

Polar bear conflict risk behaviour is shaped by maternal, individual, and environmental effects, not heritability

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Abstract

As ecosystems transform under the combined pressures of climate change and human activity, interactions between humans and wildlife are becoming increasingly common. Human-wildlife conflict is often managed by either targeting repeatedly involved individuals or modifying the conditions that make conflict more likely. Choosing which approach to emphasize depends partly on whether individual differences in conflict risk are persistent and genetically inherited or arise mainly from maternal and environmental effects. In the Western Hudson Bay subpopulation of polar bears (*Ursus maritimus*), lengthened ice-free seasons have extended fasting periods and increased the likelihood of nutritionally stressed bears entering human settlements. We investigated the genetic, maternal, and environmental contributions to conflict risk behaviour in this subpopulation using five decades of capture records and a six-generation pedigree of 4,634 individuals. We used animal models to estimate the repeatability and heritability of conflict risk behaviour across the pedigree, along with the relative contributions of additive genetic variation, maternal effects, and the environment to conflict risk behaviour for different age classes of polar bears. Conflict risk behaviour exhibited low heritability for all age classes, and was moderately repeatable in older, independent bears, but not in young, dependent bears. Maternal effects were stronger in dependent than independent bears, and observation year explained substantial variation in both age classes. Our findings indicate that conflict risk behaviour is shaped more strongly by maternal and environmental effects than by additive genetic variation, supporting proactive management of the conditions that promote conflict rather than relying primarily on responses directed at individual bears.

45 Keywords: Additive genetic variation, animal model, behaviour, climate change, human-wildlife
46 conflict, maternal effects, *Ursus maritimus*

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Introduction

Human–wildlife conflict is an increasing challenge for biodiversity conservation and wildlife management worldwide, as human activities and environmental change bring people and wildlife into more frequent contact (Nyhus 2016). Animals differ in their propensity to engage in conflict with humans, often with a subset of individuals being responsible for a disproportionate number of conflict incidents (Berezowska-Cnota et al. 2023). Whether these individual differences reflect inherited predispositions or learned responses to environmental conditions has direct implications for management (Morehouse et al. 2016, Schell et al. 2021). If behaviours that increase the likelihood of human-wildlife conflict (hereafter called conflict risk behaviour) are largely genetic, interventions should target repeatedly offending individuals, since their behaviour is unlikely to change regardless of context. If instead conflict risk behaviour is shaped primarily by environmental or experiential cues, modifying the conditions that promote risky behaviour may be more effective and more broadly applicable across populations.

Human-wildlife conflict is intensifying in the Arctic, where rapid climate change and expanding human activity are increasing opportunities for interactions between people and wildlife. Warming temperatures have increased access to the Arctic, promoting the growth of industrial development, greater resource extraction, increased tourism, and larger permanent settlements (Kerr 2002, Smith and Stephenson 2013, Dawson et al. 2018). Such interactions can carry significant costs to both humans and wildlife as encounters that escalate into conflict can result in human injury and the lethal removal of animals (Wilder et al. 2017, Heemskerk et al. 2020, Smith et al. 2023).

Interactions between humans and polar bears (*Ursus maritimus*) have become increasingly common in the Arctic (Atwood and Miller, 2021). Although attacks are rare (Wilder

et al. 2017), the presence of polar bears in and around communities leads to property damage, restricts the ability of people to move around town and on the land, and increases the risk that a bear may be shot and killed (Dowsley and Wenzel 2008, Clark et al. 2013). There is wide variation in risky behaviours in polar bears related to humans; many will avoid settlements completely, but some bears will return to communities repeatedly (Towns et al. 2009). The likelihood that a bear will engage in conflict risk behaviour depends on its genetic background, its learned behaviour, and environmental cues and stressors (Räsänen and Kruuk 2007). Here, we leveraged long-term ecological monitoring data from Western Hudson Bay polar bear subpopulation (designated as a management unit rather than a genetically unique population) to identify the contributions of genetic, maternal, and environmental effects to conflict risk behaviour to inform strategies to reduce the incidence of human-polar bear conflict.

Climate-mediated habitat loss and the presence of food attractants are important drivers of human-polar bear conflict (Atwood and Wilder 2021, Smith et al. 2023). Polar bears rely on sea ice for hunting energy-rich prey like ringed (*Pusa hispida*) and bearded (*Erignathus barbatus*) seals (Amstrup 2003, Florko et al. 2020). During the ice-free period in the spring and summer, polar bears fast onshore, relying on stored fat reserves for energy (Atkinson et al. 1996, Stirling et al. 1999). Warmer springs and earlier sea ice break-up reduce their access to prey (Stirling and Archibald 1977, Stirling et al. 1999, Pilfold et al. 2012, Cherry et al. 2013), leading to longer fasting periods and resulting in declines in body condition, reproductive success, and lower survival rates particularly of young bears (Stirling et al. 1999, Regehr et al. 2007, Molnár et al. 2010).

