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Title	Ecological insights from three decades of animal movement tracking across a changing Arctic
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Coláiste na hOllscoile Corcaigh

Title: Ecological insights from three decades of animal movement tracking across a changing Arctic

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Abstract: The Arctic is entering a new ecological state, with alarming consequences for humanity. Animal-borne sensors offer a unique window into these changes. Although substantial animal tracking data from the Arctic and Subarctic exist, most are difficult to discover and access. Here we utilize the new Arctic Animal Movement Archive (AAMA), a growing collection of 201 standardized terrestrial and marine animal tracking studies from 1991–present. The AAMA supports public data discovery, preserves fundamental baseline data for the future, and facilitates efficient, collaborative data analysis. With AAMA-based case studies, we document climatic influences on the migration phenology of eagles, geographic differences in adaptive response of caribou reproductive phenology to climate change, and species-specific changes in terrestrial mammal movement rates in response to increasing temperature.

One Sentence Summary: The Arctic Animal Movement Archive facilitates long-term and large-scale ecological studies of the Arctic and reveals the timing and extent of changes to animal behavior patterns.

Main Text

The Arctic and adjacent regions are experiencing the most rapid climate and environmental changes on Earth, caused primarily by anthropogenic greenhouse gas emissions (*1*). Striking trends include warming winter temperatures, ice loss, and earlier spring snowmelt. These changes profoundly affect conditions experienced by animals, including food availability, interspecific competition, predation and increased human disturbances (*2*). Impacts of climate change on Arctic vertebrates include rapid poleward range shifts (*3, 4*), phenological trophic mismatches (*5*), and changes in migration (*6*), foraging, and predator-prey dynamics (*7*). Because rapid environmental change in the Arctic challenges the ability of the region's fauna to adapt, a primary response will likely occur through phenotypic plasticity in the patterns, locations, and timing of their movements (*2*). Documenting and understanding these changes requires multi-decadal, pan-Arctic data at multiple trophic levels.

We demonstrate the ecological utility of the Arctic Animal Movement Archive (AAMA), an active, collaborative collection of animal tracking datasets (S.M). Marine ecology archives, such as IOOS-ATN, IMOS, OBIS-SEAMAP, and (*8*), provide insight regarding space use, movement and connectivity (e.g., *9, 10, 11*). Terrestrial animal movement archives are rare and

tend to have a regional or taxonomic focus (e.g., *12*). AAMA is the first Arctic-focused archive with both terrestrial and marine data and is hosted on the global Movebank database. The geographic scope of the AAMA (Fig. 1) includes the Arctic, Arctic-marine, and Subarctic 'boreal forests/taiga' regions defined by (*13*) and (*14*) (S.M.). The dataset contains over 15,000,000 occurrences of 8,000 individuals representing 96 species, from 1991–present (Fig. S.1–S.2, Tables S.1–S.4). Combining data from multiple AAMA studies, we show evidence of (1) climate drivers of golden eagle migration phenology, (2) climate adaptation of parturition by caribou, and (3) consequences of increased temperature and precipitation on movements of mammalian predators and herbivores.

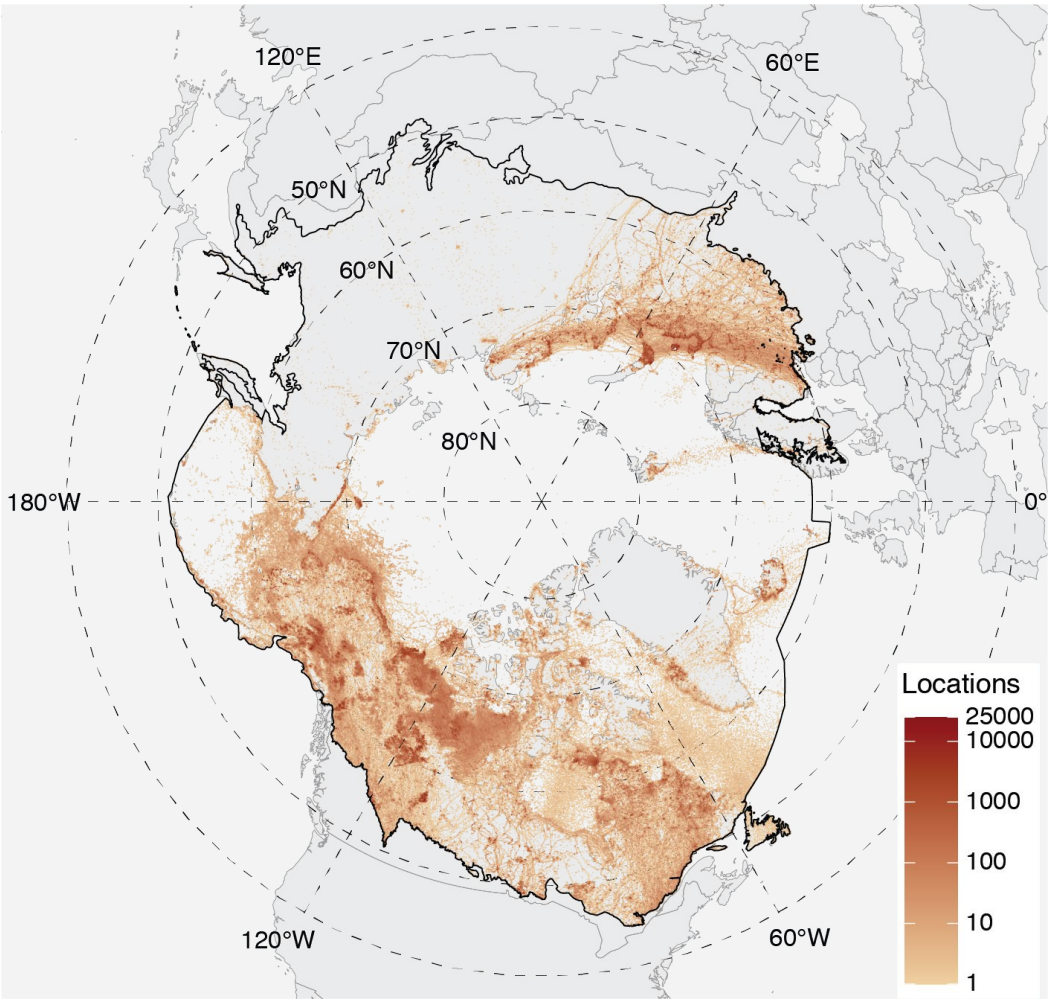

Fig. 1. Map of the AAMA boundary and data. Density of animal locations at logarithmic scale characterizes data availability, not animal density or utilization.

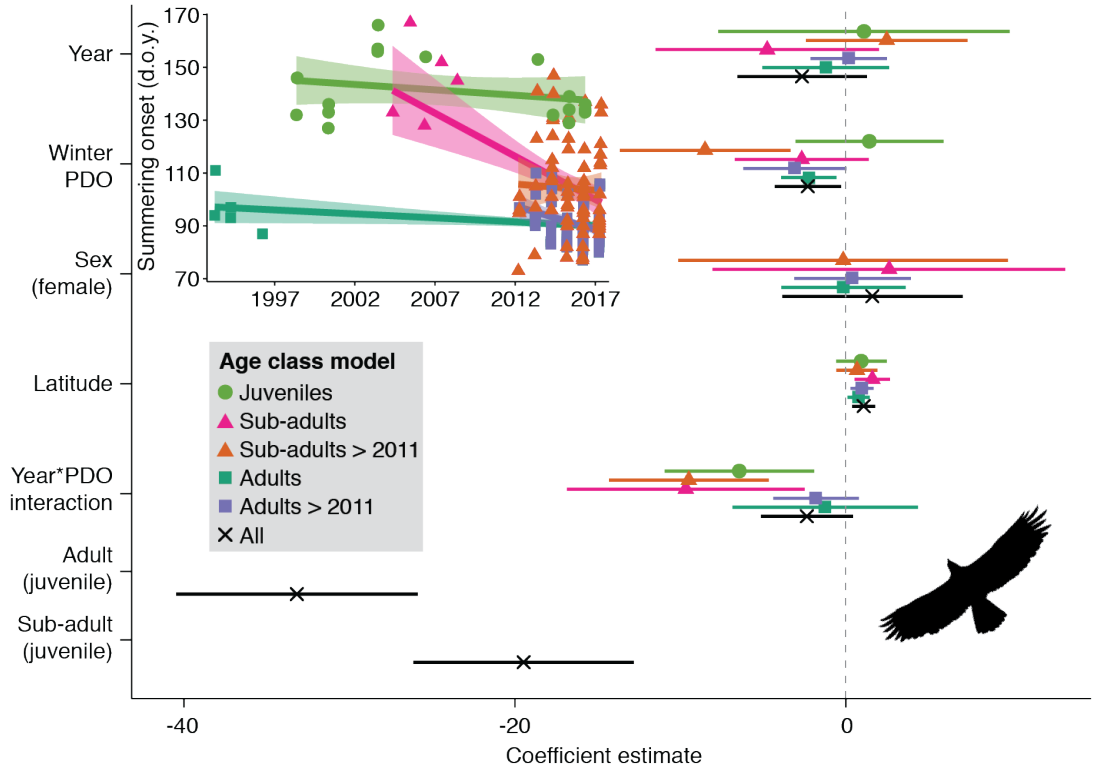

Fig. 2. Changes in the onset date of golden eagles' summering. Coefficient estimates (±95% CI) reflecting age-specific changes in response to year, previous winter PDO, sex (reference: females), latitude, the interaction of year and PDO, and age class (reference: juveniles; Tables S.8–S.9). Inset: time series of model-estimated summering.

Behavioral flexibility enables migrants to optimize energy expenditure during migration and adjust arrival at summering grounds (*15, 16*). We used tracking data from 103 individuals during 1993–2017 (S.M., Table S.5) to examine arrival timing to breeding grounds of northward migrating golden eagles ('summering'), modeling it with predictors for age, sex, summering onset latitude, year, and preceding-winter mean Pacific Decadal Oscillation index (PDO).

Mean summering date changed slowly over 25 years (-0.5 days/year). The long-term trend differed among age classes, with adults arriving earliest, followed by sub-adults and then juveniles, and was influenced by winter climate (PDO, Fig. 2; Tables S.8–S.9). Eagles of all age classes began summering later at northern latitudes (1.08 days/degree). The significant interaction of year and previous "warm-phase" PDO explains earlier summering dates for sub-adults and juveniles, highlighting their known responsiveness to environmental conditions (*16*). These warm-phase winters cause warmer and drier climate with reduced snowpack and an earlier snow-free date. Earlier adult arrival to summering grounds should result from selection and competition for territories, yet local climatic variables affect eagle condition prior to, and energy expenditure during, northward migration (*16*). For sub-adults sampled after 2011, the direct effect of PDO is significant, whereas in the full dataset the direct effect of year replaces PDO (Fig. 2). This period-related difference in inference of climatic drivers highlights the importance of compiling long-term, multi-generational observations. Given the importance of the winter PDO and known impacts of global climate change, golden eagles could face age-specific challenges during migration and at their warming Arctic summering grounds.

The timing of parturition is a key to the demography of wildlife populations, and can be an adaptive response to climate shifts (*17*). For many mammals, the period from late pregnancy through weaning has the highest energetic demands, and thus is timed to occur when vegetation productivity is highest (*18*). Caribou occur in five different ecotypes (Fig. 3) across Boreal and Arctic North America, and are facing global declines (*19*). Using data from 928 individuals during 2000–2017 in northern Canada, we used characteristic patterns of low movement during the calving season to estimate 1647 parturition dates in five populations of barren-ground, boreal, and mountain caribou (S.M., Table S.6).

We found differences in parturition timing and trends among five populations. The southern and northern-boreal populations calved earliest, followed by northern and southern mountain populations (Table S.10). Barren-ground caribou calved later despite occupying a similar latitudinal range as the northern-boreal caribou (Fig. 3). Most importantly, only northern boreal caribou exhibited significant trends towards earlier parturition (0.4–1.1 days/year, Table S.10). This is the first continental-scale retrospective evidence of potential adaptive responses to climate trends by caribou.

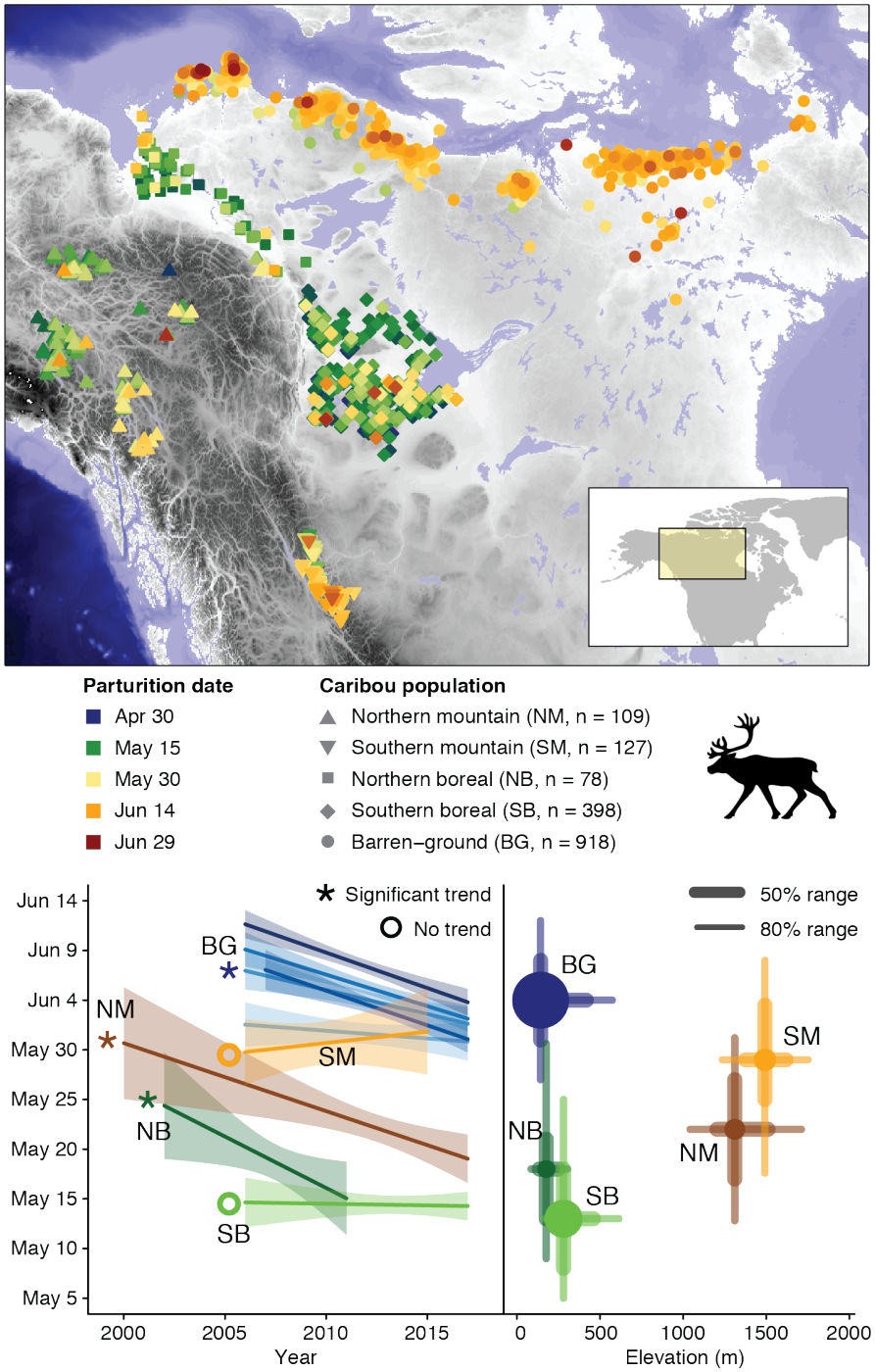

Fig. 3. Climate-change adaptation of parturition times (PT) of caribou. Top (map): PT by population. Bottom left: PT trends by population, including five BG subpopulations. Bottom right: PT dates by elevation.

