Re-Assessment of the Baffin Bay and Kane Basin Polar Bear Subpopulations

**Final Report to the Canada-Greenland Joint Commission on Polar Bear
from the Scientific Working Group (SWG) of the Canada-Greenland Joint Commission on Polar Bear**

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31 July 2016

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ACKNOWLEDGEMENTS

CHAPTER 1

INTRODUCTION

We briefly present the history of the different polar bear management systems in Nunavut/Canada and Greenland to provide the background and context on the current assessment of the status of the polar bear subpopulations in Baffin Bay (BB) and Kane Basin (KB). We summarize the results of the previous assessment of the BB and KB subpopulations in the 1990s and the framework established in 2009 for the Canada-Greenland joint management of these shared subpopulations. We describe the process leading to the decisions on major objectives of a re-assessment and the subsequent development of a research plan for re-assessing the status of the polar bear subpopulations in Baffin and Kane Basin. Finally, we present the schedule of the completion of the study.

1.1. History of Polar Bear Management in Canada and Greenland related to Baffin Bay (BB) and Kane Basin (KB)

Wildlife legislation in Canada did not address polar bear harvesting until 1935, when a hunting season from 1 October through 31 May was imposed. In 1949, hunting was restricted to native people. Arbitrary quotas for polar bears were introduced in Canada in 1967 that were based largely on the fur records from several preceding years (Lee and Taylor 1994, Prestrud and Stirling 1994).

Through a delegation of authority from the federal government, ultimate responsibility for the management of polar bears in Nunavut lies with the Government of Nunavut, as represented by the Minister of Environment (Lunn et al. 2010). However, this responsibility is

subject to the terms of the Nunavut Land Claims Agreement (NLCA) that established a system

of 'co-management' for wildlife. Under the NLCA, the Minister's decision-making authority for

wildlife management is shared with the Nunavut Wildlife Management Board and is subject to

strict requirements for consultation with Regional Wildlife Organizations and community-based

Hunters and Trappers Organizations. The intent of this co-management system is to ensure that

decisions are based on the best available science and Inuit Qaujimajatuqangit (Inuit traditional

knowledge), and that these decisions consider not only conservation as a founding principle but

also take into account the values, beliefs, views and needs of Inuit. The system is also designed

to ensure that Inuit are involved in all aspects of wildlife management including research,

monitoring, and harvest management.

Polar bears occur in relatively discrete subpopulations and are managed as such in

Canada. The annual polar bear harvest in Nunavut is within the estimated sustainable yield of

females and controlled through a male-biased, sex-selective quota system (Taylor et al. 1987,

2008b). Females accompanied by cubs, cubs, and bears in or constructing dens are protected by

law (Lunn et al. 2010). Currently, the quota year in Canada runs from 1 July through 30 June of

the following year.

In Greenland, regulations for the catch of polar bears in the entire country were enforced

beginning 1 January 1975 (prior to 1975 regulations in NE Greenland had existed since the 1937;

Born 1995 and references therein). The regulations prior to the introduction of quotas in

Greenland in 2006 to reduce hunting effort and protect females with cubs and also involved a

closed season in July-August (ibid). Furthermore, hunting of polar bears was restricted to

Greenlandic citizens who had hunting as their main occupation. Quotas for the Greenlanders´

catch of polar bears were introduced in 2005 and took effect 1 January 2006 (Lønstrup 2006).

The quota year in Greenland is between 1 January and 31 December.

The management history and harvest monitoring in Nunavut and Greenland are described

in more detail in Chapter 8.

1.2. Previous Delineations and Assessments of the Baffin Bay (BB) and Kane Basin (KB)

Subpopulations

Delineation of the Baffin Bay and Kane Basin subpopulations (Figure 1.1) was largely

based on movements of collared bears and the recapture or harvest of tagged animals and has

been well documented (PBSG 1998, SWG 2010). The BB subpopulation is bounded by the

North Water Polynya to the north, Greenland to the east and Baffin Island (Nunavut, Canada) to

the west (Taylor et al. 2001). A relatively distinct southern boundary at Cape Dyer, Baffin

Island, and the entrance to Kangerlussuaq/Søndre Strømfjord, Greenland, is evident from the

movements of collared or tagged bears (Stirling *et al.* 1980, Taylor et al. 2001).

A study of microsatellite genetic variation based on biological samples collected during

the first half of the 1990s revealed significant genetic variation between polar bears in BB and

neighboring Davis Strait (DS) and Lancaster Sound (LS), but not between BB and KB (Paetkau

et al. 1999).

The BB, KB and DS subpopulations are shared between Greenland and Canada (Taylor

et al. 2001). Population inventories involving physical mark-recapture, in combination with

satellite telemetry, were conducted jointly by Nunavut/Canada and Greenland during 1991-1997

with the objective to estimate the size of the BB and KB subpopulations. These resulted in an

estimate for BB of 2074 bears (95% CI: 1544-2604; Taylor et al. 2005, PBSG 2006) and for KB

of 164 bears (95% CI: 94-234; PBSG 2006, Taylor et al. 2008).

Due to concerns with respect to the reported harvest occurring in BB, modelling was used

to project how many bears there would be in 2004 based on the 1997 BB estimate and associated

vital rates plus the reported annual catches in Nunavut and Greenland. The results suggested that

BB would have experienced a decline to 1546 polar bears in 2004 (95% confidence interval:

690-2402; PBSG 2006). Although a similar modeling exercise was not done for KB, both

subpopulations were thought to be declining as a result of overharvest (PBSG 2006, 2010, 2015).

1.3. Canada-Greenland Joint Commission (JC) on Polar Bear and the Scientific Working Group (SWG)

The Canada-Greenland Joint Commission on Polar Bear (JC) was established with the

signing of a "*Memorandum of Understanding between the Government of Canada, the*

Government of Nunavut, and the Government of Greenland for the Conservation and

Management of Polar Bear Populations" (MOU) on 30 October 2009 (Anon. 2009). Primary

objectives of the MOU are to: "(1) to manage polar bear within the Kane Basin and Baffin Bay

management units in order to ensure their conservation and sustainable management into the

future, and, (2) establish an effective system of management which will include adhering to the

principles of conservation".

The JC subsequently established a 5-member Scientific Working Group (SWG) to

provide it with scientific advice and recommendations with respect to the conservation and

management of the BB and KB polar bear subpopulations. Two of the SWG´s members shall

represent Canadian and two Greenlandic research institutes/agencies, whereas the fifth member

is appointed by the SWG co-chairs from a research institute that is independent of both Canada and Greenland. To assist the SWG in providing the best scientific advice, external experts can be invited to participate in its work.

1.4. Subpopulation Re-Assessment

After an initial meeting in Ottawa, Canada in January 2010, the JC tasked the SWG with using the best available scientific information to:

(1) Propose Total Allowable Harvest (TAH) levels for the Kane Basin and Baffin Bay subpopulations and provide the Joint Commission with a written report of its recommendations; and,

(2) Provide science advice to the Joint Commission for monitoring the effects of habitat changes on polar bears.

The SWG provided a report to the JC at the 2nd meeting of the JC in Ilulissat, Greenland, in May 2010 (SWG 2010). The SWG noted that 100% of simulations using population viability analysis and current harvest levels showed that both the Baffin Bay and Kane Basin subpopulations declined after 10 years (PBSG 2010). The SWG also noted that simulations to assess the estimated risk of subpopulation decline are typically run 10-15 years into the future from the point in time at which data were last collected to estimate abundance and vital rates. Furthermore, it was noted that there was uncertainty surrounding the magnitude of impacts of environmental change on polar bears and that demographic rates could have significantly changed since the last inventories of these subpopulations in the 1990s.

The SWG also noted that a common Canada-Greenland management goal for the BB and KB subpopulations had not yet been specified in detail. Accordingly, the SWG assumed that a

recommended TAH for BB and KB should ensure that each subpopulation remained at the accepted science-based estimate (PBSG 2010) until new scientific inventories had been conducted and management goals established.

Acknowledging the fact that considerable uncertainty existed about the status of the BB and KB subpopulations in 2010 and that clearly defined management goals had not been identified, the SWG estimated the sustainable TAH from the BB subpopulation to be 90 bears/year and to be 1-2 bears/year from the KB subpopulation (SWG 2010).

In order to address the second question posed by the JC, the SWG summarized items that should be monitored in BB and KB together with the possible monitoring approaches. A list of general scientific areas where monitoring is required, the rationale for the monitoring, and the potential methods that can help gather data under each topic were presented. Furthermore, the SWG indicated, where possible, how monitoring can be conducted by scientists and local users concomitantly.

Based on consideration of the key parameters that should be monitored in order to determine the effects of climate change on the BB and KB polar bear subpopulations and the need to ensure that harvesting of the two subpopulations is sustainable in a changing environment, the SWG recommended that the following research needs were given priority:

(1) Subpopulation size

(2) Distribution and movements

(3) Physical condition of individual bears

(4) Vital parameters (survival and reproduction)

The SWG also noted that other data useful for determining the effects of habitat change in polar bears should be collected routinely. Collection of these data involves the active

participation of users through the submission of information and samples from harvested polar bears. Sampling from the harvest will provide important information on age and sex structure of the harvest, body condition, reproduction, and levels of pollutants in polar bears.

However, given the age of the data on abundance and vital rates (PBSG 2010) combined with large-scale environmental changes in Baffin Bay during the last decades, the SWG **strongly recommended** that new estimates of subpopulation abundance, subpopulation delineation, and vital rates be given high priority (SWG 2010).

Pilot aerial surveys in Baffin Bay in 2009 and 2010

In 2009 (i.e., prior to establishment of the SWG), scientists from the Government of Nunavut Department of Environment (GNDE) and Greenland Institute of Natural Resources (GINR) initiated a collaboration to determine the feasibility of using aerial surveys for estimating the size of polar bear subpopulations in BB and KB. A pilot survey was conducted in the Sirmilik National Park on NE Baffin Island in August 2009 to determine if the line-transect aerial survey technique could be used during the ice-free or open-water season in Baffin Bay. However, given the results from the rugged terrain and mountainous landscape, it was concluded that this method was not feasible (Stapleton 2010).

Based on the experience in 2009, scientists from Nunavut and Greenland decided to (1) conduct a pilot aerial survey over sea ice during spring in Baffin Bay, and (2) deploy satellite-transmitters on polar bears in Baffin Bay in order to collect data on distribution and movement necessary for evaluation of aerial survey data.

During 27 May-4 June 2010, a pilot survey was flown over the fast and pack ice in Baffin Bay off SE Baffin Island. The survey was determined to be a success and provided data that

demonstrated promise for the approach in BB. Based on the results of the 2010 spring pilot survey, a group of experts in polar bear ecology and population dynamics, population assessment methods and sea ice from the Greenland Institute of Natural Resources, Government of Nunavut, University of Washington, University of Minnesota, and U.S. National Marine Mammal Laboratory evaluated the data and concluded that a springtime aerial survey would be a feasible approach for estimating abundance of polar bears in BB and KB and should result in estimates with adequate precision for management purposes (Laake 2010, Stapleton et al. 2010, SWG 2011).

Survey options review

Following the advice from the SWG, the JC tasked the SWG to review and evaluate various methods for assessing the number of polar bears in BB and KB (JC 2010a). The JC further requested that the SWG´s report include evaluation of benefits and limitations of using each of the proposed methods (aerial surveys, genetic mark-recapture, and physical mark recapture) and indicated that the review should be based on a pilot aerial survey conducted in Baffin Bay in Spring 2010 (see preceding section). The SWG was also tasked with providing recommendations for one or more scenarios that represented the best way forward and, for each scenario, to identify major attributes, risks and management questions including level of funding (JC 2010a). Subsequently the JC would make recommendations on the most appropriate survey methodologies for assessing the BB and KB subpopulations (JC 2010a).

In January 2011, the SWG submitted to the JC a review of options for conducting new research including recommendations on appropriate methodologies (SWG 2011), which considered the pros and cons of using physical mark-recapture, genetic mark-recapture, or aerial

surveys for subpopulation inventories in BB and KB. The general conclusion was that the physical MR method (1) is the most well established method available for estimating abundance of polar bears, (2) is the most widely accepted and recommended method by the greater scientific community, and (3) provides the maximum information needed for sound management advice on polar bears. In addition to an abundance estimate, it provides information that could be used to assess effects on bears of climate change and pollution.

The SWG concluded that the physical MR method was superior to aerial surveys and genetic MR because it yields the most detailed information and recommended that physical MR be used for estimating the abundance of polar bears in Baffin Bay. It was stated that aerial surveys and a multiple-year genetic MR may be considered as alternatives for assessing the number of polar bears in Baffin Bay. However, the SWG noted that there are disadvantages to both methods.

Decision of the JC

In March 2011, the JC discussed survey methods for Kane Basin and Baffin Bay with Drs. Erik Born and Stephen Atkinson who represented the SWG. Following discussion of the SWG's report, the JC concluded that the genetic mark-recapture method was preferable based on lack of support by Inuit in Nunavut for physical mark-recapture, and on concerns that variability in sea-ice conditions have the potential to create an unacceptable amount of risk in obtaining accurate subpopulation estimates via aerial surveys. Thereafter, the JC recommended to the signatories of the MOU that a 3-year biopsy darting research program be developed.

1.5. A Multi-Year Research Plan for Baffin Bay and Kane Basin

In March 2011, the JC requested the SWG prepare a research plan for the re-assessment of the Baffin Bay and Kane Basin polar bear subpopulations. It was determined that preparation of such a plan was the responsibility of those members of the SWG who would serve as lead investigators on behalf of Nunavut and Greenland. Consequently, a multi-year research plan (Atkinson et al. 2011) for re-assessment of the Baffin Bay and Kane Basin subpopulations was developed by Drs. Stephen Atkinson (Nunavut), Erik Born and Kristin Laidre (Greenland Institute of Natural Resources).

The plan outlined a multi-year research program to be carried out collaboratively by scientists from Canada (Nunavut) and Greenland together with external collaborators (local people and scientists) participating in various parts of the study. The plan presented tentative schedules and budgets. The main goals of the research program were (1) to determine the size of the Baffin Bay and Kane Basin subpopulations of polar bears, and (2) evaluate how polar bears in these areas are affected by the decrease in sea ice.

The proposed research program had three basic field components: (1) Biopsying polar bears along E Baffin Island, in NW Greenland and in the Kane Basin region, (2) deployment of satellite transmitters on male and female polar bears in NW Greenland and Kane Basin, and (3) hunter collection of tissue samples from the catch of polar bears (harvest recoveries) in BB and KB (and adjacent subpopulations). A 3-year study was proposed beginning in the fall of 2011 with the purpose to:

1) Estimate the abundance and sex (and approximate age) composition of polar bears in BB and KB;

2) Compare a new estimate of abundance with those derived from previous studies (1991-1997) in-order to gain insight into subpopulations trend;

3) Delineate the boundaries of the BB and KB subpopulations and reassess the validity of these areas as a demographic unit;

4) Estimate survival and reproductive parameters (to the extent possible) in-order to facilitate population viability analyses; and,

5) Evaluate polar bear distribution with respect to environmental variables, particularly ice conditions, topography and food availability/distribution.

Results generated by the proposed research program have the following potential applications:

1) The development of an updated status report for BB including recommendations on sustainable harvest levels; and,

2) The development of models to assess the effects of changes in habitat (in particular sea ice) on bear distribution.

Schedule

In BB, main field operations were conducted during spring and fall. Due to logistical constraints (remoteness of the survey area and consideration of light conditions in fall) field work was concentrated in spring in KB. The schedule of the proposed study was:

Biopsying for genetic mark-recapture assessment

1) Fall biopsying along eastern Baffin Island fall 2011, 2012 and 2013.

2) Fall biopsying in NW Greenland fall 2012 and 2013.

3) Spring biopsying in NW Greenland 2011, 2012 and 2013.

4) Spring biopsying in Kane Basin 2012, 2013, and 2014 (optional).

Deployment of satellite radios

1) Deployment during spring in NW Greenland 2011, 2012 and 2013 of satellite radios

(satellite radios had also been deployed in these areas during spring 2009 and 2010).

2) Deployment of satellite radios during spring in Kane Basin 2012 and 2013.

Hunter collection of tissues from the polar bear catch (harvest recoveries)

1) Nunavut spring 2011 and onward.

2) Greenland spring 2012 and onward.

Data analyses

1) Genetic laboratory analyses, analyses of MR data, genetic data and satellite telemetry

data 2012 and onward

Final reporting

1) September-October 2014

1.6. Process of BB and KB Assessment (2011-2016) and Delays

Program activities

Activities (field operations, laboratory analyses, data analyses, and reporting) in

connection with the research program are summarized here. Details of the various activities are

presented in the Materials and Methods sections of the various chapters of this report.

Field activities

Personnel from several research institutions participated in planning and conducting the

field work including GINR, GNDE, University of Oslo, and University of Minnesota. In

addition, local polar bear hunters in Nunavut and Greenland participated on several flights

aiming to obtain biopsy samples from unrestrained bears and/or immobilizing bears to furnish

them with satellite radios (NW Greenland and Kane Basin). In both Nunavut and Greenland, community consultations were conducted each year and information about the study was provided through meetings and via public media to local communities and the broader public audience.

The spring and fall biopsy program (2011-2013) along Baffin Island and in W and NW Greenland from the BB subpopulation was conducted as planned. From 2011 to 2013, 1,111 bears were biopsy darted along eastern Baffin Island (and genotyped) which was substantially more than anticipated. From 2009 to 2013, 143 bears were physically marked or biopsy darted (and genotyped) in W and NW Greenland. The spring biopsying program in Kane Basin was also successful although a third spring season was needed and completed during 2014. From 2012 to 2014, 129 bears were physically marked and genotyped or biopsy darted and genotyped in KB (Chapter 2 and 5).

Additional to the original research plan and concurrent with the biopsy sampling, a systematic aerial survey using sight-resight distance sampling protocols was conducted during spring 2014 to assess the number of polar bears in the Kane Basin subpopulation. Adding this extra component allowed for a comparison of estimates of subpopulation size via two different methods (i.e., genetic MR and aerial survey).

During 2011-2013 a total of 66 satellite radios (35 F, 31 M) were deployed in W and NW Greenland (in addition 35 satellite radios had been deployed there in 2009 and 2010; 20 F, 15 M). During 2012 and 2013 a total of 36 satellite radios (21 F, 15 M) were deployed in the Kane Basin region. Some individuals were recaptured during the study and furnished with new satellite radios. Hence, a total of 91 individual bears were tagged with satellite transmitters in BB and 34 individual bears in KB (Chapter 2). The satellite radios included small ear satellite tags

developed by GINR for tracking adult male polar bears and sub-adults of both sexes (Born et al. 2010, Laidre et al. 2012).

A total of 234 hunter recoveries (tissue samples) were obtained from the catch of polar bears in Nunavut and Greenland (1993-2013). The hunter recovery program was instituted in Greenland for the first time in 2012. In addition, 635 biopsies from physical MR operations to assess BB and KB subpopulations in the 1990s (*cf.* Taylor et al. 2005, 2008) were included in the recent MR assessment analyses (Chapter 2 and 5).

In summary – All field operations were conducted as planned and were very successful. The number of biopsies obtained from the BB subpopulation was substantially higher than expected. All handling in NW Greenland and Kane Basin of individual polar bears in connection with deployment of satellite radios were made without any complications. The general pubic and local communities were informed about the operations and local polar bear hunters participated on several of the flights to obtain biopsies or immobilize polar bears.

