PhD Project: Understanding and forecasting the population dynamics of Svalbard polar bears (*Ursus maritimus*) in response to climate change.

Scientific context:

Climate change in the Arctic regions: Over the last decades the Arctic has warmed at twice the global rate (AR4 IPCC report), with notable ecological effects [1]. In particular, due to warming, sea ice extent has significantly declined since the 1980s, and is now breaking up earlier, and freezing later [2,3]. Consequently, sea ice-dependent species are experiencing drastic habitat loss, which is expected to lead to declines in several species' abundances [4,5].

Polar bears and sea-ice loss: Polar bears are predicted to be one of the species most affected by sea ice loss among arctic mammals [6,7], because they depend on sea ice for hunting seals, breeding and travelling [8]. In some areas, sea ice loss correlates with lower body condition, shifts in movement patterns [9,10] and behaviors [11–15], reduced denning probability and increased cubs' mortality [16–19]. A recent review concluded that the loss of Arctic sea ice owing to climate change is the primary threat to polar bears and can cause large declines in their numbers [20]. A better understanding of polar bear's demography and population dynamics is essential to assess and monitor the species extinction risks, and because any change in the distribution and density of this top predator can have cascading impacts, both on terrestrial and marine ecosystems.

The Svalbard polar bear population: Svalbard polar bears and the environmental conditions they face are unique in several ways. Sea ice declines are particularly severe in the Barents Sea, where Svalbard is located. Among the 19 recognized polar bear populations [21], the Barents Sea population has experienced a rate of decline in sea ice days more than twice that of any other population, equivalent to -4 days per year since 1979 [22,23]. In addition, Svalbard polar bears are characterized by a slower life history strategy than polar bears in the Hudson Bay. In Svalbard, females first reproduce at 5 years of age (versus 4 in the Hudson Bay) and the interval between two successive weaned litters is usually of 3 years (versus 2 in the Hudson Bay). Litter size is also smaller in Svalbard. Finally, polar bears in Svalbard are not hunted, providing a unique opportunity to study the demography of polar bears affected solely by natural mortality. Due to these differences, the Svalbard polar bear population may respond differently to sea-ice loss compared to other populations.

However, most studies on polar bears have been conducted in Canada and little is known about how environmental changes already occurring in Svalbard influence polar bear's demography. Only a few studies to date have focused on the demography of polar bears in Svalbard [24–27], and among them, none have yet investigated changes in demographic rates in relation to environmental variables. As a result, no forecast is yet available for this population, and we do not know whether the population of polar bears in Svalbard will decline due to sea-ice loss in the future, or if it will adapt to these changes, e.g. by switching prey, therefore avoiding demographic costs.

Objectives of the PhD

Making use of a long-term individual-based dataset collected on the Svalbard population since the 1970's, combined with detailed climate and sea-ice data from the Svalbard area, and statistical modeling tools, the objective of this project is to analyze the demography of the Svalbard polar bear in response to environmental changes related to sea-ice loss.

We plan to study and quantify the impact of climate change and sea ice condition on (1) survival, and (2) reproduction, and (3) to combine information gathered from steps 1 and 2 into a population projection model which will permit to evaluate future changes in population numbers and extinction risks under various sea-ice loss scenarios.

Data

To do so, we will analyze the individual data set from a long-term research project on the ecology of polar bears in the Barents Sea region [27], carried out by the Norwegian Polar Institute, and overseen by Jon Aars, who will co-supervise this PhD. From 1987 to 2019, 825 individual females (representing 1199 captures) were captured. Individual characteristic (body size, body condition, age), reproductive status, and litter condition and size were recorded. In addition, 311 females have been collared, while 53 females were fitted temperature and light recording geolocators tags on their ear, hereafter 'ear tag loggers' (providing data on 139 bear winters). This extensive dataset has never been studied in depth, and the various data types have not been analyzed together yet. We will use capture-recapture (CR) data to study survival, with the measures of individual characteristics serving as covariates and sea-ice and climate data serving as proxy of environmental conditions. Records of litter condition and size will allow us to study reproduction, and we will use data from ear tag loggers to study denning frequency.

