Post-conflict movements of polar bears in western Hudson Bay, Canada

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Abstract: Human-carnivore conflicts have increased as habitat has been affected by development and climate change. Understanding how biological factors, environment, and management-decisions affect the behaviour of animals may reduce conflicts. We examined how biological factors, sea ice conditions, and management decisions affected the autumn migratory movement of polar bears (*Ursus maritimus*) from 2016 to 2021 following their capture near Churchill, Manitoba, Canada, and release after a mean of 20 days (SE 2) in a holding facility. We deployed eartag satellite transmitters on 63 bears (26 males, 37 females), with 49% adults (> 5 years old), 48% subadults (3-5 years old), and 3% < 2-years-old. We compared variation in on-ice departure of bears released post-conflict (conflict) to adult females without a conflict history (non-conflict). Conflict bears departed 89 km further north (mean = 59.7°N, SE 0.2) of non-conflict bears (mean = 58.9°N, SE 0.1). Bears released later during the migratory period were less likely to re-enter a community at a rate of 5.9-6.4% per day. Of 69 releases (6 individuals requiring multiple releases), 12 bears re-entered Churchill and 13 entered Arviat, Nunavut. We suggest that the holding facility was effective at preventing additional conflicts and individuals with a high likelihood of recidivism should be held longer.

Key words: Arctic, climate change, conservation, human-wildlife conflict, *Ursus maritimus*.

Introduction

Conflict between humans and carnivores has increased in frequency and impact in association with habitat loss, human expansion, and climate change (Treves and Karanth 2003; Nyhus 2016; Abrahms 2021). If human safety and property are threatened during conflict with carnivores (Loe and Roskaft 2004; Gulati et al. 2021), it often results in the animal's death (Karanth and Chellam 2009). Tolerance towards carnivores may decline without appropriate management (Rabinowitz 1986; Woodroffe 2000) and community support for conservation programs may also decline. In turn, this may result in the politicization of conservation and therefore reduced efficacy (Torres 1996; Clark et al. 2008). One species for which conservation and management have become politicized is the polar bear (*Ursus maritimus*), due in part to their cultural importance to Indigenous communities, their threats to public safety, and their role as symbol of conservation (Dowsley and Wenzel 2008; Kovacs et al. 2011; Peacock et al. 2011; Lokken et al. 2019).

Polar bears are distributed across the circumpolar Arctic (DeMaster and Stirling 1981) in association with sea ice, which is used as a platform to hunt seals (Stirling and Archibald 1977; Thiemann et al. 2008; Sciullo et al. 2017). Bears inhabiting the seasonal sea ice ecoregion of Hudson Bay, Canada (Amstrup et al. 2008; Durner et al. 2009), including the Western Hudson (WH) subpopulation (Lunn et al. 2016), lose access to seals during the ice-free period for up to five months, resulting in seasonal mass loss (Rode et al. 2015; Pilfold et al. 2016). At freeze-up, with the exception of pregnant females in maternity dens (Ramsay and Stirling 1988), WH polar bears migrate from land onto the sea ice and resume hunting (Castro de la Guardia et al. 2017). Most human-wildlife conflicts involving WH polar bears occur from August to November during the ice-free period of Hudson Bay, with rates peaking between October and November before freeze-up (Dyck 2006; Towns et al. 2009; Laforge et al. 2017; Wilder et al. 2017).

Conflict rates involving polar bears increased from the 1970s to the early 2000s in both the town of Churchill, Manitoba, Canada (Towns et al. 2009) and Nunavut, the northernmost territory of Canada (Tyrrell 2006; Henri et al. 2010; Peacock et al. 2010). Conflict rates declined near Churchill after 2001 and may have been associated with population decline, lower recruitment, and changes to management protocols (e.g., preventative hazing, closure of the local landfill) (Heemskerk et al. 2020). The Manitoba government reported an increasing presence of bears near Churchill from 2009 to 2016 (Lunn et al. 2018) suggesting that the decline in conflicts were associated with proactive management rather than a decline in bears near the town. While residents in communities north of Churchill are seeing more bears onshore in places and at times not previously observed and report that the polar bear population has increased (Clark et al. 2008; Dowsley and Wenzel 2008; Henri et al. 2010), scientific estimates of abundance using mark-recapture found that the WH population declined by over 30% from the 1990s to 2010 (Derocher and Stirling 1995; Lunn et al. 1997; Lunn et al. 2016) and more recent estimates using aerial surveys show a decline of 35-40% from 2011 to 2021 (Stapleton et al. 2014; Dyck et al. 2017; Atkinson et al. 2022). Given the association between the timing of freeze-up and human-polar bear conflict, the trend toward increasing conflicts may be explained in part by the lengthening of the Hudson Bay ice-free period (Gagnon and Gough 2005; Parkinson 2014; Stern and Laidre 2016), which has resulted in more time spent on land (Castro de la Guardia et al. 2017). Collectively, these changes may be facilitating more interactions between humans and bears.

Food seeking behaviour by Ursidae is common and is often associated with natural food shortages (Azad et al. 2017) and anthropogenic food availability (Merkle et al. 2013; Hagani et al. 2021). Similarly, most interactions between humans and polar bears result from bears seeking alternative food sources associated with humans (Wilder et al. 2017). Although polar bears can become habituated to humans due to food conditioning, (e.g. garbage dumps; Lunn and Stirling

1985; Hopkins et al. 2010; Smith et al. 2022), most polar bears involved in conflicts were classified as being in poor condition (Wilder et al. 2017), with subadult males being both more likely to be in poor condition and disproportionately represented in conflicts (Dyck 2006; Towns et al. 2009). These characteristics may be associated with the higher metabolic rates of subadults due to growth (Molnár et al. 2009), with males growing at a faster rate than females due to their larger size (Derocher et al. 2005), lower hunting efficiency of subadults (Stirling and Latour 1978; Herrero and Fleck 1990), and the higher risk of prey kleptoparasitism by larger bears (Stirling 1974). Information on individual characteristics that influence conflict rates, such as stored energy, may be used to develop management practices that target individuals with a high likelihood of being involved in conflict.

Polar bear management in Canada falls within the jurisdiction of provinces and territories (Peacock et al. 2011). In Manitoba, the Polar Bear Alert Program in Churchill (herein "the Alert Program") was established in the 1980s to increase human safety and reduce bear mortality (Kearney 1989). The Alert Program uses various strategies to mitigate human-bear interactions, including attractant reduction and hazing bears from town as well as the capture, temporary holding, and relocation of bears away from the community (Derocher et al. 2013; Struzik 2014). Bears caught by Manitoba conservation staff may be kept in a holding facility until the sea ice forms along the western coast and then released directly onto the sea ice or released on-land outside of the Alert Program's management perimeter, usually northwest of Churchill (Kearney 1989). The goal of this management action is to reduce conflict bear recidivism, defined as a released bear re-entering a settlement the same autumn post-release. It has, however, been hypothesized that the placement of habituated bears north of Churchill has facilitated the northward movement of bears along the western coast, leading to the increased presence of bears reported in the hamlet of Arviat, Nunavut (Tyrrell 2006), which lies along the migratory path of the bears (Fig. 1). While conflict rates have increased over time in Arviat, Nunavut (Peacock et al. 2010), conflict-related mortality of bears has declined since the 1980s as non-lethal measures were implemented (Dyck 2006; Lunn et al. 2018).