Analyses

Wildlife Genetics International (Nelson, British Columbia, Canada) analyzed all genetic samples (9 nuclear markers).

Satellite telemetry data (habitat analyses) were analyzed under leadership of the Greenland Institute of Natural Resources and Dr. Kristin Laidre.

Analyses of ice metrics were conducted by Dr. Harry Stern at the Polar Science Center (University of Washington, USA) in collaboration with Laidre.

Analyses of the genetic MR recapture data were conducted at Department of Fisheries, Wildlife and Conservation Biology (University of Minnesota) under the leadership of

postdoctoral research associate Dr. Seth Stapleton, and his supervisor, Professor Todd Arnold.

Salary for Dr. Stapleton´s postdoctoral fellowship was provided by the Government of Nunavut,

Environment Canada, and GINR. Close cooperation on MR analyses was conducted with outside

expert Dr. Eric V. Regehr (US Fish and Wildlife Service).

Analyses of field observations of polar bear body condition were made by Nunavut under

leadership of Dr. Stephen Atkinson.

Population genetic analyses to determine the demographic identities of Baffin Bay and

Kane Basin subpopulation were made by Dr. Liselotte Wesley Andersen at Department of

Bioscience (University of Århus, Denmark) based on the results of analyses of nine nuclear

markers used in the genetic MR study.

All SWG members participated in various phases of analyses. External experts

(Appendix A) also participated in the analyses and in three face-to-face progress meetings of the

SWG held at the Polar Science Center, University of Washington.

Timeline of analyses and reporting

The SWG originally proposed an October 2014 deadline for submission of a final report

to the JC (SWG 2011). However, due to the time required for completion of sample processing

in the genetic laboratory this deadline could not be met. The delay was a consequence of the

largely successful field work, which exceeded expectations in terms of the quality and number of

biopsy samples. As the mark-recapture modeling could not begin until the laboratory analyses

were completed and the final datasets compiled, a new deadline for a final report of 30 April

2015 was proposed by the SWG (SWG 2014). However, further unanticipated delays occurred

related to availability of historical samples and a final comprehensive dataset was not available

until mid-December 2015. This delay put the analyses approximately 6 months behind schedule

(SWG letter to JC).

In October 2015, the SWG held a 2nd face-to-face meeting in Seattle, Washington. At the

meeting, preliminary results from analyses on abundance and vital rates, population genetic

structure, range use, distribution, seasonal movements, and trends in sea-ice habitat were

presented and evaluated. Near-final results of the analyses of range use, distribution, seasonal

movements, and trends in sea-ice habitat and genetic analyses were also presented. However,

the presentation of preliminary results from the mark-recapture modeling revealed that a

considerable amount of additional work was still required from collaborators at University of

Minnesota (SWG 2015). This work included, among other things, more in-depth error checking

and a more detailed exploration of data from the MR studies in the 1990s in order to assess bias

and potentially detect trends in abundance. This required revising the basic structure of the

population models, developing and running model simulations, and validating the final model

results before a final report could be completed.

Following this meeting the SWG and collaborators held 13 teleconferences between

November 2015 and April 2016 where progress in the MR modeling of abundance in BB and KB

was discussed and evaluated. A third face-to-face meeting was held in February 2016 to

evaluate the revised modeling results.

After detailed discussions of the results of the MR assessment of the BB and KB

subpopulations the SWG identified items for further analyses by University of Minnesota before

final results could be sent to external scientific review (SWG 2016). In May 2016, results of the

mark-recapture assessments were sent to Dr. Gary White (Professor Emeritus, Colorado State

University) for a courtesy, external peer-review. Dr. White is a world-expert in mark-recapture

population analyses. Dr. White gave the analyses a positive review and approved the analytical

methods used and their results.

In summary the analyses of sea ice, movement and habitat use were conducted according

to the original time plan. However, unanticipated delays in getting a final genetic dataset and

complications related to the modeling of the genetic data resulted in delays in preparing the final

report to the JC.

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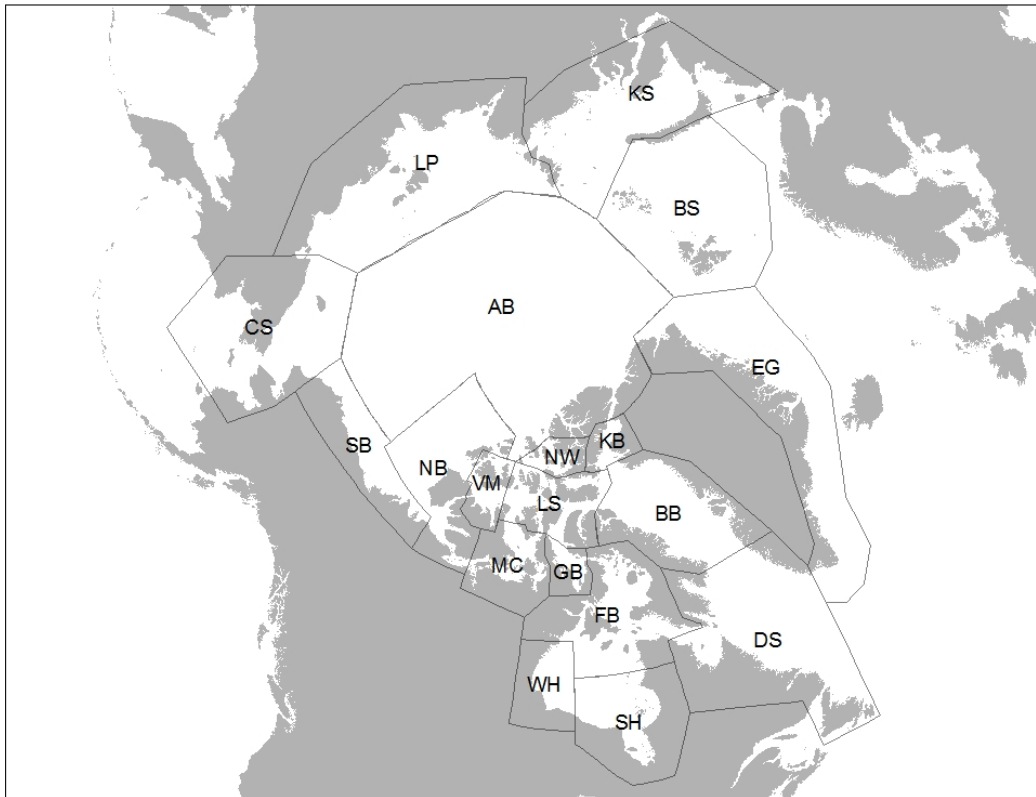
Figure 1.1. Map of the circumpolar Arctic showing the 19 subpopulations of polar bears, including Baffin Bay (BB) and Kane Basin (KB). Polar Bear subpopulations: Arctic Basin (AB), Baffin Bay, Barents Sea (BS), Chukchi Sea (CS), Davis Strait (DS), East Greenland (EG), Foxe Basin (FB), Gulf of Boothia (GB), Kane Basin, Kara Sea (KS), Lancaster Sound (LS), Laptev Sea, M'Clintock Channel (MC), Northern Beaufort Sea (NB), Norwegian Bay (NW), Southern Beaufort Sea (SB), Southern Hudson Bay (SB), Viscount Melville Sound (VM), and Western Hudson Bay (WH).

CHAPTER 2

SUBPOPULATION DELINEATION OF BAFFIN BAY AND KANE BASIN

KEY FINDINGS

Baffin Bay (BB)

- The 1990s and 2000s satellite telemetry data are comparable for analysis; approximately 92% of adult females collared in West Greenland in spring during the 2000s use the same area on Baffin Island where adult females were captured and collared in fall in the 1990s.

- There was a significant reduction in the size of the 2000s BB 95% bivariate normal kernel range (i.e. a measure of the area used by collared bears) in all months and seasons when compared to the range in the 1990s. The most marked reduction was a 60% decline in subpopulation range size summer.

- The overlap of the 1990s and 2000s BB ranges was < 50% in all months, reflecting both a contraction and shift of the BB subpopulation range in the 2000s. These shifts are related to the loss of annual sea ice and changes in breakup timing, contracting the range of the BB subpopulation and shifting the distribution of BB polar bears northward in all seasons. The BB subpopulation is still distributed within the current management boundaries.

- There were significant shifts north in the median subpopulation latitude in all seasons in BB across decades.

- Bears in the 2000s were significantly less likely to leave BB than in the 1990s (p<0.001), with reductions in the number of bears moving into Davis Strait and Lancaster Sound.

- Genetic analyses using eight polymorphic microsatellites in recent samples (2009-2014) had low genetic resolution. BB and KB polar bears could not be differentiated genetically. Also in accordance with previous genetic studies, BB-KB polar bears were found to be genetically different from polar bears in Lancaster Sound and Davis Strait.

- During the genetic mark-recapture studies in BB and KB (2011-2014) there were very low levels of recapture or harvest recovery of bears outside their subpopulation of origin.

- Satellite telemetry demonstrates that emigration from BB has been significantly reduced since the 1990s, largely due to reduced sea-ice extent in winter and absence of sea ice in summer. This suggests the BB subpopulation has become more discrete, with less exchange between it and other subpopulations.

Kane Basin (KB)

- KB mean 95% kernel ranges have generally expanded since the 1990s. The increase in range use in the 2000s occurs in all seasons, however is statistically significant only in summer (June-September), where ranges doubled between the 1990s and the 2000s. This range expansion is likely related to changes in sea ice, as KB is trending towards the characteristics of an annual ice ecoregion (like BB) where ice melts out almost completely each summer.

- There is still considerable seasonal overlap in KB subpopulation ranges for bears in the 1990s and 2000s (50-98% overlap over decades), suggesting that bears generally continue to use the same areas of KB.

- There were significant northward shifts in KB median latitude of polar bear locations in the 2000s in spring and summer, although these shifts were smaller than observed in BB. Variability in the range of latitudes has increased; bears in the 2000s use a broader range of latitudes. There has been no change during winter.

- These distribution patterns did not change with a sensitivity analysis in which bears captured in eastern KB were excluded from the 2000s data, to match the distribution of captures in the 1990s. This suggests that our key findings for KB were not influenced by the distribution of capture locations.

- **BB and KB**

   Overall, our findings based on satellite telemetry, movement of marked bears and genetics suggest that the existing boundaries of the BB and KB subpopulations continue to be relevant for harvest management purposes and population monitoring.

2.1. Subpopulation Delineation and Status Background

Cluster analyses of movement data from satellite-collared bears (Taylor et al. 2001), genetic analyses (e.g., Paetkau et al. 1999), and recaptures and harvest recoveries of marked (tagged) bears (Taylor and Lee 1995, Taylor et al. 2001) are among the methods that have been used to evaluate and delineate the boundaries of the Baffin Bay (BB) and Kane Basin (KB) subpopulations. For BB, genetic analyses suggest a lack of genetic differentiation of BB from the adjacent KB subpopulation to the north, but a significant genetic difference from polar bears in the Davis Strait (DS) subpopulation (Paetkau et al. 1999). Analyses of satellite collar data and tag returns suggest that some interchange occurs among BB and adjacent subpopulations

including DS, Lancaster Sound (LS) and KB (e.g., Taylor et al. 2001). However, for the purposes of management, BB is considered a distinct demographic unit, and its dynamics are largely driven by intrinsic rates of reproduction and mortality rather than exchange with neighboring subpopulations.

For KB, analyses of satellite collar data and tag returns suggest partial closure. However, the discreteness of this subpopulation from neighbouring units has been questioned, in part due to the lack of genetic differentiation from surrounding subpopulations and the potential for immigration from these much larger subpopulations to significantly influence demographic processes in a source-sink dynamic (Taylor et al. 2008). Particularly notable interchange occurs with BB and LS. The North Water polynya, a large area of open water in northern Baffin Bay and southern Smith Sound, is a significant regional geographic feature that exhibits substantial intra- and inter-annual variability in spatial extent and is thought to form a barrier between KB and BB – LS.

Sea ice in BB and KB has decreased markedly during the last 3 decades (Stirling and Parkinson 2006, Peacock et al. 2012, Laidre et al. 2015, Chapter 4 and 9), with earlier spring break up and later fall formation. The extent to which these trends in sea ice will affect the distribution and boundaries of these subpopulations remains uncertain and requires updated information. In particular, there is a need to re-evaluate these boundaries when undertaking studies to estimate abundance and vital rates to ensure sampling remains consistent with the distribution of the biological subpopulations.

The delineation and status of the BB subpopulation has been documented and updated by the IUCN/SSC Polar Bear Specialist Group (PBSG 1995, 1998, 2002, 2006, 2010, and http://pbsg.npolar.no/en/index.html) and annually by the Canadian Polar Bear Technical

Committee (unpublished). Based on the movements of adult females with satellite radio-collars

and the recapture or harvest of tagged animals, the BB subpopulation of polar bears is bounded

by the North Water Polynya to the north, Greenland to the east and Baffin Island, Nunavut,

Canada to the west (Taylor et al. 2001) (Figure 1.1). A relatively distinct southern boundary at

Cape Dyer, Baffin Island, and the entrance to Kangerlussuaq/ Søndre Strømfjord, Greenland, is

evident from the movements of tagged bears (Stirling et al. 1980) and from adult female polar

bears monitored by satellite telemetry (Taylor et al. 2001).

Analysis using microsatellites revealed significant genetic variation between polar bears

in BB and neighboring DS, but not between polar bears in BB and neighboring KB (Paetkau et

al. 1999). However, bears from BB-KB differed genetically from polar bears in the neighboring

LS and DS subpopulations (Paetkau et al. 1999, Peacock et al. 2015, Malenfant et al. 2016). The

original separation of the polar bears subpopulations into the two management units Kane Basin

and Baffin Bay was based on studies of movement of polar bears with satellite collars in the

1990s and the fact that the North Water Polynya in northern Baffin Bay, to a certain extent, acts

as a barrier to movement between BB and KB (PBSG 1998, Taylor et al. 2001). The samples

included in the genetic study by Paetkau et al. (1999) were collected in the early 1990s. A study

by Peacock et al. (2015) was based on more recent samples (i.e., BB: mainly 2006-2008; DS:

2005-2007; LS: mainly 2008), however the samples from KB were from the 1990s. Malenfant et

al. (2016) conducted a re-analysis and relied upon subsets of the same data in Peacock et al.

(2015). Hence, the KB-samples in Malenfant et al. (2016) were also not temporally congruent

with samples from BB, LS and DS.

Based on the movements of KB adult females with satellite collars and the recapture or

harvest of tagged animals, the boundaries of the KB subpopulation include the North Water

Polynya (to the south of KB), and Greenland and Ellesmere Island to the west, north, and east

and the southern part of Kennedy Channel to the north (Taylor et al. 2001; Figure 1.1).

There have been no new scientific studies in BB or KB to update information on

subpopulation delineation since 1997. We used new data from genetics, satellite telemetry and

information on the movements of bears amongst BB, KB and surrounding subpopulations as

detected by the recapture or harvest of marked individuals to assess the current BB boundaries.

Our objective was to use these data to support other lines of evidence relating to the delineation

of these subpopulations.

2.2. Methods

Genetics

In this study, a large recent sample of polar bear tissues was obtained from the

subsistence catch and from scientific biopsies in BB, KB, LS and DS (2009-2014). This was

obtained primarily for the genetic mark-recapture as reported in Chapters 5 and 10. Data from

these analyses were therefore available for an updated examination of population genetics in BB

and KB. The majority of the samples were collected between 2011 and 2014. Hence, in contrast

to previous studies, the samples collected in connection with the genetic mark-recapture study

were both more recent and also temporally congruent (Table 2.1).

The genetic analyses reported here used the same eight polymorphic microsatellite

markers as in MR analyses to explore to what extent polar bears in KB, BB, LS and DS differed

genetically (e.g., PBSG 2010). The decision to make these analyses was made *post hoc* and

genetic analyses were not a part of the original study plan (see Chapter 1). Hence, these analyses

were based on a platform of opportunity (i.e., the samples had been analyzed genetically and the

data were available), fully recognizing that more nuclear markers would result in a higher resolution.

Genetic data from a total of 1,364 individual polar bears from the BB, KB, LS and DS subpopulations were available for the genetic analyses. A subset of 402 polar bears sampled during the winter-spring season (Nov-June) in 2012-2014 represented all four subpopulations under consideration. This subset consisted of the spring biopsy samples from Kane Basin, and winter-spring harvest samples from BB, LS and DS. We considered the samples to have been collected within a narrow time frame (i.e., "temporally congruent") that would exclude major displacement of groups of polar bears among BB, KB, LS and DS during the sampling period (Table 2.1).

The population genetic analyses were conducted by Department of Bioscience (Aarhus University, Denmark) using standardized analytical tools and methods (ADEGENET package, Jombart 2008; ARLEQUIN Version 3.5.1, Excoffier and Lischer 2010; BA3-3.0.3, Wilson and Rannala 2003; DAPC, Jombart et al. 2010; FSTAT, Goudet 1995; GENECLASS2, Piry et al. 2004; GENELAND, Guillot et al. 2005, Guillot 2008; STRUCTURE, Prichard et al. 2000).

Satellite Telemetry Studies of Movements and Range Use

Polar bears were tagged in NW Greenland on the fast and pack ice between mid-March and mid-April 2009-2013 in Baffin Bay and mid-April to early May 2012-2013 in Kane Basin. Field operations were based out of coastal settlements in West Greenland or research stations on Ellesmere Island. Searches for bears in BB occurred out to a maximum distance of 150 km from the coast. Areas with consolidated glacier ice at the glacial terminus were also searched in both BB and KB. A total of 91 individual bears were tagged with satellite transmitters in BB and 34

individual bears in KB. Of these, 38 were AFs collared in BB and 20 collared AFs in KB (Table

2.2, Figures 2.1 and 2.2). In the 2000s, both sexes and subadults were tagged. These data were

combined with a historical data set of captured and tracked from both areas in the 1990s. In BB,

1991-1995 43 collars were deployed on AFs, with the majority deployed during the ice free

season in fall on Baffin Island (n=11 deployed in spring in NWG, 9 of which transmitted for

sufficient time to be included in the analyses) (Table 2.3). In KB, 1992-1994, 12 collars were

deployed on AFs on the west side of KB in the fjords and fast ice. Only bears captured within

the BB or KB subpopulation boundaries as defined by PBSG (2010) were included in the

comparative analysis.

Polar bears at all sites were darted and immobilized from an Ecureuil AS350 (BB) or Bell

206 LR (KB) helicopter and handled according to procedures described in Stirling et al. (1989).

Standard body measurements (standard length and axillary girth) were taken and total body mass

was estimated using the approach of Derocher and Wiig (2002). Field estimates of age and

reproductive status were recorded.

Adult female polar bears in the 2000s in both areas were fitted with TAW-4610H satellite

radio collars (Telonics, Mesa, Arizona, USA). Satellite collars provided information on

geographic location, internal transmitter temperature, and activity. Collars were programmed to

transmit during one six-hour period each day on 4-day intervals. In the 2000s, all adult male

polar bears and subadults of both sexes were fitted with SPOT-5 S227 satellite radio transmitters

(Wildlife Computers, Redmond, Washington, USA) attached to the ear similar to numbered

plastic ear tags used in conventional studies (right ear). The SPOT-5 transmitters weighed 32 g

and 60 g with attachment system (Born et al. 2010). Ear transmitters were duty cycled to extend

battery life, with most tags transmitting on 4-day intervals and others on daily intervals. Satellite

tags transmitted around noon local time each day and were programmed so that several locations were received per transmission day.

