Subpopulation delineation of Canadian polar bears (*Ursus maritimus*) in the eastern Beaufort Sea

by

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Abstract

Wildlife management often delineates a species into units to improve monitoring, population estimation, and status assessment. Polar bears (*Ursus maritimus*) are delineated in 20 subpopulations based on an International Union for the Conservation of Nature definition. This definition requires subpopulations to be geographically distinct groups of individuals with low demographic or genetic exchange. I examined whether the Southern Beaufort Sea and Northern Beaufort Sea, were spatially separated using polar bear telemetry data collected between 2007-2014. To assess possible methods of subpopulation delineation, I grouped 75 adult and sub-adult bears into spatial groups using three classification methods: an observed space-use, a capture location, and an agglomerative hierarchical clustering. I then estimated the overlap between spatial groups during the harvest (February – June) and non-harvest (July – January) periods for each classification method. My results found that polar bears within the eastern Beaufort Sea are not geographically separated based on any of the classification methods, and that 61 bears crossed a subpopulation boundary. This assessment suggests that the entire eastern Beaufort Sea region represents one subpopulation. Any boundary in the eastern Beaufort Sea that separates polar bears into groups would best be considered as delineating wildlife management units rather than unique subpopulations based on biological separation.

Preface

This thesis is an original work by Nicholas James Paroshy. Field methods were in accordance with the Canadian Council on Animal Care guidelines and approved by the University of Alberta Biological Sciences Animal Care and Use Committee (Protocols 409705, 600804, 600904, 6001004). Research was conducted under Government of Northwest Territories Department of Environment and Natural Resources permits WL003322, WL005372, WL005596, WL007376. As of June 2025, this manuscript is in preparation for submission to Biological Conservation.

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Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Wildlife management is the process of integrating scientific knowledge with sociopolitical, cultural, and economical factors to conserve species and monitor biodiversity, with goals that may include managing populations (Courbin et al. 2009; Chee and Wintle 2010, Manjerovic et al. 2014), monitoring extinction risk (Mawdsley et al. 2009), and allowing for sustainable harvests (Weinbaum et al. 2013). Scientific knowledge provides information for management plans, while sociopolitical, cultural, and economic factors help refine and optimize plans for specific goals (Riley et al. 2002, Bunnefeld and Keane 2014). Management plans are often dynamic and updated over time and can take the form of adaptive management, which updates goals in response to new information (Walters 1986, Williams 2011). Adaptive management can be useful for harvested species and species at risk, which may be under increased risk of population decline from human impacts (Williams and Brown 2014, Serrouya et al. 2019).

Adaptive management plans are typically developed at the species level, yet can include subcategories that group individuals into units (Mace 2004, Green 2005, O'Donnell et al. 2022). These units are often viewed as populations or subpopulations, which are groups of individuals that have some degree of spatial or genetic separation (Palsbøll et al. 2007, Swihart et al. 2020). Spatially distinct and identifiable units often aim to improve population estimation and status assessment through finer-scale monitoring which, in turn, allows for wildlife management strategies that can vary per unit (Green 2005).

The delineation of units has historically been driven by jurisdictional boundaries, geographic features, and human harvest activity, rather than biological factors (Taylor and Lee 1995, Bischof et al. 2016, Swihart et al. 2020). As technology has advanced, there have been attempts to delineate units to better represent biological variables, which includes using movement data, genetic information, and satellite habitat assessments (Taylor et al. 2001, Weckworth et al. 2018, Swihart et al. 2020). The use of movement data has been particularly useful for identifying spatially distinct, non-overlapping units, while the use of genetic information has been useful for identifying the amount of gene flow between units (Waples and Gaggiotti 2006). Moreover, both movement and genetics data have temporal elements, such as habitat space-use and movement rates that differ based on migration or reproductive periods (Ferguson and Elkie 2006, Nagy et al. 2011, Nicholson et al. 2019). As such, understanding movement and genetics data when delineating spatial units has been a priority for conservation and government agencies (Weckworth et al. 2018, Muir et al. 2021).

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is a federal organization responsible for the development of designatable units (DU) for the status assessment of Canadian species (Lukey and Crawford 2009, Muir et al. 2021, COSEWIC 2024). COSEWIC uses two components for identifying DUs: discreteness (i.e., heritable traits or genetic markers that are distinct across DUs such as natural barriers) and evolutionary significance (i.e., unique heritable traits not found in other DUs or elsewhere in Canada) (Muir et al. 2021, COSEWIC 2024). The International Union for Conservation of Nature (IUCN) assesses the conservation status of plants and animals across the globe through the Red List (Rivers et al. 2010, IUCN 2024b). The IUCN defines their spatial organization of a species as subpopulations, which are characterized as geographically distinct groups of individuals that have little demographic exchange with other groups of individuals within a taxon (Rivers et al. 2010, IUCN 2012, IUCN 2024a). The IUCN does not require complete isolation of subpopulations, but rather states that emigration and immigration should be less than a single individual per year (Rivers et al. 2010, IUCN 2012, IUCN 2024a).

Classifying individuals into units is common for species of concern in Canada. For example, beluga whales (*Delphinapterus leucas*) are spatially defined by COSEWIC with eight DUs in Canada, and by the IUCN with eight subpopulations in Canada, and 21 subpopulations worldwide (DFO 2010, COSEWIC 2016, Lowry et al. 2017). Comparatively, caribou (*Rangifer tarandus*) are a COSEWIC species at risk that have 12 DUs, while the IUCN recognizes 134 Canadian subpopulations in five regions (COSEWIC 2011, Gunn 2016, Weckworth et al. 2018). In contrast, grizzly bears (*Ursus arctos*) have one DU under COSEWIC, and six subpopulations under the IUCN within Canada (COSEWIC 2012, McLellan et al. 2017). Notably, five of the six grizzly bear subpopulations are highly isolated and fragmented, while the remaining subpopulation represents a Canadian continental distribution. Wolverines (*Gulo gulo*) have one DU under COSEWIC and one subpopulation in Canada under the IUCN (Tomasik and Cook 2005, COSEWIC 2014, Abramov 2016). Polar bears (*Ursus maritimus*) have one DU under COSEWIC, but have 14 subpopulations within Canada and 20 subpopulations worldwide under the IUCN (Wiig et al. 2015, Regehr et al. 2016, COSEWIC 2018, Laidre et al. 2022b).

While the COSEWIC and IUCN classification systems share commonalities for some species, their approaches result in very different classifications for others. The reasons for these differences pertain to the definition of DUs and subpopulations, as well as the rigour in applying the definitions (COSEWIC 2018). For example, polar bears met the COSEWIC criteria for discreteness, but did not meet the criteria for evolutionary significance, resulting in a single DU (Thiemann et al. 2008, COSEWIC 2018). However, the IUCN recognizes that polar bear subpopulations may have differing levels of ecological impact (e.g., sea ice loss, climate change), which may lead to altered demographic and genetic exchange rates between subpopulations (Wiig et al. 2015). As such, the IUCN attempted to account for these ecological impacts using subpopulations as monitoring units, which is supported by the historical development and the recent updates of subpopulation boundaries.

The IUCN Species Survival Commission Polar Bear Specialist Group (PBSG), a multi-national group that aims to coordinate and synthesize polar bear research, has adopted harvest and research recommendations in the development of subpopulations (Stirling 1986, Stirling 2002, Larsen and Stirling 2009). The initial development of polar bear subpopulations was driven by concerns of overharvesting (Prestrud and Stirling 1994, Stirling 2002), and were delineated using mark-recapture techniques (e.g., marked bears and bears taken by subsistence harvesters), natural barriers, and harvest management considerations (e.g., harvest activity) (Taylor and Lee 1995, Stirling 2002, Wiig et al. 2015). Over time, additional insights on population structure from genetic analyses (Paetkau et al. 1999, Peacock et al. 2015, Malenfant et al. 2016), telemetry location clustering analyses (Bethke et al. 1996, Mauritzen et al. 2002, Amstrup et al. 2005, Viengkone et al. 2018), and remote sensing habitat assessments (Laidre et al. 2022b) led to modified subpopulation delineations. Examples of modified subpopulation delineations include the Southeast Greenland and East Greenland from Laidre et al. (2022b), and the Northern Beaufort Sea (NB) and the Southern Beaufort Sea (SB) from Amstrup et al. (2004, 2005).

Recently, the PBSG adopted a modified subpopulation boundary along the coast of eastern Greenland based on Laidre et al. (2022b). Historically, only the East Greenland subpopulation was recognized by the PBSG. Using 36-years of data, Laidre et al. (2022b) investigated a spatially isolated group of genetically unique polar bears living in the southeastern region of Greenland using movement, demographic, and genetic analyses. Based on 83 satellite-tracked bears, the authors found that bears within Southeast Greenland made localized movements within fjords and used a unique year-round, freshwater glacial mélange. Bears in Southeast Greenland were a spatial disjunct group based on telemetry locations, and were the most genetically isolated group when compared to all other subpopulations. As such, the PBSG adopted the use of Southeast Greenland as a subpopulation in 2024.

The PBSG currently recognizes the SB and NB subpopulations within the Beaufort Sea, a region north of Alaska, USA and Northwest Territories and Yukon, Canada, which were first adopted in 1985 (IUCN/SSC Polar Bear Specialist Group 1986; Figure 1). The boundary delineating the SB and NB was initially placed at approximately 122°W and angled to the NW in the Amundsen Gulf due to the location of the Cape Bathurst polynya (IUCN/SSC Polar Bear Specialist Group 1986, Stirling et al. 1988, Stirling 2002; Figure 1). Supported by mark-recapture efforts, bears that were captured southwest of Amundsen Gulf were classified as the SB, while those captured northeast and east of the Amundsen Gulf were classified as the NB (Stirling 2002; Figure 1). However, in 2016, the PBSG adopted a new boundary between SB and NB (Durner et al. 2018; Figure 2), which was supported by Amstrup et al. (2004, 2005).

Using telemetry locations, Amstrup et al. (2004) clustered and identified the spatial structure of 194 female polar bears captured in SB, NB, and the neighbouring Chukchi Sea (CS) subpopulation. Clustering analyses determined that three overlapping subpopulations occurred within this region, which coincided with the SB, NB, and CS. This paper also aimed to predict the occurrence probabilities for bears in the SB, NB, and CS across the Beaufort Sea. Notably, they determined that at Tuktoyaktuk, Northwest Territories, Canada, a community at 133°W, 50% of observed bears would belong to SB and 50% of observed bears would belong to NB. This study was followed up by Amstrup et al. (2005), where the authors replicated the cluster analysis from Amstrup et al. (2004), yet framed their study in the context of polar bear harvest. Under a harvest management framework, the authors determined that the SB, NB, and CS overlapped significantly, and the SB and NB overlapped at Tuktoyaktuk. Despite the overlap between SB and NB at Tuktoyaktuk, the PBSG currently recognizes the boundary between SB and NB at 133°W (Durner et al. 2018; Figure 2). The analyses from Laidre et al. (2022b) led to updated delineation of a new subpopulation, yet the same level of rigour was not applied to the subpopulation boundary shift between the SB and the NB. The current boundary at 133°W, based on Amstrup et al. (2004, 2005), conflicts with the guidelines of the IUCN, which suggest geographically distinct subpopulations that should have little demographic exchange with other subpopulations (IUCN 2012, IUCN 2024a). There are no current analyses supporting that the Beaufort Sea includes two subpopulations that are geographically distinct, which would meet the IUCN subpopulation guidelines. Biologically supported boundaries through telemetry or genetics data are vital to determining species abundance and estimating appropriate harvest rates (Fryxell et al. 2014). Thus, if boundaries are not supported through either telemetry or genetics data, the identified subpopulations would fail to meet the criteria of a biological unit, which would reduce precision and accuracy in population estimates (Fryxell et al. 2014).