Most conflict incidents across the polar bear's range involve bears in poor body condition, or those attracted to human-derived food sources, such as waste sites and community

bone piles (Lunn and Stirling 1985, Wilder et al. 2017). Longer ice-free seasons are associated with increased human-polar bear conflict encounters, particularly near Churchill, Manitoba (Towns et al. 2009, Heemskerk et al. 2020). Escalating human-bear conflicts led to the establishment of the Polar Bear Control Program (PBCP) in 1969, and later the Polar Bear Alert Program (PBAP) in 1984 (Kearney 1989). The PBAP program aims to improve safety and reduce damage to property by decreasing food conditioning, preventing harm to bears and people, and facilitating relocations (Kearney 1989, Struzik 2014). Conservation officers patrol the area around town (Figure 1), and remove problem bears from the area by hazing them or trapping and relocating them outside of town or to a holding facility to be safely housed temporarily until the sea ice reforms. Conflict encounters in Churchill rose from 1980-2001, after which they began to decline, likely because of improved management protocols, such as the opening of an indoor garbage dump, development of the Polar Bear Holding Facility, and a decreasing population size (Heemskerk et al. 2020). Females with cubs and subadult (ages 2-5) bears are most frequently involved in conflicts, often due to limited access to high-quality food and heightened nutritional stress (Towns et al. 2009, Heemskerk et al. 2020).

We assessed the extent to which conflict risk behaviour of polar bears is heritable, shaped by maternal or social learning, or driven by environmental exposure. Using capture histories and a six-generation pedigree from the Western Hudson Bay polar bear subpopulation, we applied quantitative genetic animal models (Wilson et al 2010) to estimate the repeatable, heritable, maternal, and environmental variance components underlying conflict risk behaviour in both dependent (≤ 2 years old) and independent (≥ 3 years old) polar bears. These analyses aim to clarify the relative roles of additive genetic, maternal, and environmental influences on conflict risk behaviour. More broadly, they test whether human–polar bear conflict is likely to respond

most effectively to interventions targeting inherited behavioural predispositions or to management actions that modify environmental conditions and opportunities for conflict.

Methods

Pedigree Data

The Western Hudson Bay subpopulation in northeastern Manitoba, Canada is the site of a long-term monitoring program run by Environment and Climate Change Canada (Biddlecombe et al. 2025). Each year, the subpopulation is censused and polar bears are captured, chemically immobilized, and released. Data on abundance, population recruitment, body condition, and body size are collected, in addition to physical specimen samples from skin, fat, blood, and other sources (Biddlecombe et al. 2025).

We used pedigree data for the Western Hudson Bay subpopulation that was constructed using field and genetic data from individuals sampled between 1966-2011. Parentage was established using dam-offspring field observations and multilocus microsatellite genotyping (Malenfant et al. 2016). The resulting pedigree is comprised of 4,634 polar bears (443 sires, 923 dams, and 1,130 founders). The pedigree is 78% complete and is sufficiently interconnected to support quantitative genetic analysis (Mawass and Milot, 2025). All animal handling followed approved protocols from Environment and Climate Change Canada's Western and Northern Animal Care Committee, as well as annual wildlife research permits issued by the Province of Manitoba and Parks Canada.

We considered bears to be engaging in conflict risk behaviour if they were captured by the Manitoba Government because of their proximity to the Town of Churchill, human settlements, or the waste disposal site, causing property damage, or threatening humans (Figure 1; Towns et al. 2009, Heemskerk et al. 2020). Capture records for conflict bears were provided

by the Manitoba Government, collected through the PBCP and PBAP from 1966 to 2019. Bears were live-trapped or chemically immobilized using standard chemical immobilization techniques (Stirling et al. 1989) in the Town of Churchill (58.7684°N, 94.1650°W) and either relocated or held at the Polar Bear Holding Facility (Figure 1). While in the facility, polar bears were provided with water and were only fed in very rare cases (e.g., lone cubs) to avoid food conditioning (Pilfold et al. 2016). Individuals were measured, sexed, aged, and tagged with unique identifiers for inclusion in the pedigree (Pilfold et al. 2016; Stirling et al. 2008). Age determination was visually assumed for young bears (≤ 2 years old and still with their mothers), while older bears were aged via cementum annuli in extracted teeth (Calvert and Ramsay 1998). Adult females with cubs were released as soon as possible, while other individuals were held for a minimum of 30 days or until sea ice freeze-up (Pilfold et al. 2016).

Behavioural Dataset

Conflict risk behaviour was recorded as a binary variable (captured/not captured) for each individual in the pedigree from its year of birth to its last observation in the pedigree. Each observation occasion represented a defined monitoring interval of one year during which an individual was either involved in a recorded human-bear conflict (captured) or not involved in a recorded conflict (not captured). Individuals with capture records were assumed to be involved in conflict risk behaviour. Observations associated with natural deaths were excluded. To ensure compatibility with the animal model framework, all individuals had to be represented in the pedigree dataset. Therefore, we added 338 individuals with unknown parentage to the pedigree. We truncated records to 2010 to avoid skewing the analysis with incomplete capture histories for younger bears.

