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# Behavioral response of polar bears to aircraft activity on the northern coast of Alaska

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## Abstract

The rapid loss of arctic sea ice is forcing a larger proportion of the Southern Beaufort Sea polar bear (*Ursus maritimus*) population to spend more time on land, increasing chances of negative interactions between people and bears. In the United States, the Marine Mammal Protection Act (MMPA) protects polar bears from incidental disturbance from human activities. For the remote and roadless areas of northern Alaska, USA, effective management of small aircraft activity is necessary to limit disturbance, but effects of overflights on polar bear behavior are largely unknown. During 2021 and 2022, we intentionally exposed polar bears ($n = 115$) to systematic aircraft activity (helicopter, fixed-wing) until we observed a disruption of behavior that qualified as a level B take response (e.g., abrupt change in activity or movement) under the MMPA. We used a Bayesian logistic regression to determine what factors influence and can be used to predict when a polar bear will exhibit a level B take response and estimate the probability of an aircraft eliciting a level B take response at different altitudes above the polar bear. Aircraft type, flight altitude, landscape (barrier islands vs. mainland), and bear behavior (active vs. inactive) upon initial aircraft encounter were all important predictors of take. Probability of take rapidly increased with a decrease in flight altitude starting at 450 m for helicopter and 300 m for fixed-wing aircraft. Active (e.g., standing, walking) polar bears on barrier-island landscapes were more likely to experience take than inactive (e.g., bedded) bears on mainland landscapes. Our findings can help with assessments and management plans by quantifying disturbance to polar bears from current and future human activity that involves aircraft use.

**KEYWORDS**

Arctic, climate change, disturbance, human–wildlife conflict, Marine Mammal Protection Act, *Ursus maritimus*

Anthropogenic expansion into the Arctic has steadily increased over the last several decades, and the trajectory of industrial and commercial activity is forecasted to expand in this region as Arctic sea ice continues to diminish (Van Hemert et al. 2015, Nevalainen et al. 2017, Owen et al. 2021). In response to unreliable sea ice conditions, some species that rely on sea ice are adjusting aspects of their life-history strategies (Atwood et al. 2016*a*, *b*). For polar bears (*Ursus maritimus*) of the Southern Beaufort Sea (SBS) population in Alaska, USA, the lack of sea ice means that many bears must choose between spending more time on shore (Amstrup et al. 2006, Gautier et al. 2009, Smith and Stephenson 2013, Atwood et al. 2016*a*) or remaining on sea ice that has moved great distances from shore over unproductive water where food availability is low (Whiteman et al. 2015). When bears are on shore, the increased availability of human-provisioned food resources (e.g., food waste, hunting scraps) may concentrate them near human settlements, including industrialized portions of the Alaskan coastline (Atwood et al. 2016*b*). The majority of this region lacks a road network; therefore, rural residents, researchers, land managers, tourists, and industry rely extensively on aircraft for access (Stinchcomb et al. 2019). As polar bears spend more time on land (Atwood et al. 2016*a*) and aircraft-supported human activity (e.g., industry, tourism, research) continues to expand, polar bears may be exposed to increasing levels of aircraft activity.

The potential negative effect of aircraft disturbance on wildlife has been a pressing and unresolved issue in Arctic Alaska for decades (Stinchcomb et al. 2019). Information on the effects of aircraft on polar bears is particularly important because of current conservation concerns and legal stipulations. In the United States, polar bears are protected under the Marine Mammal Protection Act (MMPA) and were listed as threatened under the Endangered Species Act in 2008. Together, these pieces of legislation are intended to protect polar bears from harassment that qualifies as take under the MMPA. The MMPA defines 2 levels of take: level A and level B. Level A take is considered intentional harassment and includes "any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild…" (USFWS 2021:42982). This excludes military readiness activities, traditional harvest practices, or preapproved research. Level B take is viewed as unintentional or incidental disturbance and includes activities that "have the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering" (USFWS 2021:42983). Limited amounts of level B take can currently occur on an annual basis, but prior authorization must be obtained through the United States Fish and Wildlife Service (USFWS) to avoid penalties under the MMPA. The USFWS carefully monitors the amount of take occurring on the northern coast of Alaska because even incidental changes in polar bear behavior may have important biological effects on individual health (e.g., energetic costs, displacement from preferable habitat) and demography (e.g., reproductive success, recruitment, population size; Woodruff et al. 2022).

Currently, aircraft operators (e.g., oil industry, commercial, research) must ensure that their flight patterns, altitudes, and approach distances comply with regulations to avoid unauthorized take of polar bears. Current guidelines for both fixed-wing aircraft and helicopter activity state that pilots should maintain a minimum flight altitude of 457 m and a horizontal distance of 804 m from polar bears. These guidelines are largely based on observations of a bear's ability to detect the anthropogenic stimuli (sight, sound; Nicholas 2021); however, detection does not necessarily equate to disturbance. Improved understanding of polar bear response to aircraft activity is necessary to advance knowledge on what current practices may result in take and, potentially, help to mitigate future human–polar conflict. Policies need to protect polar bears and ensure that current regulations are supported by science. Management guidelines and regulatory decisions for minimizing disturbance will likely continue to lead to contention among different interest groups (e.g., industry, rural communities, land managers) without objective and defensible information on the association between aircraft stimuli and the responses of polar bears.

Most research on the association between aircraft activity and polar bear behavior has focused on denned bears (Amstrup 1993, Larson et al. 2020). Findings from these studies indicated that disturbance from aircraft traffic was the most likely stimulus to increase vigilance, elicit rapid movement, and trigger den abandonment when compared to stimulus from large machinery, vehicles, and humans on foot (Amstrup 1993, Larson et al. 2020). Previous studies, mainly on ungulates and pinnipeds, indicate that the type of aircraft can affect the level of disturbance, and helicopter traffic has shown to be more disruptive than fixed-wing aircraft (Bleich et al. 1994, Miller 1995, Born et al. 1999, Frid 2003, Goldstein et al. 2005). Although behavioral response data of non-denning bears have been collected opportunistically during aerial surveys (2000–2014) conducted by wildlife management and research agencies (Atwood et al. 2015, Wilson et al. 2017), limited data are available on the effects of both fixed wing aircraft and helicopter activity on polar bear behavior outside of the denning season (Nicholas 2021) and important information gaps remain.

Our objectives were to estimate the probability of an aircraft eliciting a level B take response at different altitudes above the polar bear and determine what factors influence the altitude that a polar bear will exhibit a level B take response. We conducted a systematic evaluation of behavioral responses of onshore polar bears to both fixed wing aircraft and helicopter traffic during the non-denning season to address these objectives.