The main objective of this study was to examine the polar bear subpopulation delineation between the SB and NB to determine if the current boundary biologically supports two subpopulations. We quantified the overlap between the SB and NB during two separate periods: the harvest period, which has implications for harvest management, and the non-harvest period, which has ecological and behavioural implications. Based on Amstrup et al. (2004, 2005), we hypothesized that bears in the Beaufort Sea subpopulations would occupy a continuous region with no discrete boundary. Our alternative hypothesis was that the Beaufort Sea is a non-continuous region with two distinct subpopulations. To test this hypothesis, we used a comparative approach to group individuals in spatial groups using three different methods: an observed space-use, a capture location, and an agglomerative hierarchical clustering algorithm with Ward's criterion. We chose a comparative approach as each method provided unique insight: the observed space-use method represented individual space-use across the Beaufort Sea, the capture location method represented a discrete reported location, similar to a harvest by Inuit, and agglomerative hierarchical clustering calculated the optimal grouping of two spatial groups. We then calculated the utilization distribution (UD) for each spatial group during the harvest period and the non-harvest period, and assessed the extent of overlap between each spatial group using the utilization distribution overlap index (UDOI). We expected that, for each classification method, the spatial groups would overlap during the harvest and non-harvest periods, yet the magnitude of overlap was unknown. Then, we determined if individuals were assigned to the same subpopulation across classification methods. We also calculated the crossing rates of individuals to determine the extent of demographic exchange between subpopulations. We then statistically compared the crossing rates between the harvest and non-harvest periods, and between adult and subadult bears. By calculating the crossing rates of individuals, we could assess the validity of the current subpopulation boundaries using the IUCN definition, which should be less than a single migrating individual per year.

Materials and Methods

Study Area and Subpopulations

The study area was centred on the eastern Beaufort Sea and Amundsen Gulf, an Arctic Ocean region in northeastern Alaska, USA, and the Yukon and Northwest Territories, Canada (Figure 2). The eastern Beaufort Sea region is influenced by a clockwise gyre, cold polar water currents, and variable wind and temperature patterns (Proshutinsky et al. 2002, Pongracz and Derocher 2017). Significant geographic features include a narrow continental shelf that extends ~120 km offshore with depths < ~80 m, open-water leads, and the Cape Bathurst polynya, which plays a significant role in primary productivity, which supports high prey density for polar bears (Harwood and Stirling 1992, Carmack et al. 2004, Henderson and Derocher 2022). Sea-ice begins to break-up in late April in the south and progresses northwards during the summer (Carmack and Macdonald 2002). Multiyear and pack ice persists throughout the summer, which provides habitat for bears (Bromaghin et al. 2015). Freeze-up begins in early to mid-October and progresses southwards (Carmack and Macdonald 2002).

The Beaufort Sea region includes polar bears in the SB and NB, and neighbours four other subpopulations: CS to the west, the Arctic Basin (AB) to the north, Viscount Melville Sound (VM) to the northeast, and the M'Clintock Channel (MC) to the east (Figure 2). The SB has declined, and is predicted to continue to decline in both short-term projections (~11.5 years, one generation) and long-term projections (≥ 23 years, ≥ two generations) (Hunter et al. 2010, Bromaghin et al. 2015, Durner et al. 2018, IUCN/SSC Polar Bear Specialist Group 2024). The NB is currently data deficient for both short-term and long-term projections, but was stable based on available data (Stirling et al. 2011, IUCN/SSC Polar Bear Specialist Group 2024). Polar bears are harvested throughout the SB and NB, with harvest being concentrated around Tuktoyaktuk (69.5°N, 133°W), Sachs Harbour (72°N, 125.3°W), Paulatuk (69.4°N, 124.1°W), and Ulukhaktok (70.7°N, 117.8°W; Hamilton et al. 2023).

We defined two within-year periods: the harvest period (February 1 - June 30, and the non-harvest period (July 1 - January 31). The harvest period overlapped with the Inuit subsistence harvest of polar bears by in the Beaufort Sea (Hamilton et al. 2023). The harvest period is also the prime feeding and mating season for polar bears (Pilfold et al. 2012, Biddlecombe et al. 2019). The non-harvest period overlapped with sea-ice break-up, which would result in the Beaufort Sea being ice-free for up to 440 km off the shore (Carmack and Macdonald 2002, Rode et al. 2022). In the non-harvest period, bears will either make long-distance movements north to remain on sea-ice, or will make southwards movements onto land (Bromaghin et al. 2015, Pongracz and Derocher 2017).

Animal Capture and Telemetry

During April-May of 2007-2012, polar bears were located by helicopter and captured through remote injection of Telazol (tiletamine hydrochloride and zolazepam hydrochloride, Zoletil®, Laboratoires Virbac, Carros, France) using standardized procedures (Stirling et al. 1989). Sex of individuals was determined during handling, and age was estimated in the lab by counting the cementum growth layer groups from an extracted vestigial premolar (Calvert and Ramsay 1998). Subadults were classified as individuals 2-4 years old, and adult bears were classified as those ≥5 years old. Animals were fitted with geographic positioning system (GPS) collars (Telonics, Mesa, AZ) linked to the Argos satellite system (CLS America Inc., Lanham, MD), programed to collect a GPS location every four hours. Collars were fitted with a programable release (CR-2a, Telonics, Mesa, AZ), which would occur two years after deployment for adult female polar bears, and one year after deployment for subadult male and female polar bears. A corrodible link was included in subadult collars. Capture and handling protocols followed the Canadian Council on Animal Care guidelines and were approved by the University of Alberta Biological Sciences Animal Care and Use Committee.

Biologically erroneous data (e.g., points where bear would have had to move >30km/hr to reach the successive point), dropped transmitters, denning females, and sea-ice drift were removed from the analysis (Togunov et al. 2020). Data was resampled to one location per day with a tolerance of 1 hour, which allowed for slight deviations in resampling time and to reduce computational load for analysis, as file sizes exceeded hardware limits for the agglomerative hierarchical clustering algorithm method (i.e. a 4-hour resampling dataset would require at least 192GB of memory). Data was filtered to include individuals with ≥30 locations during the harvest period, as smaller sample sizes are unreliable in estimating space-use (Seaman et al. 1999), which was critical for our observed space-use classification method. Data was projected to Lambert Azimuthal Equal-Area (EPSG 9820), with a central median of 130°W and a latitude of origin of 70°N, a projection which preserves area and is centered on the Beaufort Sea region.

Subpopulation Classification Methods

For each subpopulation classification method, we followed a workflow that consisted of classifying individuals to a subpopulation, calculating the utilization distribution (UD) for each subpopulation based on pooled locations for bears assigned to a subpopulation, and determining the overlap between each subpopulation using a UDOI. We classified individuals to a subpopulation using three different methods: an observed space-use, a capture location, and using agglomerative hierarchical clustering. The observed space-use method was performed as it represented individual space-use across the Beaufort Sea. The capture location method was performed as it represented a distinct reported location, which was used as a proxy to harvest by Inuit because a capture location represented a distinct observed location, similar to a harvested bear. Agglomerative hierarchical clustering was performed as it develops a predetermined number of partitioned clusters, it can handle large datasets efficiently, and due to the historic use in delineating polar bear subpopulations (Bethke et al. 1996, Mauritzen et al. 2002, Amstrup et al. 2004, 2005, Davidson and Ravi 2005).

Subpopulation Classification: Observed Space-Use

For this analysis, we followed our workflow that consisted of classifying and grouping individuals to a subpopulation, calculating the utilization distribution of each subpopulation, and determining the overlap between subpopulations. We assigned individuals to either the SB or NB based on where their highest proportion of harvest period locations were located, which was used as an estimate for temporal space-use within a subpopulation. Individual locations were intersected with the current subpopulation boundaries (Figure 2) using the 'extract' function in the 'raster' package in R, and each location was assigned an associated subpopulation region.

The number of locations for each bear in a subpopulation was then divided by the total number of locations for that bear within the harvest period, and the subpopulation with the highest proportion of locations was selected.

To determine the overlap between subpopulations, we first grouped bears based on their observed-space use subpopulation assignment and filtered the data to the harvest period. Then, we calculated the subpopulation-level UD using the autocorrelated kernel density estimator (AKDE), corresponding to the 'hr_akde' function in the 'amt' R package (Signer et al. 2019). We chose to perform UDs as they provide a probabilistic distribution of space-use (Keating and Cherry 2009, Lichti and Swihart 2011) that is consistent with polar bear subpopulation studies (Mauritzen et al. 2002, Amstrup et al. 2005). We chose to use AKDE as movement data is highly autocorrelated, which violates the assumptions of independence and identical distribution from traditional KDEs (Fleming et al. 2015). The UDs were estimated at 50% (core-use area) and 95% (total-use area; Fieberg and Kochanny 2005).

Subpopulation overlap was determined for the core-use and the total-use using the UDOI, which is the product of the area of overlap between two UDs ($A_{1,2}$) and the mean probability of encounter (APE), which is the integral of the summed product of two UDs, UD_1 and UD_2. The UD_1 and UD_2 each represent a subpopulation, and UDOI can be calculated as follows:

$$UDOI = A_{1,2} * APE, where\ APE = \iint_{\mathbb{R}^2} UD_1(x, y) * UD_2(x, y)dxdy \qquad (1)$$

We chose to use UDOI as we were interested in quantifying the shared space between subpopulations, while also quantifying the similarity of UDs (Fieberg and Kochanny 2005, Tilberg and Dixon 2022). A UDOI value of 0 represents no subpopulation overlap, and a value of 1 represents 100% overlap and identical distributions (Fieberg and Kochanny 2005). A value between 0 and 1 represents subpopulations that have a high degree of overlap, but are nonuniformly distributed (Fieberg and Kochanny 2005). The same procedure was then followed for the non-harvest period with individuals retaining their observed space-use subpopulation assignment.

Subpopulation Classification: Capture Location

For this analysis, we followed our workflow that consisted of classifying and grouping individuals to a subpopulation, calculating each subpopulation utilization distribution, and determining their overlap. We assigned an individual to a subpopulation based on their capture location as a proxy for harvest by Inuit because a capture location represented a distinct observed location, similar to a harvested bear. We classified each capture location using the 'extract' function in the 'raster' R package, then joined the classified subpopulations to the dataset using the 'inner_join' R function.

To determine the subpopulation overlap, we first grouped bears based on their capture location subpopulation assignment and filtered the data to the harvest period. Then, the subpopulation UD was calculated using the AKDE at the core-use and total-use and overlap was determined using UDOI. The same procedure was followed for the non-harvest period with individuals retaining their capture location subpopulation assignment.

Subpopulation Classification: Agglomerative Hierarchical Clustering

For this analysis, we followed our workflow that consisted of classifying and grouping individuals to a subpopulation, calculating the utilization distribution of each subpopulation, and determining the overlap between subpopulations. Notably, we used agglomerative hierarchical clustering, which is a bottom-up clustering approach, meaning that each location is initially considered to be in an independent cluster, which are then merged, based on similarity, to form larger clusters (Day and Edelsbrunner 1984). The merging of clusters continues until the algorithm reaches a pre-determined number of clusters. We performed the agglomerative hierarchical clustering algorithm until we obtained two clusters, which we used to represent the two subpopulations.

To perform agglomerative hierarchical clustering on our data, we first filtered the locations to the harvest period, and selected three input variables: latitude, longitude, and individual ID. We developed a dissimilarity matrix, which computes the dissimilarity between each observation based on the input variables, using the 'daisy' function from the 'cluster' package. We then clustered observations with Ward's method, which minimizes within-group variance, using the 'hclust' function (Ward Jr. 1963, Murtagh and Legendre 2014, Maechler et al. 2022). Then, we summarized the cluster group assignment and visualize the spatial groups using the 'cluster.stats' function from the 'fpc' package (Hennig 2023).