Animals conserve energy by modifying their behavior in response to weather conditions, with important implications for individual fitness and species resilience under climate change (*20*). We tested for effects of temperature and precipitation on seasonal movement rates (m/min) using records from 1,720 individuals of two herbivore and three predator species (black bear, grizzly bear, caribou, moose, and wolf) during 1998–2019 (S.M., Table S.7). We predicted that winter movement rates would decline relative to summer, when energetic costs of self-maintenance would be highest. Rate would also decline within seasons, during weather conditions that increase the energetic cost of movement (snow that increases energy requirements for movement, higher ambient temperatures during the summer that accelerate metabolism).

All species exhibited lower movement rates during winter relative to summer (Fig. 4). As temperatures increased in summer, wolves and black bears slowed their movement rates, while moose increased their movement rates. In winter, only barren-ground caribou increased movement rates as temperature increased. Snow impeded wolves, boreal caribou, and moose, whereas all species were generally insensitive to summer precipitation. These patterns may reflect asynchronous responses to climate change within and across trophic levels. Climate-driven variation in animal activity is likely to affect species interactions, altering energy expenditure, encounter rates, and foraging success with demographic implications for both predators and prey.

As we demonstrate, the AAMA provides a solution to Arctic data collection and sharing challenges. It serves as a critical baseline and resource to identify early signals of local or large-scale changes in animal distribution, movement responses, and adaptive traits. Continued shifts in phenology in the Arctic pose challenges to migratory species that encounter changing seasonal fluctuations along migration routes, and at Arctic summering and southern wintering grounds (*21*). Key drivers of population responses, such as migration, parturition, and foraging movement, are undergoing rapid changes, suggesting that climate change is affecting animals in ways that will shape the future of the Arctic.

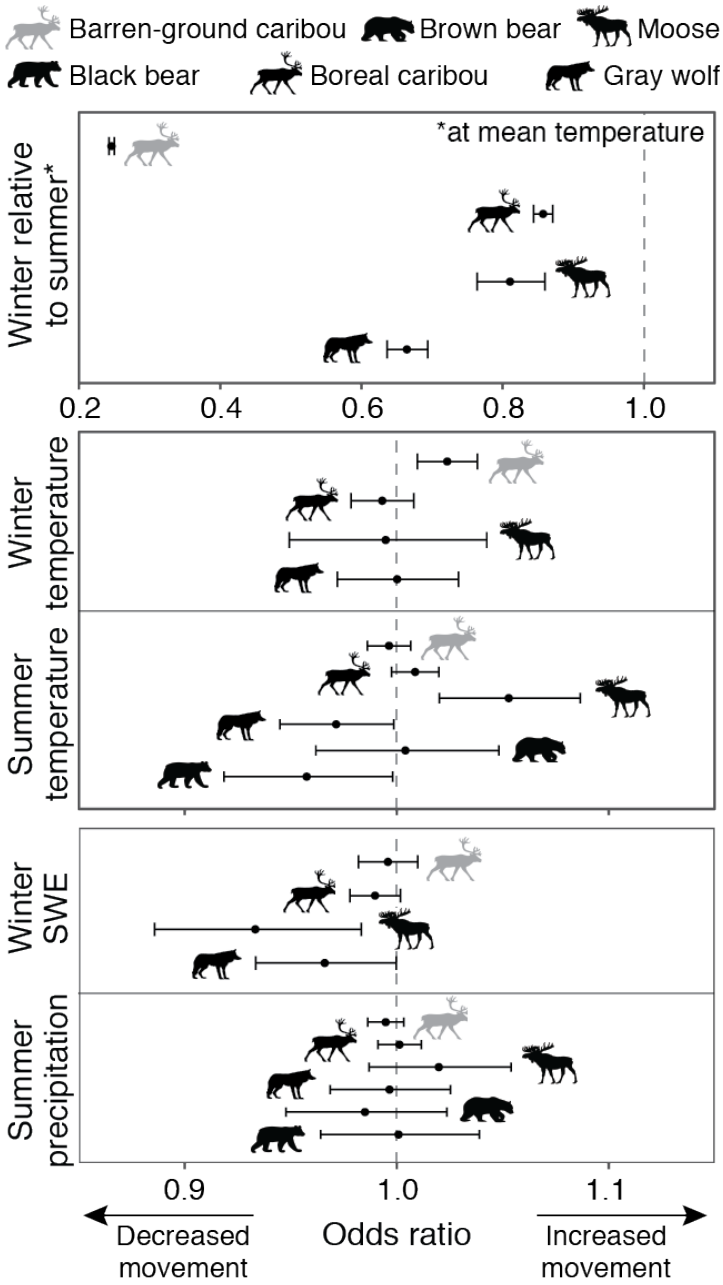

Fig. 4. Changes in species-specific movement rates in response to daily maximum temperature, summer precipitation and winter snow-water equivalent (SWE). Odds ratios for continuous covariates represent the positive or negative change in movement rates per one unit change in temperature or precipitation, respectively. Ratios were identified as neutral if credible intervals overlapped one.

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Supplementary Materials:

Methods

Figures S.1-S.2

Tables S.1-S.10

References (*22-63*)

Science AAAS

Supplementary Materials for

Ecological insights from three decades of animal movement tracking across a changing Arctic

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Materials and Methods:

Arctic Animal Movement Archive (AAMA)

The AAMA enables the discovery and use of Arctic and Subarctic animal movement data. The AAMA is hosted on Movebank (movebank.org), a global research platform for animal tracking and bio-logging data. We defined the geographic scope of the AAMA to include marine and terrestrial Arctic areas defined by the Arctic Monitoring and

Assessment Programme *(13)* (shapefile available from https://www.amap.no/about/geographical-coverage) and Subarctic land regions represented as 'boreal forests/taiga' as classified by the Nature Conservancy *(14)* (shapefile available from http://maps.tnc.org/files/metadata/TerrEcos.xml). The AAMA boundary and the observation density within it are shown in Fig. 1. We calculated the density of animal occurrences shown in Fig. 1 as location counts within 10-km hexagonal grid cells (spacing 9.68 km, area 95.98 km^2) in equal area projection in R using the *dggridR* package (*22*).

The AAMA is a living archive. Many ongoing studies continuously add data, and new participants and studies can join. Data in the AAMA are organized into studies, with each study (i.e. dataset) managed by one or more data owners. Studies participating in the AAMA as of November 2019 are listed in Table S.1. Participating studies include data within the geographic area described above and can include additional data from other regions, thus supporting inclusion of species that spend substantial portions of their annual life cycle in temperate or tropical regions, and future inclusion of species that enter the region due to northward range shifts. The AAMA preserves the data, harmonizes it, and makes it discoverable by publishing the metadata. All data are curated to ensure they are accurately stored and include sufficient descriptive detail. AAMA Participants retain ownership of their data, with the option to allow public download or limit access to approved users. Study-level information including species, tagging method, number of animals and locations, time period covered, project description and available citations, and owner contact information are publicly available, searchable online, and by API. In all cases, data owners can be contacted directly to discuss data access and proposed uses. Location and other sensor data from the majority of participating studies are available for public download from the AAMA (currently 56% of the data), and many represent datasets formally published through the Movebank Data Repository. The AAMA offers assistance for potential users in negotiating data sharing and maintains current contact information for study owners. Reasons for access-controlled sharing include (i) data are still being actively collected and are not yet quality controlled, (ii) public knowledge of animal locations could compromise conservation efforts, and (iii) legal or contractual restrictions prohibit uncontrolled public data access. The AAMA's support for public and controlled-access sharing provides a solution that preserves and allows collaboration using data that would otherwise remain undiscoverable, and in many cases would eventually be lost (e.g., after the data owner retires). All data in the AAMA were collected using appropriate animal care permissions (Table S.3). Funding sources for data collection are provided in Table S.4. Current information about participating studies, how to download or request data, and how to join the archive and provide new datasets is available at the AAMA landing page (https://www.movebank.org/cms/movebank-content/arctic-animal-movement-archive).

The organization of studies in the AAMA on the Movebank platform represents significant efforts to document and organize data using a consistent format, vocabulary, and set of quality-control procedures. This reduces the time needed to prepare data for sharing and integration in combined analyses, and provides a single access point, thus minimizing logistical efforts needed for construction of data ensembles to address large-scope research questions in meaningful meta-analyses. Furthermore, automated data feeds and management tools promote further participation by allowing data owners to efficiently add and maintain studies over time. We solicit additional participation in the AAMA, both by data owners and those conducting new analyses. As the archive and period of record grow, it will allow increasingly rigorous testing of hypotheses about human-driven, climate-induced, or other natural effects on animal movement, distribution and behavior.

Case Study 1. Long-term data reveal influence of decadal climate patterns on summering behavior in a migratory raptor

We used 569,720 location estimates collected from 146 golden eagles (*Aquila chrysaetos*) in 12 AAMA studies across western North America (Table S.5). Records were imported into R via the *move* package (*23*). We assigned all individuals to one of three age categories: juvenile (survived up to the onset of its 2nd southbound migration), sub-adult (surviving up to the onset of its 4th southbound migration), or adult (surviving past the onset of its 4th southbound migration) (*16, 24*). We incorporated into analyses instances where individuals were observed during an age-class transition. Breeding status was not considered in analyses because it was not determined for all individuals. We identified the onset of golden eagle summering behavior via a mechanistic range shift analysis (MRSA (*25*)) in R with the *marcher* package (*26*). The model was fit with the maximum likelihood method, and we used the Ornstein-Uhlenbeck model option to estimate ranging behavior. We modified the MRSA slightly by forcing the model to fail if a data gap of >30 days occurred. We inspected start dates and locations to remove

spurious model results due to tag deployments that ended during spring migration or began during summer. This process yielded 179 summering onset estimates with modelled start and end dates made by 103 eagles (Table S.5).

We used linear mixed-effects models in R via the *lme4* package (version 1.1-17) (*27*), fit by restricted maximum likelihood to assess the significance of year (fixed, continuous, scaled), eagle sex and age during migration (both fixed, categorical), latitude (fixed, continuous), and PDO (fixed, continuous) in explaining golden eagle summering onset date. For adults and subadults, we included eagle individuals as a random term to account for repeated measures for some individuals (n = 49), but not for juveniles, due to a lack of repeated measures. We mean-centered year and included an interaction between year and PDO. We averaged the monthly mean PDO (*28, 29*) of the preceding winter (November to March) to explore the influence of this large-scale climate indicator on golden eagle behavioral phenology. Multi-collinearity between predictor variables did not exceed recommended variance-inflation levels (*30*). We performed model selection in R using the *dredge* function of the *MuMIn* package (*31*) and report results from the conditional averaged models. We first ran a model including eagles of all age classes to explore differences in age classes. We then analyzed each age class separately to facilitate interpretation. Because few summering onsets before 2011 were available for adults and sub-adults, we also compared model-averaged results for the full sets of adult and subadult observations (n = 89, n = 72, respectively) to those for the post-2011 adult and subadult observations (n = 83, n = 67, respectively).

Case Study 2. Large-scale geographic differences in parturition timing of caribou

We used caribou movement data in 13 AAMA studies (Table S.6). Among the caribou in our study, woodland caribou (*Rangifer tarandus caribou*) are considered a separate subspecies from barren-ground caribou (*R. t. groenlandicus*), which are known for their long-distance calving migrations. Woodland caribou are further classified as belonging to different ecotypes, including boreal and mountain, which differ by habitat and behavioral phenotype. Following exploratory analysis, we further partitioned woodland caribou by geographic area into northern and southern mountain and boreal caribou. Barren-ground caribou data were partitioned into their largely coherent reproductive subpopulations (herds).

Parturition dates were estimated by adapting methods described in (*32*) for each of the two subspecies. For *R. t. caribou*, we analyzed movements between April 28 and June 30 and found times when movement activity decreased suddenly and persistently below 5 threshold speeds (10, 15, 20, 25, and 30 m/h), and conservatively retained those parturitions where three of five thresholds agreed within a day of each other. For barren-ground caribou, which calve significantly later and shortly after completing a long-distance migration, we adapted the individual-based method (*32*), which fits a non-calving model, in which movement rates remain constant throughout the study period, and a calving model, where there is a sudden drop in movement rate followed by a progressive increase. The models were fit using maximum likelihood, and AIC was used as a criterion to determine which model was selected. Tests for the effects of latitude, longitude, elevation, and year on parturition dates were conducted using a combination of linear models, generalized additive models, and mixed effects models, with individuals as a random effect. The *R. t. groenlandicus* (barren-ground) population is subdivided into five subpopulations (herds), which were also modeled as a random effect. Results are summarized in Table S.10.

Case Study 3: Temperature and precipitation response in movement rates of terrestrial mammals

We compiled movement paths for 1,720 individuals representing five mammalian species from 22 AAMA studies: black bear, *Ursus americanus*; grizzly bear, *U. arctos*; caribou, *R. tarandus ssp.*; moose, *Alces alces*; and wolf, *Canis lupus* (Table S.7). We calculated step lengths (m) and location sampling interval (min) along each movement time series, excluding locations with sampling intervals longer than 24 hours. We annotated movement data with daily maximum temperatures (°C) and summertime precipitation or winter snow water equivalent (SWE) estimates using the Daymet data product (*33*). To match the temporal scale of Daymet, we aggregated movements by estimating daily mean step lengths and sampling intervals for each day within an individual's time series. In order to reduce the influence of seasonally dependent behaviors (e.g., migration or parturition), we partitioned data into January-only (peak winter) and July-only (peak summer) datasets. As in case study 2, we treated the two subspecies of caribou (*R. t. groenlandicus* and *R. t. caribou*) as distinct groups within our analysis due to anticipated differences in daily movement rates. We also excluded bears from the winter analyses due to lack of data; however, the very nature of their hibernation represents a reduced overwinter movement rate..

We assessed the influence of daily maximum temperature and cumulative precipitation on daily movement rates ($m \cdot min^{-1}$) using a generalized linear mixed model (GLMM) framework with the *lme4* R package (*27*). Because movement rates are positive continuous, we used discretized step lengths (rounded to the nearest meter) as the response and location sampling interval as an offset in a GLMM with negative binomial errors. Prior to modeling, we standardized daily temperature and precipitation estimates by subtracting means and dividing by one standard deviation, each estimated at the study level by season in an effort to account for regional differences in exposure to weather conditions. We evaluated two models for each species represented by an interaction between season (January or July) and a single climate metric: season × temperature and season × precipitation. However, we used SWE ($kg \cdot m^2$) as a measure of snow cover during the winter and daily total precipitation (mm) during the summer. We included random intercepts for individual nested within study crossed within year to account for variation in individual movement rates and sample sizes within and across studies. As there was a single study for bears, we included random intercepts for individual and year only. Variable effectiveness was determined by coefficient confidence interval overlap with zero, where an overlap indicating the effect is neutral (i.e., no change).

Fig. S1.

Summary of the content of studies participating in the AAMA as of November 2019. Temporal range and number of individuals in each study (Table S.1) colored by species group (Table S.2). Note logarithmic scale on y-axis.