Statistical Analysis

We used quantitative genetic animal models to estimate the heritability, repeatability, maternal, and environmental variance components of conflict risk behaviour of polar bears (Table S1). Animal models are generalized linear mixed-effects models that estimate the genetic and non-genetic components of phenotypic trait variation among individuals in a pedigree. Pedigree structure is included as a random effect in the model to account for complex familial relationships among samples, inbreeding rates, and environmental fluctuations in traits of interest (Wilson et al. 2010). Heritability can be estimated by identifying the genetic contribution to trait values among related individuals in the pedigree (i.e., additive genetic variance; Kruuk and Hadfield 2007). In contrast, repeatability and environmental variance can be captured by including repeated measures of individual observations to account for trait values that are consistent across an individual's lifetime. While heritability may contribute to trait expression, traits may also arise from unmeasured, non-genetic environmental effects (Wilson et al 2010). These effects may be the result of shared environmental variation associated with birth year and/or sampling year (i.e., common environments) or may be from unmeasured environmental variation experienced by the individual itself (i.e., permanent environmental variance; Kruuk and Hadfield 2007).

We assessed the heritability and repeatability of conflict risk behaviour separately for dependent (≤ 2 years old) and independent (≥ 3 years old) age classes using univariate animal models (Table S1) in the R (v.4.1.3; R Core Team 2023) package *MCMCglmm* (v.2.35; Hadfield 2010). This age division reflects the average transition from maternal dependence to nutritional and behavioural independence (Ramsay and Stirling 1986), although approximately half the bears in the dependent dataset were not accompanied by an adult female when captured.

Excluding these bears from the analysis did not change the results, so we have retained them in the analysis.

We calculated narrow-sense heritability (h^2) as: $h^2 = \frac{V_A}{V_A + V_{PE} + V_M + V_{YObs} + V_{YBirth} + V_R}$,

where V_A is additive genetic variance, V_{PE} is permanent environmental variance, V_M is maternal variance, V_{YObs} annual variance, V_{YBirth} is cohort variance, and V_R is residual variance. Both models included the variance terms as random effects (Table S1), where V_{PE} was determined from individual identity (c^2), V_M from maternal identity (m^2), V_{YObs} from the observation year (y_{Obs}^2), V_{YBirth} from the birth year (y_{Birth}^2), and V_R from the residual (e^2). Maternal effects capture similarities among offspring sharing the same mother beyond those expected from additive genetic relatedness alone. Repeatability ($h^2 + c^2$) reflects the consistency of individual behaviour across time and is estimated as the combined contribution of heritable and stable environmental differences among individuals, expressed as a proportion of total phenotypic variance (Falconer and Mackay 1996; Nakagawa and Schielzeth 2010). We did not include sex and age because age was accounted for by modelling dependent and independent age classes separately, and because sex was partially confounded with maternal effects in younger bears. Including these terms would therefore not add independent information and risked introducing redundancy with the random effects structure.

Because conflict risk behaviour was recorded as a binary outcome (captured or not captured), we assigned the models to the threshold family in MCMCglmm (Hadfield and O'Hara 2015, de Villemereuil 2018). This framework assumes that each bear has an underlying continuous propensity toward conflict, and that a bear enters the captured category only when that propensity crosses a threshold. The residual variance was fixed at 1 as an identification constraint required by this model family, and an inverse-Gamma prior was applied to all

remaining random effects (de Villemereuil 2012, 2018). All variance components and heritability estimates are reported on the liability scale, which is standard for binary traits analyzed with this framework and is the appropriate scale for evolutionary inference (de Villemereuil 2018). Variance proportions are reported as means with standard errors calculated from the posterior distribution of each derived variance proportion. We ran each model for 2,000,000 iterations with a burn-in of 20,000 and thinning every 100 iterations. Effective sample sizes exceeded 8,000, and chains passed the Heidelberg diagnostic for convergence (Heidleberg and Welch 1983).

Lastly, we assessed temporal changes in conflict risk behaviour by running models separately for every decade of sampling (1970-1979, 1980-1989, 1990-1999, 2000-2009) for each age class. The model parameters were the same as for the complete sampling period models, except that we ran each model for 50,000 iterations with a burn-in of 10,000 and thinning every 10 iterations.

Results

Summary Statistics

In the dependent age class model (≤ 2 years old), 787 individuals contributed to 1,999 bear-year observations (Table S2). Of these individuals, 232 (29%) were captured at least once, and 81 (10%) had multiple capture records. On average, individuals experienced 0.79 captures and 1.7 non-captures, and approximately 31% of all observation occasions resulted in captures. Two-year old bears were involved in a higher proportion of captures than younger bears (Figure S1). The model included 362 females and 425 males, with an average capture date of October 22, and years of birth and observation spanning 1967 to 2010.

For the independent age class model (≥ 3 years old), 361 individuals with known maternal lineages contributed to 2,246 bear-year observations (Table S2). Of these individuals, 323 (90%) were captured at least once, and 113 (31%) had multiple capture records. On average, individuals experienced 1.5 captures and 4.7 non-captures, and approximately 24% of all observation occasions resulted in captures. Young bears (ages 3-5) were involved in a higher proportion of captures than older bears (Figure S1). The model included 145 females and 216 males, with an average capture date of October 21. Years of birth ranged from 1966 to 2007, years of observation from 1969 to 2010, and ages at first capture ranged from 3 to 29 years.

