur. Toutefois, en raison d'un manque de données pertinentes, il n'est pas possible d'établir la probabilité qu'une réduction donnée du troupeau mènerait à une réduction donnée de M chez les morues. Ce document décrit l'impact de la réduction du nombre de phoques gris sur le rétablissement des morues en fonction de deux approches différentes permettant de combler le manque des données. Étant donné que de nombreuses autres approches sont envisageables, ces résultats doivent être interprétés comme des simulations de scénarios portant sur l'incidence de la réduction du nombre de phoques sur la productivité de la morue, en fonction d'un ensemble d'estimations de la contribution de la prédation par les phoques sur la *M* chez les morues. En se basant sur une approche, on estime que la prédation par les phoques gris est responsable de seulement 10 % de la *M* actuelle chez les morues de 5 ans ou +. En fonction de cette estimation, la réduction du nombre de phoques ne pourrait réduire la *M* jusqu'à un niveau permettant le rétablissement des morues, parce que la *M* causée par d'autres facteurs inconnus est trop élevée pour permettre un tel rétablissement. Une deuxième approche donne des résultats plus conformes à la valeur probante des preuves selon lesquelles la prédation par les phoques constitue un facteur important de la *M* chez les morues. Cette approche attribue à la prédation par les phoques gris environ 50 % de la *M* actuelle chez les morues de 5 ans ou +. Dans le cas présent, la réduction du nombre de phoques peut réduire la *M* à un niveau qui permettrait le rétablissement des morues, mais la capture nécessaire de phoques serait considérable. Une réduction moins importante du nombre de phoques suffirait si les phoques gris ont un régime spécialisé et qu'il était possible de cibler ceux qui se nourrissent préférentiellement de morues. En se basant sur une analyse qualitative des risques, la réduction du nombre de phoques gris semblerait réduire le risque écologique pour les stocks de morues dans le sud du golfe sans menacer la sécurité de la population de phoques gris.

INTRODUCTION

A Zonal Assessment Process (ZAP) on the potential impacts of grey seals on fish populations in eastern Canada was held during October 4-8, 2010. One of the terms of reference for the meeting was to examine grey seal reduction scenarios to restore cod populations. This term of reference is addressed here for the southern Gulf of St. Lawrence cod population (the population occurring in Northwest Atlantic Fisheries Organization, or NAFO, division 4T and in subdivision 4Vn between December and April).

Cod in the southern Gulf of St. Lawrence have suffered from a high level of natural mortality (*M*) throughout the 1990s and 2000s (Swain et al. 2009). At its current level of natural mortality, this stock is expected to continue to decline even in the absence of fishing (Swain and Chouinard 2008). This increase in natural mortality appears to be restricted to older cod, cod 5 years of age and older (Swain et al. 2009; Swain 2011). It is likely that grey seal predation is an important component of this elevated natural mortality (Swain et al. 2011). For this stock to have a high probability of increasing to its limit reference point (a spawning stock biomass of 80,000 t) within about 20 years, the natural mortality (*M*) of 5+ cod would have to decrease by about 35% to a level of about 0.4, with the level of fishing mortality kept near zero (Swain 2011)[1]. In this paper, we explore grey seal reduction scenarios to reduce *M* to a level near 0.4, given different assumptions about their diet and the ability to target the seals contributing to cod *M*.

METHODS

Seal abundance

The number of grey seals contributing to the consumption of southern Gulf cod was calculated as follows. Based on the satellite tagging data, Benoît et al. (2011*c*) estimated that 11.7% of Sable seals and 86.9% of Gulf seals spent some of their time in 4T, and in 4Vn during the period (December-April) when southern Gulf cod overwinter there. We assumed that these percentages of the herds contributed to consumption of southern Gulf cod. For the Eastern Shore component of the herd, we assumed that 75% of these seals behaved like Sable seals and 25% behaved like Gulf seals. We used the Gulf abundance estimates that were obtained adjusting for variation in pup mortality related to ice conditions (M.O. Hammill and G.B. Stenson, unpublished data).