The objectives of this study were to examine the effects of management actions, changing sea ice conditions, and polar bear biology on the movement and behaviour of bears involved in conflict after their capture, relocation, and release by Manitoba conservation staff using satellite telemetry and capture data from 2016 to 2021. We predicted that bears captured due to their proximity to Churchill would depart earlier in the season and at higher latitudes than non-conflict bears (i.e., adult females collared for research with no recent history of conflict), due to their relocation along the migratory path. We examined the directionality of conflict bears post-release and predicted that bears would demonstrate an overall northward movement similar to migrating non-conflict bears as they attempt to return to the sea ice forming north of Churchill. In relation to our hypotheses, we predicted that recidivism rates in Churchill and Arviat would be influenced by management practices, sea ice conditions, and biological factors. We predicted that bears were more likely to re-enter Churchill when they were released east of, and close to, Churchill. We predicted that bears were more likely to enter Arviat when they were released farther from, and west of Churchill, and on days with low sea ice concentration along the western coast near Arviat. Finally, we predicted that bears that were released earlier in the season, on days with low sea ice concentration along the coast near Churchill, and with lower energetic stores would demonstrate a higher likelihood of recidivism at either community.

Study area

Our study was conducted along the western coast of Hudson Bay, Canada during the autumn migration from 2016 to 2021 (Fig. 1). Hudson Bay is characterized by high seasonal variation in sea ice, ranging from >90% sea ice concentration in winter to ice-free summers (Prinsenberg 1988). Sea ice initially forms mid-October along the northwest coast due to colder temperatures and freshwater runoff (Prinsenberg 1988) and is influenced primarily by temperature and wind, which combine to form a cyclonic gyre that moves sea ice southward (Gagnon and Gough 2005).

Methods

We used two datasets of polar bear locations, the first comprising "conflict" polar bears of both sexes defined as those that were captured in 2016-2021 by Manitoba conservation staff on land within the high priority management area of the Alert Program around Churchill (Kearney 1989). These bears were fitted with Doppler shift Argos® satellite-linked eartag transmitters (Telonics, Mesa, AZ; SirTrack, Hawkes Bay, New Zealand), which were programmed to sample one location every 24 h and to last up to 7 months. If family groups were captured, the mother was fitted with the transmitter. The second dataset included "non-conflict" adult female polar bears who were captured in 2016-2021 from a helicopter using remote injection of tiletamine hydrochloride and zolazepam hydrochloride (Zoletil®, Laboratories Virbac, Carros, France; Stirling et al. 1989) on land in western Hudson Bay between Churchill, Manitoba and the Manitoba-Ontario border in August-September. Non-conflict bears were fitted with GPS Argos® or Iridium satellite-linked collars (Telonics, Mesa, AZ), which were programmed to sample one location every 4 h. Collars were programmed to release after two years or were removed upon recapture. These individuals were collared for other research projects and were not targeted for this study as non-conflict bears. Given the differences in the age, sex, and reproductive status of conflict and non-conflict bears, we consider the non-conflict bears a proxy and acknowledge they may not fully represent non-conflict bears. Capture and handling protocols were approved by the

Environment and Climate Change Canada, Prairie and Northern Region Animal Care Committee and the University of Alberta BioSciences Animal Care and Use Committee, in accordance with the Canadian Council on Animal Care guidelines.

The sex of each bear was determined at capture and a premolar was extracted from bears ≥1 year old to estimate age based on cementum growth layers (Calvert and Ramsay 1995). Bears <1 year old were aged based on tooth eruption patterns. Independent bears were grouped into age classes of juvenile (< 2 years), subadult (2-5 years), and adult (> 5 years). Body mass (kg) of conflict bears was measured using a scale. Body mass of non-conflict bears was estimated by multiplying non-linear measurements of axillary girth (cm) with straight-line length (cm) (Thiemann et al. 2011). Straight line length was measured from the tip of the nose to the end of the last tail vertebra before release from the holding facility. Storage energy (MJ) was estimated separately for each age and sex class as a function of body mass and straight-line length following Molnár et al. (2009).

Hudson Bay sea ice concentration was obtained from the Sea Ice Remote Sensing group at the University of Bremen (Spreen et al. 2008; https://seaice.uni-bremen.de) at a 3 x 3 km resolution. Mean daily sea ice concentration was calculated for the release-zone, defined as the 30 km area from the coast bounded by all release locations of conflict bears between 2016 and 2021 with the exception of one outlier release location south of Churchill, and for the north-zone, defined as the 30 km area from the coast north of all release locations up to Arviat, Nunavut (Fig. 1). Sea ice concentration was also obtained from the same source at a 25 x 25 km resolution to calculate the mean daily concentration inside the WH population boundary (Lunn et al. 1997) to determine the annual freeze-up date for the WH zone, defined as the first date at which sea ice concentration was >10% for three consecutive days following Cherry et al. (2013).

Statistical analysis

For both conflict and non-conflict bears, duplicate timestamps and all relocations with a speed >10 km/h were removed following Parks et al. (2006). The intervals between polar bear telemetry locations varied from 30 min to 24 h and were standardized by subsampling to 24 h. Telemetry locations of conflict bears were filtered to those with a maximum allowable error of 1.5 km. Initial locations within the high priority Alert Program management area were defined as post-capture holding locations and were removed before analysis. The release date and location for conflict bears was obtained from Manitoba conservation staff records. On-ice departure was defined for both conflict and non-conflict bears as the first location ≥10 km offshore that was not followed by a location on-land until the following spring. The date and location of departure for each bear was determined visually using ArcGIS 10.7.1 (Environmental Systems Research Institute, Redlands, CA). Departure events were not included for bears with a gap >10 days between the last on-land location and the first offshore location. All statistical analyses were performed using R version 3.6.2 (www.rproject.org, accessed 01 Jan 2022).

We combined the conflict and non-conflict bear datasets to examine the influence of conflict status, age group, and sex on spatiotemporal variation in migration (date and latitude of on-ice departure) using robustly fitted linear multiple regression because the residuals of the regressions of departure latitude and date were non-normal despite transformations. We performed model selection on all candidate models of the global model using the Akaike Information Criterion corrected for small samples (AICc). When multiple models had $\Delta AIC_c < 2$, we chose the most parsimonious model to avoid overfitting models with uninformative covariates (Arnold 2010). We determined significance of covariates using 95% confidence intervals. We produced kernel density estimations using a kernel size of 2 SD of the departure locations of conflict and non-conflict bears for visual comparison using ArcGIS.

We examined the post-release movement of conflict bears using analysis of circular distributions. A directional vector was calculated post-release until departure or final transmission for each bear using all consecutive relocations with ≥10 locations. We then calculated the mean angular dispersion of all on-land locations weighted by individual sample size. We performed the Rayleigh Z test to determine if bear movement demonstrated unimodal clustering north as predicted. We determined significance of the Z test statistic using $p \leq 0.05$.