To determine the overlap between subpopulations, we first grouped bears based on their agglomerative hierarchical clustering subpopulation assignment and filtered the data to the harvest period. Then, the subpopulation-level UD was calculated using the AKDE at the core-use and total-use areas and overlap was determined using UDOI. The same procedure was followed for the non-harvest period with individuals retaining their agglomerative clustering subpopulation assignment.

Subpopulation Assignment and Crossing Events

Subpopulation assignment

We aimed to assess whether subpopulation assignment was consistent across classification methods to understand whether capture location, a proxy for harvest, would be comparable to the observed space-use or the agglomerative hierarchical clustering. To do so, we first summarized the number of times an individual was classified to the same subpopulation in both the observed space-use and the capture location methods. We then summarized the number of times an individual was classified to the same subpopulation in both the agglomerative hierarchical clustering and the capture location methods.

Crossing Events

We aimed to determine the number of crossing events per bear of any subpopulation boundary within the Beaufort Sea region, including the SB, NB, CS, AB, and VM. We identified crossing events by identifying all occurrences of when a bear's location, x_n, was in a different subpopulation than their previous location, x_{n-1}. For each bear, we calculated their total crossing events, and then summarized the crossing events/bear for the combined harvest and non-harvest period, for the harvest period, and for the non-harvest period. Results are presented as mean ± one standard deviation. We then performed a Welch's two-tailed *t*-test to determine whether the crossing rates differed between the harvest and non-harvest period, and performed a Welch's two-tailed *t*-test to determine whether the crossing rates differed between adult and subadult bears.

Results

Animal Capture and Telemetry

We received 139,006 locations at a 4h interval from 78 bears (56 adult females, 12 subadult females, 10 subadult males). One adult female was removed from analyses due to a long-distance emigration (Johnson et al. 2016), and two adult females with <30 locations in the harvest-period were removed from analyses resulting in a final sample size of 75 bears. Four bears lacked non-harvest period locations, and were only used for harvest period analyses. When resampling to one location/day, we retained 27,030 locations with a mean of 360 ± 241 (range: 36-1393) locations/bear, and a mean tracking period of 1.33 ± 0.85 years (range: 0.12-4.41 years) per bear. Each track at one location/day was missing a mean of 21.7% ± 17.6% locations (range: 0.4% - 71.5%). We removed 1,319 locations from dropped transmitters and 419 locations due to denning events. The final dataset included 25,468 locations, with 11,266 locations during the harvest period and 14,202 locations during the non-harvest period (Figure 3).

Subpopulation Classification: Observed Space-Use

Harvest Period

The majority of locations for 42 bears were in the SB and 33 bears were in the NB (Table 1). All individuals had >50% of locations in their assigned subpopulation during the harvest period, with a mean of 80.8% ± 17.9% locations (range: 50.3% - 100%; Table 1). The SB core-use area was 49,880 km^2 and the total-use area was 296,904 km^2 (Figure 4). The NB core-use area was 69,836 km^2 and the total-use area was 348,153 km^2 (Figure 4). Based on the UDOI, the SB and NB core-use areas overlapped at 0.045, and the total-use areas overlapped at 0.407 (Figure 4). The core-use area overlap between SB and NB was 12,222 km^2, representing 24.5% of the SB core-use area, and 17.5% of the NB core-use area. The total-use area overlap was 160,985 km^2, representing 54.2% of the SB total-use area, and 46.2% of NB total-use area.

Non-harvest Period

From the sample of 40 bears in the SB, the core-use area was 155,557 km^2 and the total-use area was 839,905 km^2 (Figure 5). From the sample of 31 bears in the NB, the NB core-use area was 216,347 km^2 and the total-use area was 1,094,715 km^2 (Figure 5). Based on the UDOI, the SB and NB core-use areas overlapped at 0.001, and the total-use areas overlapped at 0.480 (Figure 5). The core-use areas overlap between SB and NB was 8,453 km^2, representing 0.05% of SB core-use area and 0.04% of NB core-use area. The total-use area overlap between SB and NB was 662,617 km^2, representing 78.0% of SB total-use area and 60.5% of NB total-use area.

Subpopulation Classification: Capture Location

Harvest Period

The capture location of 40 bears was in the SB and the capture location of 35 bears was in the NB. The SB core-use area was 70,948 km^2 and the total-use area was 418,176 km^2 (Figure 6).

The NB core-use area was 72,723 km^2 and the total-use area was 379,441 km^2 (Figure 6). Based on the UDOI, the SB and NB core-use areas overlapped at 0.232, and total-use areas overlapped at 0.991 (Figure 6). The core-use area overlap between SB and NB was 32,823 km^2, representing 46.3% of SB core-use area and 45.1% of NB core-use area. The total-use area overlap between SB and NB was 288,051 km^2, representing 68.9% of SB total-use area and 75.9% of NB total-use area.

Non-harvest Period

From 37 bears in the SB, the core-use area was 258,728 km^2 and the total-use area was 958,117 km^2 (Figure 7). From 34 bears in the NB, the core-use area was 238,969 km^2 and the total-use area was 1,160,387 km^2 (Figure 7). Based on the UDOI, the SB and NB core-use areas overlapped at 0.235, and total-use areas overlapped at 0.942 (Figure 7). The core-use area overlap between SB and NB was 119,178 km^2, representing 46.1% of the SB core-use area and 49.9% of NB core-use area. The total-use area overlap between SB and NB was 776,764 km^2, representing 81.1% of SB total-use area and 66.9% of the NB total-use area.

Subpopulation Classification: Agglomerative Hierarchical Clustering

Harvest Period

The two clusters were cluster 1 (South), which approximated the SB and had 26 bears, and cluster 2 (North), which approximated the NB and had 49 bears. The South core-use area was 43,118 km^2 and the total-use area was 268,906 km^2 (Figure 8). The North core-use area was 69,679 km^2 and the total-use area was 354,999 km^2 (Figure 8). Based on the UDOI, the South and North core-use areas overlapped at 0.014, and total-use areas overlapped at 0.322 (Figure 8). The core-use area overlap between South and North was 7,964 km^2, representing 18.5% of the South core-use area and 11.4% of the North core-use area. The total-use area overlap between the South and North was 145,969 km^2, representing 54.3% of the South total-use area and 41.1% of the North total-use area.

Non-Harvest Period

From 24 bears in the South, the core-use area was 115,069 km^2 and the total-use area was 873,735 km^2 (Figure 9). From 47 bears in the North, the core-use area was 245,269 km^2 and the total-use area was 1,068,697 km^2 (Figure 9). Based on the UDOI, the South and North core-use areas overlapped at < 0.001, and total-use areas overlapped at 0.574 (Figure 9). The core-use area overlap between South and North was 2,082 km^2, representing 0.02% of the South core-use area and 0.01% of the North core-use area. The total-use area overlap between South and North was 658,634 km^2, representing 75.4% of the South total-use area and 61.6% of the North total-use area.

Subpopulation Assignment and Crossing Events

Subpopulation Assignment

Of the 75 bears analysed, 55 (73.3%) were assigned to the same subpopulation in the observed space-use and the capture locations methods, while 20 (26.7%) were assigned to a different subpopulation in the observed space-use and the capture locations methods (Table 2). Based on the agglomerative hierarchical clustering method, 53 (70.7%) were assigned to a cluster that most closely represented their capture location, while 22 (29.3%) were assigned to a cluster that did not closely represent their capture location (Table 3).

Crossing Events

During the pooled harvest and non-harvest periods, 61 bears (81.3%) crossed a subpopulation boundary, averaging 9.8 ± 7.6 crossings/bear (range: 1 – 36), with a total of 597 crossing events for all bears (Table 4). During the harvest period, 54 bears crossed a boundary, with 261 crossing events and a mean of 4.8 ± 4.7 crossings/bear (range: 1 – 26). During the non-harvest period, 50 bears crossed a boundary, with 336 total crossing events and a mean of 6.7 ± 4.6 crossings/bear (range: 1 – 22). Crossing rates did not significantly differ between the harvest and non-harvest period (t_{153}= 1.27, p = 0.20; Figure 10), and did not significantly differ between adult and subadult bears (t_{33} = 0.34, p = 0.74; Figure 11).

Discussion

We observed subpopulation overlap across all classification methods for the core-use and total-use areas during the harvest period. We also observed subpopulation overlap across all classification methods for the core-use and total-use areas during the non-harvest period, but only observed minimal overlap for the observed space-use and agglomerative hierarchical clustering methods for the core-use during the non-harvest period. We quantified subpopulation overlap by using UDOI, which varied widely between <0.001 to 0.924, values that represent minimal overlap between two subpopulations to values that represent almost complete overlap between subpopulations. Further, 81.3% of bears crossed a subpopulation boundary. Although there have been attempts to delineate polar bear subpopulations across the Beaufort Sea (Amstrup et al. 2004, Amstrup et al. 2005, Scharf et al. 2019), we employ a comparative approach, testing three classification methods to demonstrate that two subpopulations were not geographically separated during any period throughout the year. This lack of differentiation indicates that the eastern Beaufort Sea region did not represent two subpopulations based on the IUCN definition, which should represent geographically distinct subpopulations that have little demographic exchange with other subpopulations (IUCN 2012, IUCN 2024a).

Historically, polar bears were believed to be a single population which was distributed across the circumpolar Arctic (Pedersen 1945, as cited in Stirling 2002). Through the introduction of genetic analyses, GPS telemetry, and satellite imagery, subpopulation boundaries were investigated and inconsistently refined. Mauritzen et al. (2002) aided in the development of the Barents Sea and Kara Sea subpopulation designations and refined the boundaries of the Laptev Sea boundary using clustering algorithms based on satellite locations, yet did not use an overlap metric (e.g., UDOI) to quantify spatial separation. Laidre et al. (2022b) aided to refine the boundaries of East Greenland and develop the Southeast Greenland using genetics and movement analyses, yet focused primarily on genetics and did not quantify spatial overlap. Stirling et al. (1988) collected bear data between 1985-1987 based on mark-recapture events which led to the initial development of SB and NB boundary, and Amstrup et al. (2004, 2005) collected bear data from 1985-2003 using satellite telemetry locations and clustered individuals, yet they did not quantify spatial overlap using an overlap metric. Despite the overlap between SB and NB in Amstrup et al. (2004, 2005), the PBSG referenced these studies as rationale for a boundary shift (Durner et al. 2018). Bethke et al. (1996) clustered bears into three subpopulations, NB, VM and Parry Channel, based on locations collected between 1989 -1991, yet did not have an objective method to select the optimal number of clusters. Obbard and Middel (2012) compared space-use from bears in the Southern Hudson Bay subpopulation to the current subpopulation boundaries through UDs, but this did not lead to a refined subpopulation boundary. Viengkone et al. (2018) performed spatial overlap analyses using capture location and genetics for subpopulation assignment, and only found that subpopulations overlapped using capture location as an assignment method, yet this research did not lead to a refined subpopulation boundary.

The lack of standardized approach has led to inconsistencies in the update of subpopulation boundaries, and the PBSG discussed that few boundaries likely support the IUCN definition of a subpopulation (Durner et al. 2018). Laidre et al. (2022a) summarized the use of satellite telemetry radio transmitters on a global scale, and found that 2,740 collars were deployed between 1980-2019, yet few overlap studies were performed during this period (Obbard and Middel 2012, Viengkone et al. 2018). We recommend that the PBSG incorporate our methods of subpopulation assignment and overlap, as well as the calculation of crossing rates of bears, to quantitatively determine if the current subpopulations are supported, on a global scale, by the IUCN definition of a subpopulation. If wildlife managers want to continue to use the SB and NB as separate units, they should be considered management units within a single subpopulation. By using wildlife management units within a subpopulation, researchers can continue to understand space-use, regulate harvest, and monitor abundance to prevent local extirpation from human-impacts (Mawdsley et al. 2009, Weinbaum et al. 2013). Our study investigated the biological component of a management unit, and does not consider the sociopolitical, cultural, or economic factors, which remains an important consideration for wildlife management boundaries. As such, future research should focus on integrating the sociopolitical, cultural, and economic factors with the biological components (e.g., movement, genetics) to develop an appropriate definition of a polar bear management unit, and delineate polar bear management units across the Arctic.