## STUDY AREA

We conducted sampling flights September 23–26 of 2021 and September 24–30 of 2022 in Alaska. We chose these sample periods because of the reliable onshore presence of polar bears, as demonstrated in previous aerial surveys (Atwood et al. 2016*b*, Wilson et al. 2017). Our late September field efforts were scheduled to avoid overlap with fall whaling activities by local Indigenous communities (Barrow, Nuiqsut, Kaktovik). Our flights began after communities had reached their seasonal whaling quota, and we continued to give a wide berth (~10–15 km) to communities, occupied camps, and boats to avoid disruptions to rural community activities.

We conducted aerial surveys for polar bear along 1,030 km of the northern coast of United States, between Point Barrow, Alaska (71°23′N, 156°28′W) and the western Canadian border (69°38′N, 140°57′W; Figure 1). Our study area included barrier islands and coastal shoreline of the Arctic Coastal Plain, a flat and treeless tundra terrestrial landscape. Barrier islands are often <5 km from the mainland and are elongated land features that run parallel to the coastline. Barrier islands are sandy and vary greatly in size. Smaller islands are typically without vegetation, while larger ones may have some tundra vegetation. Other dominant fauna in the study area include an abundance of waterfowl and shorebird species during the summer season (snow free; late May to late September) and year-round presence of caribou (*Rangifer tarandus*), grizzly bears (*U. arctos*), wolves (*Canis lupus*), muskox (*Ovibos moschatus*), red fox (*Vulpes vulpes*), and Arctic fox (*V. lagopus*). The study area is typically snow and ice covered from October through early May. During our observation season in September, sea ice was far from the Alaskan coastline and unavailable to polar bears during our study (Meier et al. 2021). During flights, temperatures ranged from −2°C to 4°C and most of the study area was snow and ice free, providing visual contrast between the white polar bear on a relatively dark-colored land surface.

**FIGURE 1** Map of project study area used to assess behavioral response of polar bear to aircraft in Alaska, USA, 2021–2022 (Google Earth Pro 2022). Red brackets encompass the surveyed coastline (Point Barrow to USA-Canadian border). Point Barrow (i.e., Utqiagvik), Nuiqsut, Prudhoe Bay, and Kaktovik are human settlements located within the bounds of our study area. We did not survey within 10–15 km of the Inupiaq communities (Utqiagvik, Nuiqsut, and Kaktovik), and we started our surveys after whaling ended for the year.

# METHODS

## Sampling flights

We conducted all sampling flights in 2021 in a single-engine, Cessna 206 fixed-wing aircraft (Cessna, Wichita, KS, USA). Ground-level noise (max. sound pressure level or decibels [dB]) generated by a level-flying Cessna 206 were at the upper noise range (but within ~10 dB) when compared to 13 other fix-wing aircraft (non-jet) when tested at above ground level (AGL) from 152 m to 1,067 m (Nicholas 2021). Four observers, including the pilot, were on board each flight and were responsible for scanning the coastline and barrier islands for polar bears. After the observers detected a polar bear, each of the 3 non-pilot observers independently recorded observations. This approach allowed us to carefully review any discrepancies in records immediately after observations and to reach a consensus on the data recorded in the final dataset.

We conducted all sampling flights in 2022 in an R44 helicopter (Robinson, Torrance, CA, USA), a commonly used aircraft model for industrial and research purposes in the region. Two observers, including the pilot, were on board each flight. Both observers were responsible for scanning for polar bears, and the non-pilot recorded observations after detection. Similar to 2021, both observers independently documented observations and compared records immediately after observations to reach consensus before sampling another bear.

We used the same sampling methods (except for different aircraft types) during 2021 and 2022 to allow for comparison between the 2 observation years. While searching for polar bears, the pilot flew transects parallel to the coastline or a barrier island, at a horizontal distance of roughly 500 m from the coast or island to provide observers with an adequate angle of view for detection. To optimize bear detection while searching for polar bears, pilots flew at mean altitude (i.e., vertical distance) of 365 m ± 130 (SD). Detection probability of polar bear decreases with distance and drops below approximately 0.5 at vertical distances of >400 m (Wiig et al. 2022). Search altitudes were sometimes altered to randomize approach altitudes between 183 m and 610 m. Searches <183 m were infrequent but did occur when the aircraft encountered low cloud ceilings.

Upon bear detection, observers recorded the bear's initial behavior, the time, and the general location of the bear using landmarks and notable features. Observers were trained to identify individual behaviors that qualified as a level B take response, including when the bear 1) transitioned their behavior to running, 2) abruptly changed their direction of movement, 3) flushed into water, 4) stopped nursing, 5) abandoned their feeding site, 6) separated from a group, or 7) stopped interacting (e.g., sparring) with another bear. If the aircraft did not elicit a take response at the time of detection, the pilot immediately redirected the aircraft away from the target bear and increased the aircraft's altitude to 610 m or to the altitude of the cloud layer, whichever was lower. After the aircraft was approximately 2 km from the target bear, the pilot circled back and oriented the aircraft so that the target bear would be on the observers' side of the aircraft during the sampling flight. The sampling flight began when the aircraft was approximately 1.5 km from the bear at a randomly chosen altitude between 183 m and 610 m. The pilot flew toward the bear at a constant cruising speed (70–90 knots). The line of flight was slightly offset (~30–100 m) to create a viewing angle that facilitated direct and continuous observation of the bear by observers from the aircraft window.

If there was >1 bear at the location of detection, observers randomly picked 1 bear for sampling. If the bear exhibited a take behavioral response to the aircraft prior to the sampling flight or as a result of our initial search flight, observers documented the altitude of the aircraft at the time of the response, and recorded the flight as a take response. Immediately after the take response, the aircraft quickly departed from the area to reduce further disturbance. We focused our sampling on bears that were not running or swimming upon approach because of the difficulty in classifying a change in bear behavior that qualified as a take.

During each sampling flight, observers coded behavioral responses as no observed response, activity change (bedded to standing, standing to walking, abrupt change in direction, abandoning a feeding site, cessation of nursing), or flee (running, flushing into water). If a bear response did not meet the minimum criteria of an MMPA level B take, we repeated the sampling flight at incrementally (30–60 m) lower altitudes until we observed a take response or the aircraft reached our lowest altitude treatment level of 30 m. Any behavior classified as an MMPA level B take ended the sampling flight. After we observed a take response or reached 30 m without a take, we recorded the end time and the pilot ascended back to 457 m, flying directly over the location of the bear at initial detection to record global positioning system (GPS) coordinates. The pilot provided GPS coordinates and daily flight tracks and we used these data to verify the landscape (i.e., mainland coast or barrier island) occupied by the bear at detection.