We used multinomial logistic regressions to examine the influence of management practices, sea ice conditions, and biological factors on the recidivism rates of conflict bears using R-package *nnet* (Ripley and Venables 2021). Bears with <30 post-release locations were not included in analysis unless a post-release conflict was recorded by Manitoba conservation staff. Bears with locations <10 km of Arviat or Churchill between their release and on-ice departure were defined as recidivists, which we determined by calculating the shortest straight-line-distance from an individual's daily location to each community in ArcGIS. This definition was determined through inspection of the histogram of the nearest distance to Churchill resulting from 45 releases, which had a bimodal distribution with densities increasing before and after the 10 km threshold (Fig. A2). This bimodal distribution may be attributed to the minimum release distance from Churchill being 11 km, suggesting that some nearest distance values >10 km would be from the release locations and would not indicate recidivism. This definition of conflict compares to previous conflict management areas used that ranged from 7-20 km from Churchill (Kearney 1989; Towns et al. 2009). We used separate models to examine the influence of: 1) management practices, including the release location's distance and east-west direction from Churchill, the number of days a bear was held in the holding facility, and the release date, 2) sea ice conditions, including the daily mean release-zone sea ice concentration, the daily mean north-zone sea ice concentration, and the annual WH zone freeze-up date and 3) biological factors, including the sex, age group, and storage energy at release on a bear re-entering Churchill or entering Arviat post-release. For all models, covariates included were tested for collinearity using the variance inflation factor (VIF > 4). Model selection was performed using AIC_c with the most parsimonious model within $\Delta AIC_c < 2$ being selected as the top model. To correct for our multiple-comparison approach (n = 3 global models), we used the Bonferroni corrected level of significance ($\alpha = 0.017$) to determine significance of covariates via 99.8% confidence intervals.

Results

From 2016 to 2021, 63 individual polar bears were captured near Churchill between July 17 and December 1 and released 69 times with eartag transmitters during the autumn. Of these conflict bears, 26 were male and 37 were female including 7 accompanied by cubs (Table 1). Conflict bears included 2 juveniles, 30 subadults, and 31 adults. Conflict bear release dates ranged from August 21 to December 2 following a mean holding period of 20 days (SE 2, range 0 to 70) between a bear's conflict and release dates. Conflict bears were released a mean 15 days (SE 3) before annual fall freeze-up. Bears were released with a mean storage energy of 981 MJ (SE 96). Mean distance of release from Churchill was 35 km (SE 4, range 11 to 255) at a mean latitude of 58.9°N (SE 0.03; Fig. 1). Recidivism post-release was 36% (25/69) with 12 bears at Churchill and 13 at Arviat. The proportion of conflict bears represented in the recidivism rate was not significantly different than expected across age and sex classes (chi-square test, $X^2 = 1.4$, df = 1, p = 0.24; Table A1). We also found that 6 bears traveled north past Arviat, with 3 bears entering the Nunavut hamlet of Whale Cove (92.6°W, 62.2°N). From 2016 to 2021, 44 non-conflict adult females were captured and released with collars and recorded migrating onto the sea ice. We removed 5 of these bears due to their past history of conflict near Churchill.

We combined 40 on-ice departures from conflict bears and 39 departures from non-conflict bears between 2016 and 2021 into one dataset to analyze the date and latitude of on-ice departure. Model selection of multiple linear regressions of the date at departure resulted in three top models, with the most parsimonious model including the bear's sex (Table A3). The mean departure date of males (mean = December 7, SE 2 days) was 10 days later than females (mean = November 27, SE 2 day; Table 2; Fig. A4). This difference was consistent when an outlier was removed (Table A5). Post-hoc, two-sample t-tests showed that this difference was significant when examining non-conflict and conflict bears together (two-tailed t-test, $t = 2.87$, $df = 77$, $p = 0.0090$) and when comparing conflict females to conflict males (two-tailed t-test, $t = 2.05$, $df = 38$, $p = 0.049$). The release dates of female and male conflict bears were not significantly different (two-tailed t-test, $t = -1.41$, $df = 77$, $p = 0.17$) with a mean release date of November 8 (SE 4 days) and November 16 (SE 3 days), respectively. Conflict bears departed a mean 5.8 days (SE 1.6) after freeze-up and non-conflict bears departed a mean 3.6 days (SE 0.86) after freeze-up. Model selection of multiple linear regressions of the latitude at departure resulted in two top models, with the most parsimonious model including the bear's conflict status and age group (Table A6). The mean departure latitude of conflict bears (mean = 59.7°N, SE 0.2) was 89 km further north than non-conflict bears (mean = 58.9°N, SE 0.1; Table 2; Fig. A7). Post-hoc, two-sample t-tests showed that this difference was significant when examining all non-conflict and conflict bears together (two-tailed t-test, $t = 3.43$, $df = 77$, $p = 0.001$) and when comparing conflict females to non-conflict females (two-tailed t-test, $t = -2.50$, $df = 60$, $p = 0.017$).

Our analysis of circular distributions included 989 locations from 38 individuals, with a mean of 26 (SE 3) daily on-land locations/bear. We found that the on-land movement of migrating bears post-release clustered significantly around one mode (Rayleigh test, $Z = 103.2$, $p < 0.001$), with a mean angle of 342° (SE 1; Fig. 2), which is roughly parallel to the approximated angle of the coastline north of Churchill (325°). Despite being released on average (58.9°, SE 0.04) at the same latitude where non-conflict bears departed onto the sea ice (58.9°, SE 0.10), conflict bears continued moving northward post-release until on-ice departure.

Forty-five conflict bear releases were included in the recidivism models. Two competing top models best predicted the influence of management practices on the probability of recidivism, with the most parsimonious model including the release date (Table A8). Examination of the 99.8% confidence intervals suggested that bears released later in the season were less likely to enter a community (Table 3). Each day later in the season that a bear was released reduced the odds of recidivism by 5.9% for re-entering Churchill and 6.4% for entering Arviat (Fig. 3). One top model predicted the influence of sea ice conditions on recidivism rates, which included the daily mean sea ice concentration of the north-zone at release (Table A9). The 99.8% confidence intervals overlapping zero suggested that sea ice conditions did not influence recidivism (Table 3). Two top models predicted the influence of biological factors on recidivism rates. Both models were equally parsimonious with one including the bear's sex and the other including the bear's storage energy at release (Table A10). The 99.8% confidence intervals overlapping zero in both competing models suggested that biological factors did not influence recidivism (Table 3).

Discussion

We used telemetry and capture data to examine the movement of WH polar bears involved in human conflicts after their release by Manitoba conservation staff during the autumn migration. We found that the timing of on-ice departure differed by sex, with females departing earlier in the season than males, regardless of conflict status, while the departure location differed by conflict status, with conflict bears traveling northward post-release and departing onto the sea ice at more northerly latitudes than non-conflict bears. Conflict bears did not remain on shore longer than non-conflict bears, departing onto sea ice 3-5 days after freeze-up. Conflict bears released later in the season were less likely to re-enter a community before departure and were not influenced by the release location. Over one-third of bears released during the autumn were found again near human communities the same autumn.