While we focused on locations from satellite tracked individuals, we were limited by the sex, age, and number of bears in our study. Notably, our study contained only subadult males, subadult females, and adult female bears, thus lacking adult males. Amstrup et al. (2001) had found that male and female bears did not greatly differ in their movement, while Laidre et al. (2012) found that there was no statistical difference in the movement rates between male and female bears. Moreover, bears in our study were well distributed across the eastern Beaufort Sea region, subadults and adults did not statistically differ in their crossing rates, and did not show spatial separation across any method. As such, we believe that our study is not affected by the lack of adult male data, nor by sample size.

Another limitation of our study was that we used the two clusters in our agglomerative hierarchical clustering algorithm to match the SB and NB subpopulations, rather than statistically analyse the optimal number of clusters. Moreover, we focused on whether the current boundary would be supported in the eastern Beaufort Sea, rather than where a hypothetical boundary would be placed. Since our results demonstrated overlap at two clusters and we found that 81.3% of bears crossed a boundary, we addressed the specific objective of our study, and believe that spatial separation would be unlikely with an increased number of clusters.

The IUCN subpopulations consider both demographic and genetic separation of individuals. By using telemetry location data, we did not account for genetic differences that may be associated with individuals from the SB and NB, but low genetic divergence between the SB and NB (Paetkau et al. 1999, Peacock et al. 2015, Malenfant et al. 2016, Laidre et al. 2022b) suggests a single subpopulation. Notably, the genetic divergence between SB and NB was among the lowest compared to all other pairwise genetic comparisons for polar bear subpopulations (Paetkau et al. 1999, Peacock et al. 2015, Malenfant et al. 2016, Laidre et al. 2022b). An important consideration is that the genetic studies relied on either hunter harvested or research-based samples, which were associated to a capture location, as a measure for subpopulation assignment. In our study, we found that 26.7% of bears had more locations in a subpopulation other than their capture subpopulation. Thus, we could also assume that a similar percentage of individuals would have more location in a subpopulation other than the capture subpopulation in the polar bear genetics studies. While the low genetic divergence found in the polar bear genetics studies support interbreeding between the SB and NB, the potentially high number of misclassified individuals may have influenced the results of genetic studies.

Our study examined the IUCN subpopulation boundary between the SB and NB. Nevertheless, COSEWIC governs the species assessment of polar bears in Canada, and has not identified any DUs (COSEWIC 2018). Thiemann et al. (2008) attempted to identifying DUs for polar bears using genetics, demographic movement, life history traits, prey density, and hunting pressure data, and proposed five biologically-sound DUs within Canada. Notably, the SB and NB were grouped in a single DU (Thiemann et al. 2008). Supported by our research here, we believe that bears within the Beaufort Sea would be grouped in a single DU if COSEWIC were to develop DUs for polar bears. Nevertheless, an assessment should be performed to understand if the merged Beaufort Sea DU would demonstrate discreteness and evolutionary significance when compared to adjoining DUs.

The Beaufort Sea is an important region for subsistence harvest of polar bears by Inuit, and was the basis for having a harvest and non-harvest period. Notably, the harvest of polar bears is based on sustainability, and an annual harvest quota is based on the estimated subpopulation abundance (Vongraven et al. 2022). That study found that between 1970 and 2018, the sustainable harvest of bears had been exceeded five times in the SB and two times in the NB. We found that many bears had more locations in a subpopulation other than their capture subpopulation, and most bears crossed a boundary. Therefore, the harvest quotas could have exceeded sustainable levels in other years in both subpopulations given the possible misclassification of harvested bears and the high crossing rates. Amstrup et al. (2005) had suggested a fractional allocation to each subpopulation based on the proximity of harvest to the subpopulation boundary, which would account for bears that migrate between the SB and NB, but this management practice has yet to be used. Ultimately, the continued use of harvest location for subpopulation assignment is likely to be imprecise and inaccurate given the overlap between the SB and NB, and the porous nature of the current boundaries in the Beaufort Sea.

Global assessments have demonstrated that polar bears are differentially vulnerable to climate change, depending on the local abundance and prey diversity (Derocher et al. 2004, Stirling and Derocher 2012, Stern and Laidre 2016, Hamilton and Derocher 2019). The SB and NB are among the most vulnerable subpopulations to population decline due to climatic warming changes in sea ice type and conditions (Hunter et al. 2010, Bromaghin et al. 2015, Hamilton and Derocher 2019, Molnár et al. 2020). Moreover, polar bears have increased their land-use and open water-use (e.g., swimming events) between 1979 – 2014, which corresponded with the reduction of total sea-ice and sea-ice concentration during this sampling period (Gleason and Rode 2009, Peacock et al. 2011, Atwood et al. 2016, Pilfold et al. 2016). Given the changing behaviour of bears in response to climate change, it would be expected that subpopulation boundaries be dynamic as suggested by Derocher et al. (2004). Our results do not support the subpopulation boundary between the SB and NB, and we believe that the focus for future monitoring and management should include new movement data for polar bears throughout the circumpolar Arctic. Using our rigorous method of testing the overlap between subpopulations, the PBSG may reveal modified behaviours and space-use across the circumpolar Arctic in response to global climatic warming.

Tables

Table 1. Assigned subpopulation, locations in assigned subpopulation during harvest period (February 1 - June 30), total locations during harvest period, and percentage of locations in assigned subpopulation during harvest period for polar bears captured in the Beaufort Sea. Locations were collected from polar bears fit with GPS satellite transmitters between 2007-2014. Polar bear subpopulation assignment was used to group individuals to a subpopulation to further determine subpopulation-level overlap.

Bear ID	Assigned Subpopulation	Locations in Assigned Subpopulation during Harvest Period	Total Locations during Harvest Period	Locations in Assigned Subpopulation/Total Locations (%)
A20163	Northern Beaufort	95	185	51.4
A20415	Southern Beaufort	497	497	100.0
A20434	Southern Beaufort	25	48	52.1
A20521	Southern Beaufort	57	60	95.0
A20522	Southern Beaufort	33	62	53.2
A20667	Southern Beaufort	163	191	85.3
A20716	Southern Beaufort	42	42	100.0
A20760	Southern Beaufort	41	45	91.1
A20792	Northern Beaufort	50	79	63.3
A20854	Southern Beaufort	106	210	50.5
A20910	Southern Beaufort	77	150	51.3
A20960	Northern Beaufort	112	202	55.4
A20961	Southern Beaufort	200	200	100.0
X19450	Northern Beaufort	35	52	67.3
X31431	Northern Beaufort	190	190	100.0

X31434	Northern Beaufort	204	204	100.0
X32253	Southern Beaufort	42	42	100.0
X32268	Southern Beaufort	42	64	65.6
X32373	Northern Beaufort	26	36	72.2
X32381	Southern Beaufort	51	54	94.4
X32557	Northern Beaufort	83	83	100.0
X32606	Southern Beaufort	362	362	100.0
X32608	Southern Beaufort	71	71	100.0
X32611	Northern Beaufort	190	293	64.8
X32613	Southern Beaufort	111	187	59.4
X32614	Southern Beaufort	126	194	64.9
X32617	Northern Beaufort	56	80	70.0
X32620	Southern Beaufort	47	47	100.0
X32628	Southern Beaufort	32	43	74.4
X32643	Southern Beaufort	55	55	100.0
X32644	Northern Beaufort	172	212	81.1
X32645	Southern Beaufort	54	65	83.1
X32647	Southern Beaufort	61	61	100.0
X32649	Southern Beaufort	130	178	73.0
X32650	Northern Beaufort	46	47	97.9
X32651	Northern Beaufort	61	96	63.5
X32654	Northern Beaufort	31	44	70.5
X32655	Southern Beaufort	80	80	100.0
X32658	Northern Beaufort	9	9	100.0
X32660	Northern Beaufort	31	43	72.1
X32665	Southern Beaufort	127	208	61.1
X32670	Southern Beaufort	44	68	64.7

X32671	Southern Beaufort	124	129	96.1
X32672	Southern Beaufort	133	156	85.3
X32673	Southern Beaufort	154	156	98.7
X32675	Southern Beaufort	83	88	94.3
X32677	Southern Beaufort	42	42	100.0
X32680	Southern Beaufort	64	64	100.0
X32681	Southern Beaufort	55	109	50.5
X32682	Northern Beaufort	334	370	90.3
X32685	Northern Beaufort	294	305	96.4
X32687	Northern Beaufort	87	150	58.0
X32690	Chukchi Sea	300	352	85.2
X32692	Northern Beaufort	158	247	64.0
X32693	Northern Beaufort	149	192	77.6
X32698	Southern Beaufort	320	320	100.0
X32700	Southern Beaufort	426	613	69.5
X32701	Northern Beaufort	241	338	71.3
X32703	Northern Beaufort	106	163	65.0
X32704	Southern Beaufort	32	50	64.0
X32707	Northern Beaufort	39	58	67.2
X32711	Southern Beaufort	37	62	59.7
X32790	Southern Beaufort	51	53	96.2
X32796	Southern Beaufort	38	66	57.6
X32803	Northern Beaufort	54	59	91.5
X32804	Northern Beaufort	179	279	64.2
X32808	Southern Beaufort	116	116	100.0
X32822	Northern Beaufort	90	105	85.7
X32830	Northern Beaufort	184	184	100.0

X32832	Northern Beaufort	26	27	96.3
X32835	Northern Beaufort	201	201	100.0
X33070	Northern Beaufort	96	191	50.3
X33075	Northern Beaufort	229	234	97.9
X33077	Northern Beaufort	191	191	100.0
X33078	Northern Beaufort	271	271	100.0
X33083	Northern Beaufort	214	258	82.9
X33085	Southern Beaufort	130	150	86.7
X33087	Southern Beaufort	85	166	51.2

Table 2. The number of polar bears captured in the Beaufort Sea between 2007-2014 which were assigned a subpopulation during the harvest period (February 1 - June 30) based on the capture location classification method (rows) and the observed space-use classification method (columns). Values in paratheses represent the percentage of bears assigned to each category.

	Southern Beaufort Sea	**Northern Beaufort Sea**
Southern Beaufort Sea	31 (41%)	9 (12%)
Northern Beaufort Sea	11 (15%)	24 (32%)

Table 3. The number of polar bears captured in the Beaufort Sea between 2007-2014 which were assigned a subpopulation during the harvest period (February 1 - June 30) based on the capture location classification method (rows) and the agglomerative hierarchical clustering classification method (columns). Values in paratheses represent the percentage of bears assigned to each category.

	Cluster 1 - South	**Cluster 2 - North**
Southern Beaufort Sea	22 (29.3%)	18 (24%)
Northern Beaufort Sea	4 (5.3%)	31 (41.3%)

Table 4. The pairwise number of polar bears crossing events across a subpopulation boundary in the Beaufort Sea between 2007-2014. Values represent the total number of crossing events between two subpopulations. Bears crossed a subpopulation boundary that bordered the Arctic Basin (AB), Chukchi Sea (CS), Northern Beaufort Sea (NB), Southern Beaufort Sea (SB), and Viscount Melville Sound (VM).