Observers also documented environmental (e.g., landscape, weather conditions, food availability), demographic (e.g., number of bears in immediate area [group size], family group [female with cubs or yearlings]), and pre-sampling behavioral (e.g., bedded, standing, walking) information of the bear or bears at the location. We pooled pre-sampling, or initial, polar bear behavior into 2 categories: active (e.g., standing, walking, feeding, or running) and inactive (e.g., bedded, nursing, or sitting). When we observed family groups, we treated the group as 1 sampling unit. For example, if we observed a female with 2 cubs, a take response from any one of the 3 bears would end the sampling flight and we would assign the family group a take response. We excluded food availability (e.g., feeding site near sampled bear) from further analysis because of small sample size (*n* = 18, 16%).

On consecutive sampling days, we alternated the direction of travel (east on day 1, west on day 2) from Prudhoe Bay to avoid resampling the same individual. We recorded flight tracks of the aircraft each day to identify and avoid areas that were already surveyed, especially the previous day. Location and demographic information also helped observers determine the likelihood that sampled individuals were unique.

## Data analysis

We organized and analyzed data using SPSS (IBM, Armonk, USA) and Program R (R Development Core Team 2023) statistical software. To determine what factors influenced, and can be used to predict, when a polar bear will exhibit a level B take response, we used a Bayesian logistic regression approach to estimate observing a take response (take or no take) under different conditions. While frequentist statistics could have been used for the logistic regression analysis, the design of our study led to the Bayesian approach being more efficient for handling the structure of our data.

Our data were inherently unbalanced because we did not continue overflights below the altitude that a bear experienced take. Therefore, data were heavily skewed towards non-response records. To account for this unbalance, we applied a method of interval-censoring (Yun et al. 2011). Our method allowed take to occur at 15-m intervals below the altitude we observed take and allowed non-take to occur at 15-m intervals above observed take altitude up to 615 m. The study by Yun et al. (2011) reported this to be a statistically valid approach for these types of unbalanced data.

Further, because some bears experienced take at their initial overflight altitude, we needed to account for the possibility that take would have occurred at higher altitudes. We therefore used a Bayesian data imputation approach (Scharf et al. 2017) to assign take between the initial altitude and 615 m in such cases. The randomly assigned take altitude then served as the first altitude take was observed and we augmented data as described previously. Our analysis assumed that take could not occur above 615 m, consistent with the upper range of ground distances polar bears have previously been observed to be disturbed by snowmobile traffic while not denning (Anderson and Aars 2008).

Our Bayesian logistic regression took the following form. We modeled the observed behavioral response (i.e., take or no take), $b_{i,t}$, of individual $i$ during overflight $t$ as: $b_{i,t} \sim \text{Bernouli}(p_{i,t})$ where $p_{i,t}$ is the probability of an individual bear (or family group) exhibiting take behavior. We modeled $p_{i,t}$ as $\text{logit}(p_{i,t}) = \beta_{0,i} + \beta x_{i,t}$, where $\beta$is a vector of regression coefficients that correspond to a vector of attributes, $x_{i,t}$, associated with the conditions present during the observation (e.g., aircraft altitude), and $\beta_{0,i}$ is the intercept coefficient for individual $i$. We modeled $\beta_{0,i}$ as $\beta_{0,i} \sim \text{Normal}(\alpha, \sigma)$. We gave the population-level intercept term, $\alpha$, a vague prior of $\alpha \sim \text{Normal}(0, 1.5)$, where we set the standard deviation to 1.5 to allow for a nearly uniform distribution on the logit scale (Hooten and Hefley 2019). We also gave the inter-individual standard deviation for the intercept term, $\sigma$, a vague prior of $\sigma \sim \text{Uniform}(0, 3)$. We gave all regression coefficients vague priors $\beta \sim \text{Normal}(0, 1.5)$.

To account for uncertainty in the upper altitude that take occurred for bears that exhibited take on the first overflight, we implemented a data imputation approach (Scharf et al. 2017). We created 20 separate data sets that had different altitudes that take initially occurred for bears where we observed take on the first overflight. We randomly assigned take altitude, for these bears as follows: $alt_i \sim \text{Uniform}(b_{i,*}, 615)$, where $alt_i$ is the randomly assigned take altitude for bear $i$ and $b_{i,*}$ is the altitude that we observed take in the aircraft for bear $i$. We then assigned all altitudes $\leq alt_i$ as altitudes where take occurred and all altitudes $> alt_i$ as altitudes where take had yet to occur.

Our full model included altitude (m; which we scaled by calculating z-scores), initial behavior (active, inactive), landscape type (mainland, island), group size ($n$), and whether the bear belonged to a family group (yes, no) as explanatory variables. We included aircraft type as a 2-way interaction term with other variables. To account for the potential influence of multiple overflights affecting the altitude we observed take, we also included a variable of the number of previous overflights for each bear at each altitude flown. We included this variable (i.e., pass) in each model. We ran all subsets of the full model and used Watanabe-Akaike Information Criterion (WAIC; Hobbs and Hooten 2015) scores to compare model fit. We considered models with a $\Delta\text{WAIC} \leq 2$ from the top performing model to be competing models. We then selected the most parsimonious model from the set of competing models as our final model.

We estimated the posterior distributions for each parameter in the models with Monte Carlo Markov chains using the package runjags (Denwood 2016) to run the program JAGS (Plummer 2003) from R (R Development Core Team 2023). For each of the 20 imputed datasets, we allowed 5,000 iterations to be used for the adaptation phase of the model, with a burn in of 50,000 iterations. We obtained 100,000 samples from the posterior distribution, which we thinned by 100 to obtain 1,000 samples from the posterior distribution for model inference. We combined the set of posterior samples from each of the 20 imputed model outputs (Scharf et al. 2017) and drew inference from this set of 20,000 posterior samples that account for the uncertainty in initial take altitude.

We visually assessed each parameter's posterior distribution for convergence. We performed posterior predictive checks (Chambert et al. 2014) to determine how well the model fit our observed take data. We calculated Bayesian *P* values for 2 test statistics (mean and SD) and considered Bayesian *P* values between 0.1 and 0.9 to indicate a good fit for a given test statistic (Hobbs and Hooten 2015).

To estimate the probability of an aircraft eliciting a level B take response at different altitudes above the polar bear (objective 2), we used the predicted values of our target variable (take vs. no take) generated from our best model. We plotted the association between probability of take with different aircraft types while accounting for other variables that were included in the best model.