While our non-conflict bears may not be fully comparable to our conflict sample due to sex, age, and telemetry quality differences, we believe they provide a reasonable comparison. We used Manitoba wildlife management reports to reduce bias against recidivism in Churchill that would result from bears being removed from the analysis due to a lack of data if they were re-captured in Churchill within one month, resulting in fewer than 30 daily locations. This may have resulted in our study underestimating the number of bears involved in conflicts with Arviat, due to a lack of similar reports being available for conflict bears in the area. We believe, however, that most recidivism events were identified in this study given that most bears who were found to be in proximity to Arviat were not captured or killed. These bears thus had over one month of locations regardless of the recidivism date and were not removed from the study before analysis. Future research could deploy eartag transmitters on a random sample of non-conflict animals to reduce possible bias.

Female polar bears departed onto the sea ice earlier than males, regardless of conflict status. These results do not appear to be due to the management practice of immediately releasing family groups (Kearney 1989), as female and male conflict bears had similar release dates. Females may instead be departing onto the sea ice earlier due to their lower energetic stores as they near the end of the ice-free period (Molnár et al. 2009). While adult polar bears of both sexes lose mass over the ice-free period (Pilfold et al. 2016), males enter the fasting period with higher storage mass than females and have lower energy demands than females with cubs (Molnár et al. 2009). These results suggest that adult females may be more vulnerable to an extended fasting period than adult males and that females involved in conflict should not be held past freeze-up to avoid extending their fasting season.

Conflict bears migrated onto the sea ice at more northerly latitudes than non-conflict bears, with some eventually departing onto the sea ice north of Arviat. These bears were released, on average, two weeks before freeze-up and departed onto sea ice an average of 3-5 days after freeze-up, similarly to that of non-conflict bears. Between their release near Churchill and their on-ice departure, conflict bears demonstrated an overall northward movement despite their being released at the same latitude at which non-conflict bears departed onto the sea ice. We suggest that the more northerly departure of conflict bears may be the result of the same internal stimulus demonstrated by most WH polar bears to move northward to reach sea ice (Togunov et al. 2017) combined with the northwest placement of conflict bears by Manitoba conservation staff relative to the migratory pathway used by non-conflict bears (Fig. 1). In addition to the release locations of conflict bears being further north than the capture locations of non-conflict bears, almost three-quarters (71%; n = 45) of the conflict bears were released west of Churchill. At the same latitude east of Churchill, the area with the highest density of non-conflict bear departures, the coastline geography acts as a physical obstacle to bears attempting to move further north unless they first move west through or around Churchill.

An alternate explanation to the northward shift in on-ice departure may be that conflict bears, which are more likely to be in poor body condition (Wilder et al. 2017), may travel further distances during the migratory period with the goal of reaching more northerly latitudes in search of earlier forming sea ice to resume hunting sooner. The influence of energetics on inter-individual variation in risk-prone behaviour has been studied in other species (McNamara and

Houston 2008; Moran et al. 2021), specifically as it relates to individuals in poor condition demonstrating risk-prone behaviour to access resources (Mathot et al. 2015). These bears would thus be expected to travel further north whether they were handled and released for wildlife management or not. Non-conflict bears, conversely, may have higher energetic stores and can tolerate delayed freeze-up dates at more southerly locations, conserving energy by reducing movement but risking a longer fasting period (Molnár et al. 2010). If sea ice formation delays continue as predicted (Castro de la Guardia et al. 2013), we may see further declines in the condition of WH polar bears (Galicia et al. 2019) that, when combined with more time spent on land, may result in an increase in conflict rates in these northern communities as bears search for sea ice. Future research should examine the distances traveled relative to individual capture/release locations and dates during the migratory period to provide insight on the mechanisms driving the more northerly locations of conflict bears.

Examination of the relative densities of on-ice departure locations of conflict bears along the western Hudson Bay coast may suggest that some conflict bears in this study were habituated to human communities. Conflict bears departed onto sea ice at the highest densities in the areas surrounding Churchill and Arviat, while non-conflict bears primarily departed east of Churchill. Although departure near Churchill is not necessarily surprising given its location along the bears' migratory path, non-conflict bears avoided departing onto the sea ice immediately adjacent to Churchill. In addition, the concentration of departures at Arviat may suggest that some conflict bears have familiarity with Arviat and travel northward to the community. This explanation is further supported by the high same-year recidivism rates in Churchill (0.17) we found compared to the proportion of the WH population that are involved in conflict in Churchill annually (approximate range 0.02-0.13; Heemskerk et al. 2020), suggesting that a bear captured in Churchill is more likely to return than a non-conflict bear is to enter Churchill. Our conflict bears are a subsample of conflict bears that come near Churchill and an improved understanding of bears successfully deterred (i.e., not captured) would provide insight on the overall success of the Alert Program. Deterrence methods are less effective on food-habituated black bears (*U. americanus*) at preventing nuisance behaviour (Mazur 2010). It is thus possible that the conflict bears sampled in our study are more likely to have been habituated to human communities or human food sources before their capture and release by Manitoba conservation staff. For individuals that are not successfully deterred further understanding of the conditions and characteristics associated with high-risk individuals may improve conflict management.

When considering how to effectively manage conflict bears with a high risk of recidivism, future research should examine the conditions leading up to and including the conflict event itself. A bear that obtains anthropogenic foods before capture may be incentivized to return to the community more than a bear that was successfully hazed away or caught before feeding. Food habituation is the leading cause of human-bear conflicts in black bears and brown bears (*U. arctos*) (Spencer et al. 2007; Can et al. 2014) and is a likely factor in recidivism rates of polar bears. As such, we caution against conflict management strategies using diversionary feeding as they may have the undesired effect of attracting bears to an area in future years, leading to an increase in conflict rates (Garshelis et al. 2017). Additionally, management should consider fitting satellite transmitters onto bears that are recaptured in subsequent years. By tracking conflict bear behaviour and movement over multiple years, repeatability analyses could be used to examine inter-individual variation in conflict and recidivism to understand the conditions that may lead to habituation and the characteristics associated with high-risk recidivists. Without this information however, management can still reduce conflict rates by releasing bears later in the season when feasible.

Conflict bears released later were less likely to re-enter Churchill or enter Arviat before migrating onto the sea ice. Most conflicts occur while polar bears are on land, with rates peaking immediately before freeze-up (Towns et al. 2009; Laforge et al. 2017). Considering that the timing of polar bear migration is correlated to sea ice formation, with bears departing a mean of 2.5 days following freeze-up (Cherry et al. 2013; Miller et al. 2022), the less time between release from holding and sea ice freeze-up, the less opportunity available for bears to re-enter communities. Holding conflict bears until sea ice forms along the western coast would be an effective strategy for reducing same-year recidivism of conflict bears. Alternatively, the release location relative to Churchill did not effect recidivism rates in either community. Neither the release distance nor the direction relative to Churchill were included in the top model examining recidivism of conflict bears in either community. The recidivism model results, in addition to similar, relatively low recidivism rates in Churchill (17%) and Arviat (18%), do not support the notion that the Alert Program management practices have led to an increase in conflict bears near Arviat. Alternatively, reports of increasing polar bears in proximity to northern communities may be the result of the lengthening ice-free period in Hudson Bay especially given the decline in population abundance (Lunn et al. 2016; Atkinson et al. 2022).