Repeatability and Heritability of Conflict Risk Behaviour

Conflict risk behaviour for dependent bears was minimally repeatable, with stable differences among individuals accounting for only 2% of phenotypic variation (Table 1). The heritability of conflict risk behaviour for dependent bears was negligible ($h^2=0.01$; $SE=5.4 \times 10^{-5}$, Figure 2, Table 1). However, maternal effects contributed more strongly to behavioural variation ($m^2=0.15$; $SE=2.2 \times 10^{-4}$, Figure 2, Table 1), suggesting that maternal experience and behaviour play a role in shaping early-life conflict exposure. The remaining behavioural variation was primarily attributed to environmental variation associated with year of observation ($y_{obs}^2=0.18$; $SE=3.3 \times 10^{-4}$, Figure 2, Table 1).

Conflict risk behaviour in independent polar bears demonstrated moderate repeatability, with individual identity explaining approximately 23% of the phenotypic variance (Table 1). Heritability estimates for conflict risk behaviour in independent bears were higher than for cubs, accounting for 7% of the phenotypic variance ($h^2=0.07$; $SE=4.6 \times 10^{-4}$, Figure 2, Table 1). However, conflict risk behaviour was predominantly associated with persistent variation among individuals ($c^2=0.16$; $SE=5.5 \times 10^{-4}$), and year of observation ($y_{obs}^2=0.15$; $SE=3.6 \times 10^{-4}$),

suggesting that individual differences and annual variation in environmental conditions shaped behaviour more than genetic background.

Temporal Trends in Conflict Risk Behaviour

Across cohorts, the number of bears included in the pedigree increased through time. The occurrence of conflict risk behaviour also increased through time for the dependent age class but did not increase for the independent age class (Table S3).

For dependent bears, the contribution of individual-level effects to conflict risk behaviour declined sharply after the 1970s and remained low in subsequent decades (Figure 3, Table 2). Between 1970-1979, individual identity explained 29% of variation in behaviour, with approximately equal contributions from heritability and permanent environment ($h^2=0.15$; $SE=2.4 \times 10^{-3}$, $c^2=0.14$; $SE=2.4 \times 10^{-3}$, Figure 3, Table 2). However, by the 1980s, the effect of identity declined to nearly zero. Maternal effects remained moderate, with the highest influence observed in between 1980-1989 ($m^2=0.17$; $SE=1.2 \times 10^{-3}$, Figure 3, Table 2). Annual cohort effects increased through time, suggesting that the environmental conditions associated with year of birth increasingly shaped behavioural development (Figure 3, Table 2).

The variance in conflict risk behaviour among independent bears fluctuated through time (Figure 3, Table 2). Individual identity accounted for 14-34% of variation in behaviour, with the greatest contribution in the 1980s (Table 2). Annual environmental effects were greatest between 1970-1979 ($y_{Obs}^2=0.34$; $SE=2.7 \times 10^{-3}$) and subsequently declined through time (Figure 3, Table 2), while cohort effects and maternal effects remained consistently low throughout the study period (Figure 3, Table 2).

Discussion

Conflict risk behaviour in the Western Hudson Bay polar bear subpopulation appears to be shaped primarily by environmental and experiential factors rather than genetic differences among individuals, pointing toward the importance of environmental management over interventions targeting specific individuals. In cubs, low repeatability and heritability of conflict risk behaviour aligns with expectations for this life stage, where behaviour is strongly shaped by maternal care and immediate environmental factors. In contrast, higher levels of repeatability in independent bears indicates consistency in individual responses over time, with most of that repeatability attributable to persistent non-genetic differences among individuals rather than additive genetic variation. These differences include individual choice, social conditions, and annual variation in the environment.

Low heritability in conflict risk behaviour, estimated on the liability scale as the proportion of variation in underlying conflict propensity attributable to additive genetic variation, emphasizes the roles of behavioural plasticity and environment in shaping polar bear decision-making over heritable genetic effects. In humans, risk taking behaviour is genetically linked and heritable (Linnér et al. 2019). In contrast, we did not find strong evidence for a genetic signal in propensity to engage in conflict risk behaviour in polar bears. Our results are consistent with studies on grizzly bears (*Ursus arctos*) that have found no increase in likelihood of conflict behaviour in offspring of male conflict-prone grizzlies (Morehouse et al. 2016). Stronger maternal effects suggest that offspring sharing a mother were more similar in conflict risk behaviour than expected from additive genetic relatedness alone. This pattern is consistent with maternal social learning, shared early-life exposure, or other mother-associated effects, which the model cannot distinguish.

Despite low heritability, the moderate repeatability of conflict risk behaviour among independent bears indicates that stable differences among individuals can persist through time, with most of this consistency attributable to persistent non-genetic differences. Low heritability yet high repeatability in conflict risk behaviour suggests that the trait is most likely the result of individual choice and environmental exposure rather than a genetic response. Repeated exposure to human environments may condition bears to specific responses, such as weaned cubs returning to predictable food sources near settlements (Lunn and Stirling 1985, Wilder et al. 2017). However, given the natural history of the species, cultural transmission of the behaviour is likely to be limited or short-lived. Polar bears are largely solitary and likely rely more on asocial environmental learning than on persistent cultural inheritance (Stirling et al. 2004). The diminishing signal of maternal effects with age suggests that individual learning and environmental exposure become increasingly important drivers of behaviour relative to social learning.