[1] The southern Gulf cod population model used at the seal impacts workshop (Swain 2011) was subsequently updated for the February 2011 recovery potential assessment (DFO 2011). The updated model was calibrated using several abundance indices in addition to the research-vessel bottom-trawl survey index used for the seal impacts workshop (i.e., a sentinel bottom-trawl survey index, a sentinel longline index, several additional sentinel indices available for the 1995-2002 period, and a commercial catch rate index for 1982-1993). The estimated level of *M* from the revised model was higher than the value estimated for the seal impacts workshop. However, the percent decline in *M* required to have a high probability that SSB would increase to the limit reference point within 20 years was about the same as used here. Thus, for a given percent contribution of predation by seals to *M*, the seal removals required for stock recovery based on the revised model would be about the same as reported here.

Consumption of southern Gulf cod by grey seals

In this paper, we focus on consumption of cod aged 5 years and older, the age groups of cod with elevated *M*. These age groups correspond approximately to cod 38 cm or more in length (at the growth rates observed in the 2000s).

While it is clear that cod are an important prey of grey seals in the southern Gulf of St. Lawrence, firm quantitative estimates of the amount of cod consumed are difficult to obtain due to data gaps. Estimates differ widely depending on the assumptions used to fill these gaps (Benoît et al. 2011*a*). Using the methods and assumptions described in Benoît et al. (2011*a*), initial estimates of consumption of southern Gulf cod 38 cm or more in length by grey seals ranged from about 5,000 t to 21,000 t in 2005 depending on the approach used to fill data gaps. Using revised seal diet data made available at the October workshop, estimated consumption of this size range of cod averaged 2,500 t using approach I and 11,000 t using approach II from Benoît et al. (2011*a*). These estimates of consumption were used for the analyses presented here. Further revisions to the seal diet data subsequent to the workshop resulted in further revisions to the estimates of cod consumption using approaches I and II (Benoît et al. 2011*a*). However, the values used for the analyses reported here remained within the 95% confidence intervals for the most recent revisions to estimated cod consumption using the two approaches for filling data gaps. Both approaches used here to estimate cod consumption by grey seals are sensitive to the unverified assumptions used to fill data gaps, and are subject to possible bias in estimated seal diets and high uncertainty in the spatial variation in seasonal distributions of seals and cod. Thus, the results presented here should be interpreted as 'what-if' scenarios regarding the impacts of seal removals on cod productivity given a range of consumption estimates based on different assumptions for filling data gaps.

Effect of seal reductions on *M*

Given an estimate of the consumption of 5+ cod (i.e., 38+ cm) by grey seals (*Cs*), the rate of natural mortality due to seal predation (*Ms*) was calculated by solving the following equation for *Ms*:

$$Cs = \frac{MsB(1-\exp(-M))}{M} \quad (1)$$

where *M* is the natural mortality rate of 5+ cod and *B* is 5+ cod biomass. *B* and *M* were set at the 2009 levels from model 8 in Swain (2011). Given a value for *Ms*, natural mortality due to factors other than grey seal predation (*Mo*) was calculated as $M - Ms$. *Mo* was assumed to be independent of seal abundance. Consumption (t) of 5+ cod per seal, *c*, was calculated as *Cs*/*S* where *S* is the estimated number of seals which spent some of their time in 2009 in 4T or in 4Vn during the overwintering period. For a given reduction in seal abundance, *Cs* was calculated as *cS′* where *S′* is the reduced level of seal abundance. Ms was then re-calculated using the following equation:

$$Cs = \frac{MsB(1-\exp(-Ms-Mo))}{Ms+Mo} \quad (2)$$

and the reduced level of *M* was obtained as *Ms* + *Mo*.

RESULTS

The estimated number of grey seals that foraged in 2009 within the zones occupied by southern Gulf cod (NAFO zones 4T and 4Vn in December-April) was 103,650 animals (Fig. 1). Based on model 8 in Swain (2011), the estimated biomass of 5+ cod at the beginning of 2009 was 48,029 t and the estimated M of 5+ cod in 2009 was 0.629. Based on model 8, 5+ M would need to be reduced to a level near 0.4 in order to have a high probability of the stock increasing to its limit reference point within 20 years (Swain 2011).

