Polar bear maternal den monitoring

A custom-designed camera system used in this study to record polar bear den emergence behaviour.

A project report prepared for the Svalbard Environmental Protection Fund in 2025 by Polar Bears International.

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Contents

Summary

Maternal denning is a critical period in the life-cycle of polar bears as it provides insulation and protection for developing cubs. The timing of emergence from and abandonment of the den can influence the subsequent survival of offspring, making denning behaviours important metrics in population monitoring. Yet in a warmer, more accessible Arctic, denning bears face increased risk of disturbance and environmental change. Here, we aimed to characterize the behaviour of polar bear families during the den emergence period in Svalbard using both custom-designed cameras and commercially available trail cameras to obtain high-quality video and timelapse imagery of females and cubs during the emergence period. Between 2016 and 2024, we deployed camera monitoring systems at 21 suspected den sites and recorded polar bear activity at 19 of these. Camera systems were deployed at a further 3 suspected den sites in 2025, and data from these deployments is currently being processed.

Camera systems revealed detailed insights into den emergence behaviour, including:

- *Altered den emergence periods:* Families emerged around March 9th in Svalbard and appeared to abandon the den earlier than previously recorded in this population, with further monitoring required to establish whether this is a continuing trend. Changing the timing of denning could potentially jeopardize future survival of offspring, as cubs have less time to develop before venturing further afield to the sea ice.
- *Variable den presence*: In some cases, bears emerged from the den for less than a minute before going back inside, while other emergences lasted several hours. In terms of departing the den for good, the camera footage indicated that polar bears remained near their dens for an average stay of 12 days. However, this varied greatly between polar bear families, ranging from 2 to 31 days.
- *Den switching*: We recorded some females that switched dens – they left their original dens and were observed moving their family to a new den.
- *Maternal dependence*: Cubs appeared to rely heavily on their mothers, rarely venturing outside the den alone. Cubs were recorded outside of the den alone only 5% of the time.
- *Factors influencing behaviour at the den site:* Mothers and cubs were more likely to be seen outside and spent longer outside the den at warmer temperatures and the longer it had

been since their first den emergence. These finding further support the time spent at the den as being important for cub acclimatization and continued development.

- *Validating data from satellite telemetry devices:* We compared denning behaviours observed on camera with temperature and activity data recorded by satellite collars worn by the denning mothers to quantify how accurate inferences from collar data were. Overall, denning activities inferred from the satellite collars corresponded well with observations from camera monitoring. We then combined the collar and camera data to develop predictive models of polar bear denning behaviour, providing new tools to enhance ability to monitor denning activities across the Arctic.

Accurately identifying and understanding patterns in polar bear denning behavior is integral to anticipating responses to ongoing environmental change, and to proactively managing denning habitat and reducing potential for human–polar bear interactions. The outputs from this study deepen our understanding of behaviour during the post-emergence period and contribute new tools to better monitor denning bears remotely, which may aid in population monitoring and proactive protection and management of denning bears to minimize risks of disturbance during this critical time.

Background

In the Arctic, climate warming is occurring 2–4 times faster than the global average (Rantanen et al., 2022; Walsh, 2014) leading to loss of snow and sea ice, which are critical habitat for many Arctic species, including polar bears *Ursus maritimus* (Laidre et al., 2008; Niittynen et al., 2018; Post et al., 2009). Negative impacts on polar bear population health have already been documented in some regions (Derocher & Stirling, 1995; Regehr et al., 2010; Rode et al., 2010; Bromaghin et al., 2015; Lunn et al., 2016; Obbard et al., 2018, Archer et al., 2025). The effects of environmental change on the earliest stages of polar bear reproduction are less well understood, however, because much of early reproduction occurs in ephemeral maternal dens in the snow, where bears are difficult to monitor (Owen, 2021).