## RESULTS

During 2021, over 4 days (23–26 Sep) and approximately 20 hours of flight time, we conducted 57 sample flights using a fixed-wing aircraft. During 2022, over 5 days (24–30 Sep) and approximately 24 hours of flight time, we conducted 58 sample flights using a helicopter. Pooling years, we observed behavioral responses that qualified as level B take in 86 (75%) of the sample flights (Table 1). For the 86 take behaviors, we recorded 52 transitions into running, 16 flushes into water, 16 abrupt changes in direction of movement, 1 abandonment of a feeding site, and 1 cessation of nursing. For 29 sample bears (25%), we conducted a flight at 30 m without observing a take. Sample flights using a helicopter resulted in a greater proportion of takes (83%) as compared to fixed-wing aircraft (67%; Table 1). For bears that exhibited a take response, mean and median take altitude was 187 m ± 144 (SD) and 122 m, respectively. The mean take altitude was 33% higher with the helicopter compared to the fixed-wing aircraft (Table 1). We conducted the majority of our sample flights over barrier islands (73%). Polar bear group sizes (including 36 family groups) ranged from 1–15, with a mean group size of 1.9 ± 1.8 bears; 52% of sampled bears were active and 48% were inactive when first detected (Table 1).

Our best fitting and most parsimonious model for predicting when a polar bear will exhibit a behavioral response classified as level B take included the main effects of altitude, landscape, and a 2-way interaction between aircraft type and initial bear behavior at the time of aircraft approach (Table 2). We found no evidence of lack of convergence for our model and Bayesian *P*-values indicated good model fit (mean $P = 0.45$, SD $P = 0.44$). The probability of take increased as flight altitude decreased (Table 3; Figure 2). We also found a small but insignificant (i.e., 95% CI overlaps 0) effect of the cumulative number of overflights (pass) on the probability of eliciting a Level B take. With an increasing number of overflights, the probability of take was higher at higher altitudes than when an aircraft was first encountered by the bear (Table 3).

We used our estimates of the parameter means to calculate odds ratios for each variable in our chosen model. Bears that were sampled with a helicopter were 2.8 times more likely to exhibit a take response than bears sampled with a fixed-wing aircraft (Table 3). Active bears were 3.3 times more likely to exhibit a take response than inactive bears. Bears on barrier islands were 2.5 times more likely to exhibit a take response than those on the mainland (Table 3). Although bear group size and bears in a family group were not included in our final and most parsimonious model, the parameters were present in many of our top 10 models (Table 2). But the credible intervals of the model coefficient estimates for those variables overlapped zero and were not informative.

**TABLE 1** Descriptive results of variables collected during sampling of the response of 115 polar bears to aircraft overflights in Alaska, USA, 2021–2022. We used these variables in modeling efforts to predict and estimate the probability of observing a level B take response in polar bears.

| Metric | Fixed-wing aircraft (*n* = 57) | Helicopter (*n* = 58) | All (*n* = 115) |
|---|---|---|---|
| Mean (m) approach altitude (SD) | 356 (103) | 378 (159) | 367 (134) |
| Take | | | |
| Yes *n* (%) | 38 (66.6) | 48 (82.8) | 86 (74.8) |
| No *n* (%) | 19 (33.3) | 10 (17.2) | 29 (25.2) |
| Mean (m) take altitude (SD) | 143 (111) | 190 (162) | 187 (144) |
| Mean (*n*) number of overflights per sampled bear (SD) | 5 (2.5) | 4 (3.0) | 5 (2.8) |
| Initial behavior (*n*) | | | |
| Active (takes[a]) | 34 (27) | 26 (23) | 60 (50) |
| Inactive (takes) | 23 (11) | 32 (25) | 55 (36) |
| Landscape type (*n*) | | | |
| Mainland (takes) | 15 (10) | 16 (12) | 31 (22) |
| Barrier Island (takes) | 42 (28) | 42 (36) | 84 (64) |
| Feed site (*n*) | | | |
| Present (takes) | 7 (5) | 11 (10) | 18 (15) |
| Absent (takes) | 50 (33) | 47 (38) | 97 (97) |
| Family group (*n*) | | | |
| Yes (takes) | 15 (15) | 21 (18) | 36 (33) |
| No (takes) | 42 (23) | 37 (30) | 79 (53) |
| Mean group size (SD) | 1.9 (1.5) | 1.8 (2.0) | 1.9 (1.8) |

[a] Takes is the number of sampled bears that elicited a take response to the aircraft. For example, of the 34 sampled bears that were active during initial fixed-wing aircraft approach, 27 elicited a take response.

To illustrate interacting relationships, we used predicted means to plot curves of take probabilities at different altitudes with each aircraft type while also accounting for active and inactive initial behaviors and bears on mainland and barrier islands (Figure 2). When sampling bears on barrier islands in a helicopter, the probability of take rapidly increased at altitudes of approximately 450 m and 250 m for active and inactive bears, respectively (Figure 2A). When sampling bears on barrier islands using a fixed-wing aircraft, the probability of take rapidly increased at altitudes of approximately 250 m and 175 m for active and inactive bears, respectively (Figure 2B). When sampling bears on mainland using a helicopter, the probability of take rapidly increased at altitudes of approximately 400 m and 200 m for active and inactive bears, respectively (Figure 2C). When sampling bears on mainland using a fixed-wing aircraft, the probability of take rapidly increased at altitudes of approximately 250 m and 150 m for active and inactive bears, respectively (Figure 2D).

# DISCUSSION

Our systematic evaluation of polar bear response to aircraft overflights indicated that level B takes did occur at the current suggested altitude buffer (457 m; USFWS 2021) but were rare (~4%). Our findings suggest that the probability of take is highest among active bears on barrier islands exposed to helicopter overflights.

**TABLE 2** Top ten (+null) performing model iterations used to estimate the probability of a polar bear exhibiting a level B take response (take or no take) from overflights in Alaska, USA, 2021–2022. We used Watanabe-Akaike Information Criterion (WAIC) scores to compare model fit and change in WAIC (ΔWAIC) to rank competing models. We selected the most parsimonious model from the competing models (ΔWAIC ≤ 2) as our final model. Our final model (best fit and most parsimonious) is the top model.

| Model[a] | Number of parameters | WAIC | ΔWAIC |
|---|---|---|---|
| Altitude + behavior × aircraft + landscape + pass | 7 | 900.3 | 0.0 |
| Altitude × aircraft + behavior × aircraft + landscape + pass | 8 | 901.2 | 0.3 |
| Altitude × aircraft + behavior × aircraft + landscape × aircraft + pass | 9 | 901.7 | 0.7 |
| Altitude × aircraft + behavior × aircraft + landscape + group + family + pass | 10 | 903.6 | 2.7 |
| Altitude × aircraft + behavior × aircraft + landscape × aircraft + group + family + pass | 11 | 904.2 | 3.2 |
| Altitude + behavior × aircraft + landscape × aircraft + pass | 8 | 940.4 | 3.5 |
| Altitude × aircraft + behavior × aircraft + pass | 7 | 904.8 | 3.9 |
| Altitude × aircraft + behavior × aircraft + family + pass | 8 | 905.4 | 4.5 |
| Altitude × aircraft + behavior × aircraft + group × aircraft + pass | 9 | 907.4 | 6.5 |
| Altitude × aircraft + behavior × aircraft + family × aircraft + pass | 9 | 908.1 | 7.2 |
| Null + pass | 3 | 1,683.6 | 782.7 |

[a] Model variables included flight altitude (m), initial bear behavior at aircraft approach (active or inactive), aircraft type (helicopter or fixed wing), landscape type (mainland or island), group size, family group (yes or no), and the number of previous overflights (pass).