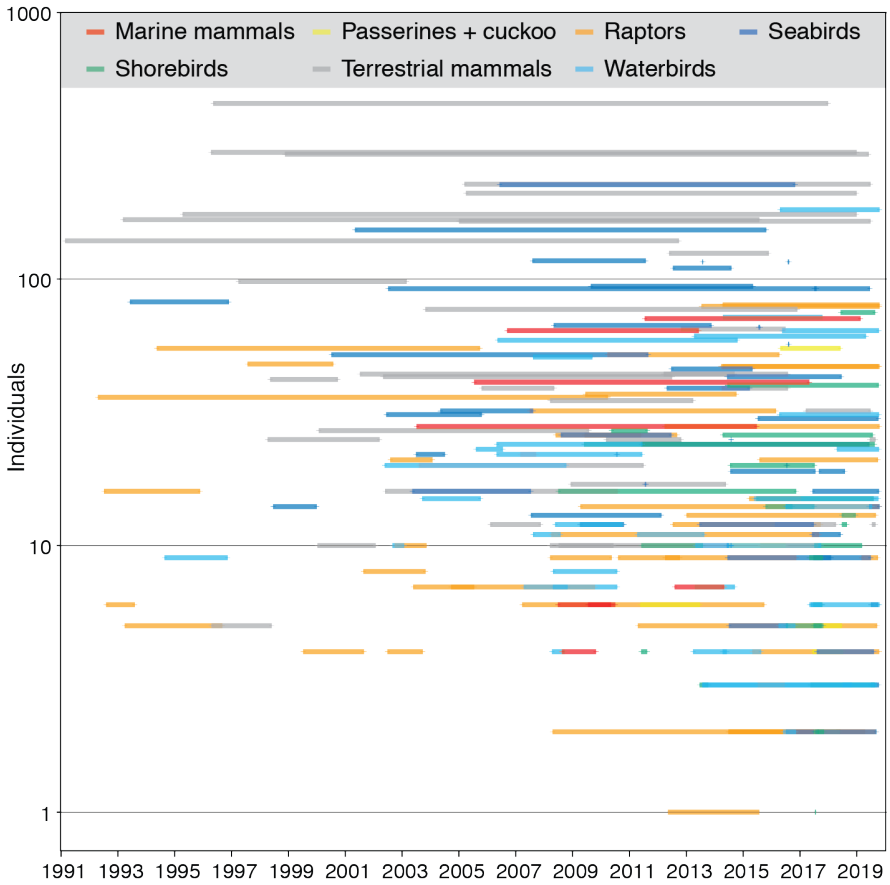

Figure S.2.

The number of locations per year per species group for data participating the AAMA as of November 2019. The number of locations includes only those with locations within the AAMA boundary. See Table S.2 for species assigned to each species group.

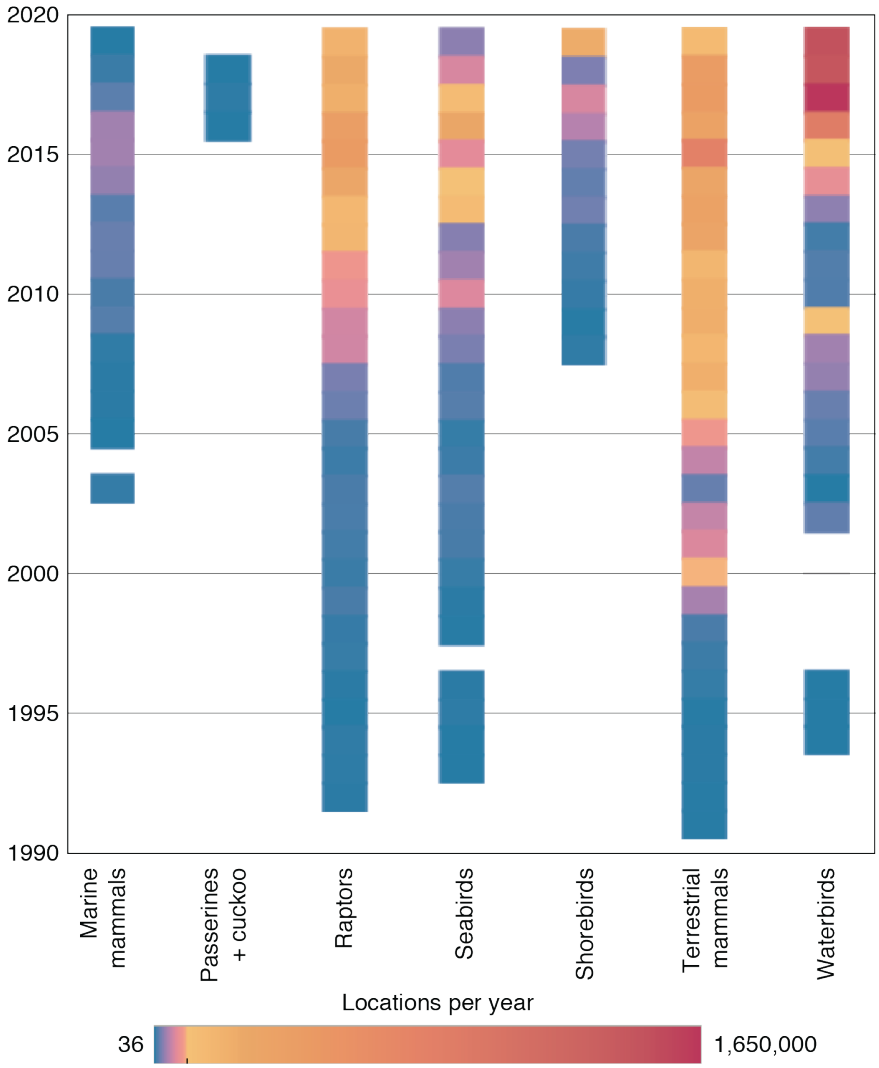

Table S1.

Studies participating in the AAMA as of November 2019. 'Study name' and 'Study ID' refer to the dataset as stored in a study on Movebank. 'Species' and 'Years' are based on locations within the AAMA boundary. 'Animals' shows the number of individuals with locations within the AAMA boundary, followed in parentheses, by the total number of animal individuals that were tracked in the study, regardless of location. Superscript 'CSx' in 'Study name' indicates studies used in the case studies where x is the case study number (Tables S.5–S.7). 'Data ref' lists the citation for published study datasets. Current information about participating studies, and information about how to join, is available at the AAMA landing page.

Study name	Study ID	Location sensors	Species	Animals	Years	Data ref.
ABoVE: ADFG Fortymile River Brown Bears	199248940	GPS	*Ursus arctos*	10 (10)	2008–2014	
ABoVE: ADFG Mulchatna Caribou	194796273	GPS	*Rangifer tarandus*	39 (39)	2014–2016	
ABoVE: BC Atlin Caribou [CS2, CS3]	238680850	GPS	*Rangifer tarandus*	10 (10)	2000–2002	
ABoVE: Boelman Alberta American Robins	136953438	GPS, Argos Doppler	*Turdus migratorius*	55 (55)	2016–2018	
ABoVE: Boutin Alberta Grey Wolf [CS3]	492444603	GPS	*Canis lupus*	44 (44)	2012–2014	
ABoVE: Boutin Alberta Moose [CS3]	302664172	GPS	*Alces alces*	25 (25)	2010–2012	
ABoVE: Hebblewhite Alberta-BC Wolves [CS3]	209824313	GPS	*Canis lupus*	27 (68)	2000–2009	
ABoVE: NPS Dall Sheep Lake Clark	240650779	GPS	*Ovis dalli*	39 (39)	2005–2008	
ABoVE: NPS Denali Bears	197244288	Radio Transmitter	*Ursus arctos*	139 (139)	1991–2012	
ABoVE: NPS Denali Wolves [CS3]	223402683	GPS	*Canis lupus*	77 (77)	2003–2016	
ABoVE: NPS Lake Clark Wolves	164639210	GPS	*Canis lupus*	17 (17)	2008–2014	
ABoVE: NPS Moose in the Upper Koyukuk Alaska	143848765	GPS	*Alces alces*	35 (35)	2008–2013	
ABoVE: NPS Wolves in Yukon-Charley Rivers National Preserve [CS3]	183074887	GPS, Radio Transmitter	*Canis lupus*	167 (167)	1993–2015	
ABoVE: NWT Dehcho Boreal Woodland Caribou [CS2, CS3]	384182382	GPS, Argos Doppler	*Rangifer tarandus*	165 (165)	2005–2019	
ABoVE: NWT Inuvik Barren Ground Caribou [CS2, CS3]	579621649	GPS, Argos Doppler	*Rangifer tarandus*	456 (456)	1996–2017	
ABoVE: NWT Inuvik Boreal Woodland Caribou [CS2, CS3]	532613794	GPS, Argos Doppler	*Rangifer tarandus*	43 (43)	2002–2012	
ABoVE: NWT North Slave Barren Ground Caribou: Bathurst [CS2, CS3]	140788890	GPS, Argos Doppler	*Rangifer tarandus*	299 (299)	1996–2018	

ABoVE: NWT North Slave Boreal Caribou [CS2, CS3]	469002388	GPS	*Rangifer tarandus*	32 (32)	2017–2019
ABoVE: NWT Sahtu Barren Ground Caribou: Bluenose-East [CS2, CS3]	148449793	GPS, Argos Doppler	*Rangifer tarandus*	210 (210)	2005–2018
ABoVE: NWT Sahtu Boreal Woodland Caribou [CS2, CS3]	151021631	GPS, Argos Doppler	*Rangifer tarandus*	20 (20)	2003–2011
ABoVE: NWT Sahtu Mountain Woodland Caribou [CS2, CS3]	151041376	GPS, Argos Doppler	*Rangifer tarandus*	16 (16)	2002–2010
ABoVE: NWT South Slave Barren Ground Caribou: Beverly and Ahiak [CS2, CS3]	242950074	GPS, Radio Transmitter	*Rangifer tarandus*	175 (175)	1995–2018
ABoVE: NWT South Slave Barren Ground Caribou: Queen Maud Gulf	149369862	Argos Doppler	*Rangifer tarandus*	5 (5)	1996–1998
ABoVE: NWT South Slave Boreal Woodland Caribou [CS2, CS3]	149370498	GPS, Argos Doppler	*Rangifer tarandus*	227 (227)	2005–2019
ABoVE: Peters Hebblewhite Alberta-BC Moose [CS3]	178994931	GPS	*Alces alces*	10 (19)	2008–2010
ABoVE: USFWS R6 Golden Eagles [CS1]	240931758	GPS	*Aquila chrysaetos*	2 (2)	2014–2019
ABoVE: USGS/WVU Raptors [CS1]	182803629	GPS	*Aquila chrysaetos, Haliaeetus leucocephalus*	9 (9)	2012–2016
ABoVE: Yukon Caribou [CS2, CS3]	168279948	GPS, Argos Doppler	*Rangifer tarandus*	294 (294)	1998–2019
ADACLIM	365245962	Solar Geolocator	*Alle alle*	94 (94)	2009–2015
ADF&G Nelchina Caribou	171485485	GPS	*Rangifer tarandus*	125 (125)	2012–2015
ADF&G Susitna Valley Moose	205534405	GPS	*Alces alces*	65 (65)	2012–2016
Adult Golden Eagle Satellite Tracking [CS1]	5009273	GPS, Argos Doppler	*Aquila chrysaetos*	14 (25)	2009–2019
Alaska Golden Eagles [CS1]	17680093	GPS, Argos Doppler	*Aquila chrysaetos*	47 (47)	2014–2019
Aquila chrysaetos interior west N. America, Craigs, Fuller [CS1]	38866222	Argos Doppler	*Aquila chrysaetos*	5 (21)	1993–1996
Aquila chrysaetos Mark Fuller North America	1111541	Argos Doppler	*Aquila chrysaetos*	6 (6)	1992–1993
Arctic breeding shorebirds; Rausch; various Canadian arctic locations	22390461	Argos Doppler	*Pluvialis squatarola, Numenius phaeopus*	40 (40)	2014–2019
Arctic fox Bylot - Argos tracking	942774711	Argos Doppler	*Vulpes lagopus*	12 (12)	2019–2019
Arctic hare Alert - Argos tracking	887332716	Argos Doppler	*Lepus arcticus*	25 (25)	2019–2019
Arctic Raptors - www.ArcticRaptors.ca	1924571	GPS	*Falco peregrinus*	26 (26)	2008–2012

Arctic shorebird migration tracking study - American Golden-Plover	565443493	GPS	*Pluvialis dominica*	13 (13)	2018–2018
Arctic shorebird migration tracking study - Dunlin	565467203	GPS	*Calidris alpina*	6 (6)	2017–2017
Arctic shorebird migration tracking study - Pectoral Sandpiper	560144617	GPS	*Calidris melanotos*	12 (12)	2018–2018
Arctic shorebird migration tracking study - Semipalmated Sandpiper	606508137	GPS	*Calidris pusilla*	1 (1)	2017–2017
Arctic Skua, Faroe Islands, GPS	922875688	GPS	*Stercorarius parasiticus*	11 (11)	2017–2018
Arctic Skua, van Bemmelen, Norway	968984187	Solar Geolocator Raw	*Stercorarius parasiticus*	43 (43)	2014–2018
Arctic Skua, van Bemmelen, Tobseda	976692287	Solar Geolocator Raw	*Stercorarius parasiticus*	5 (5)	2014–2016
Arctic Tern Alaska	727170503	Solar Geolocator Raw	*Sterna paradisaea*	9 (9)	2017–2019
Atlantic puffin in Iceland (Petersen)	943122207	Solar Geolocator	*Fratercula arctica*	13 (13)	2007–2012
Atlantic Seabird Study (Red-Throated Loons)	37025629	Argos Doppler	*Gavia stellata*	39 (62)	2012–2015
Atlantic Seabird Study (Surf Scoters)	1508766	Argos Doppler	*Melanitta perspicillata*	153 (192)	2001–2015
Azores Great Whales Satellite Telemetry Program	72289508	Argos Doppler	*Balaenoptera physalus, Balaenoptera borealis*	6 (36)	2008–2010
Bald Eagle Haliaeetus leucocephalus Mojica/Watts	7917413	GPS, Argos Doppler	*Haliaeetus leucocephalus*	11 (72)	2008–2017
Bald Eagles in coastal Alaska; Lewis	105181396	GPS	*Haliaeetus leucocephalus*	5 (13)	2011–2019
Barnacle goose (Greenland) Larry Griffin/David Cabot	6946314	GPS	*Branta leucopsis*	8 (9)	2008–2010
Barnacle goose (Svalbard) Larry Griffin	6956518	GPS, Argos Doppler	*Branta leucopsis*	24 (31)	2006–2011
Bean Goose Anser fabalis Finnmark.	11223924	GPS	*Anser fabalis*	3 (3)	2013–2019
Beringia Dunlin	939826359	Solar Geolocator Raw	*Calidris alpina*	27 (27)	2010–2011
Beringia South Migrant Golden Eagle [CS1]	212420825	GPS	*Aquila chrysaetos*	1 (1)	2012–2015
Black-bellied Plover Alaska	77248725	Argos Doppler	*Pluvialis squatarola*	15 (15)	2015–2019
Black-legged Kittiwakes; Mallory/Gaston/Akearok, Prince Leopold Island, Nunavut, Canada	40008075	GPS	*Rissa tridactyla*	10 (10)	2014–2014