Maternal denning is a crucial aspect of polar bear life history because the den protects developing offspring from extreme cold and inclement weather (Smith, 2021). Pregnant females excavate a den in the snow in the late autumn, and cubs are born in December through early January weighing only ~600g (Blix & Steen, 1979; Ramsay & Dunbrack, 1986). A female and her offspring – typically between one and three cubs – will remain in den for a further 3 to 4 months, during which time cubs continue to grow and develop (Ramsay & Stirling, 1988). The family emerge from the den in the spring and may remain at the den site for several weeks afterwards. This post-emergence period likely plays an important role in cub development by allowing acclimatization to the environment outside the den and promoting further physical and muscular development (Hansson & Thomassen, 1983; Ovsyanikov, 1998). Moreover, the timing of den exit and the and the length of the post-emergence period have been shown to have positive effects on the subsequent survival of cubs (Andersen et al., 2024; Rode, et al., 2018).

Given its important role in reproductive success and the potential for increasing anthropogenic disturbance in denning habitats, maternal denning behaviour and phenology (i.e., the timing of denning activities) have been highlighted as important metrics in population monitoring (Rode et al., 2018). Yet the denning period has also been highlighted as a time when polar bears may be particularly vulnerable to external disturbance (Woodruff et al., 2022). Rapid rates of Arctic warming means denning habitats are becoming increasingly accessible and more susceptible to human encroachment e.g., oil and gas exploration, industrial activities, and human recreation, amongst other activities (Larson et al., 2020; Rode et al., 2018; Woodruff et al., 2022). Increased

human activity is a concern because polar bears already den on land in many regions (Amstrup & Gardner, 1994; Andersen et al., 2012; Laidre et al., 2015; Lunn et al., 2004; Messier et al., 1994) and continued sea ice loss is expected to generally increase rates of land-based denning (Olson et al., 2017). Responses of denning bears to disturbance include relocation of the den, premature den emergence, or early abandonment of the den site (Woodruff et al., 2022). Along with direct disturbance, denning bears may also be vulnerable to environmental change (Wiig et al., 2008). For example, warmer temperatures, increased rainfall, and/or reduced snow accumulation may impair the structural and thermal stability of the den (Stirling & Derocher, 2012; Stirling & Smith, 2004), potentially leading to altered denning behaviour, failed reproduction, or mortality (Clarkson & Irish, 1991). As such, understanding patterns in maternal denning behaviour is integral to proactively managing denning polar bears, reducing potential for human-polar bear interactions, and anticipating responses to ongoing habitat change. However, we have relatively limited knowledge of the factors that contribute to variation in denning behaviours.

Svalbard has long provided important denning habitat for the Barents Sea polar bear subpopulation, which encompasses the Svalbard archipelago, together with Franz Josef Land and Novaya Zemlya to the East (Aars et al., 2009). Exceptional warming has profoundly altered the Barents Sea region (Lind et al., 2018; Screen & Simmonds, 2010), with effects on polar bear denning. Historically, polar bear maternal denning has mainly occurred on islands in the east of the Svalbard archipelago, on Nordaustlandet, and along the northeast coast of Spitsbergen (Lønø, 1970). Over the last four decades, later arrival of sea ice has meant some historical denning areas are becoming increasingly inaccessible to pregnant females (Derocher et al., 2011; Merkel & Aars, 2022). Given the rapid changes underway in this region, enhanced understanding of and ability to monitor denning activities is particularly important for management of the Barents Sea polar bears.

The remote and often inaccessible nature of polar bear denning habitats means that accurately monitoring behaviour in the wild can be challenging. Direct observation of polar bear dens have been possible in some more regions e.g. in Alaska (Larson et al., 2020; Smith et al., 2007, 2013), Hudson Bay in Canada (Ramsay & Stirling, 1986), and in Svalbard (Aars, 2013; Andersen et al., 2012; Hansson & Thomassen, 1983), but logistical challenges and cost mean this approach is often infeasible. Increasingly, researchers rely on satellite tracking devices (e.g., collars) to monitor polar bear behaviour (Laidre et al., 2022). Denning activities can be inferred from extended periods of

stationary location fixes (Laidre et al., 2015) or from additional data that may be collected by biologging devices attached to trackers e.g., temperature or activities rates (Fischbach et al., 2007; Olson et al., 2017; Blanchet et al., 2020). Although these approaches have been invaluable in determining broadscale patterns related to timing and location of denning, their suitability for identifying more fine scale behaviours (e.g., initial emergence, short distance movements) is unclear and such data have yet to be validated against direct observations.