The management of polar bears involved in conflict along the western coast of Hudson Bay has been the subject of controversy. Polar bears involved in conflict near Churchill are usually placed in temporary holding facilities and released onto the sea ice after freeze-up. We found that this strategy effectively reduced the likelihood of bears re-entering communities. Although the management practice of releasing conflict bears northwest of Churchill may facilitate the movement of bears northward along the coast during the autumn migration, it did not increase the likelihood of a bear moving near Arviat. As the ice-free period continues to increase, we expect that human-polar bear conflicts will increase in frequency, and that the management of conflict bears will require greater consideration in the conservation of the WH population.

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Ethics statement

Capture and handling protocols were approved by the Environment and Climate Change Canada, Prairie and Northern Region Animal Care Committee and the University of Alberta Bio Sciences Animal Policy and Welfare Committee, in accordance with the Canadian Council on Animal Care guidelines.

Competing interests

The authors declare there are no competing interests.

Author contributions

Designed the study: ENM and AED. Collected the data: ENM, NJL, DM, VT, and AED.

Analyzed the data: ENM. Wrote the paper: ENM with input from NJL, DM, VT, and AED.

Data availability

Data is available at Borealis: The Canadian Dataverse Repository (Miller 2023).

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Table 1. Summary of Western Hudson polar bears by conflict status, age, and sex [a, b]

		Non-conflict bears (n=39) [a]	Conflict bears (n=63) [b]	Conflict bear releases (n=69)	Recidivism events (n=25)
Female	Juvenile [c]	0	2	2	1
	Subadult [c]	0	17	19	5
	Adult [c]	39	18	19	8
Male	Juvenile	0	0	0	0
	Subadult	0	13	15	7
	Adult	0	13	14	4

[a] Non-conflict bears were captured on land in western Hudson Bay between Churchill, Manitoba and the Manitoba-Ontario border in August-September. These individuals were collared for other research projects and were not targeted for this study as non-conflict bears.

[b] Conflict bears were defined as those captured by wildlife officers near Churchill, Manitoba due to their proximity to the high priority management area of the Polar Bear Alert Program.

[c] Independent bears were grouped into age classes of juvenile (< 2 years), subadult (2-5 years), and adult (> 5 years).

Table 2. Parameters (including 95% confidence intervals) of best-fitting robust multiple linear regressions examining the influence of biological factors and conflict status on the timing and location of the on-ice departure of conflict (n=40) and non-conflict (n=39) Western Hudson polar bears selected using second order Akaike information criterion (AICc < 2) [a, b]

Model	Covariates	Coef.	L.CI (95%)	U.CI (95%)	P
Latitude [c]	Conflict $_{yes}$	1.104	0.464	1.745*	0.001
	Age group $_{subadult}$	-0.700	-1.402	0.002	0.050
Date [c]	Sex $_{male}$	9.945	2.892	16.010*	0.005

[a] Lower (L.CI) and upper (U.CI) limits of the 95% confidence intervals were used to determine significance, with significance indicated using *.

[b] Conflict bears were defined as those captured by wildlife officers near Churchill, Manitoba due to their proximity to the high priority management area of the Polar Bear Alert Program.

[c] Date and latitude (decimal degrees) extracted from the departure location as metrics of migratory behaviour. Departure defined as the first location 10 km offshore from the west Hudson Bay coast in autumn without returning until spring.

Table 3. Parameters (including Bonferroni corrected 99.8% confidence intervals) of best-fitting multinomial logistic regressions examining the influence of management practices (H1), sea ice conditions (H2), and biological factors (H3) on the probability of a conflict Western Hudson polar bear (n = 45) re-entering a community during the autumn migratory period selected using second order Akaike information criterion (AICc < 2) [a, b].

Model	Response	Covariates	Coef.	L.CI (99.8%)	U.CI (99.8%)	P
H1	Arviat	Release date	-0.066	-0.092	-0.040*	< 0.001
	Churchill		-0.060	-0.087	-0.034*	< 0.001
H2	Arviat	North-zone sea ice	-1.381	-2.819	0.057	0.003
	Churchill		-0.813	-1.870	0.243	0.016
H3	Arviat	$\text{Sex}_{\text{female}}$	-0.580	-2.962	1.802	0.445
	Churchill		-0.734	-3.165	1.700	0.343
	Arviat	Age Group	0.288	-1.992	2.568	0.692
	Churchill		0.105	-2.245	2.456	0.888
	Arviat	Storage energy	0.091	-8.879	9.061	0.957
	Churchill		0.935	-10.161	12.030	0.821

[a] Lower (L.CI) and upper (U.CI) limits of the 99.8% confidence intervals were used to determine significance, with significance indicated using *.

[b] Conflict polar bears defined as entering either Arviat, Nunavut or Churchill, Manitoba when located within 10 km during the same migratory period as the initial conflict and release.