	Arctic Basin	**Chukchi Sea**	**Northern Beaufort Sea**	**Southern Beaufort Sea**	**Viscount Melville Sound**
Arctic Basin	-	4	48	116	0
Chukchi Sea		-	0	4	0
Northern Beaufort Sea			-	411	14
Southern Beaufort Sea				-	0
Viscount Melville Sound					-

Figures

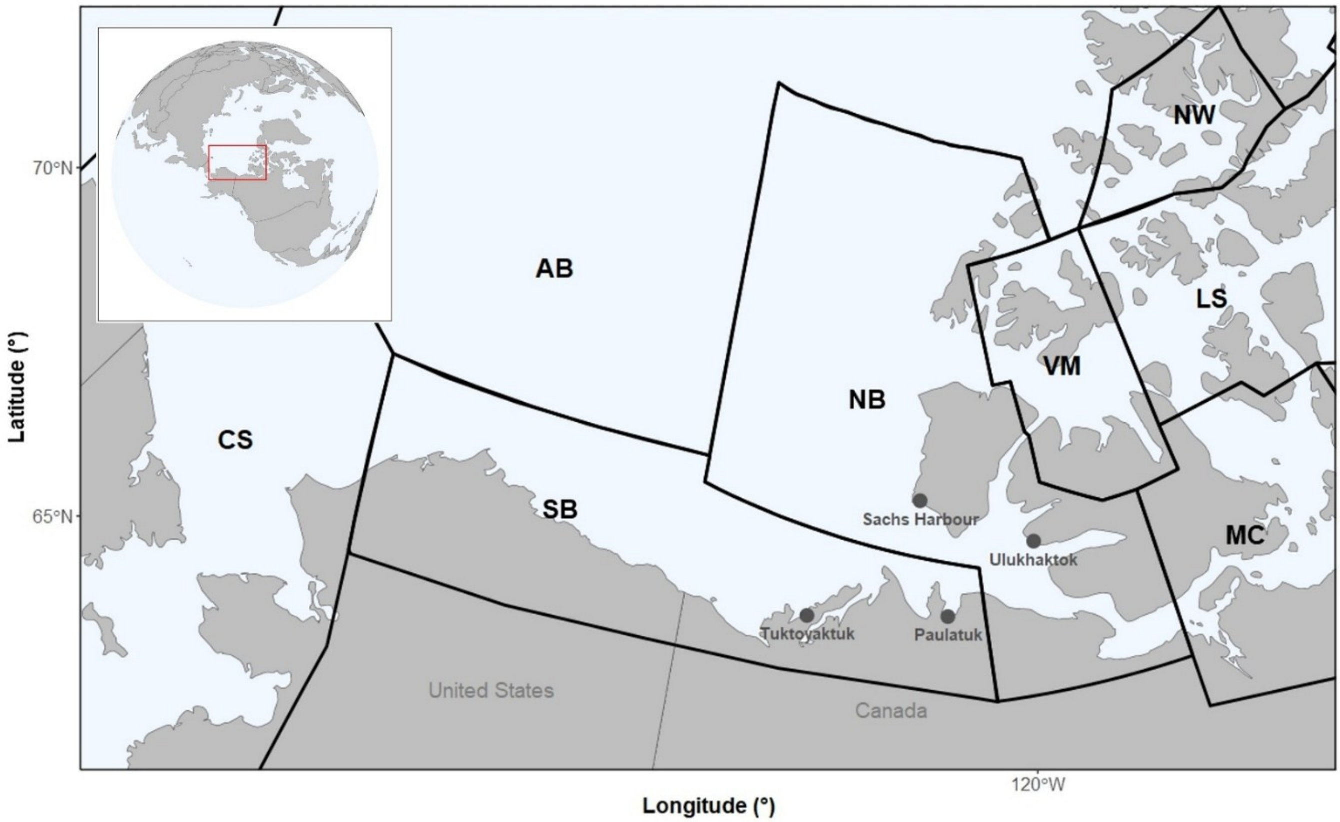

Figure 1. Past polar bear subpopulation boundaries of the Beaufort Sea region. Subpopulations are delineated by black lines following the IUCN recognized boundaries pre-2016, and are named as follows: Arctic Basin (AB), Chukchi Sea (CS), Lancaster Sound (LS), M'Clintock Channel (MC), Northern Beaufort Sea (NB), Norwegian Bay (NW), Southern Beaufort Sea (SB), and Viscount Melville Sound (VM).

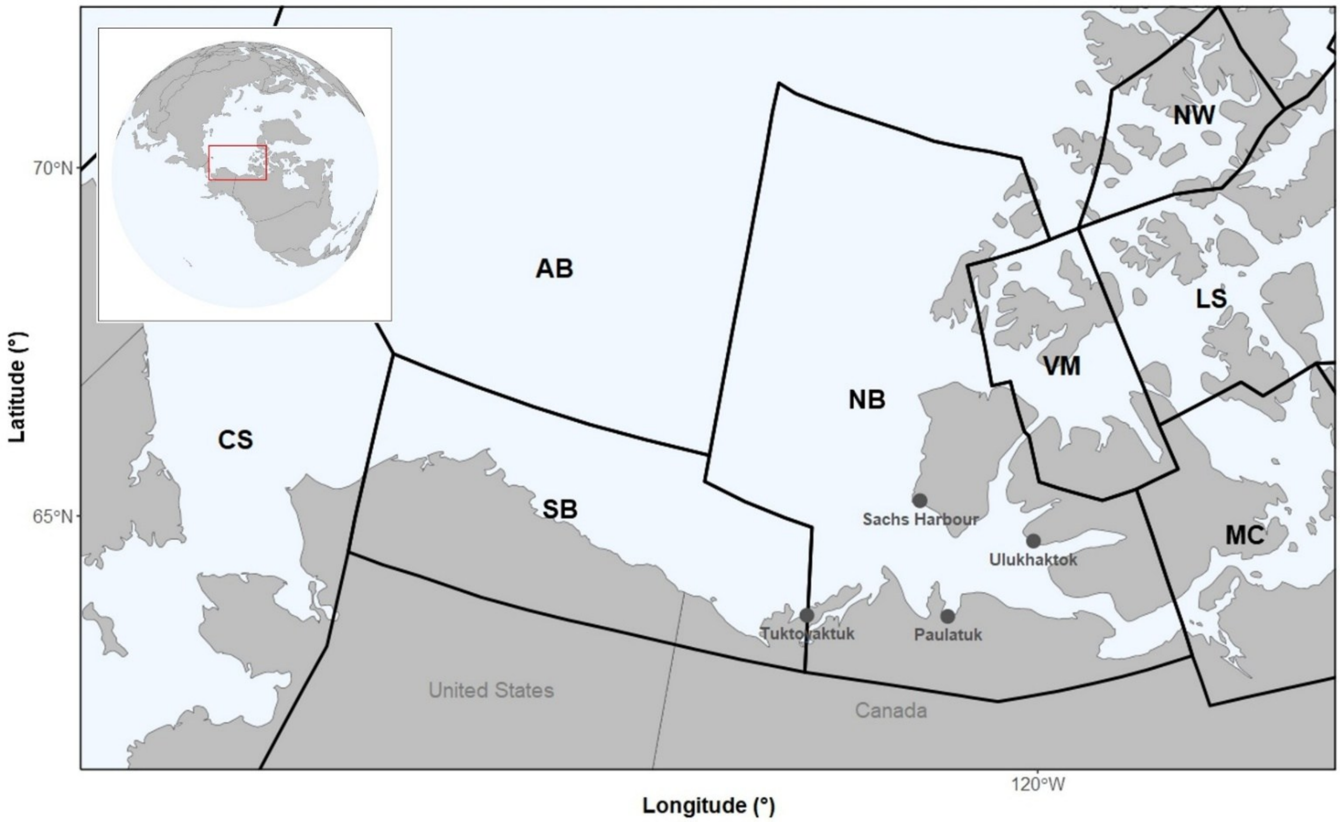

Figure 2. Current polar bear subpopulation boundaries of the Beaufort Sea region. Subpopulations are delineated by black lines following the IUCN recognized boundaries post-2016, and are named as follows: Arctic Basin (AB), Chukchi Sea (CS), Lancaster Sound (LS), M'Clintock Channel (MC), Northern Beaufort Sea (NB), Norwegian Bay (NW), Southern Beaufort Sea (SB), and Viscount Melville (VM).

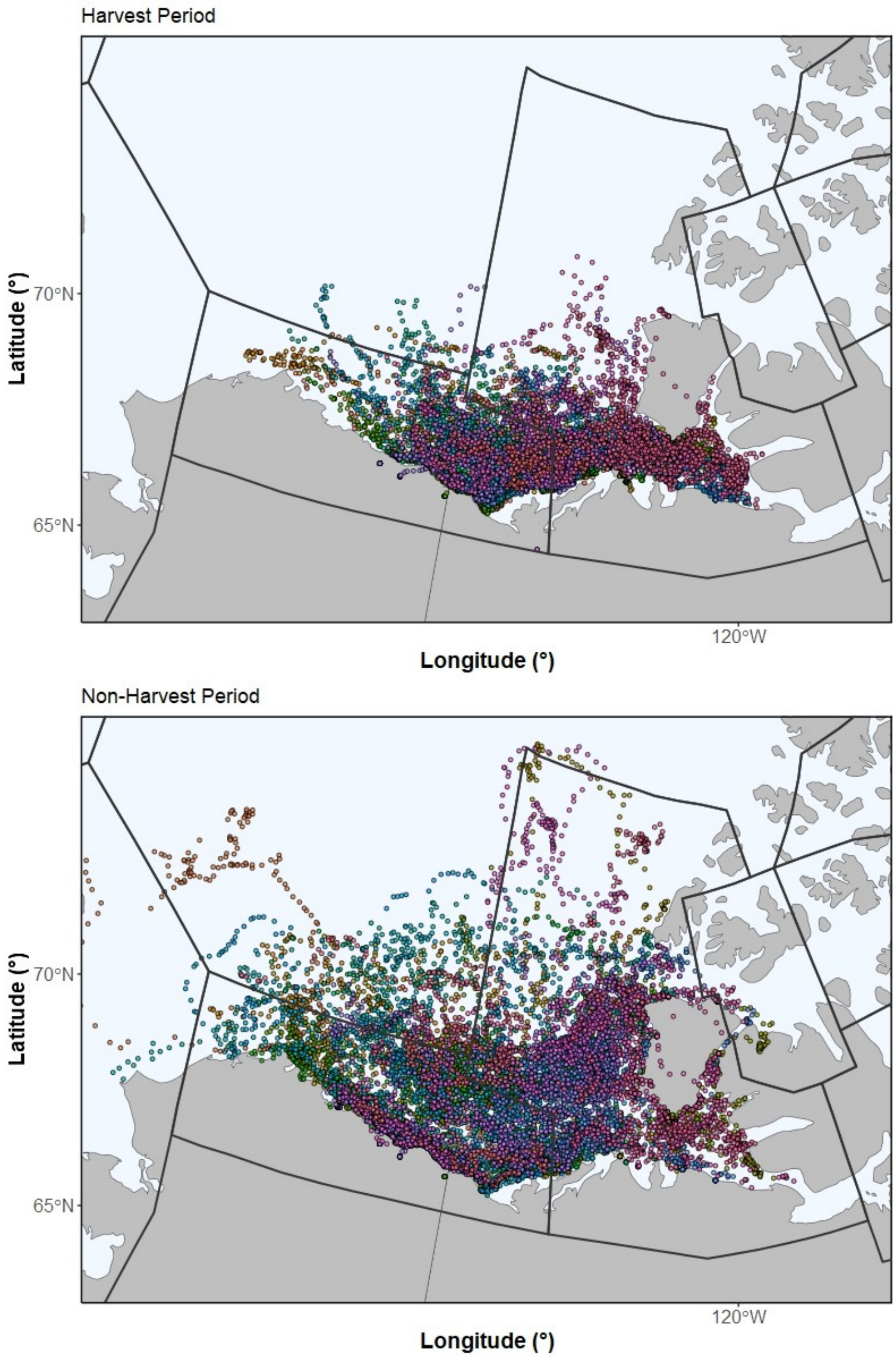

Figure 3. Polar bear locations collected from the Beaufort Sea region collected between 2007-2014 during the harvest period (February 1 - June 30, top) and non-harvest period (July 1 – January 31, bottom). Relocations are coloured by individual. Current population boundaries are represented by solid black lines.