In this project – led by Polar Bears International in partnership with the Norwegian Polar Institute and San Diego Zoo and Wildlife Alliance – we applied a novel approach for monitoring the behaviour of polar bear families emerging from maternal dens in the Svalbard, combining direct observations from trail cameras and custom-designed continuous recording cameras with data from satellite tracking collars worn by female polar bears.

Objectives

The specific aims of this project were to:

1. Remotely observe and describe the timing, behaviour, and activity patterns of polar bear family groups during the den emergence period in Svalbard, Norway.
2. Validate the accuracy of data collected via animal-bourne, collar-mounted sensors and satellite telemetry data.
3. Identify factors that influence polar bear behaviour activity patterns during the den emergence period.
4. Remotely assess female health and the development of polar bear cubs throughout the emergence period.

Methods

Data collection

The focal period of the study took place between 2016 and 2025, with data collected each year except for 2021 when the COVID-19 pandemic prevented field work going ahead.

Satellite collars

As part of a long-term research program of the Norwegian Polar Institute on the Barents Sea subpopulation of polar bears, the adult female polar bears (aged > 4 years old) in our study were captured in the Svalbard archipelago in the spring of 2015 – 2024 (see Derocher (2005) for further details on capture and sampling protocol). Females were captured in March–April (prior to entering maternity dens in the autumn) and were fitted with GPS satellite transmitting collars (TGW-4678-3 and TGW-4678-4, Telonics, AZ, USA). The collars also transmitted temperature and activity data. Temperature was measured by a thermistor mounted inside the collar (Fischbach et al., 2007). Though temperature measurements are influenced by the individual's body temperature, the data also act as a good indicator of the ambient temperature of the surrounding environment (Harris et al., 1990). Activity was measured by a mercury-tip switch inside the collar that recorded state changes at 1 s intervals across 2 h (7200 s) periods (Fischbach et al., 2007). GPS positions and collar sensor data were transmitted every two hours via the Iridium satellite system and used to calculate movement speed (km h^{-1}).

Camera installation and monitoring

In each year of the study, data from satellite collars were used to identify sites where females had potentially entered a maternal den. Potential denning females were indicated by collars that showed extended periods of low activity, high temperatures (relative to ambient temperatures) and minimal changes in locations, from fall through winter and for an extended period into spring. The location of each den site was established from GPS positions that were consistent and had the least associated error. Next, potential sites were evaluated for both accessibility and safety before the field team selected which sites to monitor. Camera monitoring equipment were installed at each site between late February and early March, as local weather conditions allowed. To minimise disturbance of denning bears, the final 1 km approach to each site was made on foot or by ski, after an initial approach via helicopter or snowmachine. We installed custom-built Raspberry Pi camera systems termed "Mini Den Cameras" (MDCs), which recorded continuous footage of the den site for several weeks. The MDCs (Figure 1) were housed in a weatherproof modified case, which also housed the camera's power source (batteries) with additional power provided by a solar panel array. Up to four trail cameras (XP9 Ultrafire, Reconyx, Holmen, WI, USA) were also installed at each site (Figure 2) and programmed to record a timelapse of one picture per minute (or one picture every 5 minutes in 2016 and 2017). In 2017 and 2018, the cameras were inactive from 21:00 to

05:00. Polar bears in Svalbard typically build maternal dens on the slopes of mountainous terrain or fjords, where deep snow accumulates high up on the lee side (Andersen et al., 2012; Merkel et al., 2020), and cameras were installed facing the slope to provide as much coverage of each denning area as possible, at an approximate distance of 100 - 1270 m from the estimated location of the den. The cameras were left in place until GPS locations from the satellite collars indicated the bear had departed the area, after which all equipment was retrieved from the field.