If 2,500 t of 5+ southern Gulf cod were consumed by grey seals in 2009, predation by grey seals would account for 11% of 5+ *M*, and it would not be possible to reduce *M* to 0.4 by seal removal (scenario 1 in Table 1). This is because *M* due to other causes would amount to 0.56.

If 11,000 t of 5+ southern Gulf cod were consumed by grey seals in 2009, predation by grey seals would account for 49% of 5+ *M*, and it would be possible to reduce *M* to 0.4 by substantial seal removals (scenario 2 in Table 1). In this case, 5+ *M* would be reduced to 0.4 if the abundance of seals that foraged in the zones used by southern Gulf cod was reduced by 70% to about 31,000 animals (a reduction of about 72,500 animals).

If grey seals show diet specialization, with a fraction of seals specializing in predation on large cod, and it is possible to target these seals for removal, then fewer seals would need to be removed to promote cod recovery. For example, if all the consumption of 5+ southern Gulf cod was due to half the seals foraging in the area occupied by the stock, and it was possible to target those seals for removal, then the required removals would be half as large, i.e. the number of seals preying on 5+ southern Gulf cod would need to be reduced by about 36,000 animals (scenario 3 in Table 1).

In all cases where it is possible to reduce seal abundance to a level that would permit recovery of southern Gulf cod, annual seal production would also need to be removed during the cod recovery period. Based on the estimates in Figure 1, seal abundance in the areas occupied by southern Gulf cod has been increasing exponentially since 1990 at a rate of about 5.5% per year. If this rate of increase were to persist after reducing seal abundance, annual production at an abundance of 31,000 seals would amount to 1,700 animals.

DISCUSSION

Given the data gaps and uncertainties associated with 1) the diets of grey seals, 2) their seasonal foraging distributions, and 3) seasonal variation in the distributions of their prey (Benoît et al. 2011*a,b*), it is not possible to specify the probability that a given level of grey seal removals will result in a given level of reduction in cod *M*. The situation is especially difficult because estimates of the percent cod in the diet and the size composition of cod consumed differ widely among the seasonal/spatial cells that have been sampled for diet, i.e., inshore areas in July-October (areas where cod densities are relatively low), the Northumberland Strait in November-April (an area where cod are absent) and off northwestern Cape Breton in November-December (an area where dense aggregations of overwintering cod occur) (Hammill 2010; Stenson et al. 2011).

Furthermore, diet estimates depend on the retention of otoliths (ear bones) in digestive tracts or faeces and so overlook partial consumption of prey in which the head is not consumed. Under

certain circumstances partial consumption of only the most energy-dense portions of prey is an optimal foraging strategy (e.g., Sih 1980; Gende et al. 2001). The conditions favouring partial consumption of prey may exist for grey seals preying on cod: 1) energy density is not uniform throughout a cod with density highest in the abdomen, in particular the liver, where energy is stored in cod; 2) consumption of the heads of large cod may incur substantial processing costs; and 3) cod are highly aggregated at certain times and places (e.g., on the overwintering grounds, during seasonal migrations) so that little searching is required to find prey once a cod aggregation has been located. Selective rejection of fish heads by seals has been reported in a number of cases (e.g., Moore 2003; Hauser et al. 2008). “Belly-biting” of cod by grey seals, in which seals consume only the abdomen of cod including the energy-rich liver, has been frequently reported by fish harvesters and has been documented for harp seals feeding on free-swimming cod off Newfoundland (Lilly and Murphy 2004). If belly-biting is an important foraging strategy of grey seals preying on large cod, then the contribution of predation by grey seals to the natural mortality of cod will be substantially under-estimated using the current methods of diet reconstruction for two reasons (Benoît et al., in review). First, the importance of cod in the diet of grey seals will be underestimated. Second, the number of cod killed per unit of cod-derived energy in the seal diet will be underestimated (i.e., more cod are required to account for a given contribution of energy to the seal diet if cod are only partially consumed).