Bowhead whale Admiralty Inlet	920007556	Argos Doppler	*Balaena mysticetus*	4 (4)	2008–2009	
Bowhead whale Cumberland Sound	467034665	Argos Doppler	*Balaena mysticetus*	41 (41)	2005–2017	
Bowhead whale Foxe Basin	467031755	Argos Doppler	*Balaena mysticetus*	28 (28)	2003–2015	
Brant Geese Sean Boyd 2002	1495582	Argos Doppler	*Branta bernicla*	10 (10)	2002–2003	
Brant Geese Sean Boyd 2005	1518377	Argos Doppler	*Branta bernicla*	23 (23)	2005–2006	
Broad-winged Hawk Alberta Boreal	77253173	Argos Doppler	*Buteo platypterus*	3 (3)	2015–2016	
Brown and Black bear (Ursus spp.), Jerry Belant, Alaska CS3	1574786	GPS	*Ursus americanus, Ursus arctos*	42 (42)	1998–2000	
Canadian Ringed Plover geolocation tracking, Bylot Island, Canada (data from Léandrii-Breton et al. 2019)	849807214	Solar Geolocator, Solar Geolocator Raw	*Charadrius hiaticula*	20 (20)	2014–2017	(*34*)
Common cuckoo, Kamchatka	290504591	Argos Doppler	*Cuculus canorus*	4 (4)	2017–2018	
Common cuckoo, Khakassia	532621861	GPS, Argos Doppler	*Cuculus canorus*	1 (4)	2018–2018	
Common Eiders; Love/Gilchrist; East Bay Island, Canada	40163576	GPS	*Somateria mollissima*	10 (10)	2014–2014	
Common Nighthawk	399353330	GPS	*Chordeiles minor*	10 (48)	2015–2017	
Common/King Eiders; East Bay Island, Nunavut; Gilchrist 2012 and 2013	8560764	Argos Doppler	*Somateria spectabilis, Somateria mollissima*	46 (46)	2012–2015	
Common/King Eiders; East Bay Island, Nunavut; Gilchrist/Mosbech 2001 and 2003	43747715	Argos Doppler	*Somateria spectabilis, Somateria mollissima*	22 (22)	2003–2004	
Common/King Eiders; Nuuk/Disko Bay/Upernavik, Greenland; Gilchrist/Mosbech; 2002 and 2003	8317873	Argos Doppler	*Somateria spectabilis, Somateria mollissima*	31 (31)	2002–2005	
Connecticut Warbler Alberta Boreal	613824346	Solar Geolocator, Solar Geolocator Raw	*Oporornis agilis*	5 (5)	2017–2018	
Distribution of spectacled eiders in Russia and Alaska 1993-1996 (data from Petersen et al. 1999)	177841261	Argos Doppler	*Somateria fischeri*	82 (82)	1993–1996	(*35*)
Disturbance of BG by IFV and IWWR	137654491	GPS	*Branta leucopsis*	64 (85)	2016–2019	
Disturbance of GWFG by IFV and IWWR	127892189	GPS	*Anser albifrons*	31 (37)	2016–2019	
Disturbance of GWFG by IFV and IWWR 2017-2018	408961322	GPS	*Anser albifrons*	23 (26)	2018–2019	

Dolphin_Union_Caribou_UAV	416289710	GPS	*Rangifer tarandus*	776 (776)	2015–2015	
Eagles Wintering in Bitterroot Valley [CS1]	17707607	GPS	*Aquila chrysaetos, Haliaeetus leucocephalus*	28 (43)	2012–2019	
Earthspan Peregrines	619061097	Argos Doppler	*Falco peregrinus*	55 (69)	1994–2005	
Eastern Montana Golden Eagles [CS1]	6853103	GPS, Argos Doppler	*Aquila chrysaetos*	12 (40)	2012–2017	
Eastern North America Golden Eagles	166509889	GPS	*Aquila chrysaetos*	52 (76)	2010–2016	
Eastern Washington Lesser Canada Goose - Delineating the breeding grounds of small Canada geese wintering in the Columbia Basin	18105431	Argos Doppler	*Branta canadensis*	4 (5)	2014–2015	
Fall Migrant Raptors - U.S. Atlantic Flyway - Biodiversity Research Institute	45525232	GPS, Argos Doppler	*Falco columbarius, Falco peregrinus*	13 (57)	2013–2019	
Foraging behaviour and fuel accumulation of pink-footed geese (data from Chudzińska et al. 2016)	49535504	GPS, Argos Doppler	*Anser brachyrhynchus*	11 (11)	2011–2013	(*36*)
FTZ Curlew	74810223	GPS	*Numenius arquata*	26 (37)	2014–2019	
FTZ Geese Wadden Sea	69724677	GPS	*Branta leucopsis, Branta bernicla*	15 (19)	2015–2019	
Glaucous Gull Barrow Alaska	116817431	GPS, Argos Doppler	*Larus hyperboreus*	14 (14)	2015–2017	
Glaucous Gull BPN KoEco Chaun 2017	958179188	GPS	*Larus hyperboreus*	2 (2)	2017–2017	
Golden Eagle (Aquila chrysaetos) Eastern N. America Mojica/Watts	7917980	GPS, Argos Doppler	*Aquila chrysaetos*	2 (3)	2008–2018	
Golden Eagle Migration, Denali, Alaska, McIntyre [CS1]	1916886	Argos Doppler	*Aquila chrysaetos*	48 (48)	1997–2000	
Golden Eagle Satellite Telemetry Data	166529112	GPS	*Aquila chrysaetos*	6 (13)	2007–2015	
Golden Eagles of Interior Alaska; Lewis [CS1]	19389828	GPS	*Aquila chrysaetos*	47 (47)	2014–2019	
Greenland White-fronted Goose tracking	947818172	GPS	*Anser albifrons*	61 (89)	2013–2019	
Gyrfalcon, High Arctic Institute, central-west Greenland	917901503	Argos Doppler	*Falco rusticolus*	4 (4)	2002–2003	(*37*)
Gyrfalcon, High Arctic Institute, east Greenland trapping station	915166703	Argos Doppler	*Falco rusticolus*	7 (7)	2004–2005	(*38*)
Gyrfalcon, High Arctic Institute, Maniitsoq trapping station	917906795	Argos Doppler	*Falco rusticolus*	10 (10)	2002–2003	(*39*)
Gyrfalcon, High Arctic Institute, northwest Greenland	915037836	Argos Doppler	*Falco rusticolus*	21 (21)	2002–2004	(*40*)

Gyrfalcons Alaska McIntyre	4846927	Argos Doppler	*Falco rusticolus*	16 (16)	1992–1995	
HawkWatch International Golden Eagles [CS1]	171287018	GPS, Argos Doppler	*Aquila chrysaetos*	7 (33)	2003–2009	(*41*)
Herring Gull QIA KoEco Korea 2017	395440520	GPS	*Larus vegae*	9 (16)	2017–2017	
Herring Gulls (Larus Argentatus); Gilchrist; East Bay Island, Canada	11815535	Argos Doppler	*Larus argentatus*	16 (16)	2008–2016	(*42*)
Hudsonian Godwit (Limosa haemastica) Canada Smith/Watts	11327614	Argos Doppler	*Limosa haemastica*	3 (3)	2013–2013	
iceSeals_NSB_Alaska_vonDuyke	732321226	Argos Doppler	*Pusa hispida, Erignathus barbatus, Phoca largha*	71 (71)	2011–2019	
Kidd et al. Rough-legged Hawk Movements in North America	109335608	GPS, Argos Doppler, Radio Transmitter	*Buteo lagopus*	80 (104)	2014–2019	
Kittiwake, Brides & Petersen, Iceland	916687231	GPS	*Rissa tridactyla*	19 (19)	2014–2017	
Latham Alberta Wolves [CS3]	178979729	GPS	*Canis lupus*	12 (12)	2006–2007	(*43*)
Lesser White-fronted Goose Anser erythropus Finnmark	11185254	GPS	*Anser erythropus*	3 (3)	2013–2019	
Lesser Yellowlegs (Tringa flavipes) Migratory Connectivity	543061768	GPS, Argos Doppler	*Tringa flavipes*	75 (80)	2018–2019	
LifeTrack Peregrine falcon	103426553	GPS	*Falco peregrinus*	21 (29)	2015–2019	
LifeTrack Rough-legged buzzards	9493874	GPS, Argos Doppler	*Buteo lagopus*	79 (80)	2013–2019	
LifeTrack Whooper Swan Latvia	92261778	GPS	*Cygnus cygnus*	5 (9)	2016–2016	
Light-bellied brent goose (Canadian High Arctic) Kendrew Colhoun	2235650	GPS, Argos Doppler	*Branta bernicla*	20 (20)	2002–2008	
Long-tailed ducks ARGOS 2019	872134463	Argos Doppler	*Clangula hyemalis*	14 (14)	2019–2019	
Long-tailed ducks GLS 2018	714362126	Solar Geolocator	*Clangula hyemalis*	19 (19)	2017–2018	
Long-tailed Jaeger Alaska	300812056	Argos Doppler	*Stercorarius longicaudus*	16 (17)	2017–2019	
Long-tailed Skua, van Bemmelen, Sweden	968980842	Solar Geolocator Raw	*Stercorarius longicaudus*	24 (24)	2011–2019	
Lower 48 GOEA Migration	577947076	GPS, Argos Doppler	*Aquila chrysaetos*	9 (14)	2019–2019	
LTDU	137245750	Argos Doppler	*Clangula hyemalis*	67 (118)	2008–2013	
Migration of Sabine's gulls from the Canadian High Arctic	208672795	Solar Geolocator	*Xema sabini*	26 (26)	2008–2012	(*44*)

Migration Patterns of Pacific Sea Ducks	6506971	Argos Doppler	*Histrionicus histrionicus, Melanitta perspicillata, Bucephala islandica*	226 (375)	2006–2016	
Migration timing in barnacle geese (Barents Sea) (data from Kölzsch et al. and Shariatinajafabadi et al. 2014)	29799425		*Branta leucopsis*	12 (15)	2008–2010	(*45*)
Migration timing in barnacle geese (Greenland) (data from Kölzsch et al. and Shariatinajafabadi et al. 2014)	31987083	GPS	*Branta leucopsis*	7 (7)	2008–2010	(*46*)
Migration timing in barnacle geese (Svalbard) (data from Kölzsch et al. and Shariatinajafabadi et al. 2014)	31888520	GPS	*Branta leucopsis*	22 (22)	2006–2011	(*47*)
Migration timing in white-fronted geese (data from Kölzsch et al. 2016)	133992043	GPS, Argos Doppler	*Anser albifrons*	59 (65)	2006–2014	(*48*)
Mountain caribou in British Columbia [CS2, CS3]	216040785	GPS, Radio Transmitter	*Rangifer tarandus*	44 (260)	2001–2016	(*49*)
Movement of long-tailed ducks marked on the Yukon-Kuskokwim Delta, Alaska 1998-2000 (data from Petersen et al. 2003)	140391801	Argos Doppler	*Clangula hyemalis*	14 (14)	1998–2000	(*50*)
North Sea population tracks of greater white-fronted geese 2014-2017 (data from Kölzsch et al. 2019)	657674643	GPS	*Anser albifrons*	72 (81)	2014–2017	(*51*)
North Slope Cackling Geese	588214579	GPS	*Branta hutchinsii*	3 (3)	2018–2018	
NPS Dall Sheep Gates of the Arctic	942509734	Radio Transmitter	*Ovis dalli*	25 (25)	1998–2002	
NPS Dall Sheep in Yukon-Charley Rivers National Preserve	673728219	GPS, Radio Transmitter	*Ovis dalli*	98 (98)	1997–2003	
NPS Denali Dall Sheep	666644968	GPS, Radio Transmitter	*Ovis dalli*	22 (22)	2007–2007	
NWT South Slave Boreal Wolves [CS3]	625331087	GPS	*Canis lupus*	12 (12)	2016–2018	
NYSDEC Raptor Tracking	2943485	GPS, Argos Doppler	*Aquila chrysaetos, Asio flammeus, Haliaeetus leucocephalus, Falco peregrinus*	36 (78)	1992–2010	(*52*)
Oystercatcher 2016 Alves Iceland	163339641	GPS	*Haematopus ostralegus*	14 (14)	2016–2016	
Oystercatcher 2017 Alves Iceland	292990053	GPS	*Haematopus ostralegus*	10 (10)	2017–2019	
Pacific Loons Alaska Colville River Delta	77252092	Argos Doppler	*Gavia pacifica*	30 (30)	2015–2019	(*53*)

Pannonic population tracks of greater white-fronted geese 2013-2017 (data from Kölzsch et al. 2019)	657965212	GPS	*Anser albifrons*	10 (10)	2013–2017	(*54*)
Parasitic Jaeger/Arctic Skua North America	630339095	Argos Doppler	*Stercorarius parasiticus*	6 (8)	2019–2019	
Peregrine Falcon, High Arctic Institute, northwest Greenland	7249090	Argos Doppler	*Falco peregrinus*	8 (8)	2001–2003	
Pomarine Jaeger North America	973570814	Argos Doppler	*Stercorarius pomarinus*	3 (3)	2019–2019	
Pre-breeding prospecting behaviour of snowy owls (data from Therrien et al. 2015)	54108884	Argos Doppler	*Bubo scandiacus*	9 (9)	2008–2010	(*55*)
Red-necked Phalarope southern Chukotka (data from Mu et al. 2018)	411155573	Solar Geolocator Raw	*Phalaropus lobatus*	2 (2)	2016–2017	(*56*)
Red-necked Phalarope, van Bemmelen, Norway	968983708	Solar Geolocator Raw	*Phalaropus lobatus*	9 (9)	2014–2018	
Red-necked Phalarope, van Bemmelen, Sweden	99570338	Solar Geolocator Raw	*Phalaropus lobatus*	12 (12)	2013–2017	
redThroatedLoon_USGS_ASC_argos	506722909	Argos Doppler	*Gavia stellata*	52 (52)	2000–2011	(*57*)
Ringed seals Igloolik	920008781	Argos Doppler	*Pusa hispida*	6 (6)	2009–2010	
Ringed Seals Resolute	467038889	Argos Doppler	*Pusa hispida*	7 (7)	2012–2014	
Ringed seals Sanikiluaq	467037497	Argos Doppler	*Pusa hispida*	64 (66)	2006–2013	
Rough-legged Buzzard in variable environment	944655375	Argos Doppler	*Buteo lagopus*	2 (2)	2014–2017	
Rusty Blackbird Alberta	613825248	GPS	*Euphagus carolinus*	2 (2)	2017–2018	
Sabine's Gulls in the Juan de Fuca Eddy	304527187	Argos Doppler	*Xema sabini*	2 (2)	2017–2019	
Seaducks in the Fehmarn Belt (southern Baltic)	1962595	Argos Doppler	*Clangula hyemalis, Aythya fuligula, Somateria mollissima, Melanitta nigra*	12 (27)	2009–2010	
Short-eared Owl, North America	7423317	Argos Doppler	*Asio flammeus*	26 (26)	2009–2011	
Skagit County Washington Western High Arctic Brant	150569357	Argos Doppler	*Branta bernicla*	2 (3)	2016–2016	
Skagit Valley / Wrangel Island Snow Goose	14050108	Argos Doppler	*Chen caerulescens*	7 (7)	2013–2014	
Skagit Valley / Wrangel Island Snow Goose 2016-17 GSM	156118432	GPS	*Chen caerulescens*	14 (14)	2016–2019	
Snow Bunting Migration Phenology	959128259	Solar Geolocator Raw	*Plectrophenax nivalis*	6 (6)	2011–2013	