Data filtering and sub-sampling – Data on locations and transmitter status from all polar bears were collected via the Argos Location Service Plus system (Toulouse, France). Location qualities are assigned by ARGOS to each position, with location qualities of 0–3 estimated to have errors of 1.5 km or less and those categorized as 'A,' 'B,' or 'Z' have no predicted accuracy. Unrealistic and poor quality locations were removed using a speed and angle filter in R version 2.13.2 (R Development Core Team 2012) using the package 'argosfilter' (Freitas et al. 2008). Positions exceeding a maximum between location travel velocity (10 km/h based on previous movement studies of polar bears, Laidre et al. 2013) and angle (measured from the track between three successive locations; set to the default) were removed by the filtering algorithm. The resulting locations for each bear were next reduced to a single position per day to reduce autocorrelation bias, standardize temporal sampling, and address the effects of variable duty cycling among the tags. To obtain a daily position for each tag, the first, best quality location within the period of peak satellite passage was selected. Daily positions, after filtering and optimal daily position selection, only consisted of ARGOS qualities 1–3. Distances between successive daily positions were calculated as the great circle route and used to compute minimum daily displacements.

As a result of variable experimental objectives in both subpopulations and decades, different duty cycles were used for tags in an effort to extend battery life or gather information from specific time periods. The 1990s collars were programmed to transmit on varying and intermittent intervals, ranging from 1 to 6 days, while the 2000s collars were all on a 4-day cycle. We sub-sampled the 1990s data and created a strict 4-, 5- or 6- day interval time series for each

individual to best match the 2000s data. This ensured that the impact of serial autocorrelation was consistent.

Captured polar bears were classified as independent adult male (AM), adult female (AF), subadult male (SM), subadult female (SF), or dependent cubs (cub of year COY, yearling YRL or 2-year old 2YR). We also classified the habitat type where the bear was first located and captured into three categories– pack ice (open or loose ice with leads and cracks), fast ice (sea ice attached to land with no open water), glacier ice (consolidated glacier ice at glacier fronts), as well as captures on land.

Data were divided into seasons: Spring (March – July, which included the peak of sea-ice coverage and initiation of sea-ice break-up), Summer (August – October, which included the end of break-up and the on-land period) and Winter (November – February, which included the freeze-up period and time when bears went back out on the sea ice). All denning periods were identified (maternity and shelter dens) (Escajeda 2016) and removed from RSF models. RSF models were only conducted on AFs to enable comparison with the 1990s. Bears with < 3 locations were removed from analyses as this was likely due to transmitter failure immediately after capture. Ages of polar bears were provisionally estimated in the field and later confirmed more accurately from counting of cementum growth layers of a pre-molar extracted during capture following methods in Calvert and Ramsay (1998). Adult females were defined as ≥ 5 years old and adult males as ≥ 6 years old. Age group status as determined in the field was verified based on tooth analyses.

We assigned each polar bear location to its respective subpopulation boundary (starting point or origin as well as the boundary where the bear was located at each time step) based on the boundaries recognized by the IUCN Polar Bear Specialist Group (PBSG 2010).

Basis for comparison of the 1990s and 2000s BB satellite telemetry data – Polar bears

within the subpopulation boundaries of BB are treated as belonging to a single management unit.

The bears range over the entire Baffin Bay with the majority of bears spending the summer on

Baffin Island during the ice-free period. There were differences in capture locations between

decades (Figure 2.1), and although these captures were all within the bounds of the BB

subpopulation per PBSG (2010) they were captured in different areas and seasons. Thus we

conducted analyses to ensure that the movement of the bears was comparable across periods. In

the 1990s, n=43 adult females were collared between 1991 and 1995. Approximately 72% of

these were captured on land on Baffin Island in fall. In the 2000s, all n=38 adult females were

captured on the spring fast ice and pack ice between 2009 and 2013 in West Greenland.

We spatially bounded the 1990s fall capture region along the coast of Baffin Island and

examined what fraction of bears collared in the 2000s (in spring) in West Greenland used the

same area the following fall. We defined fall as any period between August and November. All

West Greenland 2000s bears were considered "independent" because they were captured in

spring. Some individuals that remained resident during all seasons on or close to glaciers in

Melville Bay and bears with collars that failed to transmit for >2.5 months after spring capture

(which occurred in mid-April) were excluded from the calculations.

Monthly and Seasonal Kernel Density Estimates – Using a fixed kernel density approach

(Worton 1989), we estimated the geographic areas characterized by a high probability of use by

satellite-radio tagged AF polar bears in BB and KB. Kernel density estimators provide a non-

parametric probability of using a given point in space and are reliably used to define the

utilization distribution, or home range, for marine and terrestrial wildlife (Kie et al. 2010).

We calculated Gaussian bivariate normal kernel density estimates for each subpopulation (BB, KB, and KB West), in each decade, and for each month (n=12) and season (n=3). Kernel Density Estimates (KDEs) were calculated using the "bkde2D" function in "KernSmooth" R package (Wand 1994, Wand et al. 1995). The sample size of tagged AF differed between the 1990s and 2000s (Table 2.2, Table 2.3). To account for any potential bias in the KDEs or the fraction of overlap between decades due to differing numbers of AFs we randomly sampled with replacement from the pool of AF bears in each the two decades (1990s and 2000s) so that the sample sizes of collared bears were equivalent during each time period (n=38 bears in BB in both decades, n=12 bears in KB in both decades). We sampled bears with replacement 1,000 times for each monthly and seasonal KDE and calculated the area of the 95% contour polygon (bounding 95% of the KDE surface volume). We produced a mean and bootstrapped standard error (SE) for monthly and seasonal home ranges, calculated the fraction of overlap for each time period, and statistically compared time periods. We used the 'intersect' tool in ArcGIS to identify overlapping home ranges between subpopulations. We also estimated the proportion of home range overlap between the 1990s and the 2000s (Fieberg and Kochanny 2005) based on the bootstrapped mean. The cell size was set to 6 km and bandwidth of 50 km (approximately 50% of the 4-day movement step of AFs in this study). Cell size determines the smoothness of the resulting prediction, but has minimal impact on kernel density estimation relative to bandwidth selection. The bandwidth controls the width of the estimated kernel thereby determining how much regional variation is emphasized.

Changes in Median Latitude – We also calculated median latitude and longitude values for the 1990s and 2000s using pooled data from all AFs by season. The north-south orientation of the BB and KB subpopulation ranges allowed for this comparison. We compared changes in

median latitude and longitude across decades with t-tests at a significance level of $\alpha = 0.05$. In

the 1990s KB, all bears were caught along eastern Ellesmere Island (i.e., western KB) whereas

bears were captured in both western and eastern KB in the 2000s. We performed a sensitivity

analyses to evaluate this sampling difference with a subset of the KB bears captured in the

2000s. This subset included only those bears captured along the coast of Ellesmere Island in

western KB. We compared them to the sample from the 1990s to examine any bias in

comparison across decades.

Movements across Subpopulation Boundaries – We considered each 4 to 6 day AF bear

trajectory as a single sample and calculated the elapsed time spent in the subpopulation region of

origin (defined as where the bear was captured and tagged). Specifically, we calculated the

number of days until each polar bear left its subpopulation region of origin and plotted the time-

until-departure for each subpopulation and decade. Bears that never left their region of origin

still contributed follow-up time, but their observation time was censored at time of last

transmission. Statistical methods for censored event times were used to construct "survival"

curves (Kaplan-Meier) to characterize the distribution of exit times from BB or KB and test for

differences among different subpopulations/decades (log-rank test of equality) with $\alpha = 0.05$. We

considered two time scales for departure: (1) a departure from the region of origin to be any

length of time (4 days minimum) and (2) a departure from the region of origin that was at least

30 days long.

For bears that were observed to leave their subpopulation region of origin we

summarized which subpopulation they departed to and the month of departure. We contrasted

departures between BB and KB and across decades. As there were two capture seasons in the

1990s (spring in Melville Bay and summer on Baffin Island) we also tested whether capture

season impacted the time until departure from the region of origin.

Recaptures and Harvest Recoveries of Marked Bears

Bears included in this study were marked in springtime (April – May) or fall (August –

October) during three periods; 1991-1997, 2005-2007 and 2009-2014. From 1991 to 1997, 881

and 141 bears were captured and physically marked with ear tags and lip tattoos as part of

studies in BB and KB, respectively (Taylor et al. 2005, 2008). In preparation for genetic mark-

recapture studies in BB and KB commencing 2011, tissue samples collected from these bears

were subsequently genotyped in 2011 with two exceptions: 1) bears that were known to have

been harvested between 1991 and 2011 and 2) bears whose known or estimated age would have

been greater than 35 years in 2011. In total, this dataset consisted of 650 individuals marked in

the 1990s that would have been ≤ 35 years old and had not been harvested by the time genetic

sampling began in 2011. Samples for genotyping were available for 635 of the 650 individuals.

Genotyping followed methods described elsewhere in this report (Chapter 5).

From 2005 to 2007, 1518 bears in DS were physically marked (and subsequently

genotyped) as part of a mark-recapture study (Peacock et al. 2013). From 2011 to 2013, 1111

bears were biopsy darted along western BB (Canada) and genotyped. From 2009 to 2013, 143

bears were physically marked and genotyped or biopsy darted and genotyped in eastern BB

(Greenland). From 2012 to 2014, 129 bears were physically marked and genotyped or biopsy

darted and genotyped in KB.

Recapture or harvest recovery of physically or genetically marked individuals was

detected by two means. Prior to 2011, when biopsy darting began, marked BB and KB

individuals were identifiable by ear tags and lip tattoos. During this period, recaptures of marked individuals were recorded during physical capture sampling in BB, KB, and surrounding subpopulations. Harvest recoveries of marked bears were detected via hunter returns of ear tags and / or lip tattoos as part of the on-going harvest monitoring program across all subpopulations in Canada and Greenland (Peacock et al. 2012). From 2011 onwards, all marked individuals were genotyped and some were both physically marked and genotyped. Recapture or harvest recovery of marked individuals was detected by physical marks recorded during capture sampling and harvest monitoring or by matching the genotypes of marked bears to samples collected during capture sampling, biopsy darting or harvest monitoring.

Although recaptures and harvest recoveries of marked bears from BB and KB have been previously reported (Taylor and Lee 1995, Taylor et al. 2001, Peacock et al. 2012), we incorporated additional data to supplement and update these analyses. We focused on three areas. To facilitate interpretation of results from the recent genetic mark-recapture studies in BB and KB (Chapters 5 and 10) we examined recaptures and recoveries of individuals marked between 2011 and 2014 to test the assumption that bears marked during these studies remained within their original subpopulations over the sampling period. For bears marked in the 1990s in BB and KB, we examined the number and sex of individuals recovered in the harvest up to 2014 to assess the degree of movement amongst subpopulations over the long term and to test the hypothesis that these movements are sex biased. Finally, we examined 3 sequential, intensive mark-recapture sampling sessions in BB (1991-97 and 2011-13) and neighboring DS (2005-07), to assess movements across the BB-DS boundary.

We incorporated capture, recapture or recovery events for which the location of bears was recorded at time of observation using a GPS. Sex was determined by physical examination

or genotyping (Chapter 5 and 11). For bears marked between 1991 and 2008, age was

determined based on previous capture history, known age (in the case of cubs and yearlings) or

estimated from counts of annular rings in an extracted vestigial premolar tooth (Calvert and

Ramsay 1998). For bears "marked" from 2009 to 2013, the age of most individuals (i.e., those

remotely biopsied along eastern Baffin Island, in contrast to those immobilized and handled in

NW Greenland and in Kane Basin) could not be determined since they were not physically

handled and teeth were not available for aging. Instead, age class (cub-of-the-year, yearling,

sub-adult [ages 2 – 4], and adult) was estimated from the air at a range of 3-7 meters above

ground. Age-class was later verified in some bears from previous or future captures in which an

individual was captured and physically examined or where an individual was matched via DNA

to membership in a known family at some past or future point. We assessed the accuracy of this

system for estimating the age-class and sex of polar bears using a sample of BB bears of known

age-class (Appendix B). For all capture-recapture analyses, recaptures of an individual within

the same season and year of capture were excluded. Statistical analyses were performed using

the SPSS package (Version 24.0, IBM Corp. 2016).

2.3. Results

Overall Study Area

The boundaries of the BB polar bear subpopulation (BB) encompass an area ~1 million

km^2 in Baffin Bay, covering portions of Baffin Island and all of Bylot Island (66.2°N to 73.8°N)

in Nunavut/ Canada, as well as parts of West and Northwest Greenland (66.0°N to 77.0°N;

Taylor et al. 2005). BB is bounded by Greenland to the east, Baffin Island to the west, the North

Water polynya in the north and Davis Strait to the south (Figure 1.1, Figure 2.1). Three

communities in Nunavut and 37 communities in Greenland harvest bears from BB, although the

majority of the Greenland harvest is taken between *ca.* 72° and 76° N. Baffin Bay is ice-covered

in winter but typically ice-free in summer. During late spring and summer break-up, sea ice

recedes from Greenland westward across Baffin Bay; the last remnants of ice typically occur off

the coast of Baffin Island. Most polar bears remain on the sea ice as it recedes and then come

ashore to spend the ice-retreat period on Baffin and Bylot Islands (Taylor et al. 2005). A small

number of bears remain on land in northwestern Greenland throughout the ice-retreat period

(Born 1995, Born et al. 2011, this study).

The KB polar bear subpopulation covers roughly 150,000 km^2 and spans portions of

Nunavut, Canada, including Ellesmere Island, as well as northwestern Greenland (Taylor et al.

2008). The subpopulation ranges over Kane Basin, Nares Strait, Smith Sound and adjacent

fjords on eastern Ellesmere Island and Northwest Greenland (the Qaanaaq area). It is bounded to

the north by the Arctic Basin subpopulation (via the Kennedy Channel), to the south by the BB

and LS subpopulations, and to the west by Norwegian Bay (NW). Kane Basin forms part of the

Arctic archipelago ecoregion (Amstrup et al. 2008); sea ice remains present in the northern range

(i.e., Nares Strait-Kane Basin) throughout the year, largely due to the influx of polar pack ice

from Arctic Basin, and reaches a minimum in late summer.

Genetics

The multi-locus F_{ST} estimates were generally low, although statistically significant. The

F_{ST} analysis suggested a separation into three groups (1) BB-KB, (2) LS and (3) DS (L.W.

Andersen, Institute of Bioscience, Århus University, Denmark, personal communication). This

subdivision is in accordance with Paetkau et al. (1999), Peacock et al. (2015) and Malenfant et

al. (2016). The analyses based on the 8 markers showed that the genetic resolution was low.

Bayesian clustering methods had difficulties identifying more closely related groups without

using spatial information (i.e., site of sampling or harvest).

Using the spatial information (i.e., GPS positions of individual samples sites)

implemented in GENELAND a group structure was indicated where adult females and males

sampled during the winter-spring season were divided in an eastern and a western group

corresponding to BB-KB and LS, and a northern and a southern group corresponding to BB-KB

and DS (L.W. Andersen, Institute of Bioscience, Århus University, Denmark, personal

communication) (Table 2.1).

General Movements from Telemetry

Baffin Bay – All but n=12 of the 43 bears collared in BB between 1991 and 1995 were

captured on land on Baffin Island in fall. The remaining 12 were captured on the sea ice in

spring (n=3 off Baffin Island and n=9 in Melville Bay, West Greenland). The 1990s collared

bears transmitted through 1997 (Figure 2.3). Overall in the 1990s 72% were captured in fall on

land inside the sampled area on BI (i.e., the area in which biopsies were collected for the genetic

MR assessment), 6% were captured on the sea ice off the Baffin Island coast, and 21% were

captured on the sea ice in Melville Bay, West Greenland. In the 2000s, all n=38 adult females

(100%) were collared between 2009-2013 on the spring sea ice in West Greenland and

transmitting through April 2015 (Figure 2.1).

Adult females were tracked between ~6 months and four years. Adult male tracking

durations were shorter (~2 months) due to ear attachments. Telemetry data were truncated at 01

April 2015 so that analyses could be completed on time for reporting deadlines, therefore

locations from collared bears beyond that date were not included here.

Adult females were captured and collared in West Greenland in all reproductive states

(alone, as mating pairs, with COYs= cub of the year, yearlings, and 2-year old cubs) (Figure 2.2).

General patterns of movements show broad coverage of the BB region during the tracking period

in each year (Figures 2.4-2.11). There was a series of collar failures in 2012 that resulted from

poor release mechanisms (Figure 2.7), therefore tracking data from bears captured in that year

had shorter durations. There was some exchange between BB and KB. Most bears followed the

general pattern of moving from West Greenland to the coast of Baffin Island in the fall.

However a new pattern was observed that was not detected in the 1990s satellite telemetry data.

Of the 38 adult females collared in BB in the 2000s, n=7 (18.4%) remained in the glacier ice of

Melville Bay for the entire tracking durations. For all but one of these bears, where collar failure

occurred early, this period was between 1 and 2 years (with some bears still transmitting from

Melville Bay after April 2015). Bears that remained in Melville Bay were captured in all years

when the area was sampled (2011-2013). No bears showed this behavior in the 1990s, and only

one of the tracked bears made a single excursion onto the fast ice in Melville Bay (Taylor et al.

2001 figure 3, and Figure 2.3). Of note, this comparison may include some bias because only

one bear was captured and given a satellite collar at glacier fronts in Melville Bay in the 1990s

(Taylor et al. 2001 figure 1) even though the area was searched. Unfortunately the satellite collar

on this bear only transmitted for one day. Additionally n=2 of 38 bears captured in the 2000s

moved back and forth between Melville Bay and KB but never visited Baffin Island.

Furthermore, another two individuals in the 2000s moved between Melville Bay and KB, but in

subsequent years also moved to Baffin Island.

Kane Basin – In the 1990s, 12 adult females were captured and collared in KB along the coast of Ellesmere Island (Figure 2.11). In the 2000s, 20 adult females were captured and collared in spring along both Ellesmere Island and the western coast of Greenland (Figure 2.1). Bears captured in 2012 remained in KB subpopulation boundaries for the entire tracking period (through the period when collars were removed, April 2014) whereas with bears captured in 2013 there was more variability in movements, with individuals moving into Baffin Bay and Jones Sound. No bears collared in KB moved to Melville Bay though contact with two individuals was lost close to the West Greenland coast (Figures 2.12-2.14). One bear collared in KB in 2013 moved along the northern coast of Greenland in the Arctic Basin to Severnaya Zemlya and then to Franz Josef Land (Figure 2.14 inset). This individual was considered an outlier and excluded from further analyses. Adult males captured and satellite tagged with ear tags in KB (Figure 2.15) remained in KB during their tracking periods, which were less than 30 days.

Basis for Comparison of the 1990s and 2000s BB Satellite Telemetry Data

The analysis examined if polar bears collared on the sea ice in spring in the 2000s (in West Greenland) represented the same subpopulation sampled in fall on Baffin Island (Figure 2.1). This was conducted to ensure the comparison of movements and habitat use between the two telemetry sets was valid. Overall 92% of the bears collared in West Greenland in the 2000s entered the 1990s capture region on Baffin Island in fall, providing a solid basis for comparing the movements of polar bears captured in spring and in fall as defined by a polygon encompassing all the 1990s fall captures. Bears collared in West Greenland used nearly the entire Baffin Island coastline in fall and were spread over the whole capture region used in the

1990s, with the exception of the area around Cape Dyer. These bears thus also were

representative of the bears biopsied for the genetic MR in the 2000s.