Figure 1*: The custom-designed camera systems (termed "mini den cameras", MDC), which recorded continuous footage of polar bears at emergence from their dens in Svalbard. The left panel shows the camera viewing window, with solar panels visible in the background and the right panel shows an MDC facing the den site, with the solar array alongside.*

Footage and data from the MDCs and trail camera timelapses were processed by trained technicians, who recorded timestamped observations on the presence of females and cubs, weather and visibility, distance of polar bears to the den, and other points of interest (behaviours, other wildlife etc.). Ambient temperature was also recorded by the trail cameras and used in subsequent analyses. The behaviours of families during periods of emergence from the den were also quantitatively scored using an ethogram.

Analyses

Comparing observed denning behaviours with inferences from satellite collars

To better understand how denning behaviour inferred from satellite collars corresponds to observations from cameras, we first compared the observed timing of den emergence and final departure at each den site data recorded by cameras to the emergence and departure dates estimated based on collar sensor data. Using the trail camera data timelapses, we defined the first date of den emergence from each den as the first image when the snowpack was visibly broken open, or the focal polar bears were observed on camera. The last time the focal family was recorded on camera was designated as the observed departure date.

We calculated collar-derived den breakout and departure dates using two approaches: (1) using a segmentation analyses, which identified signals from collar temperature and activity data to define segments in the timeseries that were distinct and likely represented periods before and after den breakout (Sulich, 2019, Blanchet et al., 2020; Patin et al., 2020); and (2) a threshold temperature approach, which estimated dates of den emergence and den departure based on relative temperature changes recorded by the collar (Andersen et al., 2024; Olson et al., 2017; Rode et al., 2018a).

We also tested whether observed denning behaviours could be accurately predicted from satellite collar data by matching each data point from the collar data with a corresponding observation from the cameras and classifying: (i) whether the den had been broken out of or not, (ii) if the focal bear was inside/outside of the den, and (iii) had departed the den or not. We used these annotated collar data to develop three models that predicted observed den breakout, subsequent emergences, and den site departure based on collar temperature, activity index, and movement speed. To understand the factors influencing activity at the den site, we also developed models to predict the probability of observing a bear outside the den and the duration of emergences as a function of environmental conditions (ambient temperature) and level of cub development (indicated by the numbers of days since the family had broken out of the den).

Results

Overview

Trail cameras collected timelapse footage at 21 suspected polar bear den sites across the Svalbard archipelago between 2016–2024 (Figure 2). The custom-designed continuous recording systems (the MDCs) were deployed at 17 of these den sites over the same period. On average trail cameras

were operational for 20 days (range: 4–39 days) and the MDCs for 32 days (range: 0–94 days). Polar bears were recorded at 14 out of 21 sites monitored using trail cameras and at 9 of 17 sites monitored using MDCs. A further 3 den sites were monitored in the spring of 2025 using both trail cameras and MDCs. The monitoring equipment from 2025 have been retrieved from the field, and initial image processing for this season is underway.

Figure 2*: Trail cameras deployed at a suspected den site in Svalbard (left panel) and an image of cubs outside the den captured by the trail camera timelapse.*

Timing of den emergence

Updated information on the timing of den emergence and departure in Svalbard polar bears was established from trail camera data. Breakout dates from camera observations between 2016–2023 ranged from 1st March to 21st March (mean = 9th March, SD = 6.5 days) and departure from the den site occurred 12.1 days later (SD = 10.1). However, time at the den site varied widely, ranging from 2 – 31 days across families, with the final observation of bears by trail cameras occurring from 12th March to 4th April. We note, however, the final observation occurred on the same day that the camera ceased operating at several sites, so we relied only considered GPS-based departure dates in these cases.