We identified a consistent signal of year of observation on conflict risk behaviour, likely shaped by environmental drivers of risk-taking behaviour, such as fluctuations in sea ice condition, nutritional stress, or toxoplasmosis infection. For instance, infection by *Toxoplasma gondii* has been associated with reduced risk aversion in rodents and humans (Johnson and Johnson, 2021). Exposure to *T. gondii* has increased by 26% in the Western Hudson Bay subpopulation since the 1980s due to increasingly warm and wet summers in this region of the Arctic (Pilfold et al. 2021). Between 2015-2017, 69% of bears sampled in the subpopulation expressed antibodies for *T. gondii* (Pilfold et al. 2021), highlighting the possible, yet currently unexplored role that the pathogen may play in human-polar bear conflict.

Conflict involvement was highest among bears aged 2–5 years and was more common among independent males than independent females. Younger bears may experience greater nutritional stress and have less foraging experience than older bears, which could increase their likelihood of approaching human settlements and becoming involved in defense of life and property kills (Dyck 2006, Molnár et al. 2010, Sciullo et al. 2016). Males may be more likely to engage in risky or aggressive behaviour due to the expression of testosterone (Haug et al. 1986), or because they are often in closer proximity to town than females. Male bears are more inclined to congregate near the coastline while waiting for sea ice freeze up than females, who are more likely to position themselves inland to reduce predation risk from males (Latour 1981). Churchill is located near the coast, which may result in a larger incidence of males passing through to town to reach the shoreline prior to freeze-up. The number of capture events in late October supports this hypothesis, as well as the roles of hunger and declining body condition in driving conflict risk behaviour (Stenhouse et al. 1988, Wilder et al. 2017).

Temporal shifts in variance components reinforce the role of environmental stressors in shaping conflict risk behaviour. We identified a signal of additive genetic variation in dependent bears between 1970-1979 that sharply declined in subsequent decades. This trend more likely reflects small sample sizes in the early years of the dataset rather than a shift in evolutionary potential in the population. Observation-year effects accounted for substantial variation in conflict risk behaviour in both dependent and independent age classes, underscoring the influence of interannual environmental variability, particularly in sea-ice dynamics. Long-term monitoring indicates a sustained trend toward earlier sea-ice breakup and later freeze-up in the Hudson Bay, extending the fasting duration of the bears by up to a month (Lunn et al. 2016, Stroeve et al. 2024). Loss of sea-ice habitat may have intensified maternal energetic constraints

and altered behavioural development in cubs born in later decades. Consequently, the increasing contribution of cohort effects among dependent bears likely reflects increasing exposure to deteriorating habitat conditions rather than persistent genetic or cultural differences.

Overall, the data support the view that conflict risk behaviour in polar bears as a complex, plastic trait influenced primarily by environmental and experiential factors. Polar bears exhibit considerable behavioural flexibility and learning capacity, traits that are rooted in their cognitive abilities, large brain size, and need to respond to spatial and temporal variation in resources (Stirling et al. 2021, Rivkin et al. 2026) These variance components are consistent with conflict risk behaviour in human-dominated landscapes being shaped primarily by individual experience and maternally-associated early-life conditions rather than additive genetic differences. Repeated exposure to human environments and food reward cues likely shapes bears' tendency to investigate settlements, reinforcing conflict risk behaviour over time.

From a management perspective, these findings support prioritizing environmental interventions rather than relying on behavioural selection or lethal removals (Schell et al. 2021). Proactive strategies such as reducing attractants, improving waste management, and enhancing habitat connectivity are likely more effective than reactive conflict responses. The enclosed waste facility in Churchill was opened in direct response to increasing human-bear conflict occurrences. However, in 2024, the facility was destroyed after a severe fire and has not yet been reopened. Bears have returned to the landfill, pointing toward the need for alternate strategies to reduce conflict risk. Technologies like real-time satellite tracking and deterrent drones may help prevent conflicts before they occur (Jagielski et al. 2022; Laidre et al. 2022). Ensuring that polar bears' biological needs are met through habitat protection and conservation-oriented planning will be key to minimizing human-bear conflict in a rapidly changing Arctic.

Our results also speak to a broader debate in wildlife management over whether conflict is best reduced by targeting problem individuals or the conditions that produce them (Swan et al. 2017). Selective removal of conflict-prone individuals is increasingly common and is justified by the observation that a small subset of animals is responsible for a disproportionate share of incidents. This approach is most likely to succeed when conflict risk is a stable individual trait, rather than a response that many individuals express under the same environmental conditions. Where behaviour is driven primarily by food availability and environmental conditions, as we find here and as Artelle et al. (2016) demonstrated for grizzly bear attacks on humans in British Columbia, new individuals will fill the same ecological role as those removed, and conflict will persist. Under these conditions, reducing the circumstances that make conflict more likely, such as effective containment of waste from settlements, will be more effective than managing the individuals that respond to them. However, for management strategies to be successful in the long term, the underlying drivers of conflict risk behaviour, such as habitat loss from climate change, will need to be addressed.