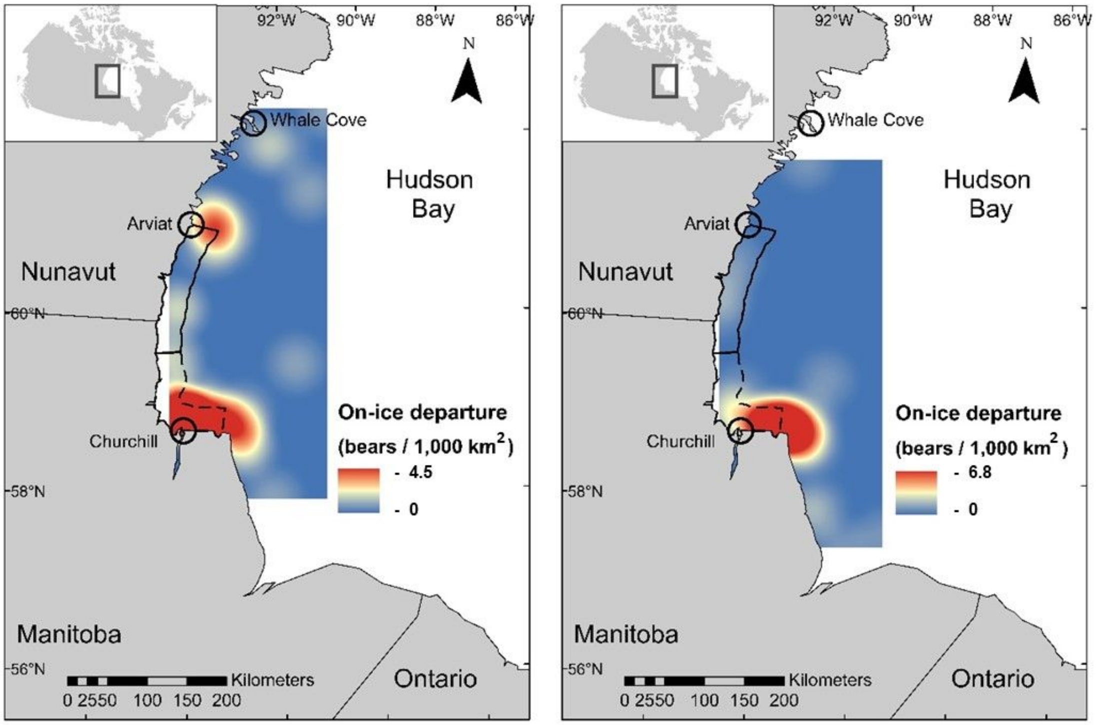

Fig. 1. Map of Hudson Bay, Canada, showing the kernel density estimations of the autumn departure locations of 40 conflict bears (left) and 39 non-conflict bears (right) from 2016 to 2021. Conflict bears were captured near Churchill, Manitoba from July to December through the Polar Bear Alert Program and were fitted with Argos satellite-linked eartags before being released (black circles). Non-conflict polar bears were captured on land between Churchill and the Manitoba-Ontario border from August to September and fitted with Argos satellite-linked or Iridium collars. Departure was defined as the first location 10 km offshore that was not followed by a location on land until the following spring using the 2016 coastline boundaries obtained from Statistics Canada (https://www12.statcan.gc.ca) projected to NAD83 UTM Zone 15N coordinate reference system (EPSG:26915). Mean daily sea ice concentration was calculated within the release-zone (dashed line), defined as the 30 km area from the coast bounded by 45 release locations of conflict bears (one southern outlier release location was removed) and the

north-zone (solid line), defined as the 30 km from the coast bounded between the northernmost release location and Arviat, Nunavut.

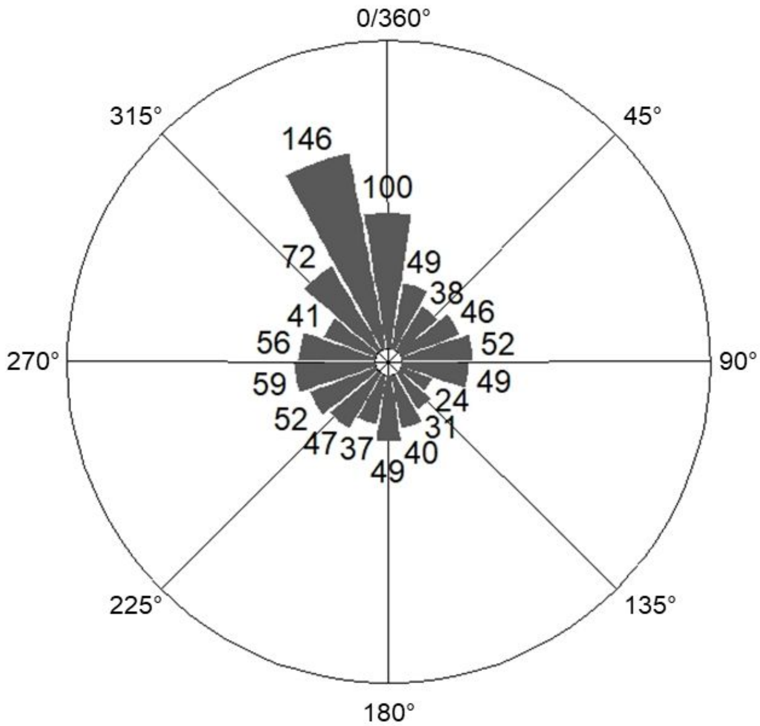

Fig. 2. Circular histogram of the post-release movement of 38 conflict Western Hudson polar bears. Conflict bears were captured near Churchill, Manitoba from July to December through the Polar Bear Alert Program and were fitted with Argos satellite-linked eartags before release. Individual movement was followed until on-ice departure or final transmission, for a minimum of 10 locations with the mean bearing calculated between consecutive locations, weighted by individual sample size. The number of locations per 20° binned angle is reported above each bar.

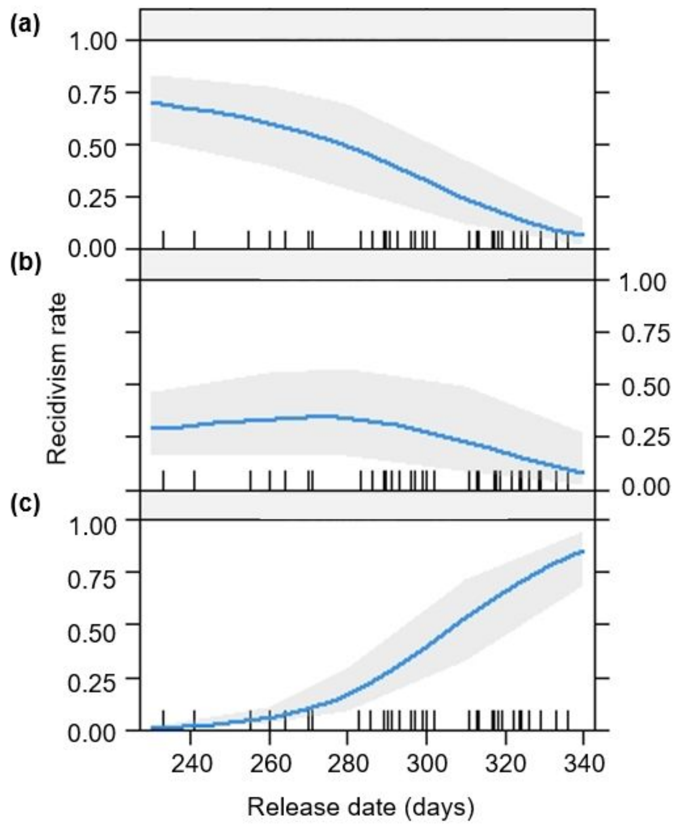

Fig. 3. Effect of the release date on the likelihood of 45 conflict Western Hudson polar bears (a) re-entering Churchill, Manitoba, (b) entering Arviat, Nunavut, or (c) not entering either community between their release by Manitoba conservation staff and on-ice departure. Recidivism rates (± 95% confidence interval) were predicted using the impact of release date, adjusted for the release distance and east-west direction from Churchill and the number of days a bear was held in the holding facility.

APPENDICES: SUPPORTING INFORMATION

Table A1. Distribution by sex and age class of conflict polar bears involved in a recidivism event during the same migratory period of their release by Manitoba wildlife management (n=24) [a, b].

	Observed		Expected [c]	
	Female	Male	Female	Male
Subadult	5	7	6.81	5.37
Adult	8	4	6.81	5.01

[a] Conflict bears were defined as those captured by wildlife officers near Churchill, Manitoba due to their proximity to the high priority management area of the Polar Bear Alert Program.

[b] Juvenile age class was removed from the chi-squared analysis due to the expected value < 5.

[c] Expected values were calculated using the proportion of each sex and age class represented in the conflict bear releases (n=69).