Earlier observations from Svalbard in 1978–1979 report breakout occurring between 17–18th March (Hansson & Thomassen, 1983), which is more than a week later than our data indicate, although considerable variation was found between the two years (ie., 1978–1979), and open dens have also been recorded in Svalbard in the first week of March (Larsen, 1985). Our finding that

bears remained at the den site for an average of 12 days after breakout is slightly longer than recorded in other regions (8.8 days in the Southern Beaufort Sea and Chukchi Sea (Andersen et al., 2024); 8 days in the Southern Beaufort Sea (Smith et al., 2007), and 9 days in Western Hudson Bay, Canada (Lunn et al., 2004), but slightly shorter than previously recorded in Svalbard (14 days; 1978–1979) (Hansson & Thomassen, 1983) and at Herald Island in the Russian Arctic (15–16 days) (Ovsyanikov, 1998). Our average date of departure from the den site was also earlier than those previously estimated for Svalbard by ~1-2 weeks (depending on estimates were from GPS or camera observations, respectively), with average departure dates of 5th April recorded in 1988–1993 (Wiig, 1998) and 17th April in 1972–2010 (Andersen et al., 2012), though we note that our estimates are based on relatively small sample sizes.

Validating behaviour inferred from collar data

Den breakout inferred from collar activity and temperature data matched camera observations well. Breakout dates from segmentation of collar temperature and activity data ranged from 15th February to 15th April, but the average breakout date across bears was similar to camera observations (10th March, SD = 15.8 days). Breakout from collar temperature thresholds ranged from 21st February to 3rd April, with an average breakout date across bears of 18th March (SD = 12.4 days). Within bears, the average difference in breakout date between threshold temperatures and camera observations was +4 days (SD = 10 days). Collar GPS data indicated departure ranged from 9th March to 15th April (mean = 22nd March, SD = 10 days). Within bears, the average difference in departure date between GPS data and camera observations was +3 days (SD = 7 days). Collar temperature thresholds also suggested departure dates from dens were, on average, 4 days later than indicated by cameras, suggesting that bears may have lingered in the area after they were last seen on camera (or possibly have moved to a new den out of view). For example, after breakout, two bears were observed to move from their original den to a new den in close proximity but still within viewing range of the cameras.