Subpopulation KDEs and Overlap of Ranges

   Baffin Bay – In BB in the 1990s, 95% kernel ranges for polar bears were similar in

winter, spring and summer, ranging from approximately 700,000 – 900,000 km^2. In the 2000s,

seasonal ranges were significantly smaller in all seasons, ranging from 255,000 to 729,000 km^2.

When the 1990s ranges were compared to the 2000s, there was a significant reduction in the size

of 95% seasonal ranges in all seasons (reduction of 20% area in winter and 30% in spring), with

the most marked reduction being a 60% decline in area of the summer range, reduced from a

mean of 716,767 km^2 (SE 57,850) to a mean of 255,992 km^2 (SE 28,627), based on 1,000

bootstrap samples standardized for sample size (Table 2.4, Figure 2.16).

   In all months except May, the home range sizes for the 2000s were significantly smaller

than those in the 1990s (Figure 2.17). In some spring months 95% monthly ranges were reduced

by 30% in late winter and spring (February, March and April) and in summer months by 50%

(August and September), with a difference of about 325,000-375,000 km^2 (Table 2.4, Figure

2.18). Home range sizes were calculated with and without the resident Melville Bay bears to test

for changes in results with inclusion of resident bears. There were minimal changes to the home

range sizes and no differences in the significance of results with or without these residents.

   Kane Basin – Seasonally, 95% ranges in KB in the 1990s fell between 89,000 and

203,000 km^2 whereas in the 2000s 95% ranges were between 152,000 and 192,000 km^2 (Table

2.4, Figures 2.19-2.21). In most months there was a reverse pattern to that in BB, where 95%

range sizes in the 2000s were generally larger than those in the 1990s. However the pattern of

increased range size was statistically significant only for June-September (p<0.001). Increases in summer range size were detected both when including all KB 2000s bears and those collared in west KB only.

Overlap of Ranges between Decades

The percent overlap quantifies the similarity in space between the home ranges across decades. In BB, the overlap of 1990s and 2000s home ranges was lowest in the summer months (July through October), ranging from 21-34% overlap. It was higher in spring and mid-winter, reaching a maximum of 61% in June, however largely was < 50% in all months. The low overlap values reflected the significant contraction of the range in most months in BB when comparing the two decades.

In KB there was a higher level of overlap in ranges between decades, ranging from about 50% in November and December to 98% in September. In general, KB bears used similar areas between decades, however in 2000s these areas were larger. When the 1990s KB bears were compared with the KB bears tagged in the western portion of the area (KB-West 2000s), the overlap was similar. In general, bears captured and tagged in KB west did not differ from the full sample of KB bears in the 2000s, though those in the western portion of KB were more likely to move into BB.

Changes in Median Latitude from Telemetry

We detected significant shifts north in the median subpopulation latitude in all seasons in BB. In winter, the shift was nearly 5 degrees north (median 68.8 in the 1990s, median 73.5 in the 2000s, p<0.001), while in the spring the shift north was about 3 degrees (p<0.001) and in

summer < 1 degree (p<0.001) (Table 2.5, Figure 2.22). In KB there were also significant shifts

north in median latitude in spring and summer but they were smaller, ~ 1 to 1.5 degrees (Table

2.5, Figure 2.23). There was no change in median latitude in KB during winter (p=0.07). We

tested both all KB 2000s bears and those in KB-west and there were no differences in

significance.

Movements across Subpopulation Boundaries from Telemetry

We examined the trajectories and departure from regions of origin BB (n=43 AFs in

1990s, n=38 AFs in 2000s) and KB (n=12 AFs in 1990s, n=20 AFs in 2000s) for bears tracked

up to 700 days in duration. Of bears captured in BB in the 1990s when departure of any length

(minimum 4 days due to duty cycling) was considered, there was movement to two

subpopuations: Davis Strait (n=14 bears) and Lancaster Sound (n=12 bears). In the 2000s, bears

moved to three subpopulations: Davis Strait (n=3), Lancaster Sound (n=3) and Kane Basin (n=5)

(Table 2.6). Overall polar bears in the 2000s were significantly less likely to leave BB than in

the 1990s (p<0.001) (Table 2.7), with large reductions in the number of bears moving into Davis

Strait and Lancaster Sound as observed in the 1990s. For example at 100 days after capture,

approximately 58% of bears were remaining in BB in the 1990s, whereas at the same time step in

the 2000s, over 90% of the collared bears were still in the area. At 300 days after capture,

approximately 60% of the bears had departed from BB in the 1990s where at the same time step

in the 2000s about <10% had left. Capture season in BB in the 1990s (spring vs. summer) was

not a factor in timing of departure from BB, there was no difference in time until departure for

the two decades (p=0.562) for either length of departure.

In KB there were no significant differences in percentage of bears departing over the

decades studied (p=0.339). In Kane Basin, 2 AF polar bears in the 1990s moved out of the area

(one to Arctic Basin and one to Baffin Bay) (Table 2.6), and movement in the 2000s was slightly

higher and included departure to Lancaster Sound, but was not significantly different (p=0.351).

The timing of departures over the annual cycle varied significantly in BB (Figure 2.24,

Figure 2.25). In the 1990s, bears were significantly more likely to depart from BB to Davis

Strait during the winter or early spring months when the area was ice covered (November and

April). Bears that departed to Lancaster Sound left BB in late spring and summer (June-

September) to move on to remnants of sea ice in the archipelago area (p=0.002, Fisher's exact

test). This pattern was weakly present in the 2000s although sample sizes were very low.

The number of boundary crossings by individual bears is shown in Table 2.9. Of the

bears that departed from BB (crossed the BB subpopulation border) in the 1990s when

departures of all time steps were considered, 5 of 26 did not return to BB (19%) at any point

during the tracking period. Of the bears that departed in the 2000s, 3 of 11 (27%) did not return

to BB.

When the threshold for departure was longer (>30 days) patterns were similar. Bears

were significantly more likely to depart from BB in the 1990s and departures primarily occurred

to Davis Strait and Lancaster Sound (Tables 2.10 and 2.11). For AF departures based on the 30

day time step, fewer bears left the subpopulations of origin (Figure 2.25). There were similar

differences in proportion of bears departing BB; significantly more bears departed in the 1990s

vs. the 2000s (p=0.009). The timing of departures was similar but sample sizes were smaller

(Table 2.12). Of the bears that departed from BB (crossed the BB border) in the 1990s when

departures >30 days were considered, 56% of the 1990s BB bears did not depart from the BB

boundaries, where as 79% of the BB bears in the 2000s did not depart from the BB boundaries

(Table 2.13).

Recaptures and Recoveries during Genetic Mark-Recapture Studies, 2011-14

From 2011 to 2014, the harvest of polar bears in BB, KB and all surrounding

subpopulations was monitored genetically by genotyping of tissue samples from harvested bears.

Of the bears genetically marked in BB during the recent mark-recapture study, 2011-2013, 85

individuals were recovered in the harvest, as detected by genotyping (Table 2.14). Of these

individuals, 84 (99%) were recovered in the BB harvest and the other bear was harvested in DS.

For bears marked in KB from 2012-2014, no individuals were recovered in the harvest in KB or

surrounding subpopulations. Also during this period of harvest monitoring, an additional 12

bears marked in the 1990s in BB and KB were recovered in the harvest. Eleven were marked in

BB, 1 was marked in KB. All of these 'old' 1990s marks were recovered in BB.

Of the bears genetically marked in BB during 2011-2013, there were 207 recapture

events during mark-recapture sampling in BB and KB from 2011 to 2014, including >1 recapture

of some individuals (Table 2.15). Two hundred and six (> 99%) of these recapture events

occurred in BB and one BB mark was recaptured in KB. For bears marked in KB during 2012-

2014, there were 29 recapture events during mark-recapture sampling in BB and KB from 2011

to 2014. Twenty-eight (> 96%) of these recaptures occurred in KB and one KB mark was

recaptured in BB.

During this recent period of mark-recapture sampling there were 66 recapture events of

bears marked in either BB or KB during 1991-1997. Fifty-four of these events were of

individuals marked in BB. Twelve were of KB individuals. For the 54 'old' BB marks, all were

recaptured in BB. Of the 'old' KB marks, 8 and 4 were recaptured in KB and BB, respectively.

For bears that were biopsied on more one occasion during the ice-free seasons in BB

between 2011 and 2013 we examined the straight line distances between mark and recapture

locations. Intervals between capture and recapture were obviously constrained to a ranged from

1-2 years. Median distances between mark-recapture varied between age and sex classes (Figure

2.26; Kruskal-Wallis, H = 18.62, P = 0.001). Bears initially marked as yearlings were recaptured

at a location farther from their initial capture site than COY and adult females. Adult males also

had larger mark-recapture distances than COY (Figures 2.26 and 2.27).

Long-term Harvest Recoveries of BB and KB Marks

Of the 881 bears marked in BB from 1991 to 1997, 181 individuals were recovered in the

harvest in Canada and Greenland between 1991 and 2014 (Table 2.16). Eighty-three percent of

recoveries occurred within BB. Recoveries of marked bears outside BB tended to be male-

biased (3.29 males per female) relative to recoveries within BB (1.85 males per female), but this

tendency was not statistically significant (Fisher's Exact test, P = 0.483).

Of the 141 bears marked in KB from 1991 to 1997, 21 individuals were recovered in the

harvest in Canada and Greenland between 1991 and 2014. Forty-eight percent of these

recoveries were within KB. There was no significant sex bias in recoveries within versus outside

KB (Fisher's Exact test, P = 0.656).

Movement of Bears between BB and DS

One hundred and fifty-five bears marked in BB during 1991 – 1997 were recovered in the harvest up to 2005, including 11 recoveries in DS. From 2005 to 2007, a total of 2,128 bears comprising 1,518 unique individuals were captured in DS. There were 13 recapture events of bears previously marked in BB recaptured during this sampling in DS.

From 2009 to 2013, 1,253 unique individuals (1,623 capture events) were recorded in BB. Sixteen (1%) of these individuals were originally marked in DS. In sum, from a total of 2,771 bears marked in either BB or DS during 2005 – 2013, we detected 29 instances (ca. 1%) where marked bears moved from one subpopulation to the other.

The straight line distance of these 29 inter-subpopulation movements was independent of the capture-recapture interval which ranged from 4 to 15 years (Table 2.15, Figure 2.28). Seventy percent of these individuals were originally captured and marked within 100 km of the boundary between BB and DS (Table 2.16, Figure 2.29). In comparison to other bears marked in these subpopulations, individuals that made inter-subpopulation movements were found significantly closer to the boundary ($\chi^2 = 169.48$, d.f. = 11, p < 0.001). Despite extensive marking of bears throughout the range of both subpopulations the recorded inter-poplation movements were clustered near the boundary (Figure 2.1).

2.4. Discussion

Genetics

The results of the analyses of migration direction and detection of first generation migrants were subtle and influenced by the lack of differentiation between Baffin Bay and Kane Basin. However the overall migration direction appeared to flow from Lancaster Sound and

Davis Strait to Baffin Bay and Kane Basin. More markers would be needed to verify this (L.W. Andersen, Institute of Bioscience, Århus University, Denmark, personal communication).

Although the genetic resolution was low due to use of only 8 nuclear markers pre-selected for other purposes these analyses support findings in previous studies (Paetkau et al. 1999, Peaccok et al. 2015, Malenfant et al. 2016) that (1) Kane Basin and Baffin Bay polar bears are not genetically different, and that (2) polar bears from Kane Basin-Baffin Bay are genetically different from polar bears from Lancaster Sound and Davis Strait.

Movements and Telemetry

BB bears home ranges have become significantly smaller, by a third to a half between the 1990s and 2000s. There is <50% overlap between areas used by bears in the 90s and what they use in the 2000s. This is consistent even when resident bears that remained in Melville Bay glacier fronts were excluded (removing any possible bias in comparisons across decades). There is a significant shift in median latitude northward in the 2000s for the core subpopulation range when compared to the 1990s. Overall analyses also indicate that BB bears are significantly less likely to depart from the BB subpopulation boundaries in the 2000s than the 1990s.

During the fall, most bears in BB are distributed on land or on the remaining pack-ice along the coastline of Baffin Island and associated islands (Ferguson et al. 1998, 2001, Taylor et al. 2001). Information from polar bear hunters with extensive experience from the Melville Bay area (Born et al. 2011) and miscellaneous observations (e.g., Taylor et al. 2001) suggest that some bears may also be present along the NW Greenland coast during the open-water season, in particular in Melville Bay. However, in this study for the first time we documented resident bears in Melville Bay via satellite telemetry. These bears remained in NW Greenland year-

round, in some cases >2 years within a series of glacier fronts. Satellite telemetry studies of bear

movements in the 1990s failed to demonstrate this behavior (Taylor et al. 2001) however only

one adult female bear was collared on the fast ice in Melville Bay (at a glacier front) and the

satellite radio only transmitted for one day (E.W. Born, pers. comm.).

KB bears home ranges have become overall larger, in some cases significantly so and

twice the size in summer. There is more overlap in home ranges for KB between the 90s and

00s, between about 50 and 98%, probably because the subpopulation area is smaller and because

the ice loss has not been as extreme (or bears can use more of the southernmost habitat still).

However, a likely explanation may be that the sea ice in the Kane Basin region has become less

consolidated (e.g., Born et al. 2011) and now resembles that of the annual sea-ice ecoregion

(rather than the archipelago region with year-round consolidated sea ice, cf Amstrup et al. 2008).

This shift in habitat likely forces bears to have larger-scale movements and large home ranges,

following well with that found by Ferguson et al. (2001). There were also significant shifts north

in median latitude in KB in spring and summer from the 90s, though the variability has increased

in the range of latitudes used and no change during winter.

Changes in Polar Bear Densities in Melville Bay, Northwest Greenland

Another result of the comparison between ranges and movements is the apparent

increased use of Melville Bay, northwest Greenland by BB bears. The telemetry data collected in

the 2000s indicate an increased use in both spring and summer (Figure 2.16) when compared to

the 1990s (see also Figure 2.3).   Of 43 polar bears that were tracked by use of satellite telemetry

during the 1990s remarkably few made excursions from offshore BB pack ice onto landfast ice

in NW Greenland (Figure 2.3, Taylor et al. 2001: Figure 3, p. 696; Born and Dietz 2009: Figure 18, p. 82). This is in contrast to heavy use of the area in the 2000s (Figure 2.9).

During the 1990s spring sampling 1992 and 1993, 55 hours of active searching was spent on the fast ice, glacier fronts, and active offshore pack ice between *ca*. 74° N and *ca*. 76° N in northwest Greenland, including offshore areas 100-150 km from the coast (i.e., ferry time excluded; Born unpublished data). In both years, there was little sign of bear activity on the fast ice in Melville Bay and along glacier fronts even though ~ 25% of the active search time was flown over fast ice and along glacier fronts. Only four of 36 bears were tagged in fast ice and glacier fronts the 1990s (Born et al. 1992, Rosing-Asvid 1993). In contrast, in 2011-2013, 85 active search hours were concentrated in the Melville Bay area north of the settlement Kullorsuaq. In each year there were signs of recent polar bear activity on the fast ice and along glacier fronts, including the consolidated pack ice in Melville Bay. Approximately 82% of captures occurred in fast ice or consolidated pack ice, and of those 25% were along glacier fronts. Differences between 1992-1993 and 2011-2013 in the allocation of sampling effort and number of polar bears captured reflect an increased density of polar bears using landfast ice and glacial fronts in Melville Bay in the 2010s. The apparent change in densities in spring time Melville Bay is worth noting and is consistent with information obtained from experienced polar bear hunters that there has been an increased occurrence of polar bears in nearshore areas in NW Greenland (Born et al. 2011).

Recoveries from Marked Bears

Use of tag recoveries or recaptures is a relatively coarse means of assessing subpopulation closure for the purpose of mark-recapture analyses, but it can facilitate the

inclusion of data from large numbers of individuals, relative to satellite telemetry. The

probability of detecting the movements of individuals between subpopulations depends on

numerous factors, including the number of marks deployed, the intensity of sampling effort

following marking, and the intensity of harvest. Additionally, the detection of movement

amongst subpopulations does not provide a means of quantifying rates of permanent emigration

or immigration. Nevertheless, data on recaptures and harvest recoveries of marked bears provide

a supplemental line of evidence to support subpopulation delineations based on more detailed

methods such as telemetry data analyses (Taylor et al. 2001) and genetics (Paetkau et al. 1999,

Peacock et al. 2015).

Short-term Movements

During the recent genetic mark-recapture studies in BB and KB (2011-2014), we

documented very low levels of recapture or harvest recovery of bears outside their subpopulation

of origin. It should be noted that bears marked in the final year of these studies had a zero

probability of recapture or recovery because harvest monitoring and biopsy darting were not

extended beyond the last year of marking. However, bears marked in the first two years of these

studies were available for recapture or recovery, subject to rates of natural mortality. The total

number of bears marked in years 1 and 2 was equivalent to ~34% and ~25% of the estimated

subpopulation size in BB and KB, respectively (Chapters 5 and 10). Despite marking a large

proportion of the subpopulation, instances of emigration were ≤ 1% of the recaptures and

recoveries of BB marks. Similarly in KB, documented cases of emigration comprised < 4% of

recaptures. Amongst these findings, rates of harvest recovery provide a more complete picture

of movement amongst subpopulations because harvest was monitored genetically in BB, KB and

all surrounding subpopulations throughout the study period. In contrast, capture effort only took place in BB and KB during the study.

We acknowledge that this work comprised a relatively short window of time, especially since harvest monitoring and biopsy darting were not extended beyond the last year of marking. However, our findings suggest that the existing subpopulation boundaries continue to be relevant for harvest management purposes and subpopulation monitoring. Bears marked in BB or KB tended to remain within their respective subpopulations at least over the short term. These units can be surveyed by means of mark-recapture or aerial survey with a reasonable degree of confidence in the assumption of closure during short-term studies.

Long-Term Harvest Recoveries

Over the period 1979-2009, Peacock et al. (2012) found that amongst harvest recoveries of bears marked in BB, 82% were recovered in BB versus other subpopulations. Using a subset of the same data plus newer recoveries, we obtained a similar level of recovery (83%) within BB. These findings imply that bears exhibit a reasonably high degree of long-term fidelity to this geographically defined unit, which is consistent with estimates of site fidelity derived from mark-recapture analyses (Chapter 5, but note that the site fidelity parameter pertains to the study area and not necessarily the subpopulation). In contrast, less than half of the KB marks deployed in the 1990s have been recovered in the harvest in KB, although the vast majority of recoveries occurred during the 1990s and early 2000s. This suggests that fidelity to KB may be lower than observed in BB. However, we note that the harvest rate in KB is an order of magnitude smaller than surrounding subpopulations; mean annual harvests in KB and BB have been 9.3 and 163 bears, respectively, over the period 1992-2014 (Chapter 8 in this report). This difference in

sampling effort (specifically, the small sample sizes in KB) may contribute to the observed differences in fidelity between the subpopulations.