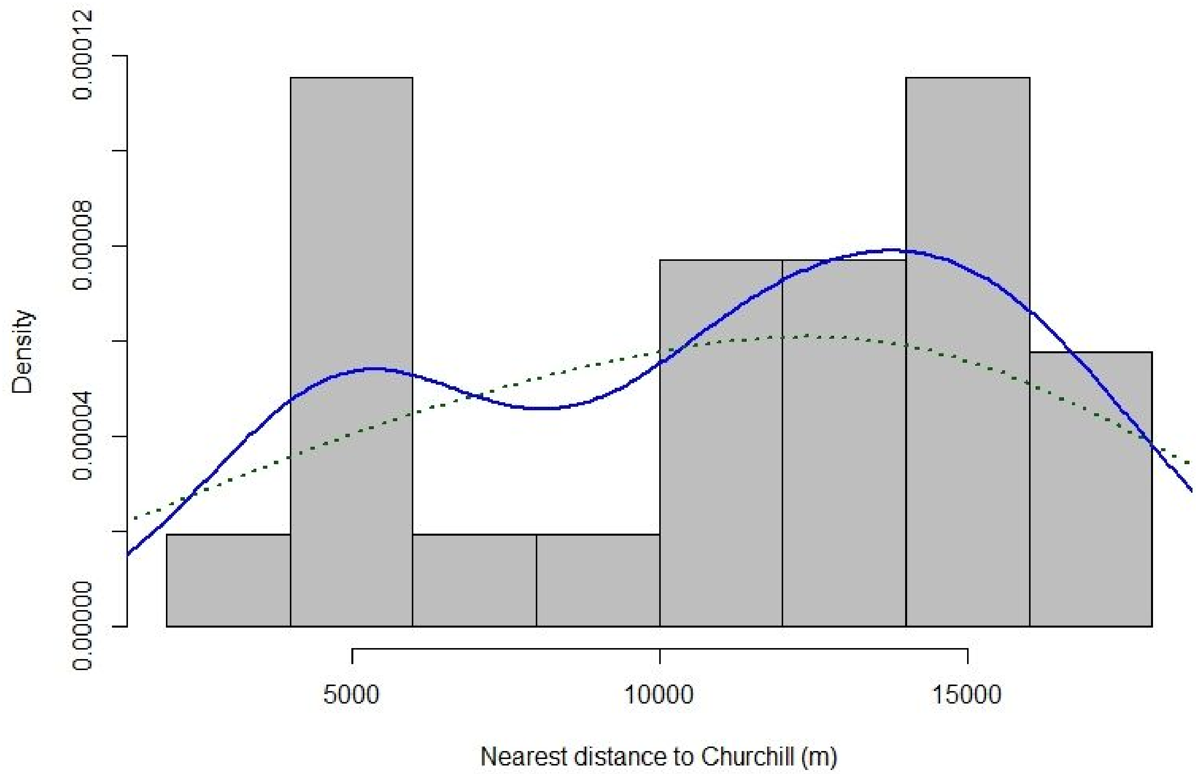

Fig. A2. Distribution of nearest distance to Churchill, Manitoba values of 45 Western Hudson polar bears released by Manitoba wildlife officers post-conflict. The straight-line distance was calculated for all land locations between a bear's release and departure onto sea ice with the nearest distance to Churchill defined as the shortest distance between a bear's locations and Churchill.

Table A3. Second order information criterion (AIC_c) and adjusted R-squared (R^2) resulting from model selection of linear regressions examining the effect of biological factors and conflict status on the date at departure of Western Hudson polar bears from 2016 to 2021 (n=79) [a, b, c].

Model	Covariates	AIC_c	ΔAIC_c	R^2
1	**Sex**	**598.5054**	**0**	**0.12**
2	Age + Sex	598.7547	0.2493	0.12
3	Conflict + Sex	599.4776	0.9722	0.11
4	Age + Sex + Conflict	600.6171	2.1117	0.11
5	Conflict	602.8835	4.3781	0.07
6	Conflict + Age	604.2771	5.7717	0.06
7	Age	604.8864	6.381	0.05

[a] The most parsimonious model with a $\Delta AIC_c < 2$ from the top model is indicated in bold.

[b] Departure defined as the first location onto sea-ice 10 km from the western Hudson Bay coast in autumn without returning until spring.

[c] Conflict status refers to whether bears had a history of being captured within the Polar Bear Alert management area or not during the autumn migratory period.

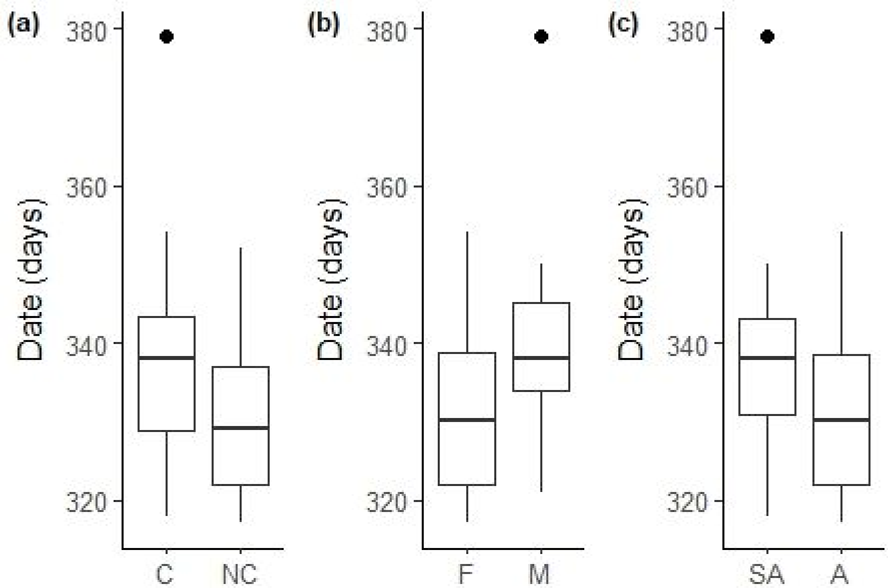

Fig. A4. Comparison of the on-ice departure date of Western Hudson polar bears (n = 79) between (a) conflict bears, defined as those who were captured near Churchill, Manitoba and released through the Polar Bear Alert Program, and non-conflict bears, defined as those with no history of human-wildlife conflict, (b) Female and male bears, and (c) subadults (2-5 years) and adults (> 5 years). Departure was defined as the first location 10 km offshore that was not followed by a location on land until the following spring. The lower quartile, median, and upper quartile values are represented by the box and the minimum and maximum values are represented by the whiskers.

Table A5. Parameters (including 95% confidence intervals) of best-fitting robust multiple linear regressions examining the influence of biological factors and conflict status on the timing of the on-ice departure of conflict (n=39) and non-conflict (n=39) Western Hudson polar bears with one outlier removed selected using second order information criterion (AIC_c) [a, b].

Model	Covariates	Coef.	L.CI (95%)	U.CI (95%)
Date [c]	Sex $_{male}$	7.056	2.349	11.760*

[a] Lower (L.CI) and upper (U.CI) limits of the 95% confidence intervals were used to determine significance, with significance indicated using *.

[b] Conflict polar bears defined as re-entering either Arviat, Nunavut or Churchill, Manitoba when located within 10 km during the same migratory period as the initial conflict and release.

[c] Date extracted from the departure location to describe migratory behaviour. Departure defined as the first location 10 km offshore from the west Hudson Bay coast in autumn without returning until spring.