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389 **Author Contributions**

390 LK, ER, and CG designed the study; ER, DM, and VM collected data; LK and LRR performed
391 the analyses; LK and LRR wrote the initial draft; and all authors contributed to revisions

392 **Conflict of Interest**

393 The authors have no conflicts of interest to declare.

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Tables

Table 1. Random-effect sizes for polar bear conflict risk behaviour (*not captured/captured*) animal models for dependent (≤ 2 years old) and independent age classes (≥ 3 years old) captured in the Western Hudson Bay subpopulation from 1966-2010. Random effects are estimated as proportions of phenotypic variation (V_P) explained by each source of variation (i.e., V_A ; V_{PE} ; V_M ; V_{YObs} ; V_{YBirth} ; V_R). h^2 =heritability, c^2 =permanent environmental, m^2 =maternal, y_{Obs}^2 =year of observation, y_{Birth}^2 =cohort, e^2 =residual variance, and $(h^2 + c^2)$ =repeatability. Values in parentheses represent standard errors.

Age classes	h^2	c^2	m^2	y_{Obs}^2	y_{Birth}^2	e^2	$(h^2 + c^2)$
Dependent	0.01 (5.4×10^{-5})	0.01 (3.7×10^{-5})	0.15 (2.2×10^{-4})	0.18 (3.3×10^{-4})	0.01 (7.6×10^{-5})	0.65 (3.4×10^{-4})	0.02 (6.6×10^{-5})
Independent	0.07 (4.6×10^{-4})	0.16 (5.5×10^{-4})	0.05 (3.1×10^{-4})	0.15 (3.6×10^{-4})	0.03 (1.6×10^{-4})	0.54 (3.4×10^{-4})	0.23 (7.7×10^{-4})

Table 2. Random-effect sizes for polar bear conflict risk behaviour (*not captured/captured*) animal models for dependent age classes (≤ 2 years old) and independent age classes (≥ 3 years old) by decade captured in the Western Hudson Bay subpopulation from 1966-2010. Random effects are estimated as proportions of phenotypic variation (V_P) explained by each source of variation (i.e., V_A ; V_{PE} ; V_M ; V_{YObs} ; V_{YBirth} ; V_R). h^2 =heritability, c^2 =permanent environmental, m^2 =maternal, y_{Obs}^2 =year of observation, y_{Birth}^2 =cohort, e^2 =residual variance, and $(h^2 + c^2)$ =repeatability. Values in parentheses represent standard errors.

Dependent Age Class							
Decade	h^2	c^2	m^2	y_{Obs}^2	y_{Birth}^2	e^2	$(h^2 + c^2)$
1970-1979	0.15 (2.4×10^{-3})	0.14 (2.3×10^{-3})	0.12 (2.2×10^{-3})	0.06 (1.3×10^{-3})	0.10 (1.9×10^{-3})	0.42 (2.6×10^{-3})	0.29 (3.4×10^{-3})
1980-1989	0.02 (5.0×10^{-4})	0.02 (3.6×10^{-4})	0.17 (1.2×10^{-3})	0.31 (1.9×10^{-3})	0.08 (1.3×10^{-3})	0.4 (1.7×10^{-3})	0.04 (6.2×10^{-4})
1990-1999	0.01 (1.3×10^{-4})	0 (8.7×10^{-5})	0.07 (3.9×10^{-4})	0.41 (1.6×10^{-3})	0.4 (1.6×10^{-3})	0.11 (5.3×10^{-4})	0.01 (1.6×10^{-4})
2000-2009	0.02 (4.2×10^{-4})	0.01 (2.6×10^{-4})	0.11 (8.2×10^{-4})	0.19 (1.5×10^{-3})	0.34 (2.2×10^{-3})	0.33 (1.6×10^{-3})	0.03 (4.9×10^{-4})
Independent Age Class							
Decade	h^2	c^2	m^2	y_{Obs}^2	y_{Birth}^2	e^2	$(h^2 + c^2)$
1970-1979	0.07 (1.4×10^{-3})	0.07 (1.4×10^{-3})	0.09 (1.5×10^{-3})	0.34 (2.7×10^{-3})	0.06 (1.4×10^{-3})	0.36 (2.1×10^{-3})	0.14 (2.0×10^{-3})
1980-1989	0.2 (2.5×10^{-3})	0.14 (2.1×10^{-3})	0.05 (3.1×10^{-4})	0.15 (3.6×10^{-4})	0.03 (1.6×10^{-4})	0.54 (3.4×10^{-4})	0.34 (3.3×10^{-3})
1990-1999	0.08 (1.3×10^{-3})	0.15 (1.5×10^{-3})	0.06 (8.9×10^{-3})	0.1 (1.1×10^{-3})	0.06 (7.2×10^{-3})	0.55 (1.2×10^{-3})	0.23 (3.3×10^{-3})
2000-2009	0.13	0.14	0.04	0.07	0.04	0.58	0.27

598	(1.6×10^{-3})	(1.6×10^{-3})	(8.0×10^{-4})	(6.8×10^{-3})	(5.4×10^{-4})	(1.0×10^{-3})	(2.3×10^{-3})
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Figures

Figure 1. Left: Map of capture area covered by the Polar Bear Alert Program (outlined in yellow), showing the locations of the Town of Churchill (red star), the town waste facility (pink star), and polar bear holding facility (blue star). Bears included in this study with were primarily captured within the Polar Bear Alert Program monitoring area. Map was generated using Google Earth Pro (2026). Right, map of the broader Arctic, showing the Western Hudson Bay subpopulation location (black outline), and Town of Churchill (red star).