Different assumptions for filling data gaps lead to very different conclusions regarding the impact of grey seal removal on the recovery of southern Gulf cod. Based on one approach, predation by grey seals is estimated to account for only about 10% of the current *M* of adult cod (ages 5+). Given this estimate, seal removal cannot reduce *M* to a level that would permit cod recovery (because *M* due to other unknown causes is too high to allow recovery). Based on a second approach, predation by grey seals is estimated to account for about 50% of the current *M* of 5+ cod. Given this second estimate, seal removal can reduce *M* to a level that would permit cod recovery. Unlike the first approach, this second approach leads to results that are consistent with the weight-of-evidence which indicates that a major component of the current high *M* of 5+ cod is likely due to predation by grey seals (Swain et al. 2011).

Based on weight of evidence, it was concluded that the most probable hypothesis for the cause of the current high level of natural mortality of southern Gulf cod is that a large fraction of this mortality is due to predation by grey seals (Swain et al. 2011). If this conclusion is incorrect and large-scale grey seal reductions are undertaken, grey seal numbers would be reduced without the benefit of promoting cod recovery. However, given the population dynamics observed for grey seals over the past 40 years, the grey seal population would be expected to be secure at this reduced level of abundance, and recovery to a higher level of abundance would be predicted once seal removals cease. If this conclusion is correct and no action is taken, grey seal abundance would be expected to remain high and cod abundance would be expected to decline further to a very low level and remain there indefinitely (or decline to extirpation, given certain functional responses of predator to prey, e.g., Gascoigne and Lipcius 2004). If the conclusion is correct and action is taken, grey seal numbers would be reduced and cod abundance would be expected to increase.

A caveat is that grey seal reductions could have impacts on other components of the ecosystem which in turn could have a negative effect on cod productivity. Negative indirect effects on cod might occur if grey seal reduction resulted in increased abundance of other predators or competitors of cod. Increased abundance of predators of large cod (the cod with high M) due to grey seal reductions is very unlikely because there are no known predators of large cod that are prey of grey seals. Increased abundance of competitors of large cod due to grey seal reductions is possible, but history suggests that large cod would dominate in any increased competition.

Cod was by far the dominant large demersal fish in the southern Gulf in earlier periods of low seal abundance, and remains the dominant large demersal fish in the southern Gulf today in terms of biomass. On the other hand, increased abundance of competitors and predators of early life-history stages of cod is a possible consequence of seal removals. Herring are an important prey of grey seals in the Gulf (Hammill 2010), and cod recruitment rate is negatively related to pelagic fish biomass in the southern Gulf (Swain and Sinclair 2000). However, herring are also an important prey of large southern Gulf cod (Hanson and Chouinard 2002). Thus, if grey seal abundance were reduced, reduced predation on herring by grey seals would be expected to be counteracted by increased predation by large cod as their abundance increased due to reduced M. Furthermore, there is a large fishery for herring in the southern Gulf (landings of 45,000 – 50,000 t in recent years, 76,000 – 93,000 t in the mid 1990s; Leblanc et al. 2010). Increased quotas in this fishery could also counteract effects of reduced predation by seals. Effects of grey seal reductions on other components of the ecosystem could also have positive effects on cod productivity. Reduced seal predation on small fish could increase prey availability for large cod. In summary, grey seal reduction would appear to reduce ecological risk to the southern Gulf cod population without jeopardizing the security of the grey seal population. The same conclusion is reached with respect to the status of two other demersal fish populations of conservation concern, white hake and winter skate in the southern Gulf of St. Lawrence (Benoît et al. 2011c).

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Table 1. Effects of grey seal removals on natural mortality (*M*) of 5+ southern Gulf of St. Lawrence cod based on three consumption scenarios. *Ms* and M_0 are the rates of natural mortality of 5+ cod due to grey seal predation and other factors, respectively. Scenarios 1 and 2 assume that total consumption of 5+ southern Gulf cod by grey seals in the 2009 reference year is 2,500 or 11,000 t, respectively. Scenario 3 is like scenario 2, except that it is assumed that all the predation is by cod specialists (amounting to 50% of the seals in the area) and that it is possible to target the cod specialists for removal.