**TABLE 3** Coefficient estimates (mean and median) from the final model used to estimate the probability of polar bear exhibiting a level B take response to aircraft overflights in Alaska, USA, 2021–2022. Our final model included altitude (m), initial bear behavior at aircraft approach (active or inactive), aircraft type (fixed-wing or helicopter), landscape type (mainland or island), and the number of previous overflights (pass) before take was recorded.

| Parameter | Mean | Median | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Intercept | −7.4 | −7.4 | −8.7 | −6.1 |
| Aircraft (helicopter)[a] | 1.8 | 1.8 | 0.4 | 3.3 |
| Altitude (m) | −5.4 | −5.4 | −6.1 | −4.6 |
| Initial behavior (active)[b] | 2.3 | 2.3 | 1.0 | 3.7 |
| Initial behavior × helicopter | 3.3 | 3.3 | 1.5 | 5.2 |
| Landscape type (barrier island)[c] | 1.5 | 1.5 | 0.2 | 2.8 |
| Pass | 0.2 | 0.2 | −0.1 | 0.4 |

[a] Fixed-wing aircraft used as the reference category.

[b] Inactive initial behavior used as the reference category.

[c] Mainland used as the landscape reference category.

Under those conditions, probability of take begins to sharply increase from zero at 400–450 m and the probability surpasses 0.5 between 350–400 m. Inactive bears on mainland that are exposed to fixed-wing aircraft were least sensitive to overflights, with probability of take surpassing 0.5 between 50–100 m (Figure 2).

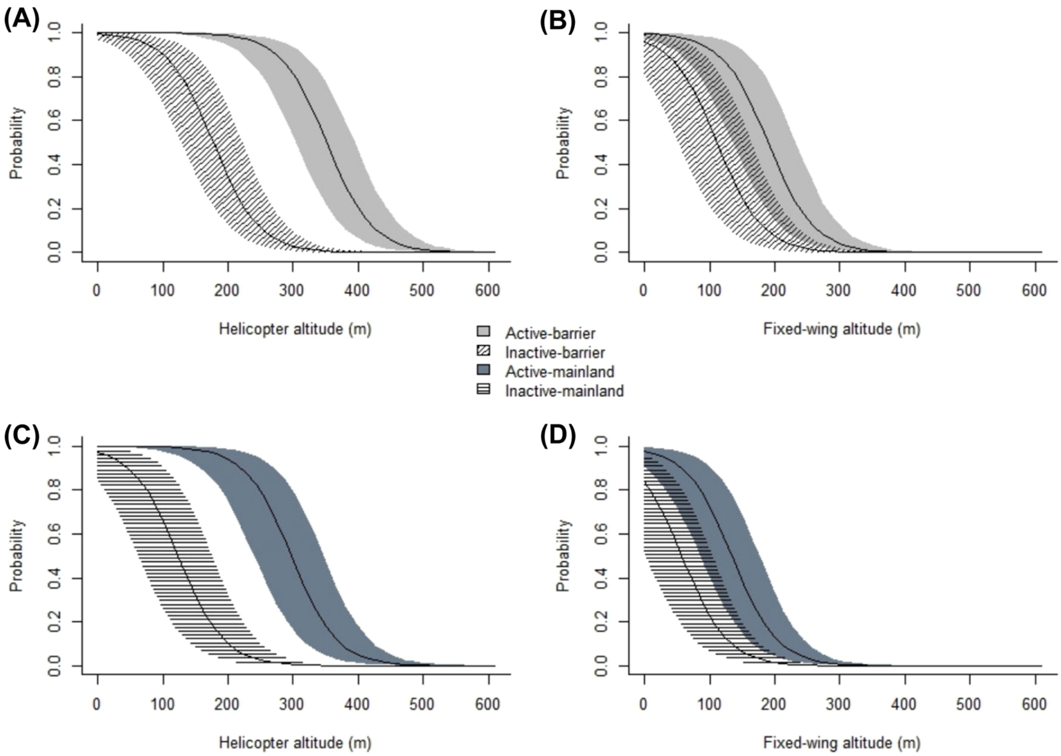

**FIGURE 2** Modeled mean probability (shaded areas = 95% CI) of observing a behavioral response in a polar bear that qualifies as a level B take to the presence of aircraft overflights in Alaska, USA, 2021–2022, at different flight altitudes for different aircraft types (helicopter, fixed-wing), initial behaviors of the bear (active, inactive), and landscape types (mainland, barrier island).

Previous studies on the effects of aircraft altitude for non-denning polar bears are not available, so there was a limited opportunity to directly compare our findings with others. For denning polar bears, however, previous research assessed behavioral response to aircraft for 3 relatively coarse distance classes (0–150 m, 151–300 m, >300 m) using opportunistic observation datasets and reported a decrease in responses that would qualify as a take (e.g., den abandonment, rapid movement) at >300 m (Larson et al. 2020). For other wildlife species, distance of an aircraft has repeatedly been found to be one of the strongest predictors of disturbance (Efroymson and Suter 2001, Goldstein et al. 2005, Fleming and Tracey 2008). We found that the probability of take for polar bears began to rapidly increase for helicopter overflights at approximately 450 m (Figure 2), which was within the range of previously documented aircraft-distance thresholds causing a behavioral disturbance to other wildlife species. Studies on bighorn sheep (*Ovis canadensis canadensis*) and mountain goat (*Oreamnos americanus*) showed a behavioral response to helicopter overflights starting at 400 m (MacArthur et al. 1982) and 500 m (Côté et al. 2013), respectively. For another marine mammal in the region, ringed seals (*Phoca hispida*), probability of flushing into water (type of take response) also began increasing as distances between the seal and helicopter dropped below 500 m, and the probability of a flush remained constant at 0.30 from 550 m out to a distance of 1,100 m (Born et al. 1999). In comparison, we found that the probability of take approached zero between 200–350 m for fixed-wing and 300–550 m for helicopter.