We will use readily available temperature data (from a weather station in Svalbard), arctic-oscillation related data, and sea ice data (derived from satellite observations).

Approach

1) Survival of female polar bears and influence of individual and environmental variables:

We will use hierarchical models in a Bayesian framework to analyze individual CR data, with the aim of uncovering the effects of environmental variables as well as individual traits on survival of female polar bears. First, we will use a multi-state model structure to account for reproductive status of females (alone, with one or several cubs, yearlings, or dependent two-year old bears). With this model structure, we will evaluate the influence of various individual characteristics (age, body condition, body size, level of pollutants) on survival. We will also use mixture models to include unexplained heterogeneity between females due to for instance to birth conditions or intrinsic individual quality [28].

Based on earlier studies in Svalbard and other Arctic areas, we anticipate that: 1) Adult survival is in general high for prime age females (5-15 years old) and low thereafter. 2) Survival varies on an annual basis with a particular effect from variation in sea ice cover and the length of the ice-free period. Although cubs, subadults and old females will be most affected [18], there could also be an effect on the prime age adults (as shown in years with a long period with little sea ice in Southern Beaufort Sea [19]. 3) There will be an additional heterogeneity in survival explained by the space use strategy of the bears (pelagic or near-shore). Near-shore bears will be affected more by longer periods without sea ice around land areas (pelagic bears will mostly be in the pack ice in summer).

2) Reproduction rates and survival of cubs

We will use mixed models to analyze variance in reproduction indices (e.g. frequency of maternity denning, production rate, litter size). We will include the same predictor variables as those described in the previous section. Furthermore, we will investigate potential links between the various components of reproductive success and survival. To do so, we will include the variables identified as relevant in the first step in the CR model proposed by Cubaynes et al. (2021) [29]. This will allow us to investigate potential trade-offs between demographic rates while accounting for dependence within family units and correcting for potential biases in the data (e.g. due to different capture probability of females depending on their reproductive state).