Scenario	Seal reduction (%)	Seal reduction (numbers)	Seal abundance	Total 5+ cod consumption (t) *Cs*	*Cs*/seal	*Ms*	M_0	Total *M*	*Ms*/*M*
1	0%	0	103650	2500	0.02412	0.070	0.559	0.629	0.112
	70%	72555	31095	750	0.02412	0.021	0.559	0.579	0.036
	100%	103650	0	0	-	0	0.559	0.559	0
2	0%	0	103650	11000	0.10613	0.309	0.320	0.629	0.491
	60%	62190	41460	4400	0.10613	0.113	0.320	0.433	0.261
	70%	72555	31095	3300	0.10613	0.084	0.320	0.404	0.207
3	0%	0	51825	11000	0.21225	0.309	0.320	0.629	0.491
	60%	31095	20730	4400	0.21225	0.113	0.320	0.433	0.261
	70%	36278	15548	3300	0.21225	0.084	0.320	0.404	0.207

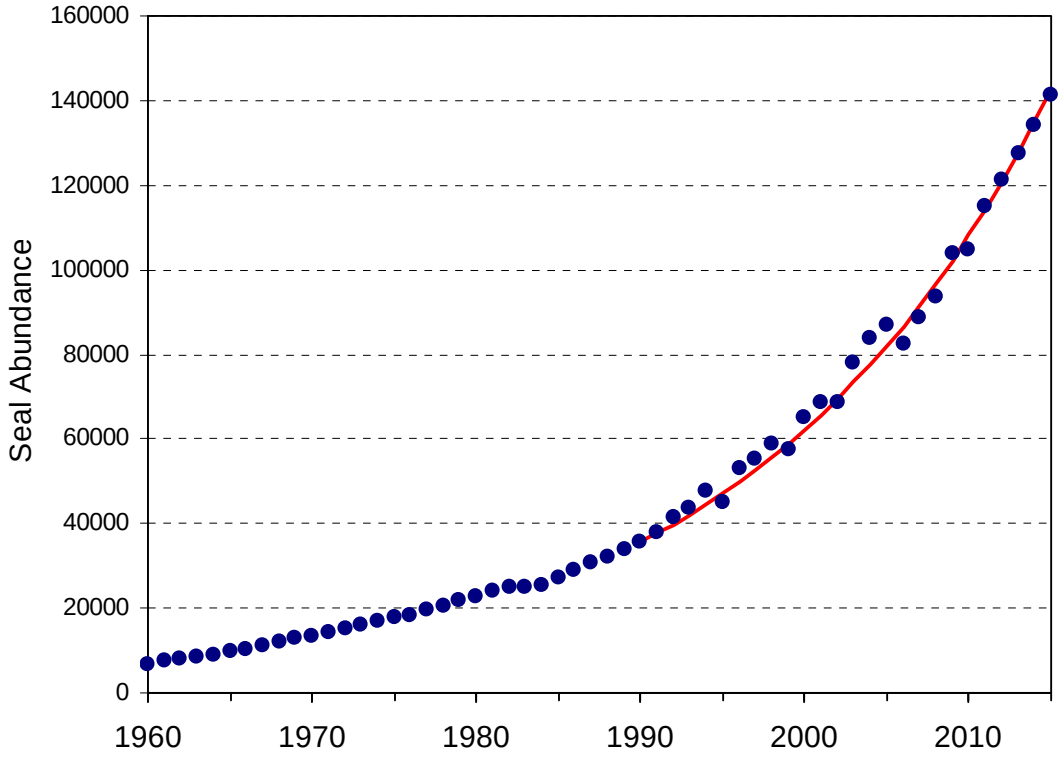

Figure 1. Estimated abundance of grey seals occurring in NAFO Division 4T at some time in the year and/or in subdivision 4Vn at some time in the December – April period. Line shows the time trend for a rate of increase of 5.547% per year.