Sex and Age Class

Sex and age differences in movements and distribution patterns are well documented for many mammal species (e.g., Mabry et al. 2013). Until recently, studies of polar bear movements and the delineation of subpopulations have relied primarily on data collected from satellite collared adult females (e.g., Taylor et al. 2001, Amstrup et al. 2004, Parks et al. 2006, Cherry et al. 2013). Even now, studies of the movements of sub-adults and adult male polar bears are limited by available technology. Satellite transmitters attached to sub-adult and adult males have only lasted 4-5 months, limiting research to studies of seasonal movements and habitat use (Amstrup et al. 2001, Laidre et al. 2013). The extent to which subpopulation boundaries as currently defined reflect the long-term distribution of sub-adults and male polar bears therefore remains uncertain. This is an important area requiring on-going investigation because of the implications for defining biological populations or harvest management units that can be accurately monitored by methods such as mark-recapture.

Using data on the distance between capture and recapture locations, Taylor et al. (2001) found a tendency for sub-adults to exhibit longer-range movements than adults in BB and KB. Similar data from our study (2011-2013) suggest that mark-recapture distances were greater for bears initially marked as yearlings, relative to adult females and COY. This may reflect a degree of dispersal amongst young bears away from their maternal (natal) range post-weaning. This is a common phenomenon among mammals and is often male biased (Greenwood 1980), but sample sizes for yearlings in our study were insufficient to test for sex effects in mark-recapture

distances. However, using measures of genetic relatedness (kin structure analysis), Zeyl et al.

(2009) demonstrated a slight male bias in effective dispersal of polar bears. Nevertheless,

fidelity to natal range was relatively strong in that study, suggesting that regardless of sex,

dispersal of offspring is unlikely to be a major factor in determining the broad scale

(subpopulation) structure of polar bears. With harvest recoveries, the sex ratio of marked BB

bears harvested outside BB tended to be male biased relative to recoveries within the

subpopulation but not significantly so. Collectively, these findings provide some support for the

notion that subpopulation boundaries, delineated using data on the movements of satellite

collared adult females are relevant to polar bears of all sex and age classes as also suggested by

Taylor et al. (2001).

Movement between Baffin Bay and Davis Strait

The boundary between the BB and DS subpopulations is not delineated by a landmass or

area of open water that creates an obvious barrier to the movement of polar bears. During the

winter and spring, this boundary is spanned by both land fast and pack ice that provides an easy

platform for bears to move between these subpopulations (Stirling et al. 1980). Nevertheless,

bears in these two subpopulations have consistently shown distinct differences in studies of

genetics (Paetkau et al. 1999, Peacock et al. 2015), movements (Taylor et al. 2001) and diet

(Thiemann et al. 2008), suggesting that there is a real boundary between them. This boundary is

likely the result of ocean current patterns caused by a submarine ridge between SE Baffin Island

and Central West Greenland and associated differences in patterns of sea-ice formation and

break-up in Baffin Bay and Davis Strait, respectively (Taylor et al. 2001).

Since 1990, there have been 3 periods of intensive mark-recapture study in BB and DS. These data provided an opportunity to examine movements between DS and BB. Additionally, DS has likely undergone a substantial increase in abundance since the 1970s and presently has one of the highest densities of polar bears amongst subpopulations (Peacock et al. 2013). Furthermore it may be speculated that because of a higher rate of sea-ice loss in Davis Strait compared to Baffin Bay during the last decades (e.g., Laidre et al. 2015) an increased number of polar bears may have immigrated to BB from DS. We were therefore keen to examine the hypothesis that this apparent expansion happening concomitantly with sea-ice loss in Davis Strait had resulted in the movement of bears from DS to BB, thereby influencing our estimate of abundance for BB.

The intensity of marking effort (i.e., number of unique individuals marked) in these subpopulations was equivalent to 41% (BB 1991-97), 70% (DS 2005-07) and 44% (BB 2011-2013) of estimated abundance at the time of marking. Despite this extensive marking of bears throughout the seasonal ranges of both subpopulations we detected very few cases of movement between DS and BB. Approximately 1% of bears sampled in DS were recaptures of bears marked in BB and vice versa. Our results support the notion that the boundary between these two subpopulations remains relatively strong and does not support the hypothesis that subpopulation expansion and sea-ice loss in Davis Strait have resulted in a large-scale northward movement of DS bears into BB, at least during the period from 2005 to 2013.

Bears that were documented to have moved between BB and DS tended to be those originally captured close to the management unit boundary (< 100 km). This clustering of inter-subpopulation movements around the boundary does not itself demonstrate the significance of the boundary as a barrier to movements. Instead it may reflect the high degree of fidelity that

BB and DS bears show to their seasonal on-shore range. A similar degree of fidelity has been

previously documented in BB (Taylor et al. 2001) and other subpopulations (Stirling et al. 2004).

Taylor et al. (2001) examined distances between capture and recapture locations for bears

marked in BB during the 1990s finding that 59% were recaptured within 100 km of their original

capture location. Amongst all BB bears marked between 2011 and 2013, 50 % (n = 166) of

recaptures were within 100 km of initial capture location (GN unpublished data) suggesting that

the tendency of local fidelity of BB bears has remained unchanged since the 1990s. Strong inter-

annual fidelity to terrestrial habitat is further supported by our finding that distances between

capture and recapture locations for bears that moved between DS and BB were independent of

capture intervals ranging from 4 to 15 years. Bears appear to exhibit fidelity over long periods.

In conclusion, using data from satellite telemetry, recapture and / or harvest recovery of

marked bears and genetic we found no evidence to suggest a change in the delineation of the BB

and KB subpopulations. The boundaries of these subpopulations appear to be relevant from the

stand point of mark-recapture or other forms of periodic survey and for harvest management

purposes.

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Table 2.1. Polar bear samples (n = 1,364; sampling period: 2009-2014) from Baffin Bay (BB),

Kane Basin (KB), Lancaster Sound (LS) and Davis Strait (DS) that were included in the

population genetic analyses. The total sample was subdivided according to season, age category

and sex for the analyses. A subset of 402 samples collected during winter and spring (2012-

2014) represented all four subpopulations.

	BB	KB	LS	DS	N
	Biopsies and Harvest	**Biopsies**	**Harvest**	**Harvest**	**Total**
Period of sampling	2009-2014	2012-2014	2011-2013	2012-2013	
Total Sample	1051	99	142	72	1364
Winter-spring (WS)[1]	140	99	114	49	402
Winter-spring-adults (WSA)[2]	109	78	84	37	308
Winter-spring-subadults (WSS)[2]	31	21	30	12	94
Winter-spring-adults-females (WSAF)[3]	54	54	15	11	134
Winter-spring-adult-males (WSAM)[3]	55	24	69	26	174

[1]Winter defined as: November-February and spring defined as March-June

[2]A=adults and S=subadults

[3]F=females and M=males

Table 2.2. Sample sizes (number of individuals) polar bears captured and tagged with collars or ear tags in the 1990s and 2000s in BB and KB. In total 134 bears were tagged in BB and 46 bears were tagged in KB over two decades.

		AF	AM	SF	SM	2YR	TOTAL
1990s	BB	43					43
	KB	12					12
2000s	BB	38	30	4	6	13	91
	KB	20	9		5		34

Table 2.3. Breakdown of adult females (AF) collared in the 1990s and 2000s. Total n=113 AF bears over both decades and subpopulations.

		AF alone	AF+AM	AF+COY	AF+YRL	AF+2YR	Sum
1990s	BB	9		19	13	2	43
	KB	3		5	3	1	12
2000s	BB	10	2	6	12	8	38
	KB	5	1	7	3	4	20

Table 2.4. 95% mean kernel range sizes (in sq km) estimated from a bootstrap method for each of 38 bears in BB and 12 bears in KB by decade, month and season. The bootstrap was used to generate kernel range sizes based on equal sample sizes between decades (see Methods). Data are reported with bootstrapped SE of the mean in parentheses. Fraction of overlap is the 95% kernel probability area from the 1990s overlapped by the same in the 2000s. KB_West is reported only for bears tagged in western KB for direct comparison to the 1990s (where no bears were tagged in East KB). Data here include all bears in BB, including the resident bears in Melville Bay, though we also investigated bootstrap range size values without resident bears and significance remained.

	BB				KB_All Bears				KB_West	
	1990s mean (SE)	2000s	P value comparing 95% area between decades	Overlap	1990s	2000s	P value comparing 95% area between decades	Overlap	2000s	Overlap (with KB ALL 1990s)
January	684,409	558,957		0.40	86,556	163,892		0.77	175,730	0.77
	(60,692)	(56,594)	<0.001		(6,890)	(27,619)	0.007		(23,649)	
February	707,387	513,732		0.39	105,788	171,441		0.81	183,981	0.81
	(55,079)	(40,662)	0.005		(5,426)	(34,036)	0.057		(23,205)	
March	852,935	580,767		0.45	136,942	205,921		0.70	232,299	0.73
	(50,240)	(36,287)	<0.001		(15,859)	(49,119)	0.180		(38,259)	
April	795,859	506,739		0.46	131,963	183,184		0.73	180,913	0.69
	(45,652)	(26,529)	<0.001		(15,331)	(38,786)	0.219		(32,718)	
May	564,658	473,825		0.58	130,730	122,598		0.68	115,925	0.69
	(37,090)	(35,679)	0.078		(19,002)	(15,355)	0.741		(14,792)	
June	521,410	430,766		0.61	68,696	124,227		0.88	103,783	0.85
	(32,633)	(31,829)	0.047		(11,854)	(13,578)	<0.001		(9,942)	

July	536,992	376,891		0.52	54,681	130,518		0.91	112,655	0.88
	(32,000)	(30,062)	<0.001		(7,986)	(12,414)	<0.001		(13,872)	
August	596,411	216,881		0.21	68,649	119,251		0.90	106,314	0.92
	(44,692)	(18,958)	<0.001		(12,391)	(13,419)	<0.001		(11,694)	
September	551,395	226,427		0.26	74,368	131,558		0.98	109,697	0.84
	(48,280)	(21,538)	<0.001		(13,130)	(15,871)	<0.001		(14,187)	
October	459,230	276,198		0.34	99,855	153,820		0.91	132,177	0.75
	(43,932)	(29,264)	<0.001		(15,807)	(25,424)	0.072		(23,717)	
November	594,280	474,604		0.58	156,120	172,068		0.54	166,048	0.53
	(33,388)	(25,867)	<0.001		(22,728)	(23,943)	0.631		(20,773)	
December	702,091	524,787		0.52	150,392	143,969		0.54	137,782	0.53
	(35,173)	(38,123)	<0.001		(20,855)	(20,739)	0.826		(19,024)	
Winter	906,657	729,022		0.65	203,858	192,619		0.56	210,364	0.64
	(55,609)	(44,240)	0.012		(37,301)	(34,357)	0.826		(26,680)	
Spring	837,036	585,659		0.57	137,563	177,495		0.80	189,301	0.82
	(58,976)	(33,379)	<0.001		(17,600)	(37,516)	0.337		(37,470)	
Summer	716,676	255,992		0.24	89,066	152,747		0.97	141,118	0.94
	(57,850)	(28,627)	<0.001		(14,251)	(21,784)	0.014		(20,697)	

Table 2.5. Box plot statistics for median latitude (and interquartile range) for each season, subpopulation, and decade of polar bears tracked by use of satellite telemetry in BB and KB during the 1990s and 2000s. See Table 2.3 for sample sizes. In the case of BB 2000s, the resident bears in Melville Bay glacial fronts were not included

	Q1	Median	Q2	t statistic	df	p value
Winter						
BB 90s	66.90	68.88	72.13	-17.34	1683.4	p<0.001
BB 00s	69.76	72.01	74.90			
KB 90s	77.28	78.62	79.17	-1.86	173.54	p=0.07
KB 00s all	77.03	78.96	79.41			
Spring						
BB 90s	67.99	70.87	73.51	-18.18	1615.99	p<0.001
BB 00s	70.88	72.90	74.48			
KB 90s	77.63	77.91	79.13	-4.06	617.76	p<0.001
KB 00s all	77.25	79.06	79.42			
Summer						
BB 90s	67.26	70.29	72.96	-4.20	1758.07	p<0.001
BB 00s	69.51	70.68	71.60			
KB 90s	77.77	77.89	78.50	-5.47	840.41	p<0.001
KB 00s all	77.27	78.89	79.43			

Table 2.6. Movements of all polar bears (AF + AM) captured and tracked in the 1990s and 2000s from BB and KB. Movement to another subpopulation is enumerated if the bear departed for any length of time (4 days or greater).

Time period	Subpopulation of origin	n	Arctic Basin	Baffin Bay	Davis Strait	Kane Basin	Lancaster Sound
			Movement to other subpopulation during tracking period				
1990s	BB	43	0	0	14	0	12
2000s	BB	91	0	0	3	5	3
1990s	KB	12	1	1	0	0	0
2000s	KB	34	2	2	0	0	3

Table 2.7. Summary of observed and expected departures from region of origin (capture site) to any other subpopulation region in the 1990s and 2000s for AF polar bears for departures on all time steps. Log rank rest of equality conducted on each subpopulation comparing decades.

Subpopulation Decade	n	Observed departures	Expected departures	(O-E)^2/E	(O-E)^2/V
BB 1990s	43	26	15.7	6.72	12.1
BB 2000s	38	11	21.3	4.96	12.1
KB 1990s	12	2	3.29	0.509	0.871
KB 2000s	20	6	4.71	0.356	0.871

BB: $\chi^2 = 12.1$, df = 1, p = 0.000515

KB: $\chi^2 = 0.9$, df = 1, p = 0.351

Table 2.8. Timing of departures from Baffin Bay in the 1990s and 2000s for radio-collared adult female polar bears for departures of all time steps. Data are reported as number of AF bears departing to another subpopulation for the 1990s (with number of AF bears in 2000s in parentheses).

Month of departure from BB	Davis Strait	Lancaster Sound	Kane Basin
1	1 (0)	1 (0)	0 (3)
2	0 (0)	0 (0)	0 (0)
3	0 (0)	0 (0)	0 (0)
4	1 (1)	0 (0)	0 (0)
5	0 (0)	1 (1)	0 (0)
6	0 (0)	2 (1)	0 (0)
7	1 (0)	2 (0)	0 (1)
8	0 (0)	1 (0)	0 (0)
9	0 (0)	3 (0)	0 (0)
10	0 (0)	2 (1)	0 (0)
11	7 (0)	0 (0)	0 (0)
12	4 (2)	0 (0)	0 (1)

Table 2.9. Number of subpopulation boundary crossings made by individual AF bears in each subpopulation and decade for departures of all time steps.

	Number of subpopulation boundary crossings by individual AFs												
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
BB 90s	17	3	7	1	3	1	3	0	3	3	1	0	1
BB 00s	27	3	4	0	2	0	0	1	1	0	0	0	0
KB 90s	10	0	1	0	0	0	0	0	0	1	0	0	0
KB 00s	14	1	2	0	1	1	0	0	1	0	0	0	0

Table 2.10. Movements of AF polar bears captured and tracked in the 1990s and 2000s from BB and KB. Movement to another subpopulation is enumerated if the bear departed for of >30 days or more.

Time period	Subpopulation of origin	n	Movement to other subpopulation during tracking period				
			Arctic Basin	Baffin Bay	Davis Strait	Kane Basin	Lancaster Sound
1990s	BB	43	0	0	14	0	12
2000s	BB	38	0	0	3	5	3
1990s	KB	12	1	1	0	0	0
2000s	KB	20	2	1	0	0	3

Table 2.11. Summary of observed and expected departures from region of origin (capture site) to any other subpopulation region in the 1990s and 2000s for radio-collared adult female polar bears for departures of >30 days or more. Log rank rest of equality conduced on each subpopulation comparing decades.

Subpopulation Decade	N	Observed departures	Expected departures	(O-E)^2/E	(O-E)^2/V
BB 1990s	43	19	12.4	3.580	6.760
BB 2000s	38	8	14.6	3.020	6.760
KB 1990s	12	1	2.06	0.532	0.914
KB 2000s	29	4	2.96	0.367	0.914

BB: $\chi^2 = 6.8$, df = 1, p = 0.009

KB: $\chi^2 = 0.9$, df = 1, p = 0.339

Table 2.12. Timing of departures from Baffin Bay in the 1990s and 2000s for radio-collared AF polar bears for departures of >30 days or more. Data are reported as number of AF bears departing to another subpopulation for the 1990s (number of AF bears departing in 2000s in parentheses).

Month of departure from BB	Davis Strait	Lancaster Sound	Kane Basin
1	1 (0)	1 (0)	0 (3)
2	0 (0)	0 (0)	0 (0)
3	0 (0)	0 (0)	0 (0)
4	1 (1)	0 (0)	0 (0)
5	0 (0)	1 (1)	0 (0)
6	0 (0)	2 (1)	0 (0)
7	1 (0)	2 (0)	0 (1)
8	0 (0)	1 (0)	0 (0)
9	0 (0)	3 (0)	0 (0)
10	0 (0)	2 (1)	0 (0)
11	7 (0)	0 (0)	0 (0)
12	4 (2)	0 (0)	0 (1)

Table 2.13. Number of subpopulation boundary crossings made by individual radio-collared adult female bears in each subpopulation and decade for departures of >30 days or more. 0 denotes the number of bears that never cross a boundary, so n=24 bears in BB 90s never departed from BB. Percentages shown as percent of total tagged bears.

	Number of subpopulation boundary crossings by individual AFs							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
BB 90s	24 (56%)	8 (19%)	6 (14%)	1 (2%)	1 (2%)	1 (2%)	1 (2%)	1 (2%)
BB 00s	30 (79%)	3 (8%)	2 (5%)	0	1 (3%)	1(3%)	0	1(3%)
KB 90s	11 (92%)	0	0	0	0	0	0	1 (8%)
KB 00s	16 (80%)	1 (5%)	0	1 (5%)	1(5%)	0	1(5%)	0

Table 2.14. Number and subpopulation location of harvest recoveries of bears marked genetically between 2011 and 2014. Data presented as number of individuals.

Subpopulation	Subpopulation Recovered[1]						
Marked	BB	KB	LS	FB	DS	NW	GB
BB	84	0	0	0	1	0	0
KB	0	0	0	0	0	0	0

[1] BB, Baffin Bay; KB, Kane Basin; LS, Lancaster Sound; FB, Foxe Basin; DS, Davis Strait; NW, Norwegian Bay; GB, Gulf of Boothia

Table 2.15. Recaptures of bears marked genetically between 2011 and 2014 in BB and KB. Data presented as number of recapture events. Some individuals were recaptured more than once. Excludes multiple recaptures of same individual within a season. Also includes COY that were not initially sampled but later seen as yearlings with mother and sampled.

Subpopulation Marked[1]	Subpopulation Recaptured	
	BB	KB
BB	206	1
KB	1	28

[1] BB, Baffin Bay; KB, Kane Basin

Table 2.16. Recoveries of polar bears tagged in Baffin Bay (1990-1997) in the harvest in Canada and Greenland, 1990 to 2014.