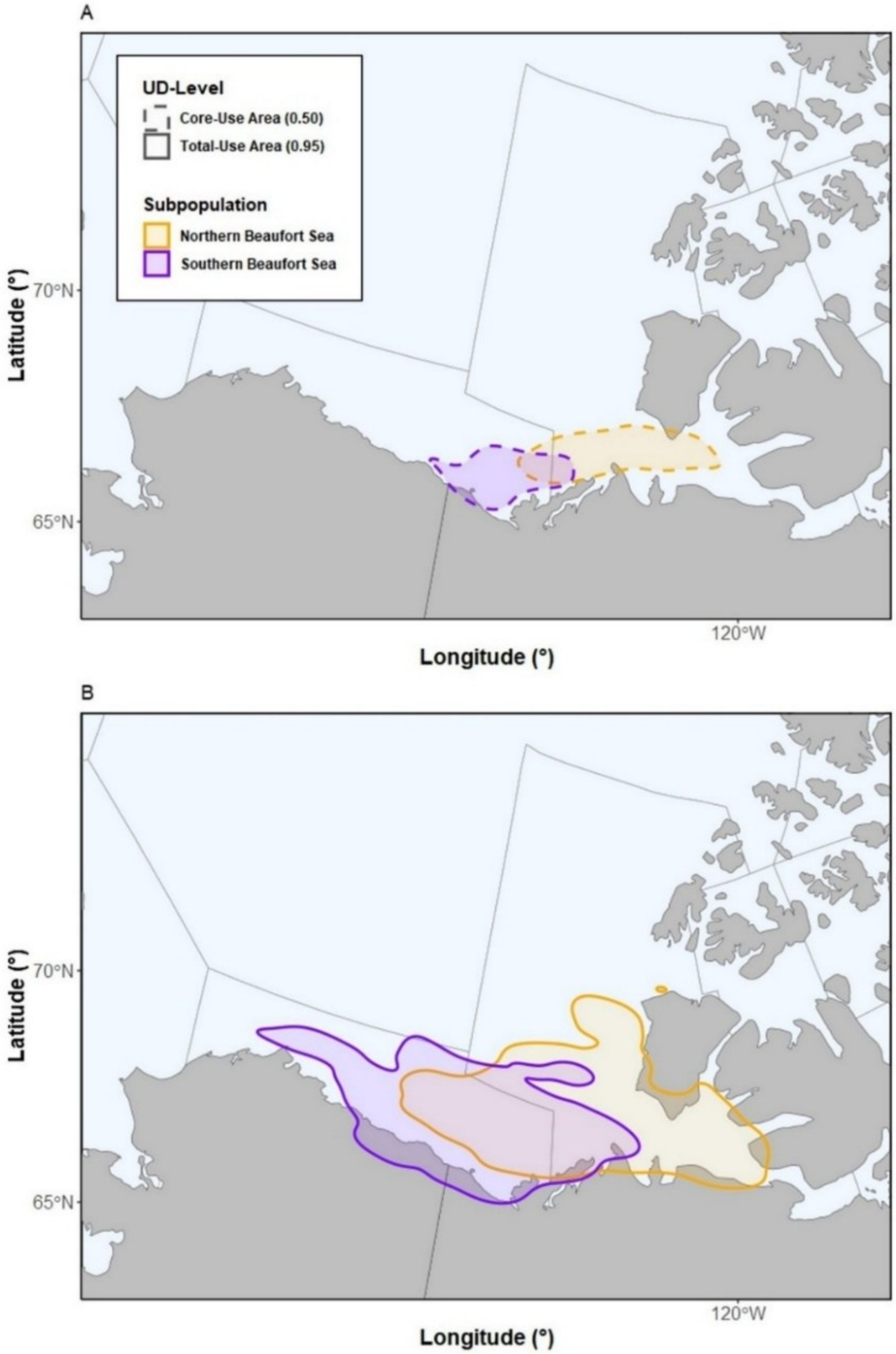

Figure 4. Utilization distributions for polar bear subpopulations during the harvest period (February 1 - June 30) classified using the observed space-use method for the Northern Beaufort Sea (orange) and Southern Beaufort Sea (purple) subpopulations for A) core-use area - 0.50 UD (dashed lines) and B) total-use area - 0.95 UD (solid lines). Bears were tracked through satellite GPS tracking between 2007-

2014 in the eastern Beaufort Sea. Utilization distributions were calculated based on harvest period relocations at a 1-day sampling interval. Current population boundaries are represented by solid grey background lines.

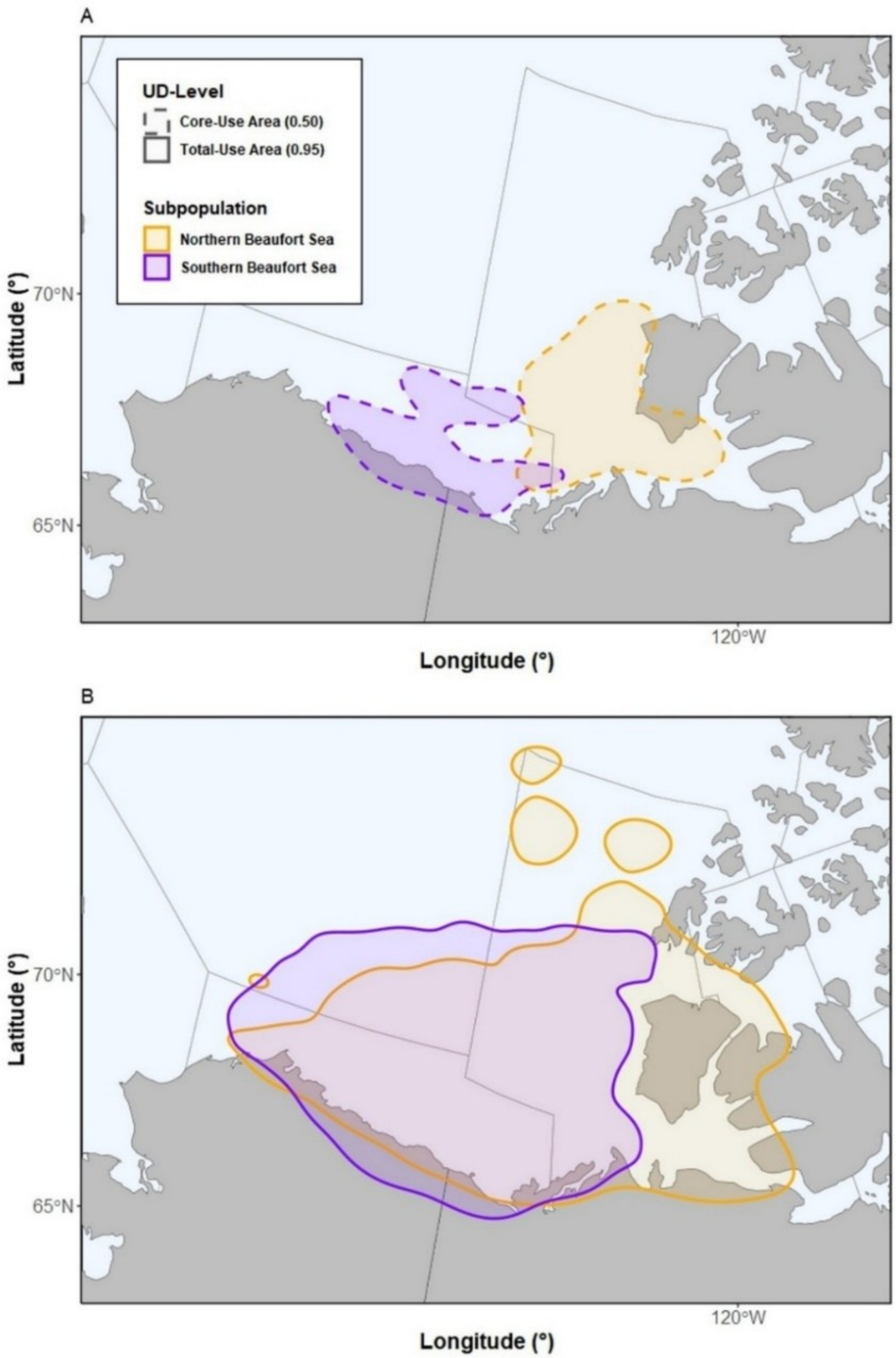

Figure 5. Utilization distributions for polar bear subpopulations during the non-harvest period (July 1 – January 31) classified using the observed space-use method for the Northern Beaufort Sea (orange) and Southern Beaufort Sea (purple) subpopulations for A) core-use area - 0.50 UD (dashed lines) and B) total-use area - 0.95 UD (solid lines). Bears were tracked through satellite GPS tracking between 2007-

2014 in the eastern Beaufort Sea. Utilization distributions were calculated based on non-harvest period relocations at a 1-day sampling interval. Current population boundaries are represented by solid grey background lines.

