The impact of changing climate on reproduction of Northwest Atlantic harp seals, *Pagophilus groenlandicus*.

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Summary
Climate related declines in sea ice seriously impact species such as the Northwest Atlantic harp seal that rely on ice for reproduction and feeding. Harps feed and give birth on ice along the southern edge of the seasonal pack ice - an area that is rapidly changing due to global warming. Although climate change has been shown to affect harp seals directly through increased mortality of young, it may also impact indirectly through changes in prey and subsequent reproductive rates. Late term pregnancy rates were estimated from samples collected between 1954 and 2014 off Newfoundland, Canada. Since the early 1980s, pregnancy rates declined while inter-annual variability increased with late term pregnancy rates among mature females falling to <0.3 in 2011. Using a beta regression model to explore the importance of a variety of biological and environmental conditions, we found that while the general decline in fecundity is associated with increased population size, including the late term abortion rates captured much of the large inter-annual variability. Changes in the abortion rate can be described by a model that incorporated late January ice cover and capelin biomass. It is likely that ice cover is also a proxy for ecosystem changes in prey.

Introduction
As the Arctic warms, declining sea ice will seriously impact species that rely on ice for reproduction and/or feeding. Although impacts on Arctic marine mammals have been examined, little is known about impacts on sub-Arctic species who face rapid change along the ice edge they inhabit. The Northwest Atlantic harp seal (*Pagophilus groenlandicus*) is an abundant, migratory species that summers in the Arctic but winters off Atlantic Canada where it gives birth on the pack ice each March. Over the past 4 decades this area has shown warmer temperatures and deterioration in ice conditions required by harp seals, resulting in increased mortality of harp seal pups that rely on ice for nursing and resting (e.g. Stenson and Hammill, 2014). Data on harp seal reproductive rates since the 1950s are available from Newfoundland (Nfld), Canada. Sjare and Stenson (2010) found that pregnancy rates declined from 85 - 95 % in the late 1970s to 65 - 70 % by the early 1990s and varied between 45 and 70 % from 2000 - 2004. During this period, the population increased from less than 2 million to more than 7 million seals (Hammill et al., 2014). Although these changes suggest a density-dependent response, population size does not explain the variability observed. At the same time, dramatic changes in the Northwest Atlantic ecosystem have occurred suggesting that other factors have influenced reproductive rates (Sjare and Stenson 2010). In this study we explore the influence of density-dependent and independent factors on the reproductive rates in northwest Atlantic harp seals.

Methods
Fecundity rates, defined as the proportion of mature females that were pregnant, were obtained from female harp seals collected annually between October and February from Nfld since 1979. Bowen et al (1981) provided data between 1954 and 1978. Seals were considered mature if there was a *corpus luteum* (CL) or *corpus albicans* (CA) present. Pregnant females contained a large, luteinized CL and a foetus. Seals that lacked a foetus, but with a CL ≥ 13 mm or CA ≥ 12 mm, a ruggose uterus and a large

uterine horn, were assumed to have pupped recently. If collected prior to February 15th, it was assumed that those pups did not survive and were classified as a late term abortion.

Data on environmental (NAO, ice cover January 29) and biological (seal abundance and prey) factors that might influence harp seal fecundity were collected. The prey field (available only since 1995) was approximated using relative biomass indices for three common prey: capelin (*Mallotus villosus*), sand lance (*Ammodytes americancus*) and Arctic cod (*Boreogadus saida*) from DFO's fall bottom trawl survey. We modelled pregnancy rates since 1954 using fixed-dispersion, beta regression models. The model had the form (using a log link) :

$$\textit{fecundity rate}_t \sim \textit{population size}_t + \textit{abortion rate}_t + \textit{ice coverage}_t + \textit{NAO}_t + \textit{fecundity rate}_{t-1}$$

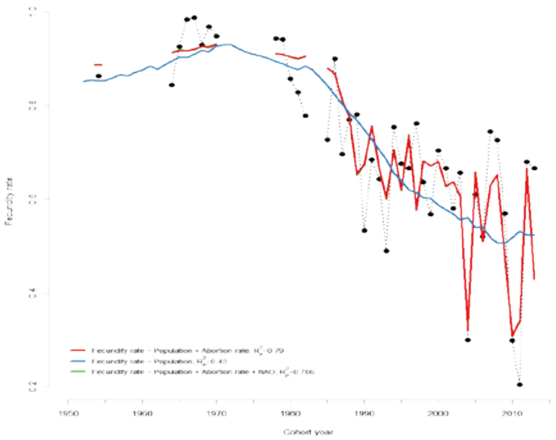
Similarly, abortion rate was modelled as a function of the available habitat and prey availability the previous fall.

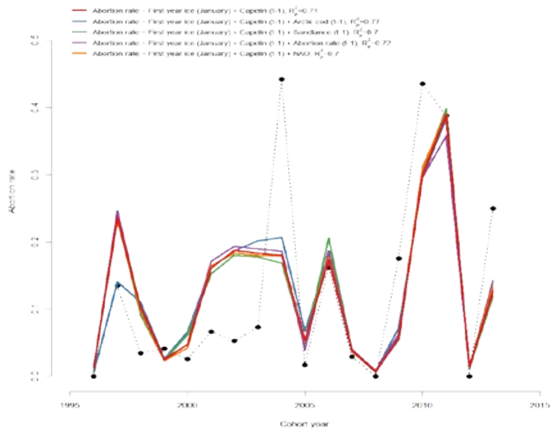
$$\textit{abortion rate}_t \sim \textit{ice coverage}_t + \textit{NAO}_t + \textit{capelin biomass}_{t-1} + \textit{sandlance biomass}_{t-1} + \textit{Arctic cod biomass}_{t-1}$$

We built all possible candidate models (without interactions), and ranked and selected the best model based on the Akaike Information Criterion corrected for small sample sizes(AICc) and the derived measure evidence ratio (E_i).

Results and Discussion

The most parsimonious model to describe the fecundity rate included population size and abortion rate as explanatory variables. The model that includes only population size captures the general decrease in fecundity but fails to capture the increasing variability. When abortion rate is included, this variability is captured. All relationships were negative. Abortion rates were best described by the model that included ice coverage (Jan 29) and capelin biomass.





Declining ice impacts harp seals directly through increased mortality of pups but also indirectly through reduced reproductive rates. Seals may be responding to years when ice does not appear to be forming up normally for pupping, but ice conditions may also be a proxy for other ecosystem conditions. Buren et al (2014) found that capelin biomass and spawning are correlated with ice conditions in the northwest Atlantic.

References

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