	Recovered in Harvest (1990-2014)		
Sex of Bear	**In Baffin Bay**	**Outside Baffin Bay**	**Total**
Female	53	7	60
Male	98	23	121

Figure 2.1. Distribution of capture locations of polar bears with satellite collars in BB and KB during the 1990s and the 2000s, respectively. See Table 2.2 for sample sizes. Note in 1990s bears in BB were mainly captured on Baffin Island in fall (12 were captured on sea ice in spring; 3 along Baffin Island and 9 in NW Greenland) whereas during the 2000s all bears were captured and tagged with satellite transmitters on the sea ice in NW Greenland in spring.
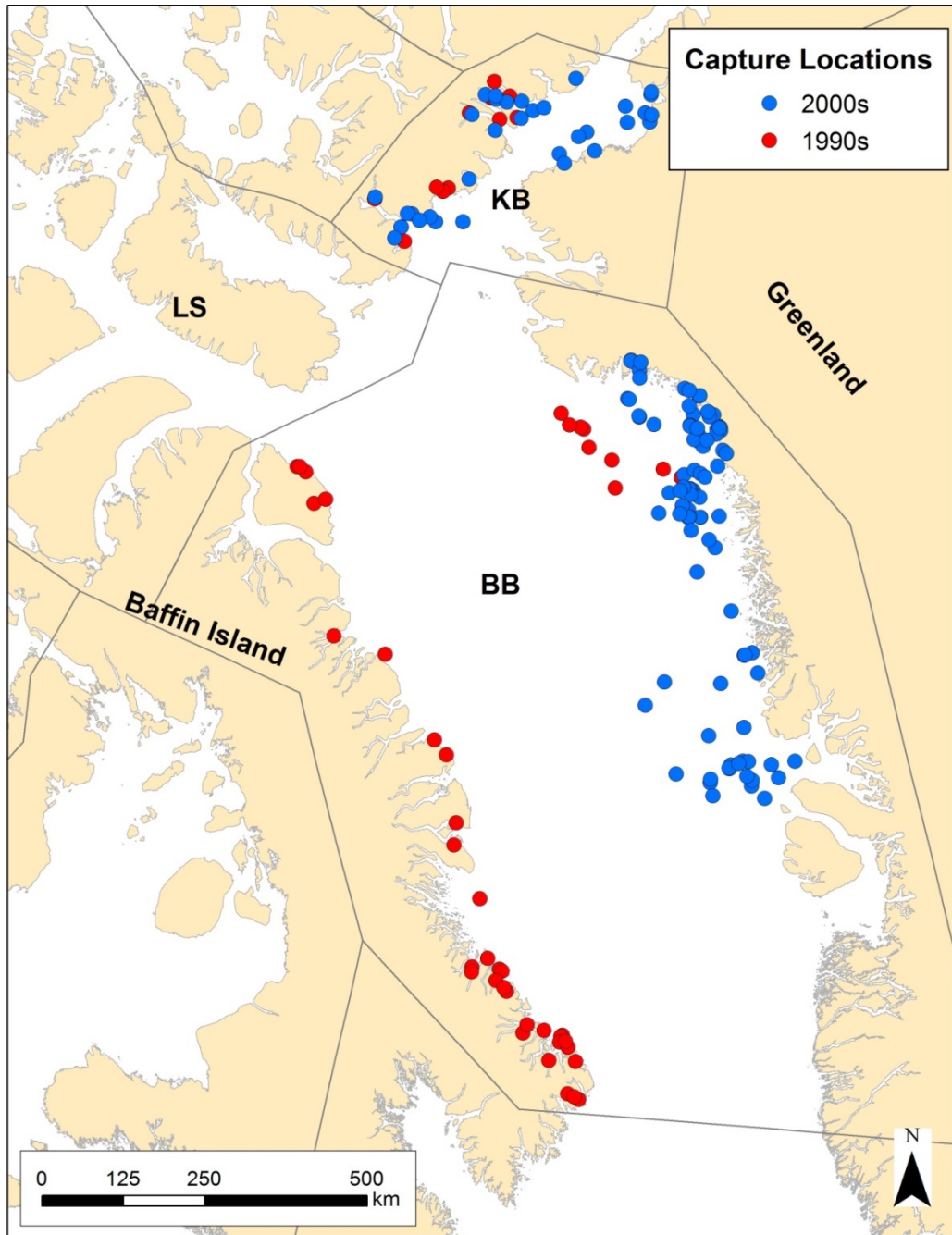
Figure 2.2. Distribution of ages and family groups of a total of 139 individual polar bears

captured in spring in northwest Greenland, 2009-2013.
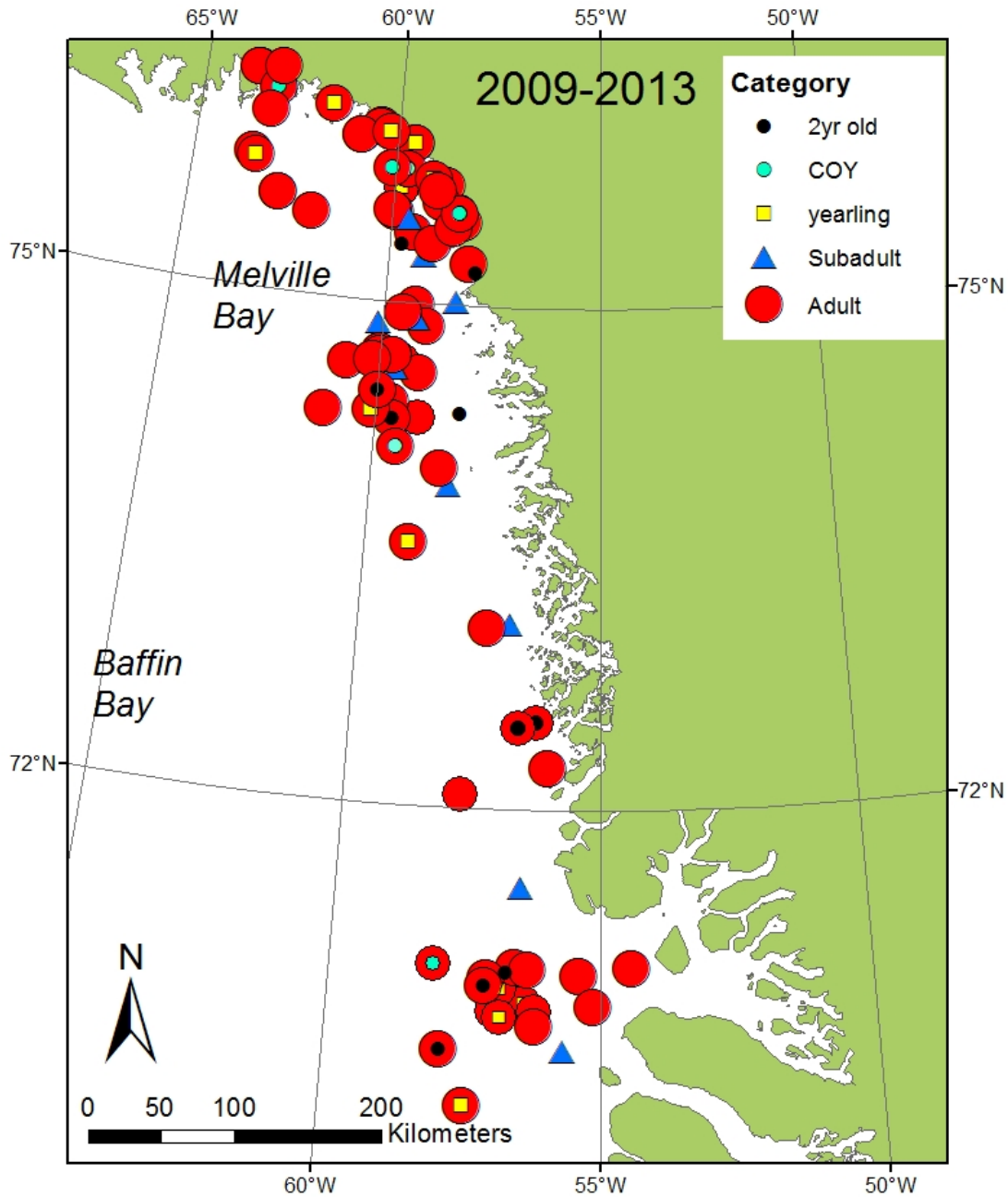
Figure 2.3. Tracklines from n=43 adult female polar bears satellite collared in the 1990s in BB.