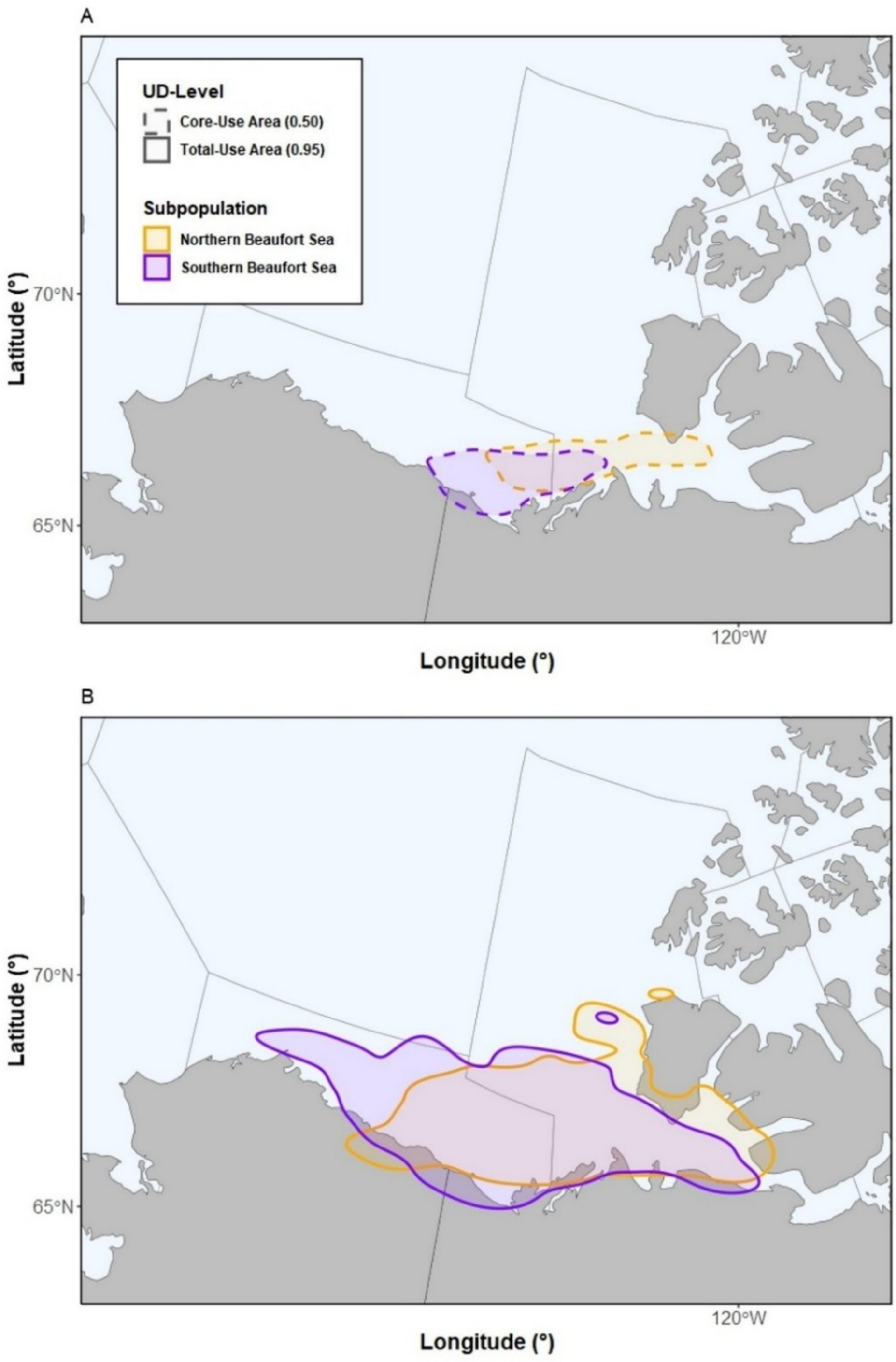

Figure 6. Utilization distributions for polar bear subpopulations during the harvest period (February 1 - June 30) classified using the capture location method for the Northern Beaufort Sea (orange) and Southern Beaufort Sea (purple) subpopulations for A) core-use area - 0.50 UD (dashed lines) and B) total-use area - 0.95 UD (solid lines). Bears were tracked through satellite GPS tracking between 2007-

2014 in the eastern Beaufort Sea. Utilization distributions were calculated based on harvest period relocations at a 1-day sampling interval. Current population boundaries are represented by solid grey background lines.

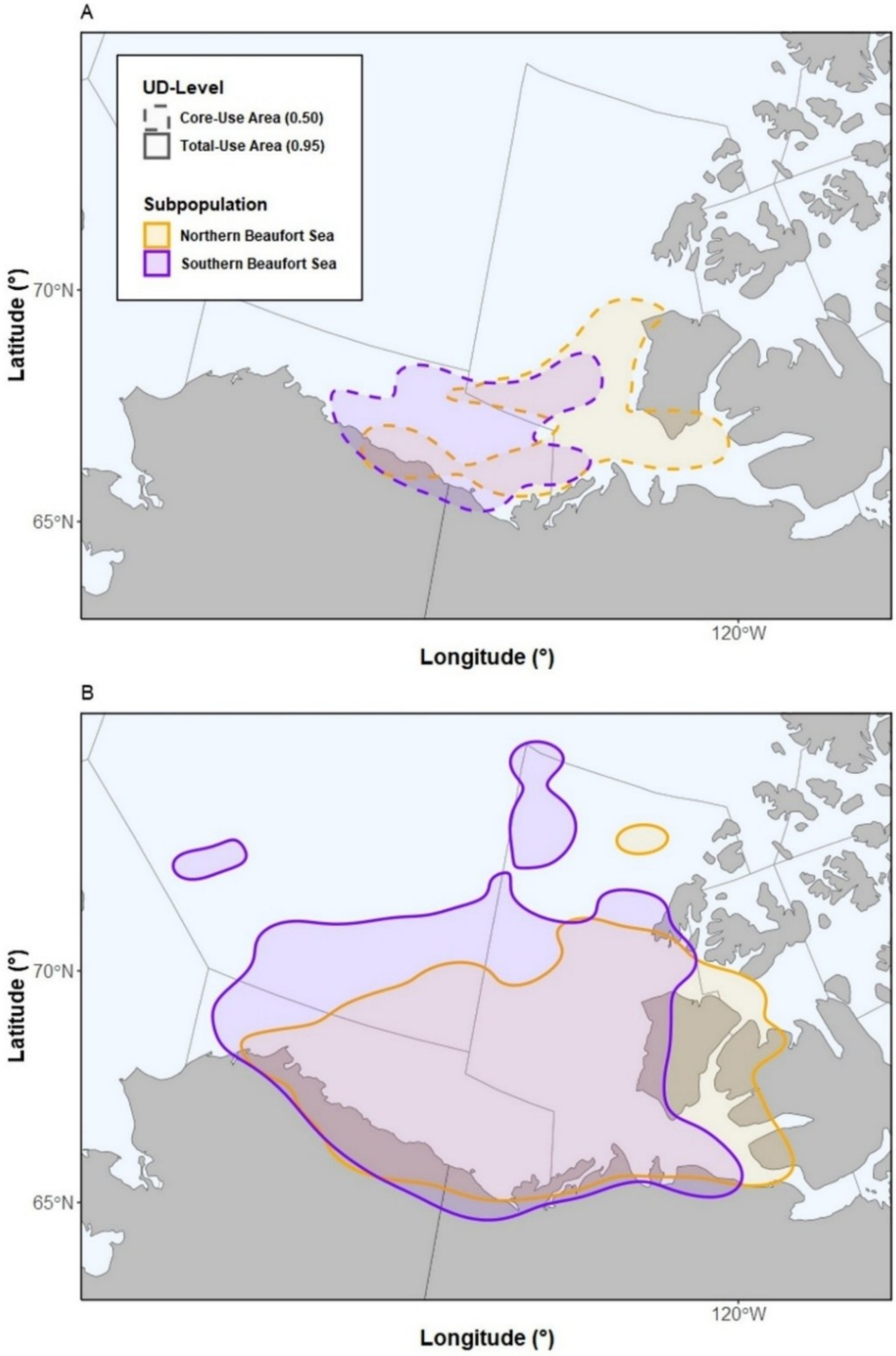

Figure 7. Utilization distribution for polar bear subpopulations during the non-harvest period (July 1 – January 31) classified using the capture location method for the Northern Beaufort Sea (orange) and Southern Beaufort Sea (purple) subpopulations for A) core-use area - 0.50 UD (dashed lines) and B) total-use area - 0.95 UD (solid lines). Bears were tracked through satellite GPS tracking between 2007-

2014 in the eastern Beaufort Sea. Utilization distributions were calculated based on non-harvest period relocations at a 1-day sampling interval. Current population boundaries are represented by solid grey background lines.

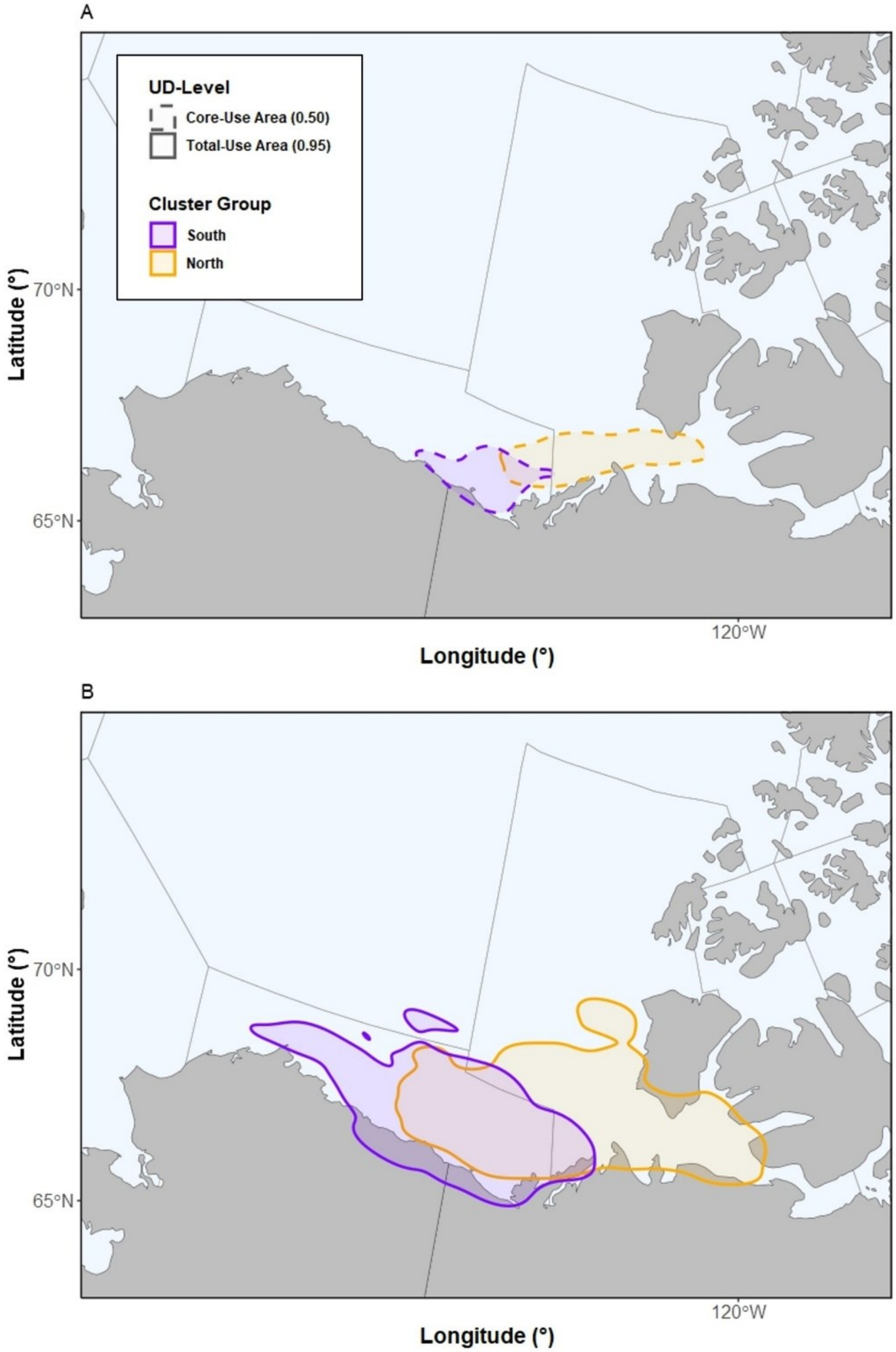

Figure 8. Utilization distributions for polar bear subpopulations during the harvest period (February 1 - June 30) classified using the agglomerative hierarchical clustering method for South (purple) and North (orange) for A) core-use area - 0.50 UD (dashed lines) and B) total-use area - 0.95 UD (solid lines). Bears were tracked through satellite GPS tracking between 2007-2014 in the eastern Beaufort Sea. Bears

were assigned to a cluster group through agglomerative hierarchical clustering at k = 2. Utilization distributions were calculated based on harvest period relocations at a 1-day sampling interval. Current population boundaries are represented by solid grey background lines.