Snow bunting, Svalbard	540289187	Solar Geolocator Raw	*Plectrophenax nivalis*	10 (10)	2014–2016	
Snowy owl - North America	12112706	Argos Doppler	*Bubo scandiacus*	32 (32)	2007–2016	
Snowy owls from Barrow Alaska 1999-2001 (Fuller)	944461692	Argos Doppler	*Bubo scandiacus*	4 (4)	1999–2001	
Solovki Larus Track	312267867	GPS	*Larus fuscus, Larus argentatus, Larus marinus*	6 (6)	2017–2019	
Taiga Bean Geese Larry Griffin	35342375	GPS	*Anser fabalis*	4 (6)	2013–2014	
TBMUCOMU.GastonMontevecchi.NWAtlantic	14381504	Solar Geolocator	*Uria lomvia, Uria aalge*	117 (122)	2007–2011	
Thayer's Gulls from the Canadian High Arctic	176466071	Argos Doppler	*Larus thayeri*	5 (5)	2016–2017	
Thick-billed murre Elliott Coats 2010	248994009	GPS	*Uria lomvia*	22 (22)	2010–2010	
Thick-billed murre Elliott Coats 2011	249266943	GPS	*Uria lomvia*	17 (17)	2011–2011	
Thick-billed murre Elliott Coats 2013	376145741	GPS	*Uria lomvia*	116 (116)	2013–2013	
Thick-billed murre Gaston PLI 2014	394802766	GPS	*Uria lomvia*	10 (10)	2014–2014	
Thick-billed murre Gilchrist and Elliott Coats 2016	287187244	GPS	*Uria lomvia*	20 (20)	2016–2016	
Thick-billed murre Gilchrist and Elliott Coats 2017	318843635	GPS	*Uria lomvia*	92 (92)	2017–2017	(*58*)
Thick-billed murre Gilchrist and Elliott Digges 2015	358865092	GPS	*Uria lomvia*	66 (66)	2015–2015	
Thick-billed murre Gilchrist and Elliott Digges 2016	249737372	GPS	*Uria lomvia*	116 (116)	2016–2016	
Thick-billed murre Gilchrist Cape Graham Moore 2016	11815535	GPS	*Uria lomvia*	57 (57)	2016–2016	
Thick-billed Murres; Gaston/Akearok, Prince Leopold Island, Nunavut, Canada	40012605	GPS	*Uria lomvia*	10 (10)	2014–2014	
Thick-billed Murres; Gilchrist; Cape Graham Moore, Canada	33622846	GPS	*Uria lomvia*	25 (25)	2014–2014	
Thick-billed Murres; Gilchrist; Digges Island, Canada	10006517	GPS	*Uria lomvia*	110 (110)	2012–2014	
Tobseda Barnacle Goose	2231619	Argos Doppler	*Branta leucopsis*	15 (15)	2003–2005	
Tracking movements of Peregrine Falcons Falco peregrinus from breeding populations in Arctic Eurasia	934079034	Argos Doppler	*Falco peregrinus*	37 (37)	2009–2016	
Tracking post-fledging dispersal and migration of juvenile Peregrine Falcons Falco peregrinus in Arctic Russia	922820594	Argos Doppler	*Falco peregrinus*	9 (9)	2010–2012	

Upper Midwest Bald Eagle Project	166277154	GPS	*Haliaeetus leucocephalus*	15 (37)	2015–2017	
USGS WERC Dixon Field Station Compiled Avian Telemetry	619097045	GPS	*Anas acuta, Anas americana, Anas clypeata, Anas discors, Anser albifrons, Chen caerulescens, Chen rossii, Circus cyaneus*	184 (1020)	2016–2019	
Vega Gull BPN KoEco Russia Chaun 2017	407469571	GPS	*Larus vegae*	5 (5)	2017–2017	
Wader migration German Wadden Sea: bar-tailed godwits	5666500	Argos Doppler	*Limosa lapponica*	4 (8)	2011–2011	
Wader migration German Wadden Sea: grey plovers	533575900	Argos Doppler	*Pluvialis squatarola*	10 (14)	2011–2013	(*59*)
Washington State Surf Scoter	41656517	Argos Doppler	*Melanitta perspicillata*	32 (34)	2004–2007	
Washington State White-winged Scoter	949577211	Argos Doppler	*Melanitta fusca*	16 (19)	2003–2007	
Western GOEA Conservation CS1	20050095	GPS, Argos Doppler	*Aquila chrysaetos*	4 (80)	2015–2019	
Whimbrel Numenius phaeopus Acadian Peninsula	161439311	Argos Doppler	*Numenius phaeopus*	3 (6)	2017–2019	
Whimbrel Numenius phaeopus North America Smith/Watts/Winn	7073245	Argos Doppler	*Numenius phaeopus*	24 (36)	2009–2019	
White fronted Goose QIA KoEco Korea 2017	402496791	GPS	*Anser albifrons*	6 (11)	2017–2017	
White-fronted goose (Greenland) Larry Griffin	2235641	GPS	*Anser albifrons*	4 (4)	2008–2008	
White-fronted goose full year tracks 2006-2010 Alterra IWWR	467107447	GPS, Argos Doppler	*Anser albifrons*	7 (7)	2007–2008	(*60*)
Whooper swan (Icelandic) Larry Griffin II	2279366	GPS	*Cygnus cygnus*	51 (57)	2007–2009	
Whooper swan (Icelandic) Larry Griffin/Colin Pennycuick	2235656	Argos Doppler	*Cygnus cygnus*	9 (9)	1994–1996	
Whooper swan (Icelandic) Larry Griffin/Kendrew Colhoun	2235659	GPS, Argos Doppler	*Cygnus cygnus*	11 (11)	2007–2008	
Whooper swans in Latvia 2016	182459847	GPS	*Cygnus cygnus*	6 (11)	2017–2019	(*61*)
yellowBilledloon_USGS_ASC_argos	506737915	Argos Doppler	*Gavia adamsii*	92 (92)	2002–2019	(*62*)

Table S2.

Species-level and species group summary of data from studies participating in the AAMA as of November 2019.

Species	Species group	Studies	Location sensors
Alces alces	Terrestrial mammals	4	GPS
Alle alle	Seabirds	1	Geolocator
Anas acuta	Waterbirds	1	GPS
Anas Americana	Waterbirds	1	GPS
Anas clypeata	Waterbirds	1	GPS
Anas discors	Waterbirds	1	GPS
Anser albifrons	Waterbirds	10	GPS, Argos Doppler
Anser brachyrhynchus	Waterbirds	1	GPS, Argos Doppler
Anser erythropus	Waterbirds	1	GPS
Anser fabalis	Waterbirds	2	GPS
Aquila chrysaetos	Raptors	18	GPS, Argos Doppler
Asio flammeus	Raptors	2	Argos Doppler
Balaena mysticetus	Marine mammals	3	Argos Doppler
Balaenoptera borealis	Marine mammals	1	Argos Doppler
Balaenoptera physalus	Marine mammals	1	Argos Doppler
Branta bernicla	Waterbirds	5	GPS, Argos Doppler
Branta canadensis	Waterbirds	1	Argos Doppler
Branta hutchinsii	Waterbirds	1	GPS
Branta leucopsis	Waterbirds	8	GPS, Argos Doppler
Bubo scandiacus	Raptors	3	Argos Doppler
Bucephala islandica	Seabirds	1	Argos Doppler
Buteo lagopus	Raptors	3	GPS, Argos Doppler, Radio transmitter
Buteo platypterus	Raptors	1	Argos Doppler
Calidris alpina	Shorebirds	2	GPS, Geolocator
Calidris melanotos	Shorebirds	1	GPS
Calidris pusilla	Shorebirds	1	GPS
Canis lupus	Terrestrial mammals	7	GPS, Radio transmitter
Charadrius hiaticula	Shorebirds	1	Geolocator
Chen caerulescens	Waterbirds	3	GPS, Argos Doppler
Chen rossii	Waterbirds	1	GPS
Chordeiles minor	Raptors	1	GPS
Circus cyaneus	Raptors	2	GPS
Clangula hyemalis	Seabirds	5	Argos Doppler, Geolocator
Cuculus canorus	Passerines+cuckoo	2	GPS, Argos Doppler
Cygnus cygnus	Waterbirds	5	GPS, Argos Doppler
Erignathus barbatus	Marine mammals	1	Argos Doppler
Euphagus carolinus	Passerines+cuckoo	1	GPS
Falco columbarius	Raptors	1	Argos Doppler
Falco peregrinus	Raptors	8	GPS, Argos Doppler
Falco rusticolus	Raptors	5	Argos Doppler
Fratercula arctica	Seabirds	1	Geolocator
Gavia adamsii	Seabirds	1	Argos Doppler
Gavia pacifica	Seabirds	1	Argos Doppler

Gavia stellata	Seabirds	2	Argos Doppler
Haematopus ostralegus	Shorebirds	2	GPS
Haliaeetus leucocephalus	Raptors	6	GPS, Argos Doppler
Histrionicus histrionicus	Seabirds	1	Argos Doppler
Larus argentatus	Shorebirds	2	GPS, Argos Doppler
Larus fuscus	Seabirds	1	GPS
Larus hyperboreus	Shorebirds	2	GPS, Argos Doppler
Larus marinus	Seabirds	1	GPS
Larus thayeri	Shorebirds	1	Argos Doppler
Larus vegae	Shorebirds	2	GPS
Lepus arcticus	Terrestrial mammals	1	Argos Doppler
Limosa haemastica	Shorebirds	1	Argos Doppler
Limosa lapponica	Shorebirds	1	Argos Doppler
Melanitta fusca	Seabirds	1	Argos Doppler
Melanitta nigra	Seabirds	1	Argos Doppler
Melanitta perspicillata	Seabirds	3	Argos Doppler
Numenius arquata	Shorebirds	1	GPS
Numenius phaeopus	Shorebirds	3	Argos Doppler
Oporornis agilis	Passerines+cuckoo	1	Geolocator
Ovis dalli	Terrestrial mammals	4	GPS, Radio transmitter
Phalaropus lobatus	Seabirds	3	Geolocator
Phoca largha	Marine mammals	1	Argos Doppler
Plectrophenax nivalis	Passerines+cuckoo	2	Geolocator
Pluvialis dominica	Shorebirds	1	GPS
Pluvialis squatarola	Shorebirds	3	Argos Doppler
Pusa hispida	Marine mammals	4	Argos Doppler
Rangifer tarandus	Terrestrial mammals	17	GPS, Argos Doppler, Radio transmitter
Rissa tridactyla	Seabirds	2	GPS
Somateria fischeri	Seabirds	1	Argos Doppler
Somateria mollissima	Seabirds	5	GPS, Argos Doppler
Somateria spectabilis	Seabirds	3	Argos Doppler
Stercorarius longicaudus	Seabirds	2	Argos Doppler, Geolocator
Stercorarius parasiticus	Seabirds	4	GPS, Argos Doppler, Geolocator
Stercorarius pomarinus	Seabirds	1	Argos Doppler
Sterna paradisaea	Seabirds	1	Geolocator
Tringa flavipes	Shorebirds	1	GPS, Argos Doppler
Turdus migratorius	Passerines+cuckoo	1	GPS, Argos Doppler
Uria aalge	Seabirds	1	Geolocator
Uria lomvia	Seabirds	13	GPS, Geolocator
Ursus americanus	Terrestrial mammals	1	GPS
Ursus arctos	Terrestrial mammals	3	GPS, Radio transmitter
Vulpes lagopus	Terrestrial mammals	1	Argos Doppler
Xema sabini	Seabirds	2	Argos Doppler, Geolocator

Table S.3.

Permits, licenses and approved protocols for research, animal handling and tagging related to studies participating in the AAMA as of November 2019. ACC = Animal Care Committee, ACUC = Animal Care and Use Committee, AWC = Animal Welfare Committee, IACUC = Institutional Animal Care and Use Committee, WCC = Wildlife Care Committee.

Study name	Authorizing institutions, permits and protocols
ABoVE: ADFG Fortymile River Brown Bears	Alaska Department of Fish and Game Protocol 08-08
ABoVE: ADFG Mulchatna Caribou	Alaska Department of Fish and Game Division of Wildlife Conservation 2013-10, 2015-33
ABoVE: BC Atlin Caribou	British Columbia Provincial authority under the BC Wildlife Act
ABoVE: Boelman Alberta American Robins	Alberta Environment and Parks 16-025, 17-084, 18-305; IACUC protocols AC-AAAR9409, AC-AAAW4470
ABoVE: Boutin Alberta Grey Wolf	University of Alberta Animal Use Protocol 00000040
ABoVE: Boutin Alberta Moose	University of Alberta Animal Use Protocol 00000102
ABoVE: Hebblewhite Alberta-BC Wolves	University of Alberta Canadian Care and Animal Use Committee Protocol 353112; University of Montana 056-06-MHCES-010207, 059-08MHCES-120908
ABoVE: NPS Dall Sheep Lake Clark	National Park Service LACL-2005-SCI-0012
ABoVE: NPS Denali Bears	US National Park Service research permits and IACUC protocols
ABoVE: NPS Denali Wolves	US National Park Service research permits DENA-2005-SCI-0019, DENA-2011-SCI-0002, DENA-2016-SCI-009; Alaska Department of Fish and Game permits Burch_08-008, Burch_09-012, Burch_11-005, Meier_12-006, Arthur_DenaliNP_15-093, Borg_NPS_16-012; US National Park Service IACUC protocols NPS IACUC 2010-1, AKR_YUCH and DENA_Burch_Wolves_2013, AKR_DENA_Borg_Wolves_2016.A3
ABoVE: NPS Lake Clark Wolves	US National Park Service research permits LACL-2009-SCI-0001, LACL-2009-SCI-0018, LACL-2011-SCI-0018; Alaska Department of Fish and Game scientific permits 08-058, 09-003, 10-001, 11-054, 12-004, 13-009, 14-008, and 15-008; US Fish and Wildlife Service IACUC Protocol 2008023; US National Park Service IACUC protocols AKR_LACL_Mangipane_Wolf_2012_A3, AKR_LACL_Mangipane_Wolves_2015.A3
ABoVE: NPS Moose in the Upper Koyukuk Alaska	State of Alaska IACUC Protocol 07-11
ABoVE: NPS Wolves in Yukon-Charley Rivers National Preserve	National Park Service Research Permit YUCH_DENA_Burch_Wolves_2013.A3
ABoVE: NWT Dehcho Boreal Woodland Caribou	Annual Northwest Territories wildlife research permits WCC protocols, including NWTWCC 2018-019
ABoVE: NWT Inuvik Barren Ground Caribou	Government of the Northwest Territories wildlife research permits and WCC protocols
ABoVE: NWT Inuvik Boreal Woodland Caribou	Government of the Northwest Territories wildlife research permits and WCC protocols
ABoVE: NWT North Slave Barren Ground Caribou: Bathurst	Government of the Northwest Territories wildlife research permits and WCC protocols
ABoVE: NWT North Slave Boreal Caribou	Annual Northwest Territories wildlife research permits WCC protocols, including NWTWCC 2017-010, NWTWCC