Based on decades of previous research involving other wildlife species, we expected polar bears to be more sensitive to helicopters than fixed-wing aircraft (Bleich et al. 1994, Miller 1995). Dall's sheep (*Ovis dalli dalli*) were twice as likely to flee during helicopter overflights as compared to fixed-wing aircraft (Frid 2003). Ringed seals were

8 times more likely to exhibit an escape response to a helicopter than a fixed-wing aircraft (Born et al. 1999). These previous studies noted that the differences in response may be related noise disturbance, with helicopters generally being louder (higher dB levels) and generating lower frequencies (Hz) that can be detected by wildlife at greater distances as compared to fixed-wing aircraft (Born et al. 1999, Owen et al. 2021). Also, most research-related polar bear captures occur from a helicopter, and the acute physiological response of polar bears to helicopter capture are similar to the most intense events of natural behavior (Whiteman et al. 2022). Therefore, previous negative experiences by individual bears to helicopter activity may have contributed to elevated sensitivity and vigilance.

Polar bears were more likely to exhibit a level B take behavioral response when the bear was active prior to sampling. The probability of take on an active bear was greater at higher altitudes compared to inactive bears (Figure 2). Findings from studies involving other species support our results. For example, ungulates have a stronger response to aircraft activity when animals were active upon aircraft approach (Miller 1995). Specifically, barren-ground caribou (*R. t. groenlandicus*) that were initially resting were the least reactive to overflights compared to animals that were moving or feeding (Calef et al. 1976, Efroymson et al. 2001). Woodland caribou (*R. t. caribou*) also exhibited more intense behavioral responses to aircraft presence if animals were initially walking compared to resting (Harrington and Veitch 1991, Efroymson et al. 2001). Exhibiting a take response (e.g., abrupt change in movement or direction) requires a smaller change in its physiological state (respiration, heart rate) and activity level if a polar bear is already standing or walking as compared to if it was in an inactive state (e.g., bedded, resting; Pagano and Williams 2019). Also, an active bear is likely more alert than a sleeping or resting bear. We often observed resting bears in dug outs in the gravel or the side of bluffs, landscape features potentially reducing exposure to both wind and aircraft sound. Wind speed and direction has been reported to affect bear behavior (Togunov et al. 2022) and response to snowmobile disturbance (Andersen and Aars 2008), respectively. We did not include data on wind speed because we were unable to accurately estimate wind speed on the ground at each sampling location. Wind direction was less relevant because we often conducted repeat overflights on the same bear from different directions. During future research, accounting for these variables may help to explain variation in bear response to aircraft because of the influence of wind on sound.

The landscape occupied by the polar bear was an important predictor of take in our models. Polar bears appeared to be more tolerant of overflights when located on the mainland coast, and their predicted take altitudes were higher when overflights were conducted over the barrier islands. We speculate the observed behavioral differences speak to how polar bears and people are using each landscape type on the northern coast of Alaska. Barrier islands are considered critical habitat for polar bears and provide important areas for resting, corridors for travel, and refuge from human disturbance (USFWS 2021). Aircraft activity near barrier islands may be perceived as a more novel stimulus by polar bears because low-flying aircraft are relatively infrequent in this landscape as compared to the mainland coast. Unexpected and infrequent disturbance is more likely to cause a behavioral response in wildlife than chronic and frequent disturbance, especially when the disturbance is noise related (Francis and Barber 2013). Human infrastructure is absent on most barrier islands and small aircraft seldom have flight paths over barrier islands unless the aircraft is equipped with special gear (e.g., floats) for open-water landing. Also, polar bears may be more accustomed to disturbance and conflict on the mainland coast because it is shared with human settlements, industrial development, and grizzly bears.

Family group (i.e., female with offspring) was not retained in the final model. When a family group was sampled, we observed that all bears in the group exhibited the same reaction. Therefore, for our analysis, we treated a family group as one sampling unit. Although this is a valid approach, this may have affected our results. For example, when a female with 2 cubs exhibited a take response, this was only considered 1 take instead of 3. We did not include vigilant behavioral reactions in our analysis because this response alone does not qualify as a take. We did note that many family groups were quick to become vigilant; however, family groups did not exhibit take responses at greater rates compared to lone bears. Results from previous studies investigating ungulate response to aircraft activity, that also accounted for family group, are mixed. Both Côté (1996) and Goldstein et al. (2005) reported no relationship between family groups and behavioral response in mountain goats, while Ballard (1975) reported female mountain goats with young were the most sensitive to aircraft disturbance. In Svalbard, the behavioral responses of polar bears to approaching snowmobiles were examined with females with cubs being the most sensitive to disturbance, having the longest flight initiation distances, and the farthest displacement rates (Andersen and Aars 2008). Of course, aircraft overflights and snowmobile approaches are not the same stimulus. Additional data collection may be necessary to ensure that family groups are appropriately protected from disturbance.

Group size also was not retained in the final models and we excluded food availability or presence of a feed site because of small sample size. We anticipate that these variables may be linked to our study area. Polar bears on the northern coast reliably congregate near Iñupiat communities that participate in the traditional harvest of bowhead whale (*Balaena mysticetus*). Local harvest and disposal practices result in community bone piles, which act as highly attractive supplemental feed sites (Bentzen et al. 2007, Schliebe et al. 2008, Herreman and Peacock 2013, Miller et al. 2015). Researchers reported that the percentage of onshore polar bears that were within 16 km of Utqiagvik (near Point Barrow), Kaktovik, and Cross Island (Nuiqsuit's whale haul out location 15 km north of Prudhoe Bay) rose from 64% to 78% in the days after a whale harvest, and 40% of those bears were near Kaktovik (Atwood et al. 2016*b*). Because we conducted our aerial surveys after whaling season and gave 10–15-km buffers to Utqiagvik and Kaktovik, we suspect that large groups of bears with access to feed sites may have been on shore but unavailable for sampling. Cross Island was the only location with whale remains that was included in our sampling area and the majority of our samples with larger group sizes occurred on or near this location. Therefore, spatial variability in group size was lacking and we had a small proportion (16%) of observations where bears were near a feed site. Further research that includes other whale carcass areas is necessary to determine exactly how group size and feed sites affect polar bear reaction to aircraft presence.