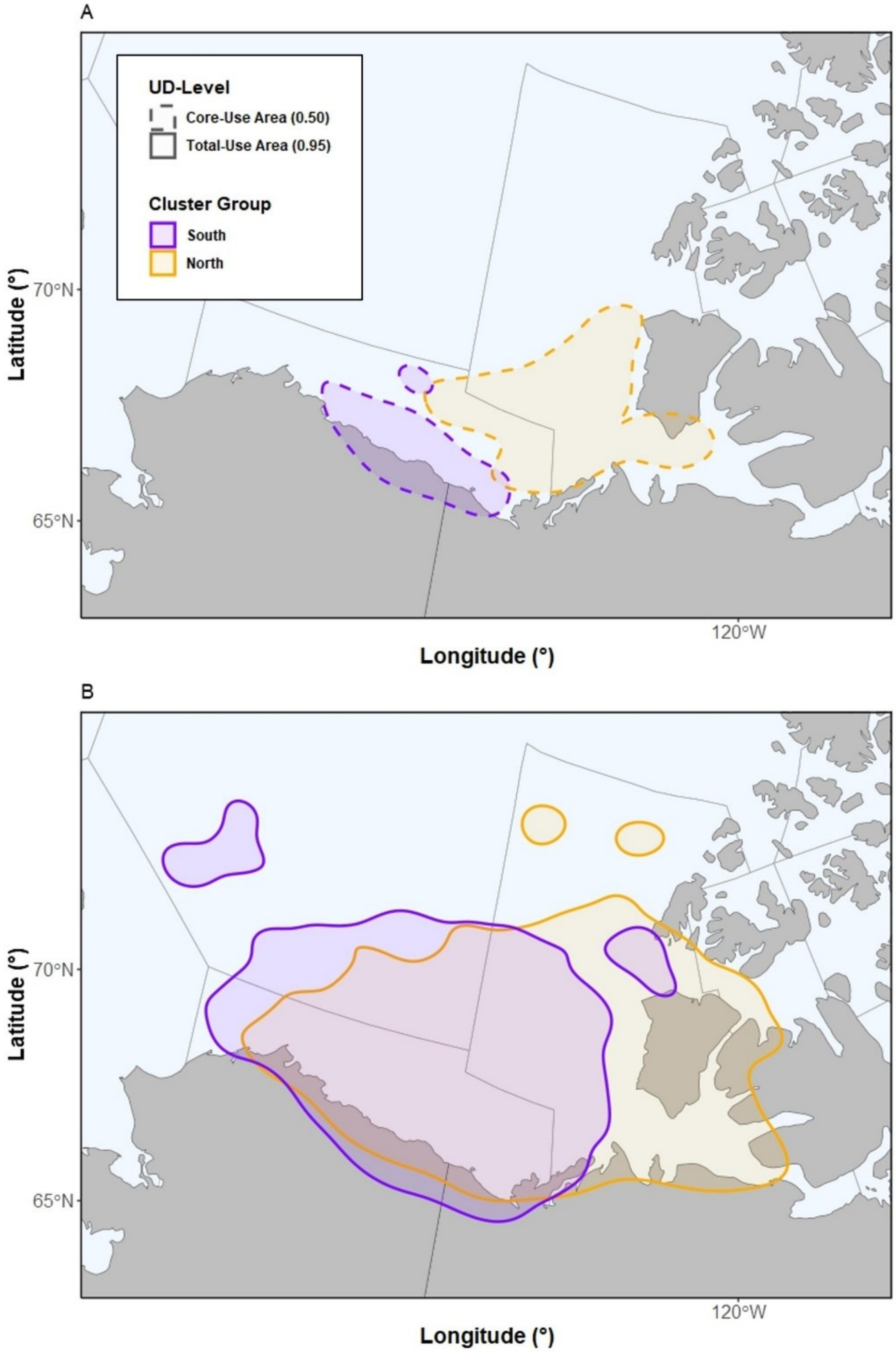

Figure 9. Utilization distributions for polar bear subpopulations during the non-harvest period (July 1 – January 31) classified using the agglomerative hierarchical clustering method for South (purple) and North (orange) for A) core-use area - 0.50 UD (dashed lines) and B) total-use area - 0.95 UD (solid lines). Bears were tracked through satellite GPS tracking between 2007-2014 in the eastern Beaufort

Sea. Bears were assigned to a cluster group through agglomerative hierarchical clustering at k = 2. Utilization distributions were calculated based on non-harvest period relocations at a 1-day sampling interval. Current population boundaries are represented by solid grey background lines.

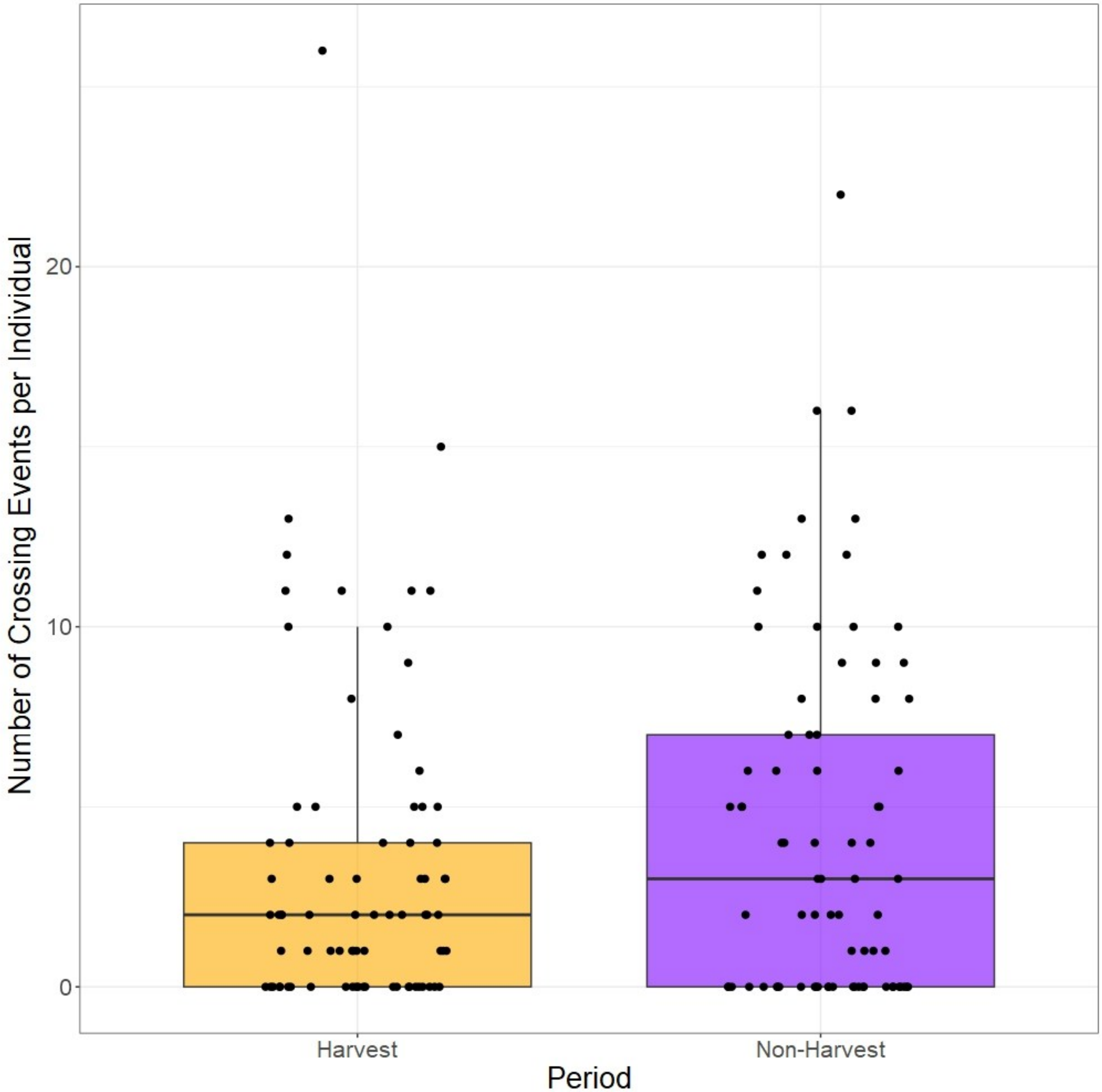

Figure 10. Boxplot representing the number of crossing events per polar bear during the harvest period (February 1 - June 30, orange) and the non-harvest period (July 1 – January 31, purple) in the Beaufort Sea, Canada.

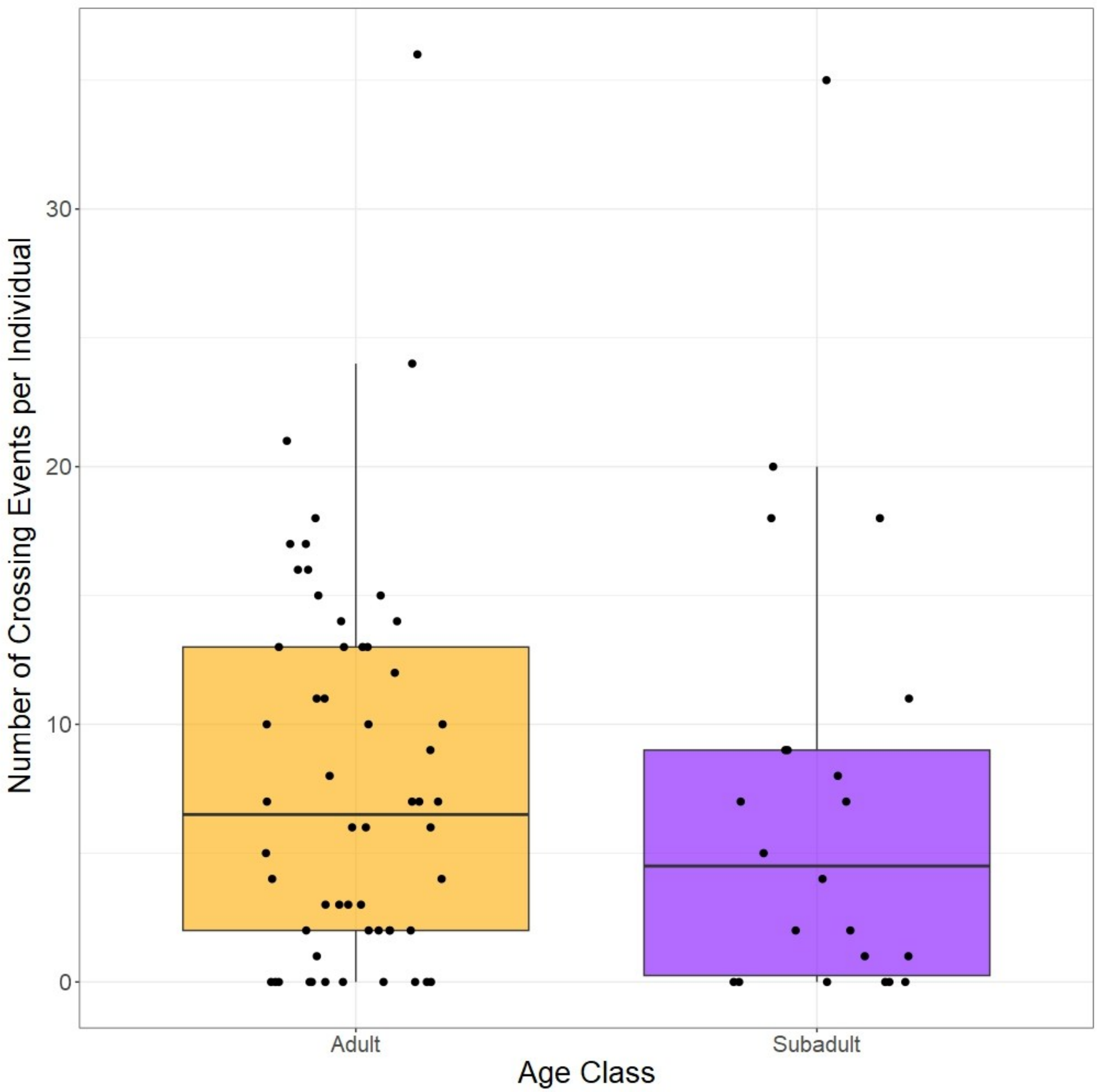

Figure 11. Boxplot representing the number of crossing events per polar bear in the Beaufort Sea, Canada based on age class, where adults (orange) were >5 years old and subadults (purple) were 2-4 years old.

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