	2018-001
ABoVE: NWT Sahtu Barren Ground Caribou: Bluenose-East	Government of the Northwest Territories wildlife research permits and WCC protocols
ABoVE: NWT Sahtu Boreal Woodland Caribou	Government of the Northwest Territories wildlife research permits and WCC protocols
ABoVE: NWT Sahtu Mountain Woodland Caribou	Government of the Northwest Territories wildlife research permits and WCC protocols
ABoVE: NWT South Slave Barren Ground Caribou: Beverly and Ahiak	Government of the Northwest Territories Wildlife Research Permit WL5000771; Government of the Northwest Territories WCC Protocol NWTWCC 2019-020; reviewed annually
ABoVE: NWT South Slave Barren Ground Caribou: Queen Maud Gulf	Government of the Northwest Territories Wildlife Research Permit WL5000771; Government of the Northwest Territories WCC Protocol NWTWCC 2019-020; reviewed annually
ABoVE: NWT South Slave Boreal Woodland Caribou	Government of the Northwest Territories Wildlife Research Permit WL5000771; Government of the Northwest Territories WCC Protocol NWTWCC 2019-020; reviewed annually
ABoVE: Peters Hebblewhite Alberta-BC Moose	University of Montana Protocol 056-06-MHCES-010207Amendment
ABoVE: USFWS R6 Golden Eagles	US Federal Master Banding Permit 23720; US Fish and Wildlife Service Permit MB204815-0; State of Colorado Scientific Collection License 20TRb4182a; State of Wyoming permits 863, 2066
ABoVE: USGS/WVU Raptors	Boise State University IACUC Protocol 692-980-020
ABoVE: Yukon Caribou	Yukon Government Department of Environment
ADACLIM	Danish Polar Center and the Government of Greenland, Ministry of Environment and Nature and Department of Fisheries, Hunting and Agriculture Permits 512-240, 512-258, 07-501, 66.24/23, 66.01.13, 2011-047447, 2012-065815, 2013- 083634, 2014-098814, 2015-115290
ADF&G Nelchina Caribou	Alaska Department of Fish and Game Protocol 2012-021
ADF&G Susitna Valley Moose	Alaska Department of Fish and Game Protocol 2012-022
Adult Golden Eagle Satellite Tracking	US Federal Bird Banding Permit 23353
Alaska Golden Eagles	Alaska Department of Fish and Game Protocol 2013-036
Aquila chrysaetos interior west N. America, Craigs, Fuller	US Federal Bird Banding Permit 20537, sub-permit to Permit 06714; US Fish and Wildlife Service Patuxent Wildlife Research Center; Boise State University IACUC
Aquila chrysaetos Mark Fuller North America	US Fish and Wildlife Service Patuxent Wildlife Research Center, Boise State University IACUC
Arctic breeding shorebirds; Rausch; various Canadian arctic locations	US Federal Bird Banding Permit
Arctic fox Bylot - Argos tracking	Université du Québec à Rimouski CPA-64-16-169 (R3); Parks Canada Agency SIR-2018-28021
Arctic hare Alert - Argos tracking	Université du Québec à Rimouski CPA-68-17-184 (R2); Government of Nunavut ML-2018-020
Arctic Raptors - www.ArcticRaptors.ca	Environment Canada Banding Permit 10833; University of Alberta Animal Use Protocol AUP00000042
Arctic shorebird migration tracking study - American Golden-Plover	US Federal Master Banding Permit 23269, ACUC Protocol 2017-007; State of Alaska permits 17-134, 18-161

Arctic shorebird migration tracking study - Dunlin	US Federal Master Banding Permit 23269, ACUC Protocol 2017-007; State of Alaska permits 17-134, 18-161
Arctic shorebird migration tracking study - Pectoral Sandpiper	US Federal Master Banding Permit 23269, ACUC Protocol 2017-007; State of Alaska permits 17-134, 18-161
Arctic shorebird migration tracking study - Semipalmated Sandpiper	US Federal Master Banding Permit 23269, ACUC Permit 2017-007; State of Alaska permits 17-134, 18-161
Arctic Skua, Faroe Islands, GPS	Animal work was approved by the Danish Nature Agency by permission to the Copenhagen Bird Ringing Centre (J.nr. SN 302-009).
Arctic Skua, van Bemmelen, Norway	Norwegian Food Safety Authority (FOTS) IDs 6328, 6329, 5276, 6328, 7421, 8538, 15726
Arctic Skua, van Bemmelen, Tobseda	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) "On Wildlife".
Arctic Tern Alaska	Federal Permit 09700; Alaska Scientific Permit 17-162; National Zoological Park IACUC 15-20, 18-06
Atlantic puffin in Iceland (Petersen)	Ringing Office at the Náttúrufræðistofnun Íslands Permit 199
Atlantic Seabird Study (Red-Throated Loons)	US Federal Bird Banding permits 23769, 22636; US Fish and Wildlife Service Permit MB48614B; annual state permits for Delaware, Maryland, North Carolina, Virginia; US Geological Survey Patuxent Wildlife Research Center IACUC Protocol 2010-10
Atlantic Seabird Study (Surf Scoters)	US Federal Bird Banding permits 23769, 22636; US Fish and Wildlife Service Permit MB48614B; annual state permits for Delaware, Maryland, North Carolina, Virginia; US Geological Survey Patuxent Wildlife Research Center IACUC Protocol 2010-10
Azores Great Whales Satellite Telemetry Program	Direcção Regional do Ambiente (Regional Directorate of the Environment, Regional Government of the Azores) (until 2018), Direcção Regional dos Assuntos do Mar (Regional Directorate for Sea Affairs, Regional Government of the Azores) (after 2018) permits LMAS-DRAM/2018/06, 80/2017/DRA, 37/2016/DRA, 30/2015/DRA, 34/2014/DRA, 20/2013/DRA, 31/2012/DRA, 51/2011/DRA, 16/2010/DRA, 20/2009/DRA, 76/2008/DRA
Bald Eagle Haliaeetus leucocephalus Mojica/Watts	US Federal Bird Banding Permit 21567; William & Mary IACUC Protocol 2018-04-27-12927, IBC Protocol 2017-06-21-12181
Bald Eagles in coastal Alaska; Lewis	US Federal Bird Banding Permit 21678; US Fish and Wildlife Service Region 7 IACUC Protocol 2013-002
Barnacle goose (Greenland) Larry Griffin/David Cabot	British Trust for Ornithology Licence A/5436 and Endorsement 06-01w
Barnacle goose (Svalbard) Larry Griffin	British Trust for Ornithology Licence A/5436 and Endorsement 06-01w
Bean Goose Anser fabalis Finnmark.	Norwegian Food Safety Authority (FOTS) IDs 6472/2014/82889-1, 15595/18/72904
Beringia Dunlin	US Federal Master Banding Permit 23269, IACUC Protocol 2016-005; State of Alaska permits 16-111, 17-102, 18-160
Beringia South Migrant Golden Eagle	Montana Department of Fish, Wildlife and Parks Scientific Collector's Permit 2012-003, US Federal Bird Banding Permit 22637

Black-bellied Plover Alaska	Federal Permit 09700; Alaska Scientific Permit 15-108, 17-162; National Zoological Park ACUC Protocol 14-30, 15-20; USGS Alaska Science Center ACUC 2015-09
Black-legged Kittiwakes; Mallory/Gaston/Akearok, Prince Leopold Island, Nunavut, Canada	Canadian scientific and access permits NUN-SCI-08-55, NUN-MBS-12-03, NUN-SCI-12-04, WRP2013040, banding permits 10694, 10322, animal care protocols 0800AG01, WM-01-11
Bowhead whale Admiralty Inlet	Animal Care Approval FWI-ACC_AUP_2003-2017_016; Licence to Fish for Scientific Purposes S-2003-2017-1006-NU
Bowhead whale Cumberland Sound	Animal Care Approval FWI-ACC_AUP_2003-2017_016; Licence to Fish for Scientific Purposes S-2003-2017-1006-NU
Bowhead whale Foxe Basin	Animal Care Approval FWI-ACC_AUP_2003-2017_016; Licence to Fish for Scientific Purposes S-2003-2017-1006-NU
Brant Geese Sean Boyd 2002	Simon Fraser University permits 781B-06, 999B-06
Brant Geese Sean Boyd 2005	Simon Fraser University permits 781B-06, 999B-06
Broad-winged Hawk Alberta Boreal	University of Alberta IACUC Protocol AUP00001523; Federal Banding Permit 10277; National Zoological Park ACUC 15-16; Environment and Climate Change Canada 10277
Brown and Black bear (Ursus spp.), Jerry Belant, Alaska	National Park Service
Canadian Ringed Plover geolocation tracking, Bylot Island, Canada (data from Léandri-Breton et al. 2019)	Parks Canada Agency research and collection permits SIR-2013-13934, SIR-2015-18822; Université du Québec à Rimouski ACC CPA-56-14-141, CPA-56-14-141-R1, CPA-56-14-141-R2, CPA-56-14-141-R3; Environment and Climate Change Canada permits 10772, 10772N
Common cuckoo, Kamchatka	Zoological Institute RAS permits 2017-04-17, 2017-04-17; Kaliningrad Regional Agency for Protection, Reproduction and Use of Animal World and Forests permits 12, 17; Kamchatka Krai Government Ministry of Natural Resources and Ecology Permit 38
Common cuckoo, Khakassia	Zoological Institute RAS permits 2017-04-17, 2018-03-22; Kaliningrad Regional Agency for Protection, Reproduction and Use of Animal World and Forests permits 12, 17; Ministry of Natural Resources and Environment of the Republic of Khakassia permits 9, 18
Common Eiders; Love/Gilchrist; East Bay Island, Canada	University of Windsor Animal Use Permits 15-05, 19-11
Common Nighthawk	University of Alberta AUP00001523; National Zoological Park and Conservation Biology 15-16, 18-66; Texas Tech University 15032-04; University of South Dakota 23-05-13-16C, 15-05-16-19C; Environment and Climate Change SFCQ2017-02, US Federal Bird Banding permits 09700, 22199, 22834; Environment and Climate Change Canada Scientific Permit to Capture and Band Migratory Birds 10277, 10365, 10619H, 10534, 10169, 10887, regional permits
Common/King Eiders; East Bay Island, Nunavut; Gilchrist 2012 and 2013	University of Windsor Animal Use Permits 15-05, 19-11

Common/King Eiders; East Bay Island, Nunavut; Gilchrist/Mosbech 2001 and 2003	University of Windsor Animal Use Permits 15-05, 19-11
Common/King Eiders; Nuuk/Disko Bay/Upernavik, Greenland; Gilchrist/Mosbech; 2002 and 2003	University of Windsor Animal Use Permits 15-05, 19-11
Connecticut Warbler Alberta Boreal	Smithsonian Institution ACUC NZP-IACUC 17-05, 18-66; Environment and Climate Change Canada 10277
Distribution of spectacled eiders in Russia and Alaska 1993-1996 (data from Petersen et al. 1999)	US Federal Bird Banding Permit 20022, US Fish and Wildlife Service Permit MB789758
Disturbance of BG by IFV and IWWR	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) Permission Akt.Z. 33.19-4202-04-15/1956
Disturbance of GWFG by IFV and IWWR	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) Permission Akt.Z. 33.19-4202-04-15/1956
Disturbance of GWFG by IFV and IWWR 2017-2018	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) Permission Akt.Z. 33.19-4202-04-15/1956
Dolphin_Union_Caribou_UAV	Nunavut Wildlife Research Permit WL2015–037, IACUC exemption 07/10/2015; UAV flights in compliance with Transport Canada regulations
Eagles Wintering in Bitterroot Valley	US Federal Bird Banding Permit 23353
Earthspan Peregrines	Boise State University IACUC; Earthspan IACUC; US Federal Master Banding Permit 20127; National Park Service Assateague Island National Seashore and US Fish and WIldlife Service Chincoteague and Laguna Atascosa National Wildlife Refuges permits in Maryland (55662), Virginia (026310) and Texas (SPR-0390-047)
Eastern Montana Golden Eagles	US Federal Bird Banding Permit 22622
Eastern North America Golden Eagles	Boise State University IACUC Protocol 692-980-020
Eastern Washington Lesser Canada Goose - Delineating the breeding grounds of small Canada geese wintering in the Columbia Basin	US Federal Bird Banding Permit 06508
Fall Migrant Raptors - U.S. Atlantic Flyway - Biodiversity Research Institute	US Federal Bird Banding Permit 22636
Foraging behaviour and fuel accumulation of pink-footed geese (data from Chudzińska et al. 2016)	Danish Ministry of Environment License to Aarhus University Department of Bioscience
FTZ Curlew	Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung (Kiel, Germany) file numbers V 312-7224.121-37(42-3/13) and V 241-35852/2017(88-7/17)
FTZ Geese Wadden Sea	Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung (Kiel, Germany) file numbers V 312-7224.121-37(42-3/13) and V 241-35852/2017(88-7/17)
Glaucous Gull Barrow Alaska	US Federal Bird Banding Permit 09700; Alaska Scientific Permit 15-189; North Slope Borough scientific study permits 16-169, 16-174; National Zoological Park ACUC 15-33
Glaucous Gull BPN KoEco Chaun 2017	Gimpo City Permit 2017-1
Golden Eagle (Aquila chrysaetos) Eastern N. America Mojica/Watts	US Federal Bird Banding Permit 21567; William & Mary IACUC Protocol 2018-04-27-12927, IBC Protocol 2017-06-21-12181
Golden Eagle Migration, Denali, Alaska, McIntyre	Oregon State University ACUC AUF Permit 1962
Golden Eagle Satellite Telemetry Data	Boise State University IACUC Protocol 692-980-020

Golden Eagles of Interior Alaska; Lewis	US Federal Bird Banding Permit 21678; US Fish and Wildlife Service Region 7 IACUC Protocol 2012-013
Greenland White-fronted Goose tracking	British Trust for Ornithology Licence A/5436 and Endorsement 11-57w
Gyrfalcon, High Arctic Institute, central-west Greenland	Danish Polar Center permits 512-162, 512-167, 512-179, 512-212, 512-232, 512-254
Gyrfalcon, High Arctic Institute, east Greenland trapping station	Danish Polar Center permits 512-162, 512-167, 512-179, 512-212, 512-232, 512-254
Gyrfalcon, High Arctic Institute, Maniitsoq trapping station	Danish Polar Center permits 512-162, 512-167, 512-179, 512-212, 512-232, 512-254
Gyrfalcon, High Arctic Institute, northwest Greenland	Danish Polar Center permits 512-162, 512-167, 512-179, 512-212, 512-232, 512-254
Gyrfalcons Alaska McIntyre	Oregon State University ACUC AUF Permit 1962
HawkWatch International Golden Eagles	US Federal Master Bird Banding Permit 21384; state permits administered by Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, Wyoming Game and Fish Department, Nevada Department of Wildlife, and New Mexico Department of Game and Fish.
Herring Gull QIA KoEco Korea 2017	Gimpo City Permit 2017-1
Herring Gulls (Larus Argentatus); Gilchrist; East Bay Island, Canada	Government of Canada animal care protocols EC-PN-09-026, EC-PN-13-0; Government of Nanuvut animal care protocols NUN-SCI-08-04, NUN-SCI-11-04; WL-2013-044, WL-2009-029; Banding Permit 10650.
Hudsonian Godwit (Limosa haemastica) Canada Smith/Watts	Government of the Northwest Territories Wildlife Research Permit WL500153 and WCC Approval NWTWCC 2013-009; Environment Canada Western and Northern ACC Approval EC-PN-13-006; Environment Canada Scientific permits 10565J, 10565N, 10565M; Environment Canada Wildlife and Landscape Science Directorate and Canadian Wildlife Service ACC Approval EC-PN-14-006
iceSeals_NSB_Alaska_vonDuyke	National Marine Fisheries Service Research Permits 358-1787, 15324; Alaska Department of Fish and Game ACUC protocols 2010-13R, 2016-23
Kidd et al. Rough-legged Hawk Movements in North America	US Federal Master Bird Banding permits 22636, 24140
Kittiwake, Brides & Petersen, Iceland	Ringing Office at the Náttúrufræðistofnun Íslands Permit 199
Latham Alberta Wolves	University of Alberta ACUC Protocol 471503
Lesser White-fronted Goose Anser erythropus Finnmark	Norwegian Food Safety Authority (FOTS) IDs 6472/2014/82889-1, 15595/18/72904
Lesser Yellowlegs (Tringa flavipes) Migratory Connectivity	Alaska Department of Fish and Game IACUC Protocol 0058-2019-39
LifeTrack Peregrine falcon	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) “On Wildlife”.
LifeTrack Rough-legged buzzards	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) “On Wildlife”.
LifeTrack Whooper Swan Latvia	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) “On Wildlife”.