Beyond the scope of our study, we envision numerous opportunities for future research to further characterize the relationship between aircraft activity and polar bear disturbance. Assessments during different seasons (e.g., early summer, winter) and on different landscapes (e.g., sea ice) may reveal different polar bear responses. The body condition of polar bears after the whaling season may be better than before the whaling season (McKinney et al. 2017). The reduced access to food prior to whaling may change the bear's behavior and their response to human activity. Understanding polar bear capacity to habituate to aircraft activity, and longevity of behavioral disruption following aircraft disturbance may also be important areas for future research. Previous research reported that black bears (*U. americanus*) have the ability to become habituated to certain aircraft types (i.e., unmanned) relatively quickly with stress levels diminishing after 5 flights (Ditmer et al. 2019). McLellan (1990) reported that grizzly bears that were not previously immobilized by aircraft became accustomed to the stimulus and occasionally did not display any vigilance behavior to their presence. Studies on effects of jet aircraft on desert ungulates also reported that heart rate and behavior returned to pre-disturbance conditions in <5 minutes after overflights (Weisenberger et al. 1996, Krausman et al. 1998). We did not statistically assess the longevity of the behavioral disruption because we left the sampling area immediately after a take response. We opportunistically observed bears as we departed and noted that most bears that exhibited a take response returned to a vigilant standing position within 5–10 seconds after the aircraft departed the bear's location. Our suggestions for future research may help further explain variation in the behavioral response of polar bear to aircraft activity beyond the factors (flight altitude, landscape occupied, bear activity level) that we estimated to be influential.

## MANAGEMENT IMPLICATIONS

Our study provided federal agencies, industry, and commercial aircraft pilots with quantitative information that can be used to support policy and mitigate conflict related to interactions between aircraft and polar bears along the northern coast of Alaska. Our results can also be used by wildlife managers to estimate the level of take that might occur under different management and human activity (e.g., development, tourism) scenarios to more accurately account for disturbance related to aircraft overflights as changes in the arctic environment shift the seasonal and spatial distribution of polar bear.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## ETHICS STATEMENT

Our study design was approved by the University of Alaska Fairbanks' Institutional Animal Care and Use Committee (IACUC permit 1780623) and we were permitted for polar bear take under the USFWS's research permit (MA82088B-1).

## DATA AVAILABILITY STATEMENT

Data on response of sampled polar bear to aircraft are available upon request.

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## REFERENCES

Andersen, M., and J. Aars. 2008. Short-term behavioural response of polar bears (*Ursus maritimus*) to snowmobile disturbance. Polar Biology 31(4):501–507.

Amstrup, S. C. 1993. Human disturbances of denning polar bears in Alaska. Arctic 46:246–250.

Amstrup, S. C., G. M. Durner, W. R. Johnson, and T. L. McDonald. 2006. Estimating potential effects of hypothetical oil spills on polar bears. Alaska Science Center, U.S. Department of the Interior, U.S. Geological Survey, Anchorage, USA.

Atwood, T. C., B. G. Marcot, D. C. Douglas, S. C. Amstrup, K. D. Rode, G. M. Durner, and J. F. Bromaghin. 2016*a*. Forecasting the relative influence of environmental and anthropogenic stressors on polar bears. Ecosphere 7(6):e01370.

Atwood, T. C., E. Peacock, M. A. McKinney, K. Lillie, R. Wilson, D. C. Douglas, S. Miller, and P. Terletzky. 2016*b*. Rapid environmental change drives increased land use by an Arctic marine predator. PLoS One 11(6):e0155932.

Atwood, T. C., E. Peacock, M. A. McKinney, K. Lillie, R. Wilson, and S. Miller. 2015. Demographic composition and behavior of polar bears summering on shore in Alaska. U.S. Geological Survey, Administrative Report, Anchorage, Alaska, USA.

Ballard, W. 1975. Mountain goat survey technique evaluation. Alaska Department of Fish and Game Federal Aid in Wildlife Restoration Project W-17–7, final report; Job 12.2R, Anchorage, USA.

Bentzen, T. W., E. H. Follmann, S. C. Amstrup, G. S. York, M. J. Wooler, and T. M. O'Haram. 2007. Variation in winter diet of southern Beaufort Sea polar bears inferred from stable isotope analysis. Canadian Journal of Zoology 85:596–608.

Bleich, V. C., R. T. Bowyer, A. M. Pauli, M. C. Nicholson, and R. W. Anthes. 1994. Mountain sheep *Ovis canadensis* and helicopter surveys: ramifications for the conservation of large mammals. Biological Conservation 70(1):1–7.

Born, E. W., F. F. Riget, R. Dietz, and D. Andriashek. 1999. Escape responses of hauled out ringed seals (*Phoca hispida*) to aircraft disturbance. Polar Biology 21(3):171–178.

Calef, G. W., E. A. DeBock, and G. M. Lortie. 1976. The reaction of barren-ground caribou to aircraft. Arctic 1:201–212.

Chambert, T., J. J. Rotella, and M. D. Higgs. 2014. Use of posterior predictive checks as an inferential tool for investigating individual heterogeneity in animal population vital rates. Ecology and Evolution 4:1389–1397.

Côté, S. D. 1996. Helicopter disturbance. Wildlife Society Bulletin 24(4):681–685.

Côté, S. D., S. Hamel, A. St-Louis, and J. Mainguy. 2013. Do mountain goats habituate to helicopter disturbance? Journal of Wildlife Management 77(6):1244.

Denwood, M. J. 2016. Runjags: an R package providing interface utilities, model templates, parallel computing methods and additional distributions for MCMC models in JAGS. Journal of Statistical Software 71:1–25.

Ditmer, M. A., L. K. Werden, J. C. Tanner, J. B. Vincent, P. Callahan, P. A. Iaizzo, T. G. Laske, and D. L. Garshelis. 2019. Bears habituate to the repeated exposure of a novel stimulus, unmanned aircraft systems. Conservation Physiology 7(1): coy067.

Efroymson, R. A., and G. W. Suter. 2001. Ecological risk assessment framework for low-altitude aircraft overflights: estimating effects on wildlife. Risk Analysis 21(2):263–274.

Fleming, P. J., and J. P Tracey. 2008. Some human, aircraft and animal factors affecting aerial surveys: how to enumerate animals from the air. Wildlife Research 35:258–267.

Francis, C. D., and J. R. Barber. 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. Frontiers in Ecology and the Environment 11:305–313.

Frid, A. 2003. Dall's sheep responses to overflights by helicopter and fixed-wing aircraft. Biological Conservation 110: 387–399.

Gautier, D. L., K. J. Bird, R. R. Charpentier, A. Grantz, D. W. Houseknecht, T. R. Klett, T. E. Moore, J. K. Pitman, C. J. Schenk, J. H. Schuenemeyer, and K. Sørensen. 2009. Assessment of undiscovered oil and gas in the Arctic. Science 324(5931): 1175–1179.

Goldstein, M. I., A. J. Poe, E. Cooper, D. Youkey, B. A. Brown, and T. L. McDonald. 2005. Mountain goat response to helicopter overflights in Alaska. Wildlife Society Bulletin 33:688–699.

Google Earth Pro. 2022. Map of Alaskan Coastline 70°20′36″N, 148°20′06″W. https://earth.google.com/web/@70.34343031,-148.33512714,-55102.43286742a,776820.7346157d,35y,0.0447h,0t,0r/data=OgMKATA. Accessed 8 Sep 2023.