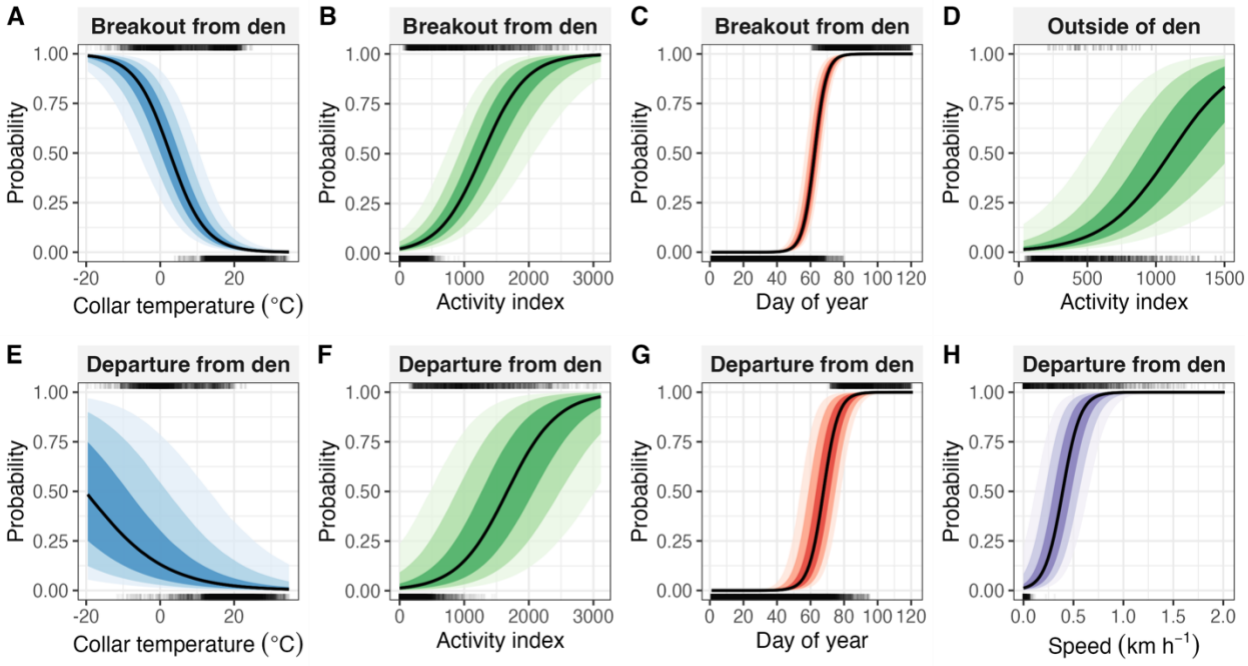

Figure 3*: Predictive models linking polar bear denning phenology observed using trail cameras at suspected den sites in Svalbard to data from satellite collars worn by suspected denning females. Panels A-C predict the probability a bear had broken out of the den, panel D predicts the probability the bear was outside the den but had not departed, and panels E to H predict the probability a bear had departed the den site. Variables that were identified as significant predictors are shown, with black lines indicating the median and shaded regions indicating uncertainty intervals.*

Overall, camera observations generally supported collar-inferred data as giving reasonable approximations of den phenology. Our predictive models of den emergence behaviours were able to predict den breakout and subsequent den site departure from data with a reasonably high degree of accuracy by combining information on temperature, activity, movement speed collected by collars, as well as time of year (Figure 3). However, our predictive model to detect short forays from the den prior to final departures had poor predictive power, potentially due to a limited data set (i.e., bears spent most of their time in the den), but also likely because the collar data (transmitted every two hours) are too coarse to detect short term shifts in temperature or activity, particularly since most emergences from the den lasted less than 15 minutes. Other tools may be considered here to provide such data, e.g. small ear tags with light and temperature loggers have also been used on polar bears in Svalbard, and light outside dens in spring compared to inside has proved successful in determining when bears breakout of dens and spend time outside (Merkel et al., 2023). However, recapture of individuals is necessary to retrieve such data.

Behaviour at the den site

Behaviour and activity patterns of polar bear families during the post-emergence period was characterised in terms of frequency of emergences and amount time spent outside the den (Archer et al., 2025). Number of emergences ranged a minimum of 2 emergences observed at one site to a maximum of 68 emergences at another (Table 1). Bears largely emerged in the daytime, with only 6% of emergences occurring at night. The duration of emergences was variable, lasting for an average of 27 mins (95% confidence intervals: 21–35 mins) and ranging from < 1 minute up to 470 minutes. In 77% of observations of emergences, bears remained within 20 body lengths (i.e., < ~40m) of the den. Cubs were observed outside of the den without the mother on only 9 occasions (5% of total emergences), with these emergences lasting an average of five minutes (95% CI: 1–10 mins). Cubs remained within one body length of their mother (i.e., < ~2 m) in 78% of observations, and were recorded more than five body lengths from their mother (i.e., > ~10m) in 5% of observations. Both the presence of mothers and cubs outside the den and the duration of emergences were affected by external temperature, days since first breakout, and time of day (Figure 4, 5). Mothers and cubs had higher probabilities of being observed outside the den and spent more time outside at warmer temperature, and the longer it had been since initial den breakout.