Note the general absence of tracks on the fast ice in West and Northwest Greenland.
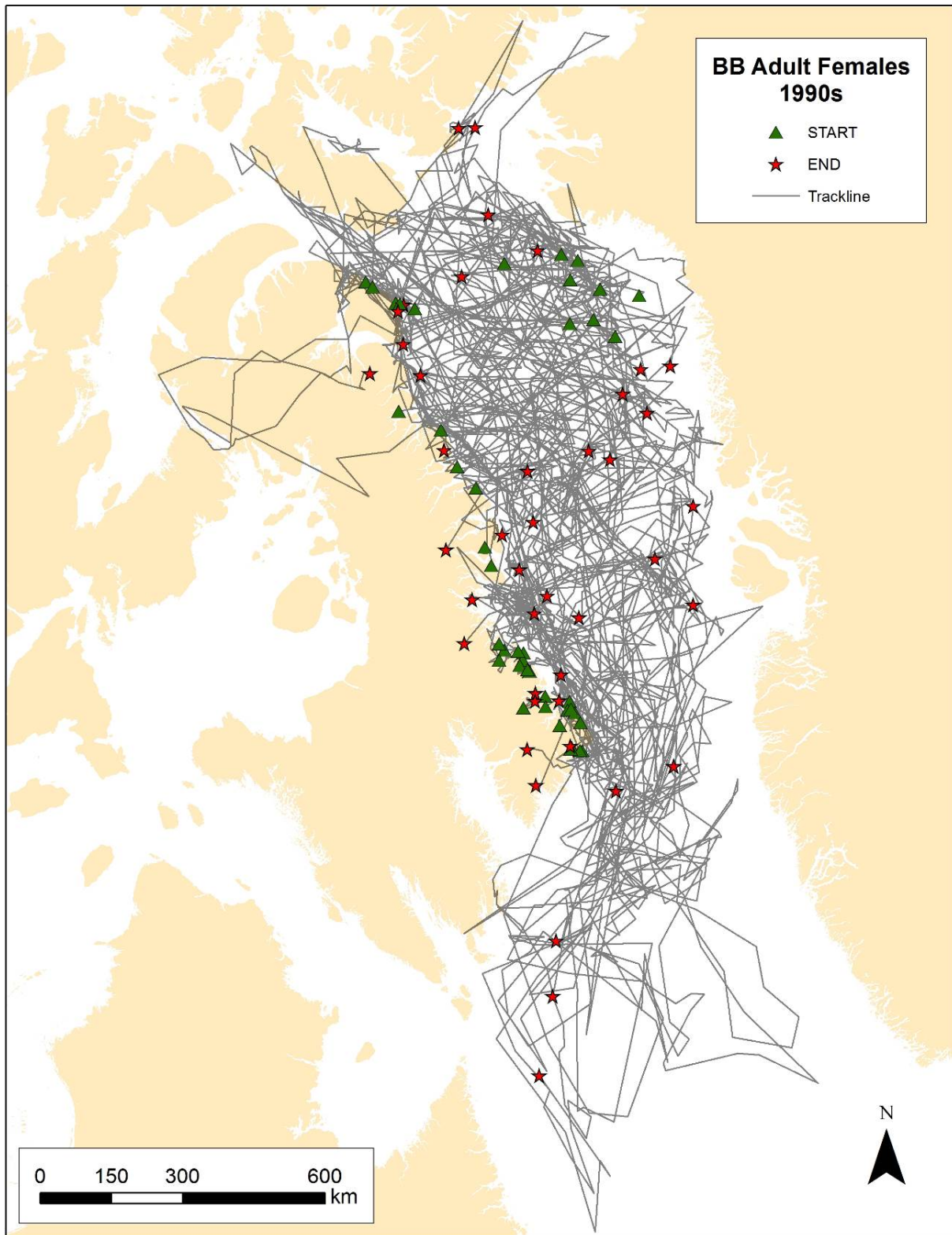
Figure 2.4. Tracklines from n=5 adult female polar bears satellite collared in 2009 in BB.
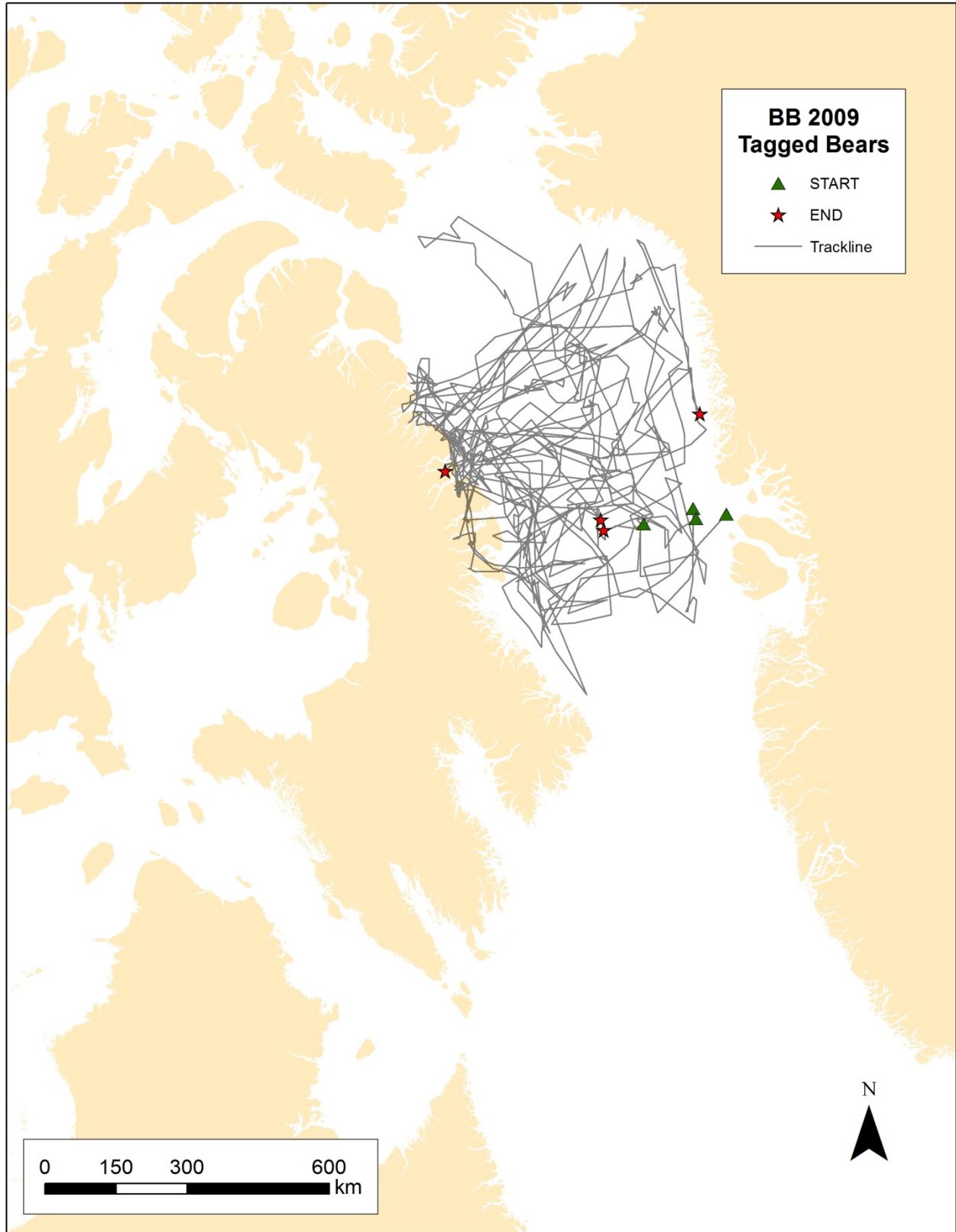
Figure 2.5. Tracklines from n=9 adult female polar bears satellite collared in 2010 in BB.
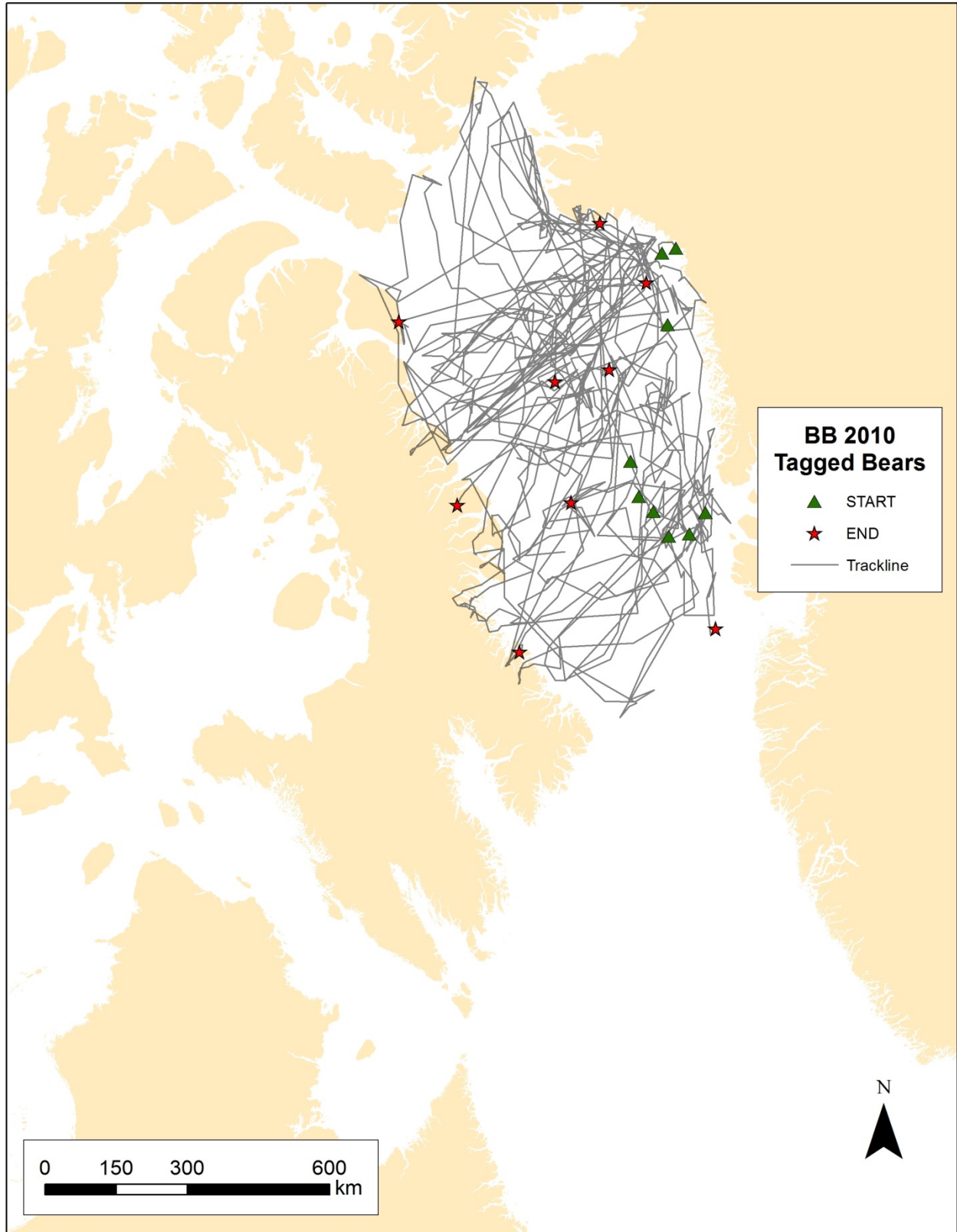
Figure 2.6. Tracklines from n=12 adult female polar bears satellite collared in 2011 in BB.
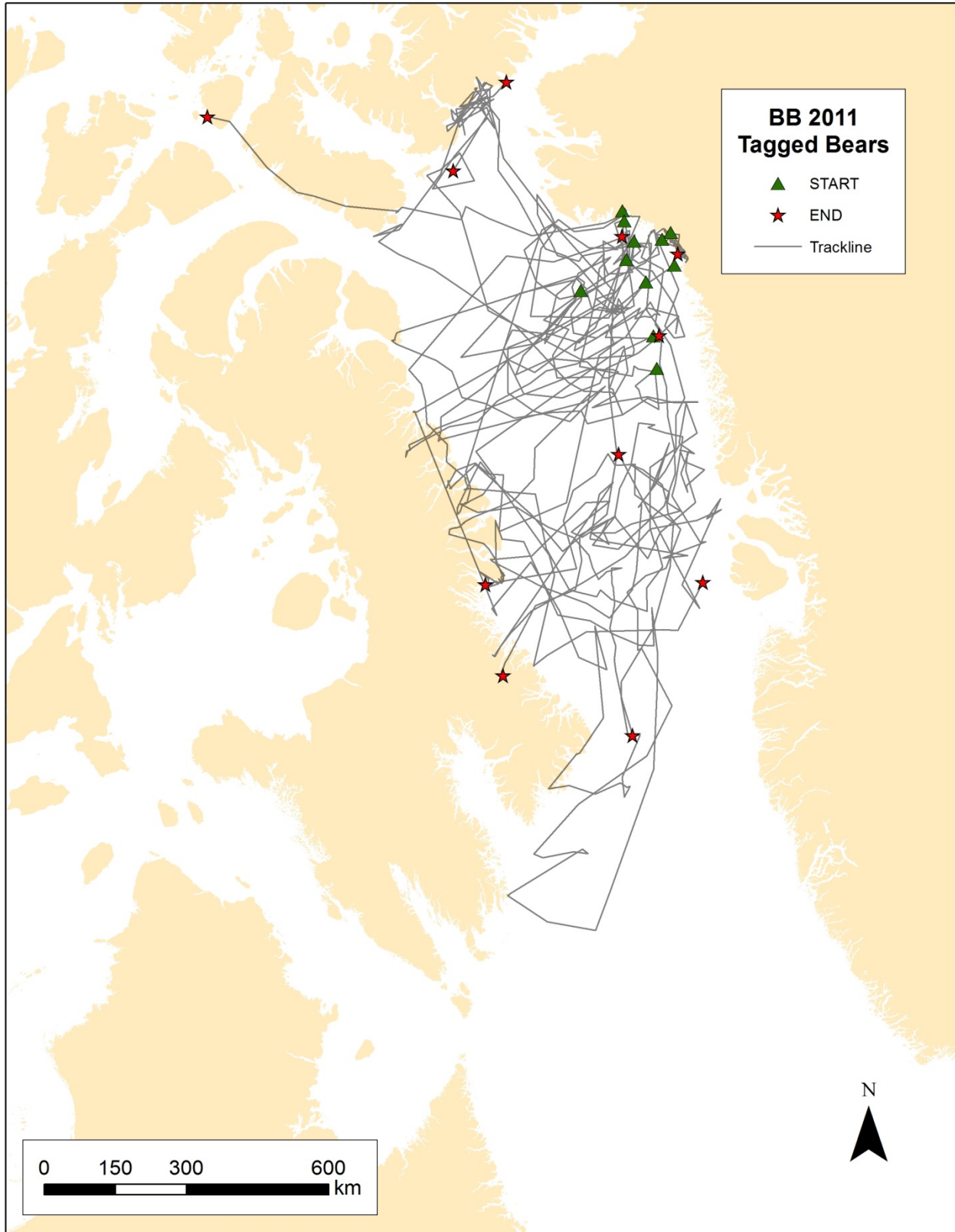
Figure 2.7. Tracklines from n=11 adult female polar bears satellite collared in 2012 in BB.
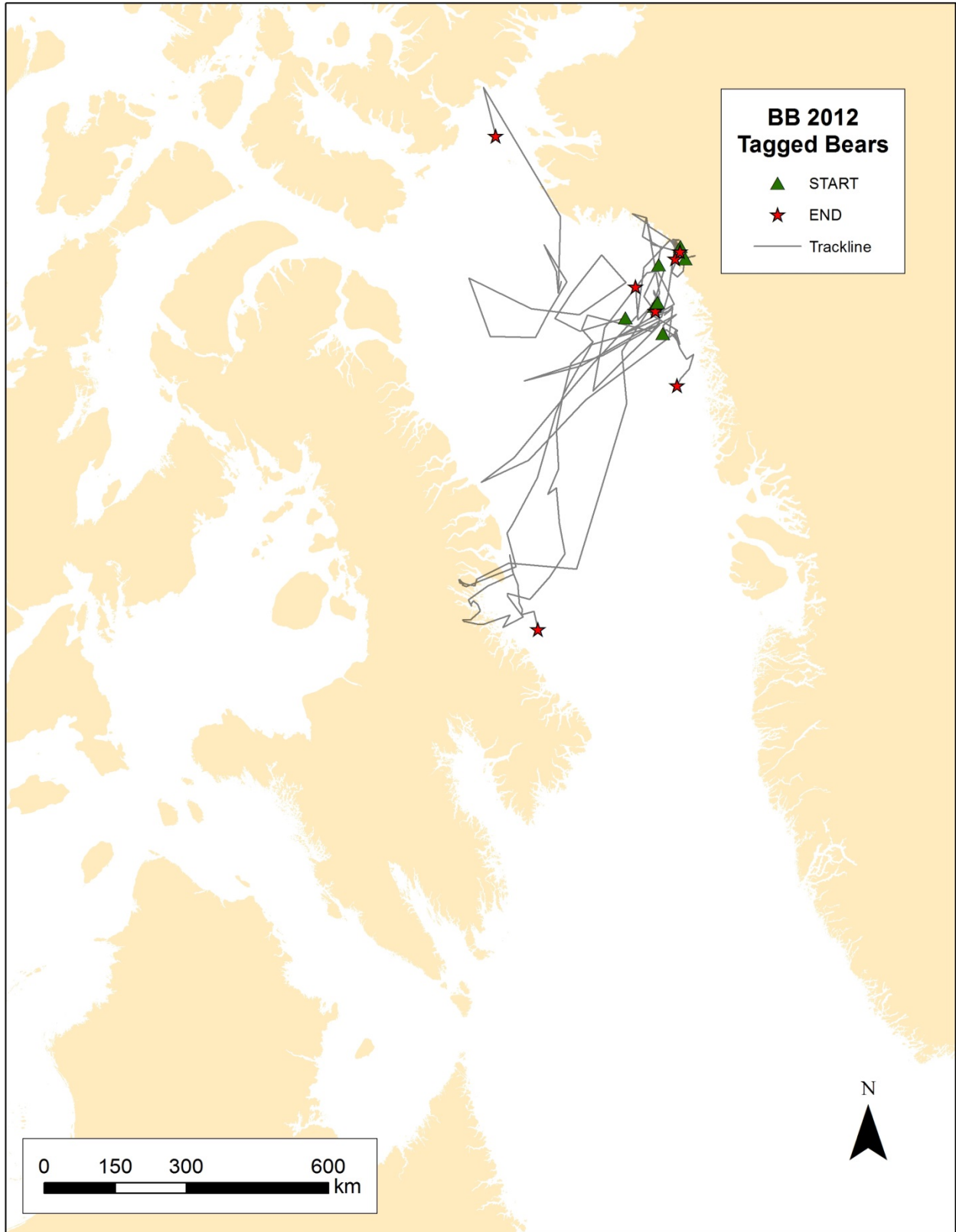
Figure 2.8. Tracklines from n=9 adult female polar bears satellite collared in 2013 in BB.
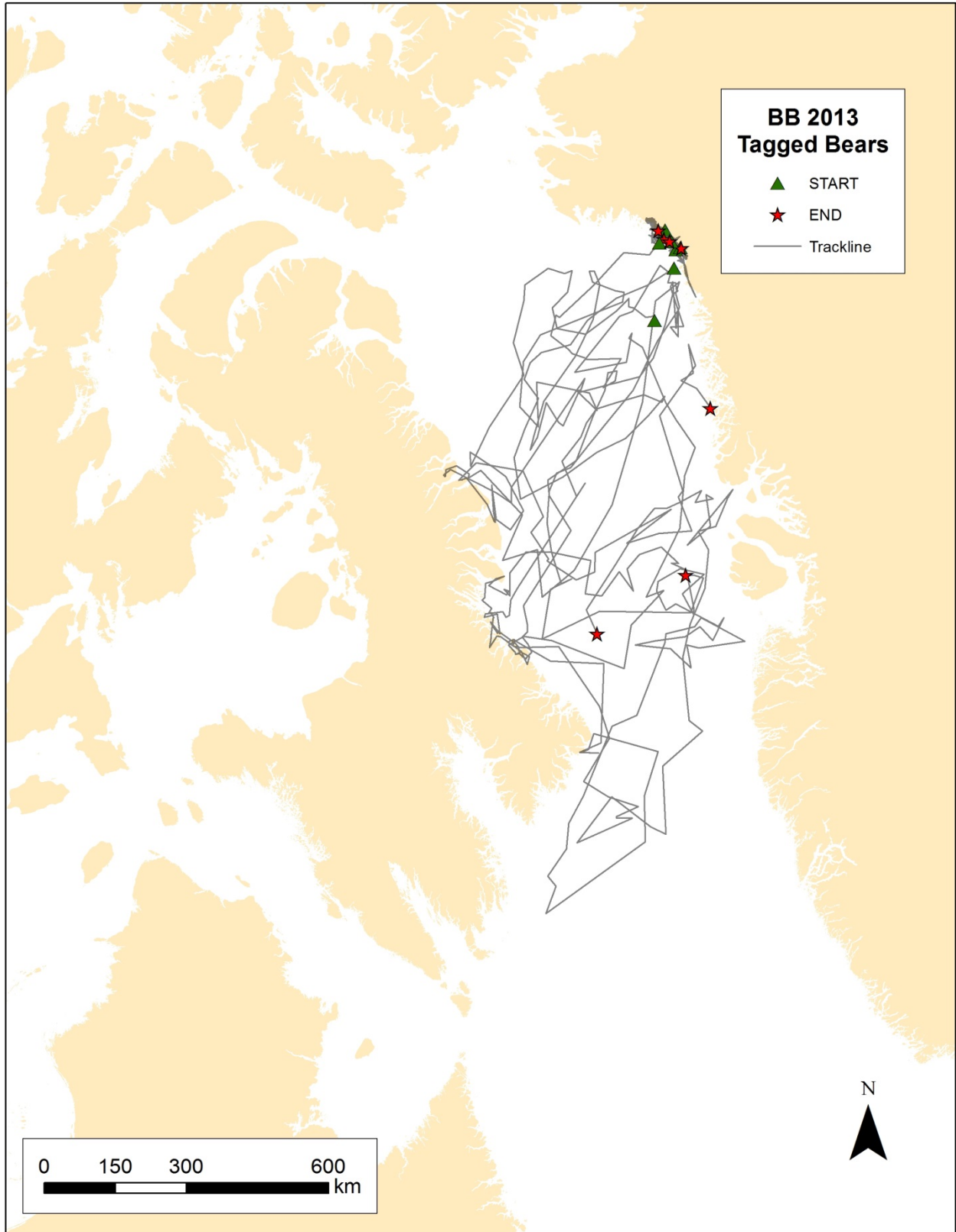
Figure 2.9. Tracklines from all adult female bears (n=38) collared between 2009 and 2013

shown together through April 2015, excluding bears where collars failed after a few days.
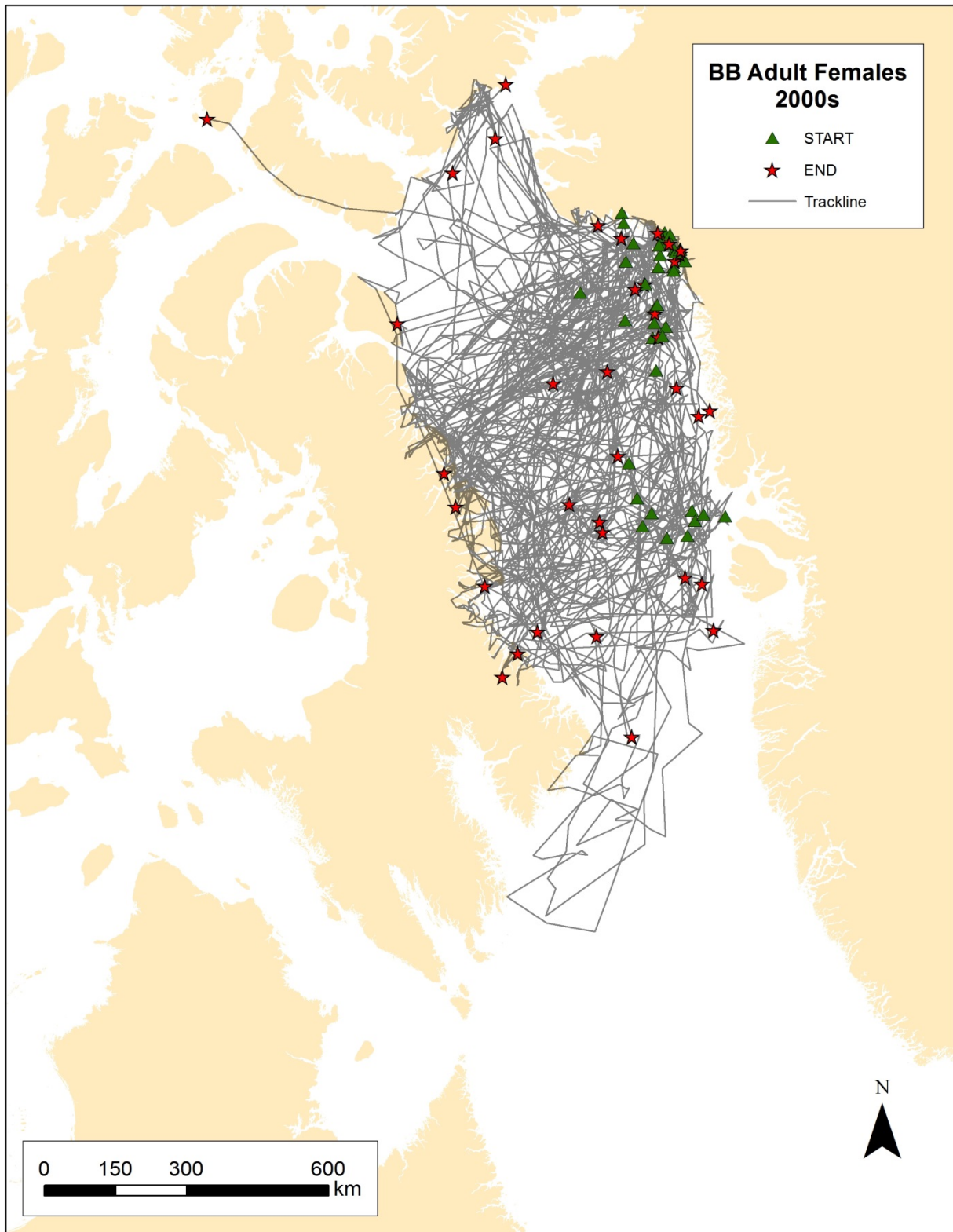
Figure 2.10. Tracklines from n=32 adult male bears tagged with ear transmitters between 2009-

2013.
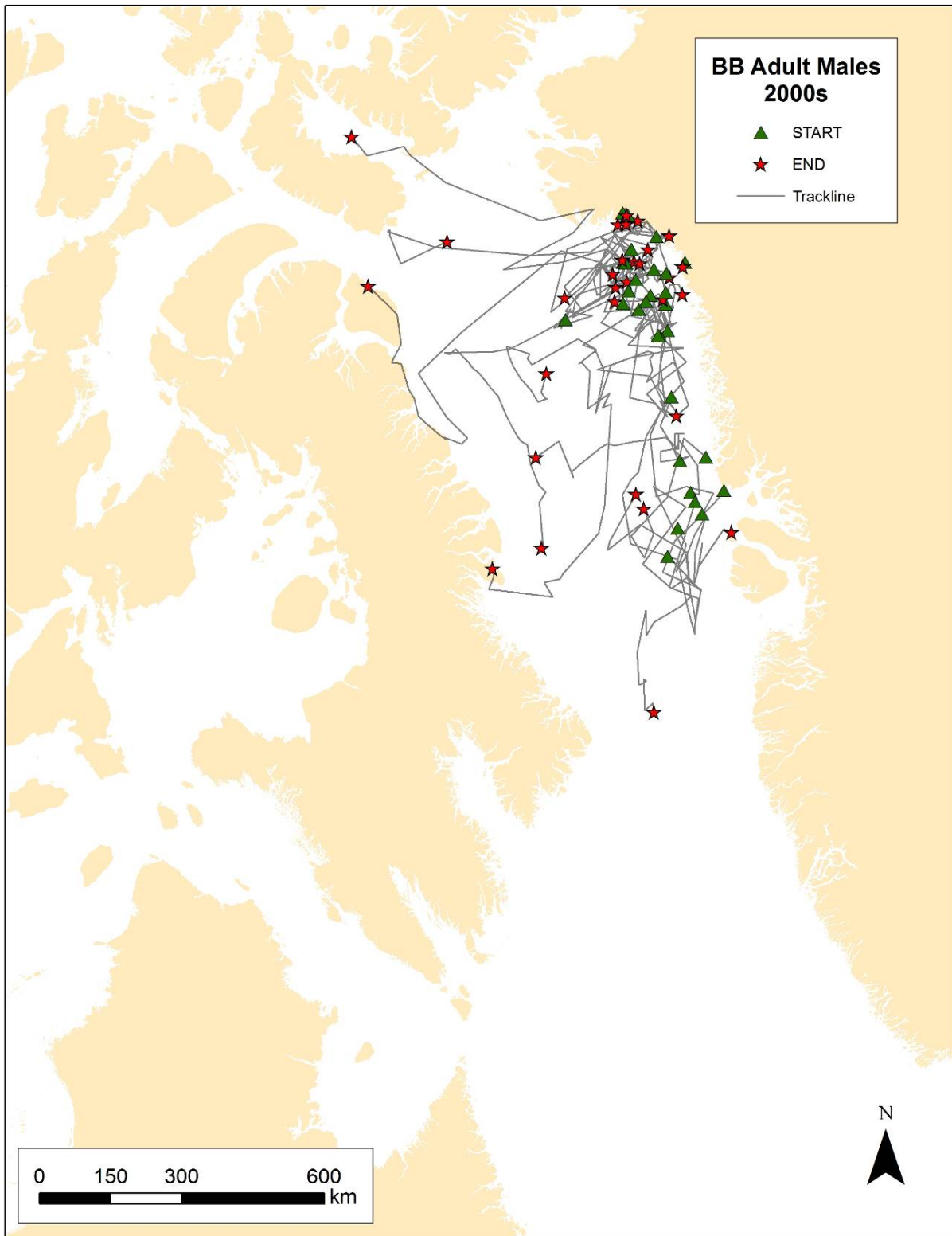
Figure 2.11. Tracklines from n=12 adult female polar bears satellite collared in the 1990s in