Figure 2. Proportion of variance explained by random effects for polar bear conflict risk behaviour (*not captured/captured*) for dependent age classes (≤ 2 years old) and independent age classes (≥ 3 years old) in the Western Hudson Bay subpopulation observed in Churchill, Manitoba between 1966 and 2010.

Figure 3. Proportion of variance explained by random effects for polar bear conflict risk behaviour (*not captured/captured*) for dependent age classes (≤ 2 years old) and independent age classes (≥ 3 years olds) in the Western Hudson Bay subpopulation observed in Churchill, Manitoba by decade between 1970 and 2009.

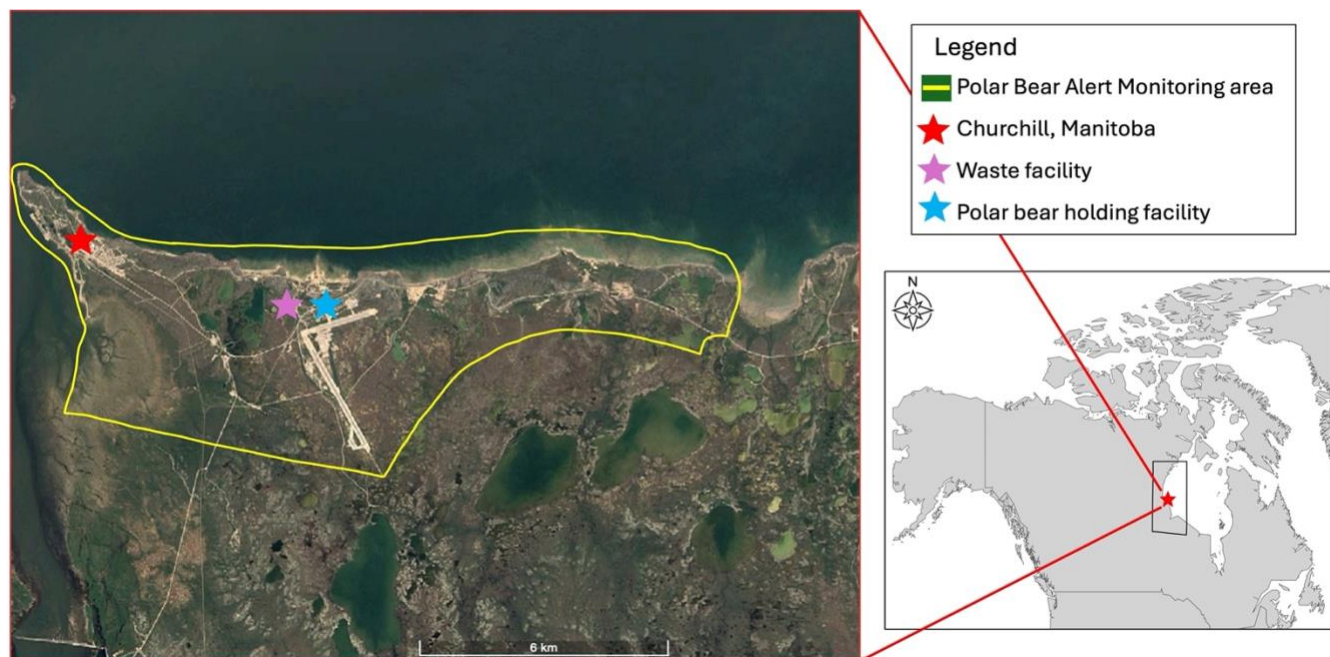


Figure 1

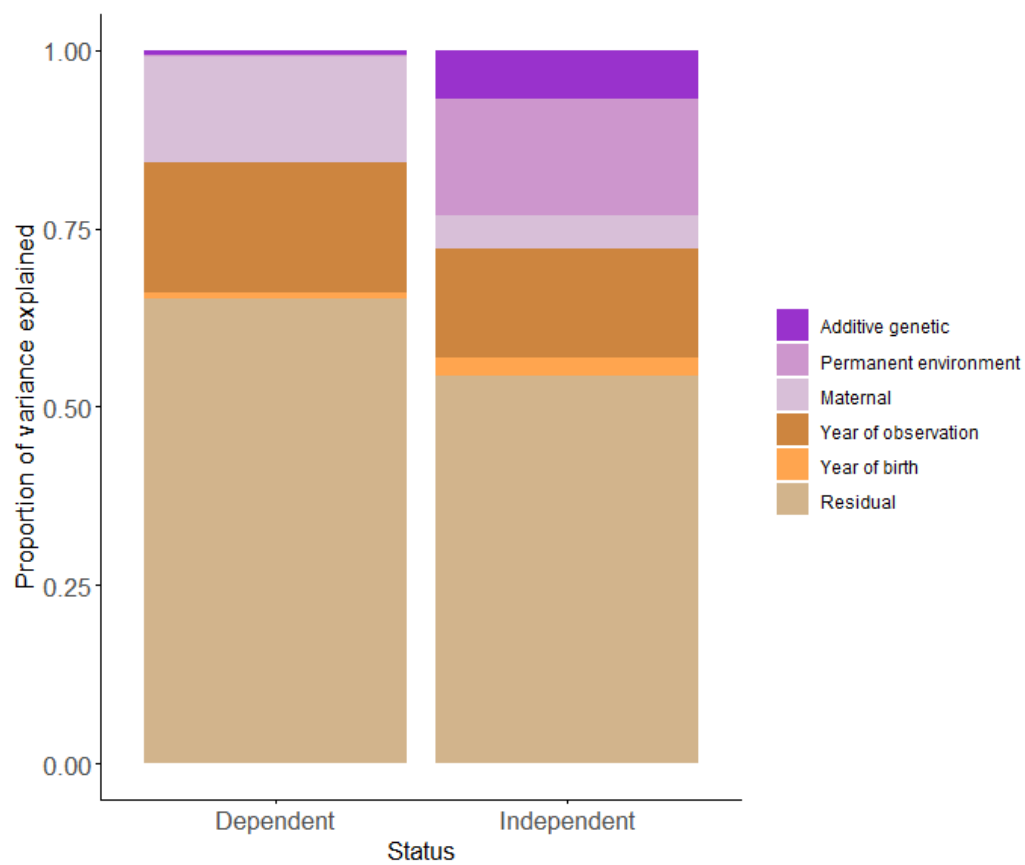


Figure 2

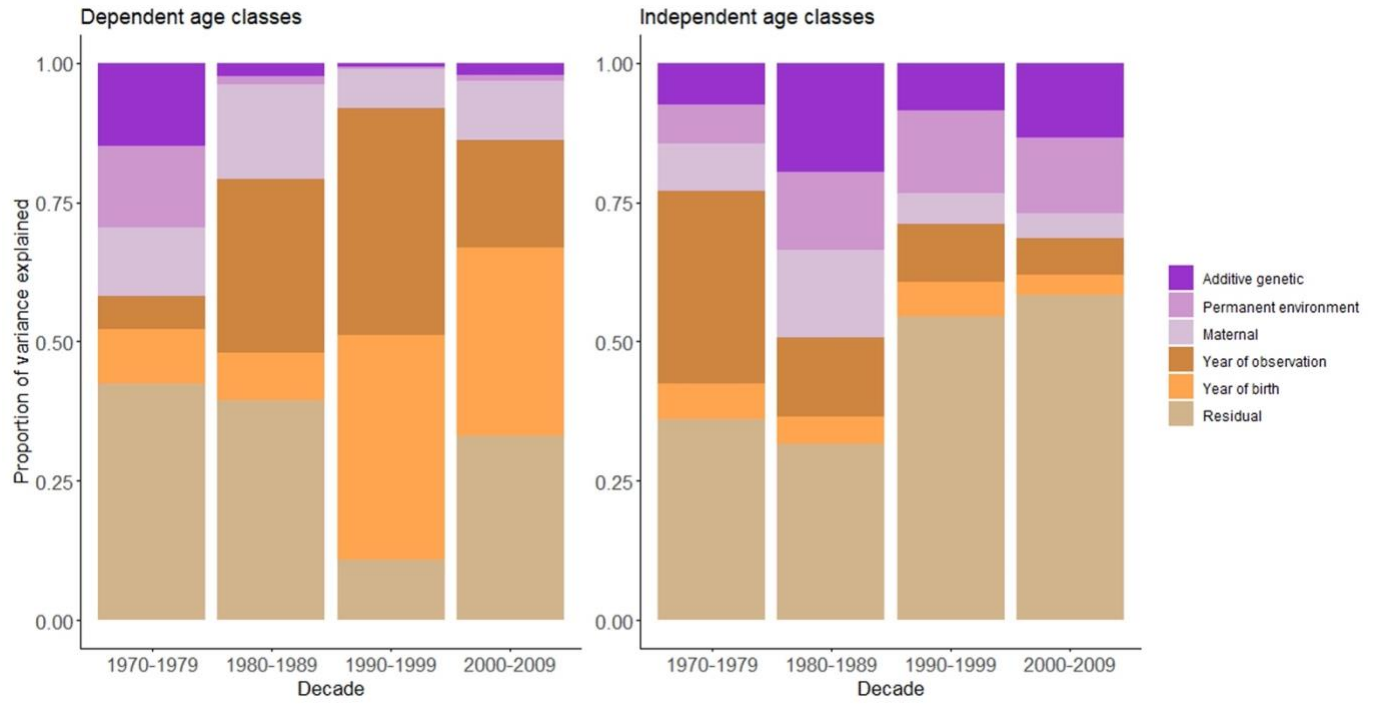


Figure 3