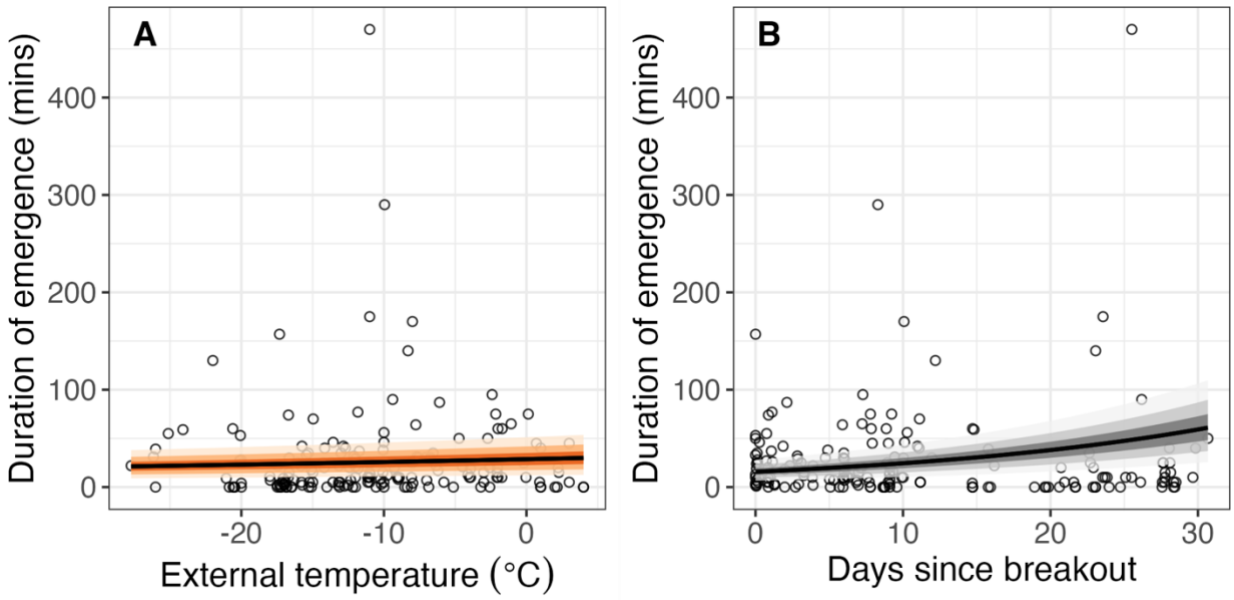

Figure 4*: Duration of emergences outside of the den as a function of external temperature (A) and days since first den breakout (B). Black lines indicate the median and shaded regions indicating uncertainty intervals.*