Harrington, F. H., and A. M. Veitch. 1991. Short-term impacts of low-level jet fighter training on caribou in Labrador. Arctic 1:318–327.

Herreman, J., and E. Peacock. 2013. Polar bear use of a persistent food subsidy: insights from non-invasive genetic sampling in Alaska. Ursus 24:148–163.

Hobbs, N. T., and M. B. Hooten. 2015. Bayesian models: a statistical primer for ecologists. Princeton University Press, Princeton, New Jersey, USA.

Hooten, M. B., and T. J. Hefley. 2019. Bringing Bayesian models to life. CRC Press, Boca Raton, Florida, USA.

Krausman, P. R., M. C. Wallace, C. L. Hayes, and D. W. DeYoung. 1998. Effects of jet aircraft on mountain sheep. Journal of Wildlife Management 62:1246–1254.

Larson, W. G., T. S. Smith, and G. York. 2020. Human interaction and disturbance of denning polar bears on Alaska's North Slope. Arctic 73(2):195–205.

MacArthur, R. A., V. Geist, and R. H. Johnston. 1982. Cardiac and behavioral responses of mountain sheep to human disturbance. Journal of Wildlife Management 46:351–358.

McKinney, M. A., T. C. Atwood, S. J. Iverson, and E. Peacock. 2017. Temporal complexity of southern Beaufort Sea polar bear diets during a period of increasing land use. Ecosphere 8(1):e01633.

McLellan, B. N. 1990. Relationships between human industrial activity and grizzly bears. Bears: Their Biology and Management 8:57–64.

Meier, W. N., D. Perovich, S. Farrell, C. Haas, S. Hendricks, A. A. Petty, M. Webster, D. Divine, S. Gerland, L. Kaleschke, et al. 2021. Sea ice. NOAA Technical Report OAR ARC 21-05. Arctic Report Card 9. https://doi.org/10.25923/y2wd-fn85. Accessed 9 Sep 2023

Miller, N. P. 1995. Report on effects of aircraft overflights on the National Parks System. Executive Report to Congress. No. NPS-D-1062. United States Department of the Interior, Washington, D.C., USA.

Miller, S., J. Wilder, and R. R. Wilson. 2015. Polar bear–grizzly bear interactions during the autumn open-water period in Alaska. Journal of Mammalogy 96:1317–1325.

Nevalainen, M., I. Helle, and J. Vanhatalo. 2017. Preparing for the unprecedented—towards quantitative oil risk assessment in the Arctic marine areas. Marine Pollution Bulletin 114(1):90–101.

Nicholas, B. L. 2021. Noise levels for aircraft on Alaska's North Slope for polar bear and walrus impacts analysis. US DOT Volpe Center Draft Report DOT-VNTSC-FWS-21-01. U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Owen, M. A., A. M. Pagano, S. S. Wisdom, B. Kirschhoffer, A. E. Bowles, and C. O'Neill. 2021. Estimating the audibility of industrial noise to denning polar bears. Journal of Wildlife Management 85:384–396.

Pagano, A. M. and T. M. Williams. 2019. Estimating the energy expenditure of free-ranging polar bears using tri-axial accelerometers: a validation with doubly labeled water. Ecology and Evolution 9:4210–4219.

Plummer, M. 2003. JAGS: a program for analysis of Bayesian graphical models using Gibbs Sampling. Technische University at Wien, Vienna, Austria.

R Development Core Team. 2023. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Scharf, H., M. B. Hooten, and D. S. Johnson. 2017. Imputation approaches for animal movement modeling. Journal of Agricultural, Biological and Environmental Statistics 22:335–352.

Schliebe, S., K. D. Rode, J. S. Gleason, J. Wilder, K. Proffitt, T. J. Evans, and S. Miller. 2008. Effects of sea ice extent and food availability on spatial and temporal distribution of polar bears during the fall open-water period in the Southern Beaufort Sea. Polar Biology 31:999–1010.

Smith, L. C., and S. R. Stephenson. 2013. New Trans-Arctic shipping routes navigable by midcentury. Proceedings of the National Academy of Sciences 110(13):E1191–E1195.

Stinchcomb, T. R., T. J. Brinkman, and S. A. Fritz. 2019. A review of aircraft-subsistence harvester conflict in Arctic Alaska. Arctic 72(2):131–150.

Togunov, R. R., A. E. Derocher, N. J. Lunn, and M. Auger-Méthé. 2022. Drivers of polar bear behavior and the possible effects of prey availability on foraging strategy. Movement Ecology 10(1):50.

U.S. Fish and Wildlife Service [USFWS]. 2021. Marine mammals; incidental take during specified activities; North Slope, Alaska. Federal Register 86(148):42982–43074.

Van Hemert, C., P. L. Flint, M. S. Udevitz, J. C. Koch, T. C. Atwood, K. L. Oakley, and J. M. Pearce. 2015. Forecasting wildlife response to rapid warming in the Alaskan Arctic. BioScience 65:718–728.

Weisenberger, M. E., P. R. Krausman, M. C. Wallace, D. W. De Young, and O. E. Maughan. 1996. Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates. Journal of Wildlife Management 60:52–61.

Whiteman, J. P., H. J. Harlow, G. M. Durner, R. Anderson-Sprecher, S. E. Albeke, E. V. Regehr, S. C. Amstrup, and M. Ben-David. 2015. Summer declines in activity and body temperature offer polar bears limited energy savings. Science 349: 295–298.

Whiteman, J. P., H. J. Harlow, G. M. Durner, E. V. Regehr, S. C. Amstrup, A. M. Pagano, and M. Ben-David. 2022. The acute physiological response of polar bears to helicopter capture. Journal of Wildlife Management 86:e22238.

Wiig, Ø., S. N. Atkinson, E. W. Born, S. Stapleton, T. Arnold, M. Dyck, K. L. Laidre, N. J. Lunn, and E. V. Regehr. 2022. An on-ice aerial survey of the Kane Basin polar bear (*Ursus maritimus*) subpopulation. Polar Biology 45:89–100.

Wilson, R. R., E. V. Regehr, M. S. Martin, T. C. Atwood, E. Peacock, S. Miller, and G. Divoky. 2017. Relative influences of climate change and human activity on the onshore distribution of polar bears. Biological Conservation 214:288–294.

Woodruff, S. P., E. M. Andersen, R. R. Wilson, L. S. Mangipane, S. B. Miller, K. J. Klein, and P. R. Lemons. 2022. Classifying the effects of human disturbance on denning polar bears. Endangered Species Research 49:43–56.

Yun, E., J. Kim, and C. Kim. 2011. Logistic regression method in interval-censored data. Korean Journal of Applied Statistics 24:871–881.

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