Light-bellied brent goose (Canadian High Arctic) Kendrew Colhoun	British Trust for Ornithology Licence A/5436
Long-tailed ducks ARGOS 2019	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) "On Wildlife". St Petersburg State University Ethic Committee Permission 131-03-4.
Long-tailed ducks GLS 2018	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) "On Wildlife".
Long-tailed Jaeger Alaska	US Federal Bird Banding Permit 09700; Alaska scientific permits 15-33, 17-162, 18-156, 19-157; National Zoological Park ACUC 15-33, 18-06; National Park Service AKR_DENA_Harrison_Jaegers_2018; Environment and Climate Change Canada Scientific Permit 10565N; Government of Nunavut wildlife research permits WL2018-052, WL2019-041; Environment Canada Western and Northern ACC approvals EC-PN-13-006, 18JR01, 19JR01; Environment Canada scientific permits 10565J, 10565M, 10565N; Environment Canada Wildlife and Landscape Science Directorate and Canadian Wildlife Service ACC Approval EC-PN-14-006
Long-tailed Skua, van Bemmelen, Sweden	Jordbruks verket permits M160-11, M470-12, M472-12
Lower 48 GOEA Migration	US Federal Bird Banding permits 23353, 24140
LTDU	US Federal Bird Banding permits 23769, 22636; US Fish and Wildlife Service Permit MB48614B; annual state permits for Delaware, Maryland, North Carolina, Virginia; US Geological Survey Patuxent Wildlife Research Center IACUC Protocol 2010-10
Migration of Sabine's gulls from the Canadian High Arctic	CWS Animal Care EC-PN-11-020; CWS Scientific Permit NUN-SCI-09-01; Government of Nunavut Wildlife Research Licence WL 2010–042; Nunavut Water Board Licence 3BC-TER0811; Indian and Northern Affairs Land Use Reserve 068H16001; CWS Banding Permit 10694
Migration Patterns of Pacific Sea Ducks	Simon Fraser University permits 781B-06, 999B-06
Migration timing in barnacle geese (Barents Sea) (data from Kölzsch et al. and Shariatinajafabadi et al. 2014)	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) Permission 33-42502-04-10/0307; Institute of Avian Research, Wilhelmshaven, Germany; National Park Administration of Lower Saxony, Wilhelmshaven, Germany
Migration timing in barnacle geese (Greenland) (data from Kölzsch et al. and Shariatinajafabadi et al. 2014)	British Trust for Ornithology Licence A/5436 and Endorsement 06-01w
Migration timing in barnacle geese (Svalbard) (data from Kölzsch et al. and Shariatinajafabadi et al. 2014)	British Trust for Ornithology Licence A/5436 and Endorsement 06-01w
Migration timing in white-fronted geese (data from Kölzsch et al. 2016)	Russian Academy of Sciences Institute of Geography (no approval needed); Wageningen Environmental Research (no approval needed)
Mountain caribou in British Columbia	British Columbia Wildlife Act Permits FJ08-59586, FJ07-40107 and FJ17-282173

Movement of long-tailed ducks marked on the Yukon-Kuskokwim Delta, Alaska 1998-2000 (data from Petersen et al. 2003)	US Federal Bird Banding Permit 20022, US Fish and Wildlife Service Permit MB789758
North Sea population tracks of greater white-fronted geese 2014-2017 (data from Kölzsch et al. 2019)	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) Permission Akt.Z. 33.19-4202-04-15/1956, AZ 33.19-42502-04-15; Royal Netherlands Academy of Arts and Sciences AWC DEC NIOO13.14;
North Slope Cackling Geese	US Fish and Wildlife Service IACUC 2018-010 and appropriate state and federal permits
NPS Dall Sheep Gates of the Arctic	No permits were required (research conducted prior to the establishment of the National Park Service IACUC).
NPS Dall Sheep in Yukon-Charley Rivers National Preserve	No permits were required (research conducted prior to the establishment of the National Park Service IACUC).
NPS Denali Dall Sheep	US National Park Service permits DENA-2005-SCI-0019, DENA-2011-SCI-0002, DENA-2016-SCI-009; Alaska Department of Fish and Game permits Burch_08-008, Burch_09-012, Burch_11-005, Meier_12-006, Arthur_DenaliNP_15-093, Borg_NPS_16-012; US National Park Service IACUC protocols NPS IACUC 2010-1, AKR_YUCH and DENA_Burch_Wolves_2013, AKR_DENA_Borg_Wolves_2016.A3
NWT South Slave Boreal Wolves	Government of the Northwest Territories Wildlife Research Permit WL5000771; Government of the Northwest Territories WCC Protocol NWTWCC 2019-020; reviewed annually
NYSDEC Raptor Tracking	US Federal Bird Banding permits 10072, 20723, 20734, 21963
Oystercatcher 2016 Alves Iceland	Icelandic Institute of Natural History
Oystercatcher 2017 Alves Iceland	Icelandic Institute of Natural History
Pacific Loons Alaska Colville River Delta	Federal Permit MB789758-0; Alaska Scientific Permit 15-108; National Zoological Park ACUC 15-20; US Geological Society Alaska Science Center ACUC 2015-09, 2016-04; US Geological Society IACUC Protocols 2008-23, 2010-4, 2014-12, 2016-04, 2017-05
Pannonic population tracks of greater white-fronted geese 2013-2017 (data from Kölzsch et al. 2019)	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) AZ 33.19-42502-04-15/1956; Royal Netherlands Academy of Arts and Sciences AWC DEC NIOO13.14; Hunting and Fishing Department of Zala County Government Office (Hungary) XX-H-004/1386-2/2012; Hunting and Fishing Department of Bács-Kiskun County Government Office (Hungary) BKH/001/1135-2/2016

Parasitic Jaeger/Arctic Skua North America	US Federal Bird Banding Permit 09700; Alaska scientific permits 17-162, 18-156, 19-157; National Zoological Park ACUC 15-33, 18-06; Environment and Climate Change Canada scientific permits 10565J, 10565M, 10565N; Government of Nunavut wildlife research permits WL2018-052, WL2019-041; Environment Canada Western and Northern ACC protocols EC-PN-13-006, 18JR01, 19JR01; Environment Canada Wildlife and Landscape Science Directorate and Canadian Wildlife Service ACC Protocol EC-PN-14-006
Peregrine Falcon, High Arctic Institute, northwest Greenland	Danish Polar Center permits 512-162, 512-167, 512-179, 512-212, 512-232, 512-254
Pomarine Jaeger North America	US Federal Bird Banding Permit 09700; Alaska Scientific permits 17-162, 18-156, 19-157; National Zoological Park ACUC 15-33, 18-06; Environment and Climate Change Canada scientific permits 10565J, 10565M, 10565N; Government of Nunavut wildlife research permits WL2018-052, WL2019-041; Environment Canada Western and Northern ACC protocols EC-PN-13-006, 18JR01, 19JR01; Environment Canada Wildlife and Landscape Science Directorate and Canadian Wildlife Service ACC Protocol EC-PN-14-006
Pre-breeding prospecting behaviour of snowy owls (data from Therrien et al. 2015)	Université Laval Animal Care permits
Red-necked Phalarope southern Chukotka (data from Mu et al. 2018)	Princeton University IACUC protocols 2073F-16 and 2073F-19
Red-necked Phalarope, van Bemmelen, Norway	Norwegian Food Safety Authority (FOTS) IDs 6328, 6329, 5276, 6328, 7421, 8538, 15726
Red-necked Phalarope, van Bemmelen, Sweden	Permits by Jordbruks verket to Lund University, Sweden. Permit numbers: M160-11, M470-12, M472-12
redThroatedLoon_USGS_ASC_argos	US Geological Survey IACUC protocols 2008-23, 2010-4, 2014-12, 2016-4, 2017-05
Ringed seals Igloolik	Animal Care Approval FWI-ACC_AUP_2006-2014_009; Licence to Fish for Scientific Purposes S-2006-2014-1014-NU
Ringed seals Resolute	Animal Care Approval FWI-ACC_AUP_2006-2014_009; Licence to Fish for Scientific Purposes S-2006-2014-1014-NU
Ringed seals Sanikiluaq	Animal Care Approval FWI-ACC_AUP_2006-2014_009; Licence to Fish for Scientific Purposes S-2006-2014-1014-NU
Rough-legged Buzzard in variable environment	Norwegian Food Safety Authority (FOTS) IDs 6472/2014/82889-1, 15595/18/72904
Rusty Blackbird Alberta	Environment Canada 10277 AJ; National Zoological Park ACUC Protocol 15-16
Sabine's Gulls in the Juan de Fuca Eddy	Canadian scientific and access permits NUN-SCI-08-55, NUN-MBS-12-03, NUN-SCI-12-04, WRP2013040, banding permits 10694, 10322, animal care protocols 0800AG01, WM-01-11
Seaducks in the Fehmarn Belt (southern Baltic)	Danish Animal Welfare Committee (Dyreforsøgstilsynet) Permit 2009/561-1589

Short-eared Owl, North America	US Federal Bird Banding and State Scientific permits, IACUC Protocol 2009007
Skagit County Washington Western High Arctic Brant	US Federal Bird Banding Permit 06508
Skagit Valley / Wrangel Island Snow Goose	US Federal Bird Banding Permit 06508
Skagit Valley / Wrangel Island Snow Goose 2016-17 GSM	US Federal Bird Banding Permit 06508
Snow Bunting Migration Phenology	University of Windsor Animal Use permits 13-20, 18-02
Snow bunting, Svalbard	Norwegian Food Safety Authority (FOTS) ID 4701; Governor of Svalbard Approval 2014/00375-5
Snowy owl - North America	Université Laval ACC permit no 2006-163,, Environment and Climate Change Canada bird banding permit no 10648, Parks Canada permit no SIR-2007-1091
Snowy owls from Barrow Alaska 1999-2001 (Fuller)	US Fish and Wildlife Service Patuxent Wildlife Research Center, Boise State University IACUC
Solovki Larus Track	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) “On Wildlife”.
Taiga Bean Geese Larry Griffin	British Trust for Ornithology License A/5436 and Endorsement 11-02w
TBMUCOMU.GastonMontevecchi.NWAtlantic	Canadian scientific and access permits NUN-SCI-08-55, NUN-MBS-12-03, NUN-SCI-12-04, WRP2013040, banding permits 10694, 10322, animal care protocols 0800AG01, WM-01-11
Thayer's Gulls from the Canadian High Arctic	Canadian Wildlife Service NUN-SCI-16-05, NIRB 16YN020/124659, NPC 148548, Acadia 04-17, Canadian Wildlife Service Banding Permit 10694
Thick-billed murre Elliott Coats 2010	McGill University Animal Care Protocol 2015-7599
Thick-billed murre Elliott Coats 2011	McGill University Animal Care Protocol 2015-7599
Thick-billed murre Elliott Coats 2013	McGill University Animal Care Protocol 2015-7599
Thick-billed murre Gaston PLI 2014	Canadian scientific and access permits NUN-SCI-08-55, NUN-MBS-12-03, NUN-SCI-12-04, WRP2013040, banding permits 10694, 10322, animal care protocols 0800AG01, WM-01-11
Thick-billed murre Gilchrist and Elliott Coats 2016	McGill University Animal Care Protocol 2015-7599
Thick-billed murre Gilchrist and Elliott Coats 2017	McGill University Animal Care Protocol 2015-7599
Thick-billed murre Gilchrist and Elliott Digges 2015	McGill University Animal Care Protocol 2015-7599
Thick-billed murre Gilchrist and Elliott Digges 2016	McGill University Animal Care Protocol 2015-7599; Government of Nunavut animal care protocols NUN-SCI-16-03, NUN-SCI-16-04; Animal care EC-PN-16-017
Thick-billed murre Gilchrist Cape Graham Moore 2016	McGill University Animal Care Protocol 2015-7599; Government of Nunavut animal care protocols NUN-SCI-16-03, NUN-SCI-16-04; Animal care EC-PN-16-017
Thick-billed Murres; Gaston/Akearok, Prince Leopold Island, Nunavut, Canada	McGill University Animal Care Protocol 2015-7599
Thick-billed Murres; Gilchrist; Cape Graham Moore, Canada	McGill University Animal Care Protocol 2015-7599
Thick-billed Murres; Gilchrist; Digges Island, Canada	McGill University Animal Care Protocol 2015-7599

Tobseda Barnacle Goose	No permissions were required according to the §44 and §6 of the Federal Law of the Russian Federation No. 52 from 24.04.1995 (last update 18.02.2020) "On Wildlife".
Tracking movements of Peregrine Falcons Falco peregrinus from breeding populations in Arctic Eurasia	Russian Federation permits
Tracking post-fledging dispersal and migration of juvenile Peregrine Falcons Falco peregrinus in Arctic Russia	Russian Federation permits
Upper Midwest Bald Eagle Project	Boise State University IACUC Protocol 692-980-020
USGS WERC Dixon Field Station Compiled Avian Telemetry	US Federal Bird Banding Permit 21142, California Department of Fish and Wildlife Scientific Collection Permit SC-8090
Vega Gull BPN KoEco Russia Chaun 2017	Gimpo City Permit 2017-1
Wader migration German Wadden Sea: bar-tailed godwits	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) 33-42502-04-10/0307; Institute of Avian Research, Wilhelmshaven, Germany; National Park Administration of Lower Saxony, Wilhelmshaven, Germany
Wader migration German Wadden Sea: grey plovers	Lower Saxony State Office for Consumer Protection and Food Safety (LAVES) 33-42502-04-10/0307; Institute of Avian Research, Wilhelmshaven, Germany; National Park Administration of Lower Saxony, Wilhelmshaven, Germany
Washington State Surf Scoter	US Federal Bird Banding Permit 06508
Washington State White-winged Scoter	US Federal Bird Banding Permit 06508
Western GOEA Conservation	US Federal Bird Banding Permit
Whimbrel Numenius phaeopus Acadian Peninsula	US Federal Bird Banding Permit 21567; William & Mary IACUC Protocol 2018-04-27-12927, IBC Protocol 2017-06-21-12181
Whimbrel Numenius phaeopus North America Smith/Watts/Winn	Government of the Northwest Territories Wildlife Research permits WL500153, WL500252; Government of the Northwest Territories Wildlife Care Committee protocols NWTWCC 2013-009, NWTWCC 2014-007; Environment Canada Wildlife and Landscape Science Directorate and Canadian Wildlife Service ACC Approval EC-PN-14-006; Environment Canada scientific permits 10565J, 10565N, and 10565M
White fronted Goose QIA KoEco Korea 2017	Gimpo City Permit 2017-1
White-fronted goose (Greenland) Larry Griffin	British Trust for Ornithology Licence A/5436 and Endorsement 11-57w
White-fronted goose full year tracks 2006-2010 Alterra IWWR	Russian Academy of Sciences Institute of Geography (no approval needed); Wageningen Environmental Research (no approval needed)
Whooper swan (Icelandic) Larry Griffin II	British Trust for Ornithology Licence A/5436
Whooper swan (Icelandic) Larry Griffin/Colin Pennycuick	British Trust for Ornithology Licence A/5436
Whooper swan (Icelandic) Larry Griffin/Kendrew Colhoun	British Trust for Ornithology Licence A/5436
Whooper swans in Latvia 2016	Latvian Ringing Centre Permit 171
yellowBilledLoon_USGS_ASC_argos	US Geological Survey IACUC protocols 2008-23, 2010-4, 2014-12, 2016-4, 2017-05

Table S.4.