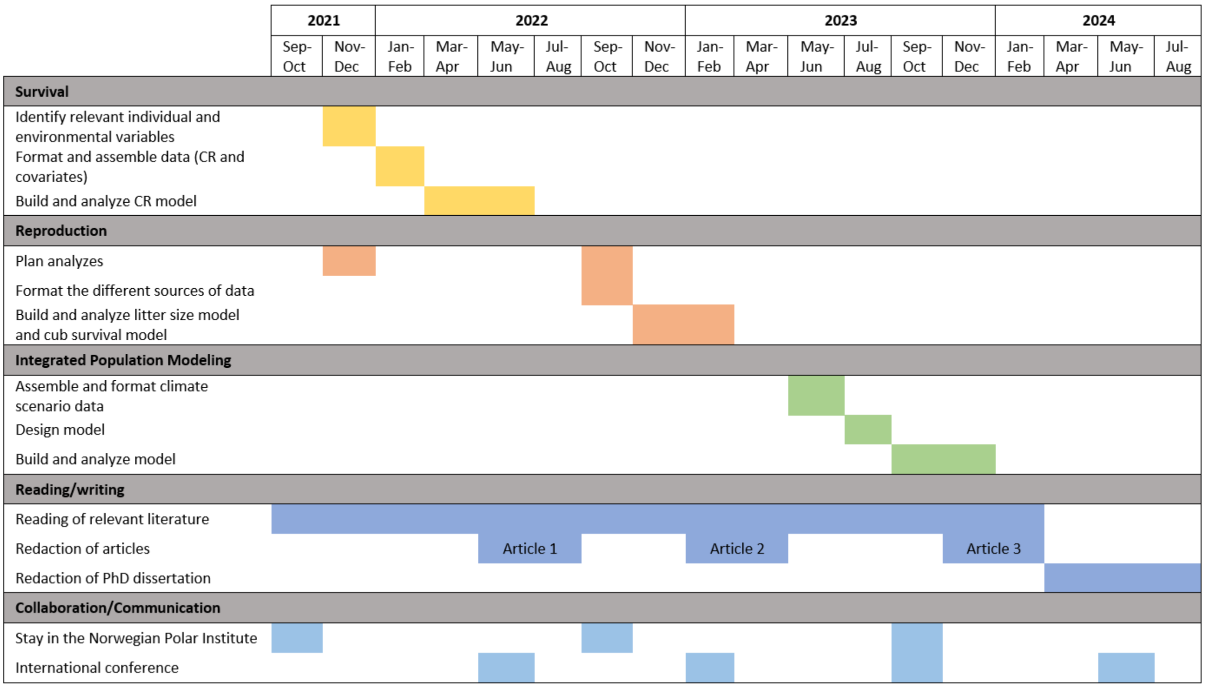
With an operational sex ratio of maybe two adult males per adult female (females have dependent cubs for more than two years and are available for mating only each third year if the cubs survive), it is not likely that finding a mate is a factor that limit female reproduction. We hypothesize that most available females will mate in spring, but that some might not be in sufficient condition to start a long denning period and to provide milk to cubs in winter, and that sea ice conditions in summer and autumn together with age will explain much of the variance in birth rates. We expect important variability among individuals regarding their vulnerability to changes in environmental conditions depending on their geographic area, space use reproductive status, and other individual traits such as e.g. experience (age) and body condition. The near-shore bears will be most vulnerable to poor ice years, through a longer period with low access to seals. However, in more extreme years, late arrival of sea ice in autumn may prevent pelagic bears from arriving to their preferred denning areas [30,31], and maybe also to find alternative areas in time to give birth. We further predict that in bad ice years (long ice-free periods including early break up in the very important hunting period in spring when polar bears hunt ringed seal cubs on the ice in the fjords), survival of the cubs after they leave the dens in spring will be severely reduced. When females reproduce, we predict that litter size will be smaller, or that the litter will be lost, in spring following bad ice years.

3) *Modelling the population dynamics under various environmental scenarios*

Using the Bayesian hierarchical modelling framework, we will combine the sub models designed in the previous sections for survival and reproduction and include the selected predictor variables. We will use an integrated population model (IPM) to combine the different types of data at our disposal (population counts, GPS-data, CR data, fata from ear tag loggers). An IPM has been parametrized for another polar bear population [16,20]. However, this model assumes that all individuals are independent from each other while in Svalbard, mother polar bears care for offspring for at least 2-years during which offspring survival and body condition are dependent upon mother survival status and body condition. In parallel, mother polar bears' breeding probability, litter size probability and body condition may also vary depending on the number and age of dependent offspring. The dependency among individuals' demographic rates can have important consequences at the population level and may be essential to include to accurately project population dynamics [29]. The novelty in our approach is that we will include the multiple-year dependence existing among individuals within family units in our model. Using this model, we will provide predictions of the demographic response of the Svalbard polar bears under various climate and sea ice cover scenarios (e.g. with earlier sea ice break up, and later freezing). Importantly, the very wide range of duration of the ice-free period in Svalbard across years allows us to predict the demographic response without extrapolating.

Supervision team: This PhD will be conducted under the supervision of Olivier Gimenez (DR CNRS), statistician expert in the analysis of CR data, and Jon Aars, senior research scientist at the Norwegian Polar Institute who oversees the Polar bear project. The work will also be conducted in collaboration with Sarah Cubaynes (Assistant Professor, EPHE), an ecologist who has previously developed a statistical model including multiple-year dependency among individuals polar bears (to be extended in section 3 of the PhD).

Timeline



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