Table A6. Second order information criterion (AIC_c) and adjusted R-squared (R^2) resulting from model selection of linear regressions examining the effect of biological factors and conflict status on the latitude at departure of Western Hudson polar bears from 2016 to 2021 (n=79) [a, b, c].

Model	Covariates	AIC_c	ΔAIC_c	R^2
1	**Conflict + Age group**	**221.8681**	**0**	**0.17**
2	Conflict + Age group + Sex	222.5452	0.6771	0.13
3	Conflict	225.2664	3.3983	0.13
4	Conflict + Sex	225.7613	3.8932	0.13
5	Sex	229.1024	7.2343	0.09
6	Age group + Sex	230.7045	8.8364	0.07
7	Age group	236.3879	14.5198	0.0002

[a] The most parsimonious model with a $\Delta AIC_c < 2$ from the top model is indicated in bold.

[b] Departure defined as the first location onto sea-ice 10 km from the western Hudson Bay coast in autumn without returning until spring.

[c] Conflict status refers to whether bears had a history of being captured within the Polar Bear Alert management area or not during the autumn migratory period.

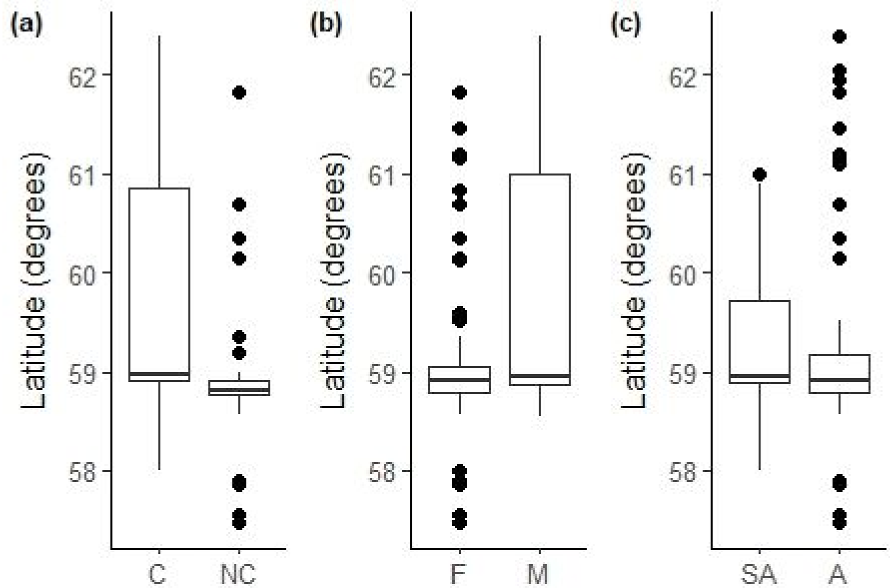

Fig. A7. Comparison of the on-ice departure latitude of Western Hudson polar bears (n = 79) between (a) conflict bears (C), defined as those who were captured near Churchill, Manitoba and released through the Polar Bear Alert Program, and non-conflict bears (NC), defined as those with no history of human-wildlife conflict, (b) female and male bears, and (c) subadults (2-5 years) and adults (> 5 years). Departure was defined as the first location 10 km offshore that was not followed by a location on land until the following spring. The lower quartile, median, and upper quartile values are represented by the box and the minimum and maximum values are represented by the whiskers.

Table A8. Second order information criterion (AIC_c) and Akaike weights (W) resulting from model selection of multinomial logistic regressions examining the effect of management practices (H1) on the likelihood of a polar bear re-entering a community during the autumn migratory period from 2016 to 2021 (n=45) [a].

Model	Covariates	AIC_c	ΔAIC_c	W
1	Date + East-west direction	85.802	0	0.34
2	**Date**	**87.149**	**1.347**	**0.17**
3	Date + Days held	88.348	2.546	0.10
4	Distance to Churchill	88.499	2.697	0.09
5	East-west direction + Distance to Churchill	88.813	3.011	0.08
6	Date + Distance to Churchill	89.270	3.468	0.06
7	Date + East-west direction + Days held	89.712	3.910	0.05
8	Distance to Churchill + Days held	90.051	4.249	0.04
9	Date + East-west direction + Distance to Churchill	90.714	4.912	0.03
10	Date + Distance to Churchill + Days held	92.099	6.297	0.02
11	East-west direction	92.307	6.505	0.01
12	East-west direction + Distance to Churchill + Days held	92.784	6.982	0.01
13	East-west direction + Days held	94.394	8.592	0.01
14	Date + East-west direction + Distance to Churchill + Days held	95.502	9.700	0.00
15	Days held	95.992	10.190	0.00

[a] The most parsimonious model with a $\Delta AIC_c < 2$ from the top model is indicated in bold.

Table A9. Second order information criterion (AIC_c) and Akaike weights (W) resulting from model selection of multinomial logistic regressions examining the effect of sea ice conditions (H2) on the likelihood of a polar bear re-entering a community during the autumn migratory period from 2016 to 2021 (n=45) [a].

Model	Covariates	AIC_c	ΔAIC_c	W
1	**North-zone sea ice** [b]	**71.935**	**0**	**0.78**
2	Release sea ice [c] + North sea ice	75.644	3.709	0.12
3	North-zone sea ice + Freeze date [d]	76.290	4.355	0.09
4	North-zone sea ice + Release-zone sea ice + Freeze date	80.196	8.261	0.01
5	Release-zone sea ice	86.319	14.384	0.00
6	Release-zone sea ice + Freeze date	90.796	18.861	0.00
7	Freeze-date	100.127	28.192	0.00

[a] The most parsimonious model with a $\Delta AIC_c < 2$ from the top model is indicated in bold.

[b] North-zone sea ice calculated as the mean daily sea ice concentration for the north-zone, defined as the 30 km area from the coast north of all release locations of conflict bears up to Arviat, Nunavut.

[c] Release-zone sea ice calculated as the mean daily sea ice concentration for the release-zone, defined as the 30 km area from the coast bounded by all release locations of conflict bears.

[d] Freeze-up date defined as the date at which mean sea ice concentration of the WH population zone is greater than 10% for three consecutive days.

Table A10. Second order information criterion (AIC_c) and Akaike weights (W) resulting from model selection of multinomial logistic regressions examining the effect of management practices (H3) on the likelihood of a polar bear re-entering a community during the autumn migratory period from 2016 to 2021 (n=45) [a].

Model	Covariates	AIC_c	ΔAIC_c	W
1	**Sex**	**100.677**	**0**	**0.41**
2	**Age Group** [b]	**101.616**	**0.939**	**0.26**
3	**Storage energy** [c]	**101.701**	**1.024**	**0.25**
4	Sex + Age Group	105.746	5.069	0.03
5	Sex + Storage energy	105.869	5.192	0.03
6	Age Group + Storage energy	106.769	6.092	0.02
7	Sex + Age Group + Storage energy	111.553	10.876	0.00

[a] The most parsimonious model with a $\Delta AIC_c < 2$ from the top model is indicated in bold.

[b] Bears were classified as subadults (2-5 years) or adults (> 5 years) before release.

[c] Storage energy (MJ), defined as the energy available in the form of stored fat, was calculated using girth (cm) and straight-line (cm) measurements collected before release.