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Table S.5.

Studies used in Case Study 1, 'long-term data reveal importance of decadal climate patterns on summering behavior in a migratory raptor'.

Study	Start	End	Animals	Summering onsets
ABoVE: USFWS R6 Golden Eagles	2015	2017	2	6
ABoVE: USGS/WVU Raptors	2013	2013	1	1
Adult Golden Eagle Satellite Tracking	2012	2017	10	18
Alaska Golden Eagles	2014	2017	33	61
Aquila chrysaetos interior west N. America, Craigs, Fuller	1993	1996	6	6
Beringia South Migrant Golden Eagle	2013	2015	1	3
Eagles Wintering in Bitterroot Valley	2013	2017	17	30
Eastern Montana Golden Eagles	2013	2017	11	20
Golden Eagle Migration, Denali, Alaska, McIntyre	1998	2000	6	6
Golden Eagles of Interior Alaska; Lewis	2015	2017	10	15
HawkWatch International Golden Eagles	2003	2008	4	9
Western GOEA Conservation	2015	2017	2	4

Table S.6.

Studies used in Case Study 2, 'large-scale geographic differences in parturition timing of caribou'.

Study	Start	End	Animals	Parturitions
ABoVE: BC Atlin Caribou	2000	2001	7	7
ABoVE: NWT Dehcho Boreal Woodland Caribou	2007	2017	80	164
ABoVE: NWT Inuvik Barren Ground Caribou	2006	2017	193	387
ABoVE: NWT Inuvik Boreal Woodland Caribou	2002	2012	23	56
ABoVE: NWT North Slave Barren Ground Caribou: Bathurst	2006	2017	90	142
ABoVE: NWT North Slave Boreal Caribou	2017	2017	15	15
ABoVE: NWT Sahtu Barren Ground Caribou: Bluenose-East	2006	2017	103	165
ABoVE: NWT Sahtu Boreal Woodland Caribou	2007	2011	11	22
ABoVE: NWT Sahtu Mountain Woodland Caribou	2008	2010	3	4
ABoVE: NWT South Slave Barren Ground Caribou: Beverly and Ahiak	2006	2017	109	224
ABoVE: NWT South Slave Boreal Woodland Caribou	2006	2017	122	219
ABoVE: Yukon Caribou	2000	2017	71	98
Mountain caribou in British Columbia	2001	2015	90	127

Table S.7.

Studies used in Case Study 3, 'temperature and precipitation response in movement rates of terrestrial mammals'.

Study	Start	End	Animals	Species
ABoVE: BC Atlin Caribou	2000	2002	10	*Rangifer tarandus caribou*
ABoVE: Boutin Alberta Grey Wolf	2013	2014	20	*Canis lupus*
ABoVE: Boutin Alberta Moose	2010	2012	24	*Alces alces*
ABoVE: Hebblewhite Alberta-BC Wolves	2000	2011	53	*Canis lupus*
ABoVE: NPS Denali Wolves	2004	2016	68	*Canis lupus*
ABoVE: NPS Wolves in Yukon-Charley Rivers National Preserve	2003	2015	47	*Canis lupus*
ABoVE: NWT Dehcho Boreal Woodland Caribou	2007	2018	85	*R. tarandus caribou*
ABoVE: NWT Inuvik Barren Ground Caribou	2006	2018	264	*R. tarandus groenlandicus*
ABoVE: NWT Inuvik Boreal Woodland Caribou	2002	2012	26	*R. tarandus caribou*
ABoVE: NWT North Slave Barren Ground Caribou: Bathurst	2009	2019	172	*R. tarandus groenlandicus*
ABoVE: NWT North Slave Boreal Caribou	2017	2018	20	*R. tarandus caribou*
ABoVE: NWT Sahtu Barren Ground Caribou: Bluenose-East	2006	2019	120	*R. tarandus groenlandicus*
ABoVE: NWT Sahtu Boreal Woodland Caribou	2004	2011	15	*R. tarandus caribou*
ABoVE: NWT Sahtu Mountain Woodland Caribou	2008	2010	3	*R. tarandus caribou*
ABoVE: NWT South Slave Barren Ground Caribou: Beverly and Ahiak	2006	2019	156	*R. tarandus groenlandicus*
ABoVE: NWT South Slave Boreal Woodland Caribou	2006	2018	174	*R. tarandus caribou*
ABoVE: Peters Hebblewhite Alberta-BC Moose	2008	2010	18	*Alces alces*
ABoVE: Yukon Caribou	2000	2019	219	*R. tarandus caribou*
Brown and Black bear (Ursus spp.), Jerry Belant, Alaska	1998	2000	40	*Ursus spp.*
Latham Alberta Wolves	2006	2007	7	*Canis lupus*
Mountain caribou in British Columbia	2001	2016	172	*R. tarandus caribou*
NWT South Slave Boreal Wolves	2016	2018	7	*Canis lupus*

Table S.8.

Mixed-model results from Case Study 1, 'long-term data reveal importance of decadal climate patterns on summering behavior in a migratory raptor'. Conditional average linear mixed-model results for golden eagle summering onset dates from 1993 to 2017. Only models in which the parameter of interest is retained within the model are used in the averaging. We scaled year by centering on the mean and dividing by the standard deviation. Here we list the covariates, coefficient estimates from model averaging ('estimate'), standard errors ('se'), Satterthwaite degrees of freedom ('df'), z-values, and p-values ('Pr(>|z|)'). The full model did not have the highest weight for juveniles or sub-adults > 2011, but we report it here for consistency with other age class models.

covariate	estimate	se	df	z-value	Pr(>|z|)
All golden eagle age classes (N = 179):					
Full model: df = 11, BIC = 1420, AICc = 1386.5, R^2 = 0.68, weight = 0.712					
year	-2.6429	2.0015	140	1.313	0.189
latitude	1.0774	0.3595	139	2.976	0.003
wPDO	-2.2927	1.0208	131	2.230	0.026
age:sub-adult	-19.4730	3.3982	124	5.690	< 0.001
age:adult	-33.1718	3.7255	165	8.842	< 0.001
sex:male	1.6117	2.7835	81	0.575	0.565
year:wPDO	-2.3417	1.4212	155	1.636	0.102
Adult golden eagles (n = 89):					
Full model: df = 9, BIC = 590.8, AICc = 570.7, R^2 = 0.37, weight = 0.451					
year	-1.2118	1.9583	78	0.610	0.542
latitude	0.7673	0.3429	53	2.204	0.028
wPDO	-2.2371	0.8535	53	2.584	0.010
sex:male	-0.1475	1.9167	47	0.076	0.939
year:wPDO	-1.2476	2.8593	79	0.430	0.667
Adult golden eagles > 2011 (n = 83):					
Full model: df = 8, BIC = 548.3, AICc = 530.9, R^2 = 0.39, weight = 0.257					
year	0.1717	1.1802	57	0.144	0.886
latitude	0.9727	0.3582	56	2.673	0.008
wPDO	-3.0814	1.5912	49	1.915	0.055
sex:male	0.4051	1.7995	45	0.222	0.825
year:wPDO	-1.8036	1.3218	53	1.343	0.179
Sub-adult golden eagles (n = 72):					
Full model: df = 8, BIC = 600.9, AICc = 585.0, R^2 = 0.49, weight = 0.755					
year	-4.7449	3.4452	65	1.353	0.176
latitude	1.5994	0.5505	66	2.851	0.004
wPDO	-2.6644	2.0656	46	1.266	0.206
sex:male	2.6074	5.4413	44	0.470	0.638
year:wPDO	-9.6732	3.6669	48	2.588	0.010
Sub-adult golden eagles > 2011 (n = 67):					
Full model: df = 8, BIC = 552.8, AICc = 537.6, R^2 = 0.41, weight = 0.337					
year	2.4633	2.4982	49	0.967	0.333

latitude	0.6672	0.6334	46	1.032	0.302
wPDO	-8.5069	2.6366	33	3.162	0.002
sex:male	-0.1708	5.0829	43	0.033	0.974
year:wPDO	-9.4866	2.4671	51	3.768	<0.001

Juvenile golden eagles (n = 18):
Full model: df =6, BIC = 142.8, AICc = 145.0, R^2 = 0.50, weight = 0.057

year	1.0892	4.4923	NA	0.230	0.818
latitude	0.9474	0.7820	NA	1.121	0.262
wPDO	1.4309	2.2793	NA	0.579	0.563
year:wPDO	-6.4330	2.3073	NA	2.546	0.011

Table S.9.

Model selection results (weight > 0.01) from Case Study 1, 'long-term data reveal importance of decadal climate patterns on summering behavior in a migratory raptor', evaluating the influence of year (fixed, continuous, centered and scaled), latitude of summering behavior start (fixed, continuous), eagle sex (fixed, categorical; excluded in 'Juvenile' model), eagle age (fixed, categorical; only included in 'All' model), mean monthly PDO index for the proceeding winter (PDO; fixed, continuous), and the interaction of year and PDO. We included individual identifier as a random term and fit our linear mixed-effect model by restricted maximum likelihood. Here we present a subset of the models, ranked by model weight, including their degrees of freedom (df), log-likelihood (LL), pseudo-R^2 (Nagelkerke's modified statistic; R^2), Bayesian Information Criterion (BIC), Akaike Information Criterion corrected for small sample sizes (AICc), and delta AICc (delta).

Model covariates	df	LL	R^2	BIC	AICc	delta	weight
All golden eagle age classes:							
year + latitude + PDO + age + sex + year:PDO	11	-681.5	0.68	1420	1387	0.00	0.712
year + latitude + PDO + age + sex	10	-684.1	0.68	1420	1389	2.87	0.170
year + latitude + PDO + age + year:PDO	9	-686.6	0.68	1420	1392	5.76	0.040
year + PDO + age + sex + year:PDO	10	-685.6	0.67	1423	1393	6.01	0.035
year + latitude + age + sex	9	-686.9	0.67	1421	1393	6.40	0.029
Adult golden eagles:							
year + latitude + PDO + sex + year:PDO	9	-275.2	0.37	590.8	570.7	0.00	0.451
year + latitude + PDO + sex	8	-277.3	0.37	590.4	572.3	1.62	0.201
year + PDO + sex + year:PDO	8	-277.5	0.33	590.8	572.7	2.00	0.166
year + PDO +sex	7	-279.5	0.33	590.5	574.4	3.72	0.070
year + latitude + PDO + year:PDO	7	-280.3	0.36	591.9	575.9	5.20	0.034
latitude + PDO + sex	7	-280.7	0.33	592.8	576.8	6.06	0.022
PDO + sex	6	-282.3	0.30	591.5	577.5	6.85	0.015
year + latitude + sex	7	-281.1	0.32	593.7	577.6	6.92	0.014
year + latitude + PDO	6	-282.5	0.36	591.9	577.9	7.24	0.012
Adult golden eagles > 2011:							
year + latitude + PDO + sex + year:PDO	8	-256.5	0.39	548.3	530.9	0.00	0.257
year + latitude + PDO + year:PDO	7	-258.0	0.39	546.9	531.5	0.58	0.192
latitude + PDO + sex	6	-259.5	0.38	545.5	532.1	1.22	0.140
year + latitude + PDO + sex	7	-258.6	0.38	548.1	532.7	1.80	0.104
latitude + PDO	5	-261.0	0.38	544.1	532.8	1.93	0.098
year + latitude + PDO	6	-260.1	0.38	546.8	533.4	2.48	0.074
year + PDO + sex + year:PDO	7	-259.7	0.34	550.3	534.9	3.96	0.036
year + PDO + year:PDO	6	-261.3	0.34	549.0	535.6	4.72	0.024
year + PDO + sex	6	-261.7	0.33	549.9	536.4	5.54	0.016
year + latitude + sex	6	-262.0	0.34	550.5	537.1	6.22	0.011
year + PDO	5	-263.3	0.33	548.6	537.3	6.38	0.011
PDO + sex	5	-263.3	0.31	548.7	537.3	6.44	0.010

Sub-adult golden eagles:							
year + latitude + PDO + sex + year:PDO	8	-283.4	0.49	600.9	585.0	0.00	0.755
year + latitude + PDO + year:PDO	7	-286.1	0.49	602.1	587.9	2.93	0.174
year + PDO + sex + year:PDO	7	-287.6	0.43	605.1	590.9	5.91	0.039
year + latitude + PDO + sex	7	-288.9	0.44	607.8	593.6	8.65	0.010
year + PDO + year:PDO	6	-290.2	0.43	606.0	593.7	8.68	0.010
Sub-adult golden eagles > 2011:							
year + PDO + sex + year:PDO	7	-260.6	0.39	550.6	537.1	0.00	0.443
year + latitude + PDO + sex + year:PDO	8	-259.6	0.40	552.8	537.6	0.55	0.337
year + PDO + year:PDO	6	-263.1	0.39	551.5	539.6	2.57	0.122
year + latitude + PDO + year:PDO	7	-262.1	0.40	553.7	540.1	3.05	0.096
Juvenile golden eagles:							
year + PDO + year:PDO	5	-63.2	0.48	140.8	141.3	0.00	0.372
Null	2	-69.0	0.00	143.8	142.8	1.49	0.177
latitude	3	-67.9	0.12	144.4	143.4	2.15	0.127
Year	3	-68.3	0.07	145.3	144.3	3.04	0.081
PDO	3	-68.6	0.04	145.9	145.0	3.67	0.059
year + latitude + PDO + year:PDO	6	-62.7	0.50	142.8	145.0	3.75	0.057
year + PDO	4	-67.2	0.18	145.9	145.4	4.14	0.047
year + latitude	4	-67.5	0.15	146.5	146.1	4.76	0.034
latitude + PDO	4	-67.5	0.15	146.6	146.1	4.82	0.033
year + latitude + PDO	5	-66.6	0.24	147.6	148.1	6.85	0.012

Table S.10
Population-level summary statistics for caribou parturition analysis (case study 2). The trend for mountain caribou was modeled by generalized additive models (GAMs) that include linear latitude and longitude effects and a spline on elevation. The woodland caribou trend models only include latitude and longitude effects. The barren-ground trend model is a linear mixed effects models with random intercepts and slopes (year effect) on herd (sub-population) as a random effect. The r^2 values are the *conditional* as opposed to *marginal* r^2 following (*63*). The *p*-value and trend are on the collective main effect and do not account for variation among herds.

Population	N	Obs. period	Parturition date, mean	Parturition date, sd	Parturition minimum date	Parturition maximum date	Trend	Trend se	*p*-value	r^2
N. mountain	109	2000-2017	22-May	8.351275	5-May	25-Jun	-0.68	0.220	0.002	0.26
S. mountain	127	2006-2015	29-May	9.590992	30-Apr	21-Jun	0.23	0.347	0.513	0.13
N. boreal	78	2002-2011	18-May	8.320673	3-May	11-Jun	-1.04	0.459	0.027	0.07
S. boreal	398	2006-2017	13-May	9.183419	29-Apr	25-Jun	-0.03	0.156	0.832	0.002
Barren-ground	918	2006-2017	4-Jun	6.390228	22-May	29-Jun	-0.43	0.061	<0.001	0.44