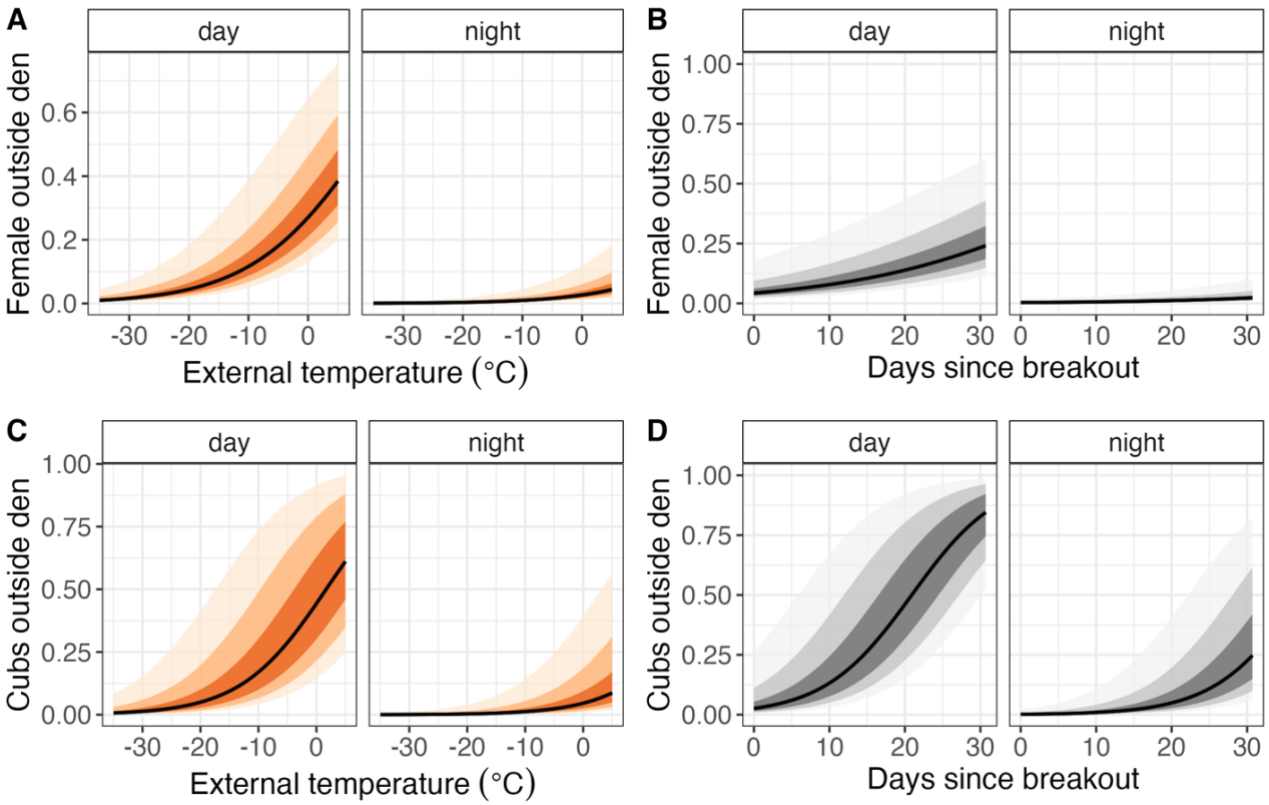

***Figure 5**: Probability of a female polar bear in Svalbard, Norway (2016 – 2023) being observed outside of the den as a function of external temperature (A) and days since first den breakout (B) and probability of her cub(s) being observed outside of the den as a function of temperature and days since breakout (D). Black lines indicate the median and shaded regions indicating uncertainty intervals.*

Future outputs

The findings described above (using data from 2016-2023) have been published in a study by Archer et al. (2025) in *The Journal of Wildlife Management*. Analyses of data from 2024-2025 is ongoing, as is the quantitative behavioural analyses of the continuous footage from the MDC systems. We anticipate at least one further publication that integrates both trail camera data and the more detailed behavioural information obtained by the MDC systems to characterise fine scale behaviour during emergences, as well as metrics of female and cub health.

Conclusions and conservation implications

By combining camera monitoring of polar bear den sites with data from collar-mounted sensors, we were able to develop predictive models of den breakout, subsequent emergences from the den,

and final departure from the denning area. These models can be applied to classify key aspects of polar bear denning from data collected remotely from satellite collars, which are often deployed as part of monitoring and research programs. Accurately identifying and understanding patterns in denning behaviour is integral to anticipating responses to ongoing environmental change, and to proactively managing denning habitat and reducing potential for human-polar interactions.

We also characterised the behaviour of females and cubs after first breakout from the den and assessed the role of local environmental conditions in influencing their behaviour around the den site. Our results also add some additional insight to recent research that found a positive relationship between the length of the post-emergence period and subsequent litter survival (Andersen et al., 2024): a quicker departure post-breakout means that cubs have likely spent insufficient time outside the den to physiological and behaviourally develop and mature, with knock-on impacts on their subsequent survival. Through continued analyses of the finer scale behaviour data collected by the custom-built MDC systems, we aim to further resolve the sensitivity and importance of the den emergence period.

An obvious next step to build on our study would be to further establish the broader factors that influence denning phenology and post-emergence behaviours (Escajeda et al., 2018). Our small sample size and relatively short study duration – less than a decade i.e., insufficient to detect phenological changes (Brown et al., 2016) – meant that we had limited ability to explore environmental influences on denning phenology. However, though we observed considerable variation in dates of den breakout, departure, and time spent at the den site, we generally observed a shorter post-emergence period and earlier den site departure compared to previous studies of this subpopulation (Andersen et al., 2012; Hansson & Thomassen, 1983; Wiig, 1998), emphasising that further monitoring is warranted to detect any advance in the timing of denning. Given the positive effects of longer denning/later den departure on cub survival that have been described in other subpopulations (Andersen et al., 2024; Rode et al., 2018a), any long-term changes in denning phenology would be of concern, and could be a response to the exceptional changes in temperature and sea ice conditions underway in the Svalbard archipelago (Lind et al., 2018; Screen & Simmonds, 2010).

Overall, this project has provided tools to further aid in the monitoring of a vulnerable period in cub development and advances our knowledge of a critical but somewhat poorly understood period

of polar bear life-history, when families may face increasing threats due to Arctic warming and associated human expansion into denning areas.

Ethics

All animal handling and protocols were approved by the Norwegian Animal Research Authority, in accordance with the relevant guidelines and regulations and under permits issued by the Governor of Svalbard.

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