KB.
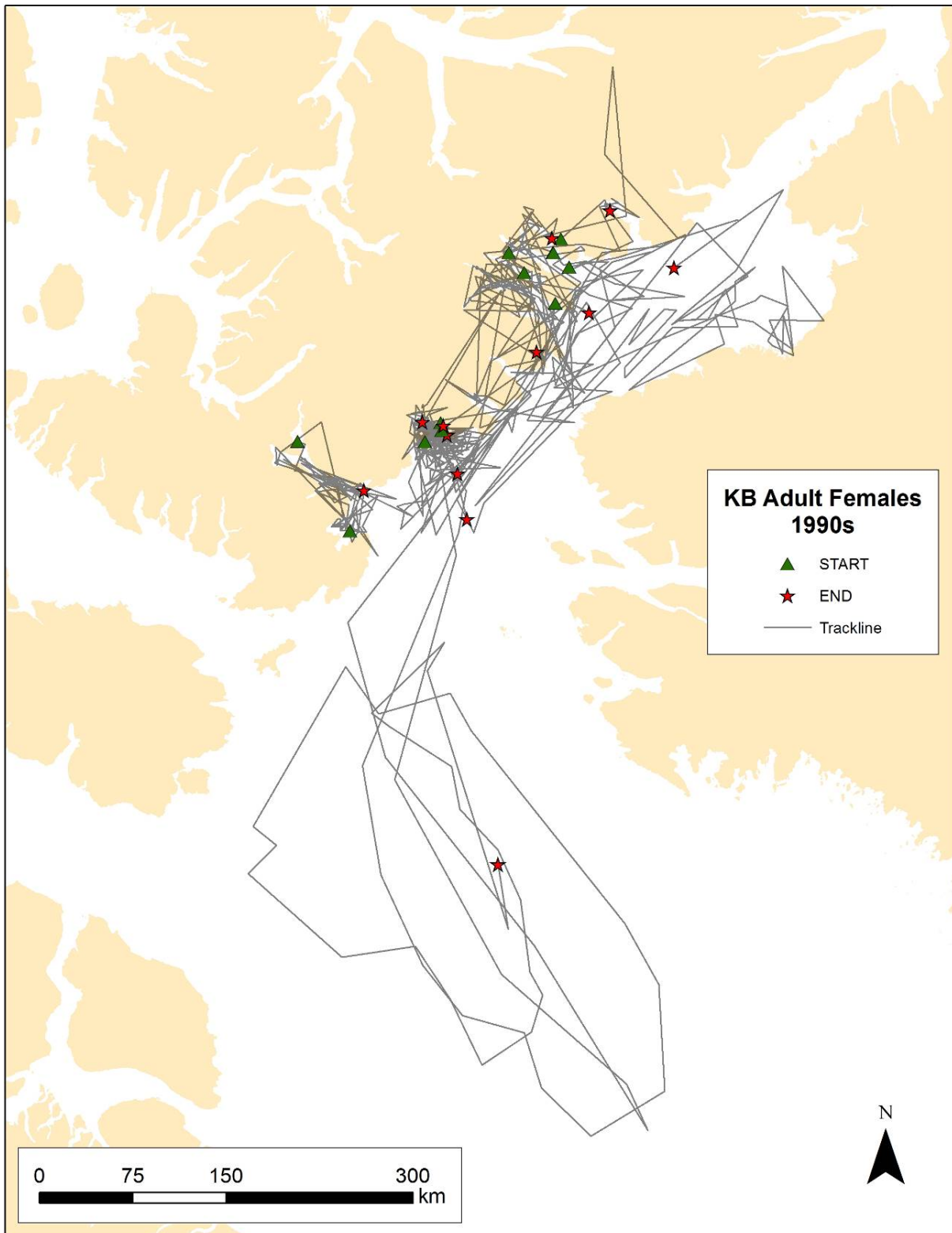
Figure 2.12. Tracklines from n=9 adult female polar bears satellite collared in 2012 in KB.
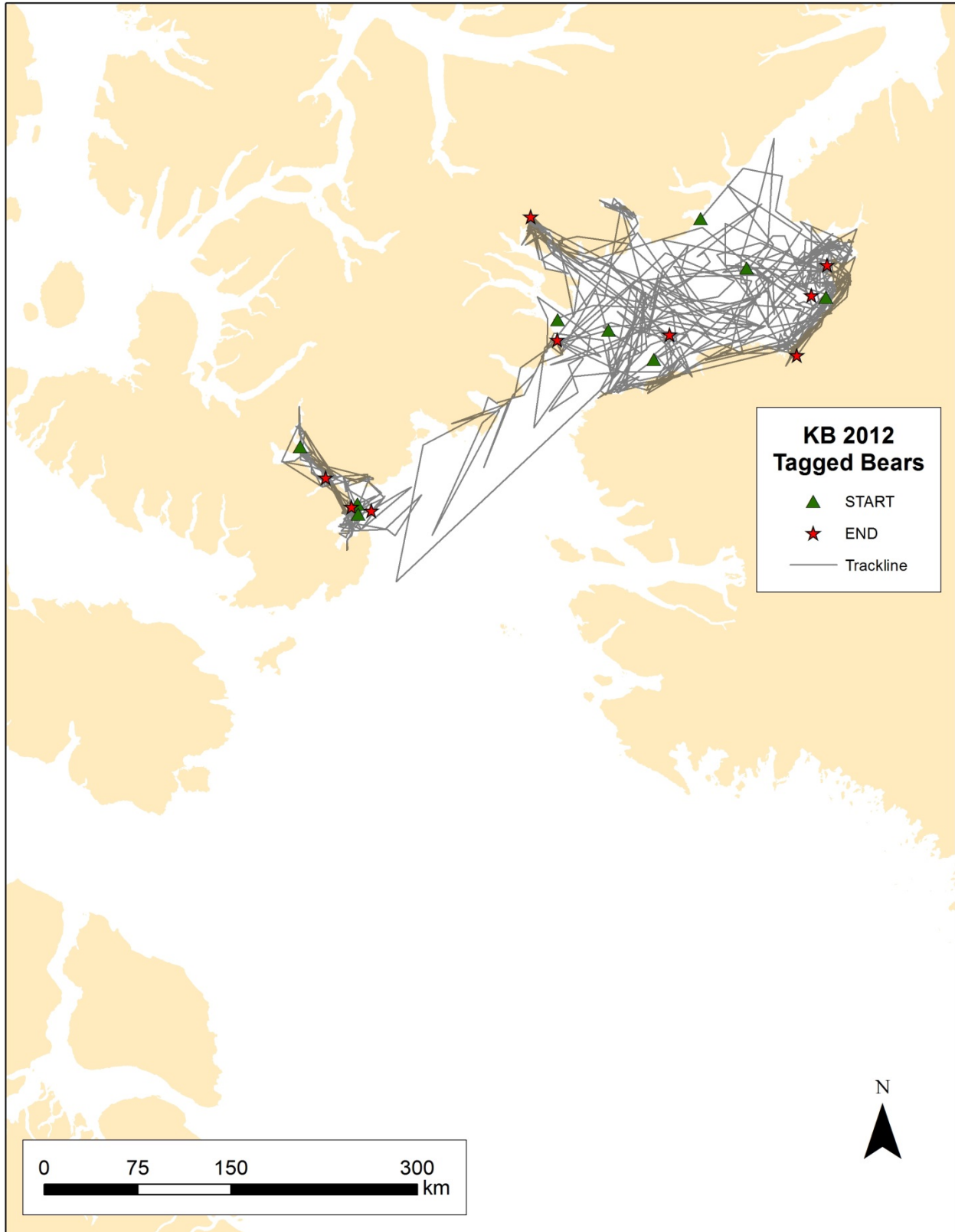
Figure 2.13. Tracklines from n=11 adult female polar bears satellite collared in 2013 in KB.
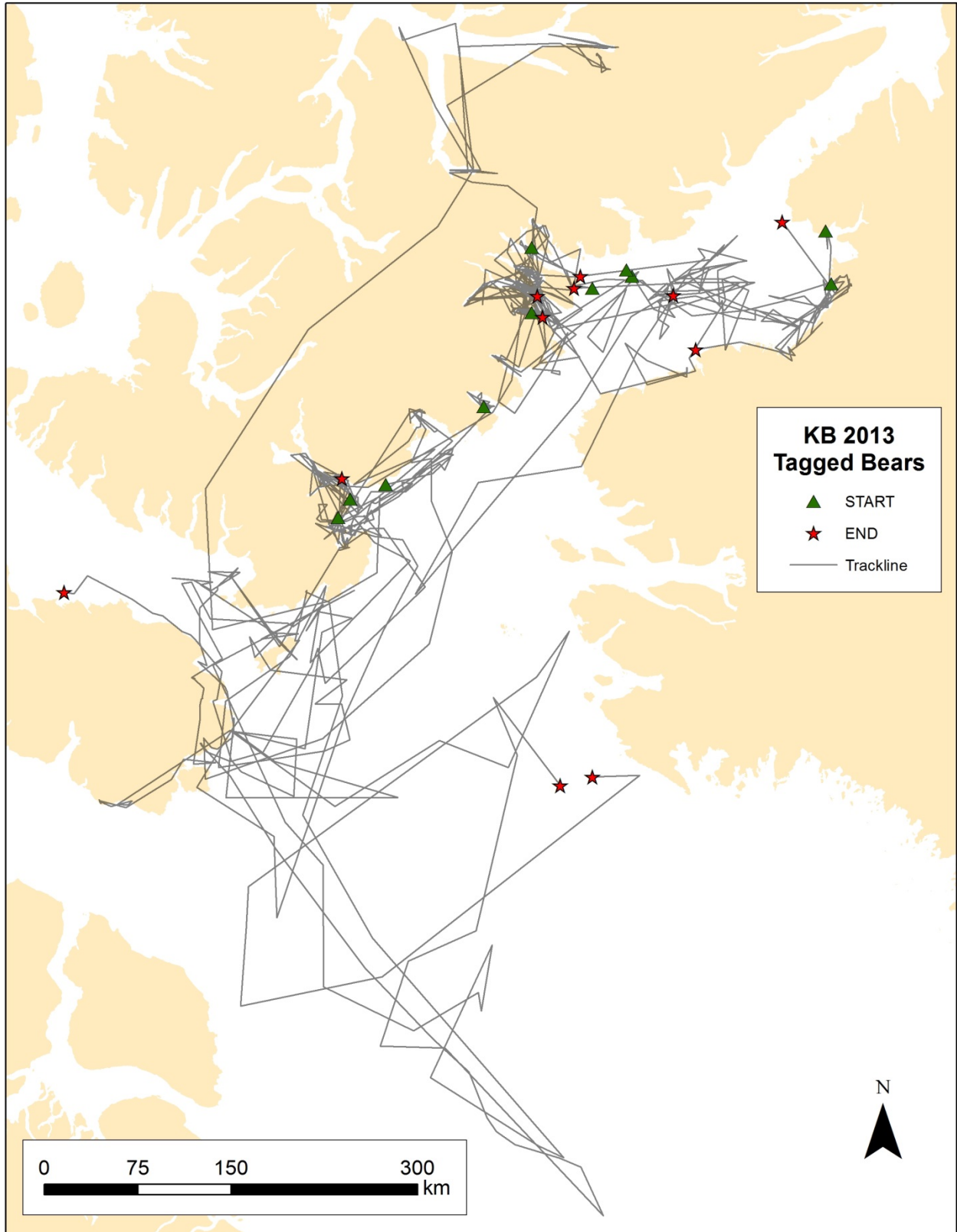
Figure 2.14. Tracklines from n=20 adult female polar bears satellite collared in 2012 and 2013

shown through April 2015 in KB. Inset shows n=1 bear that moved to Russia, excluded from

analyses.
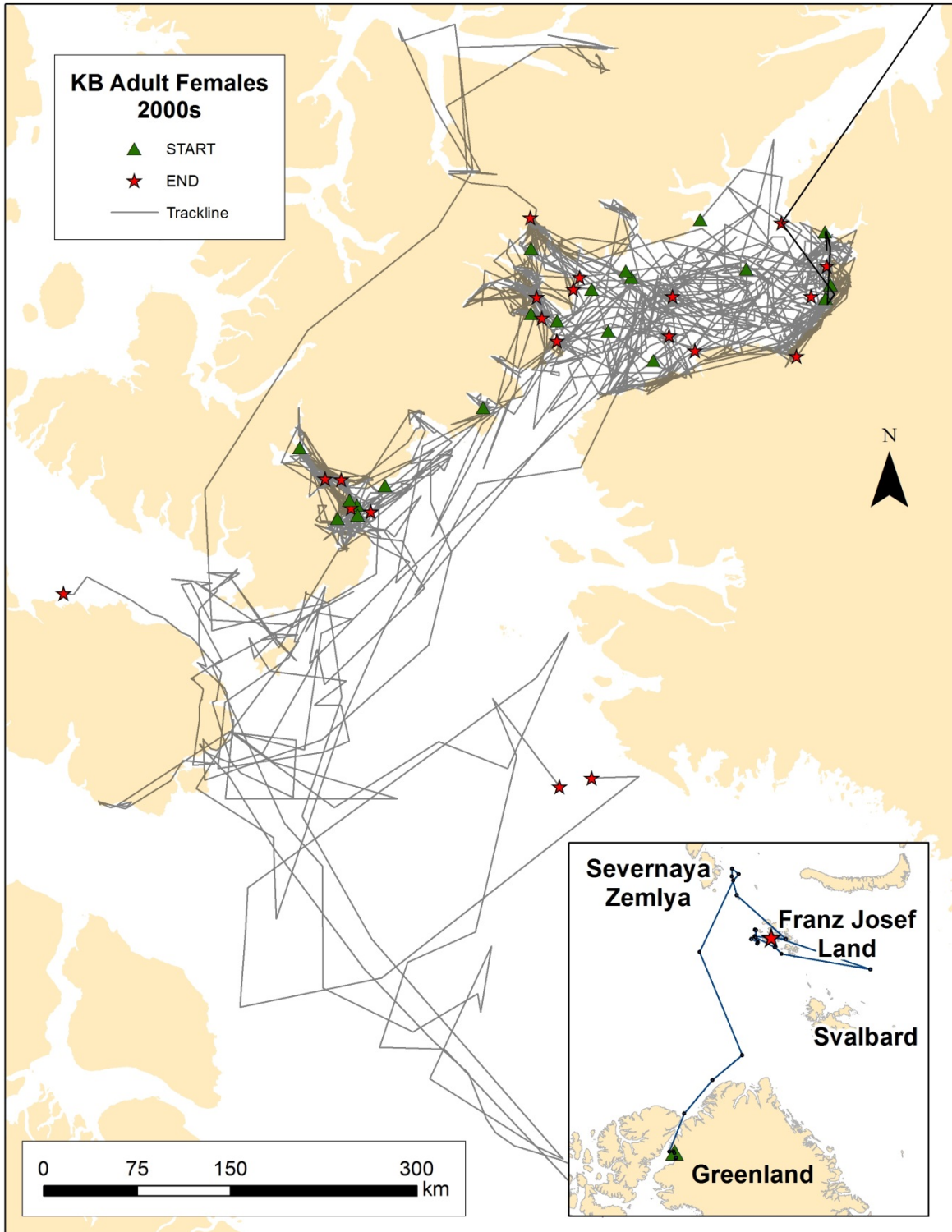
Figure 2.15. Tracklines from n=9 adult male polar bears satellite tagged with ear tags in 2012 and 2013 in KB.
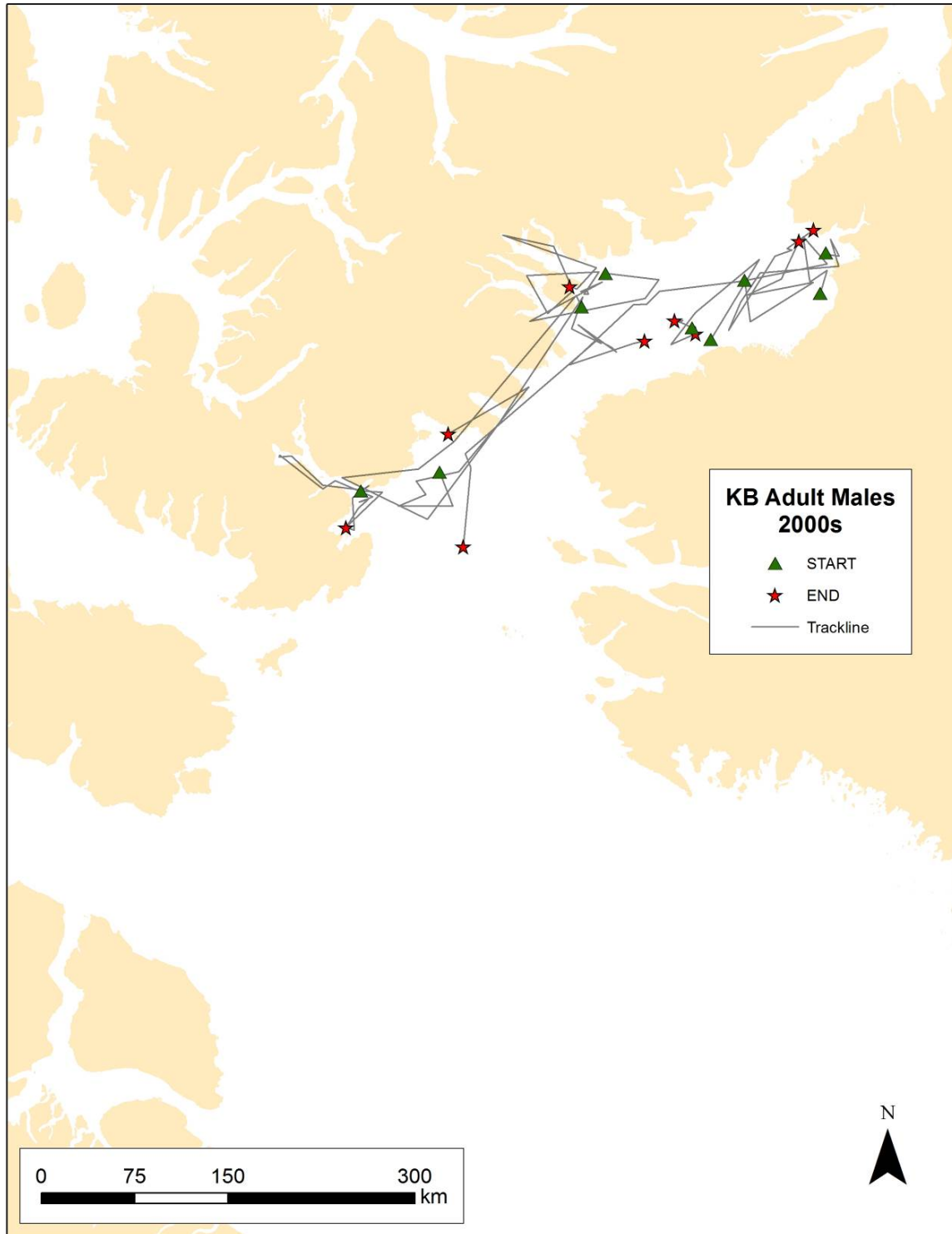
Figure 2.16. 95% kernel ranges for bears captured in 1990s and 2000s in BB by season (winter, spring and summer). See Table 2.4

for areas, overlap and tests for significance between decades.
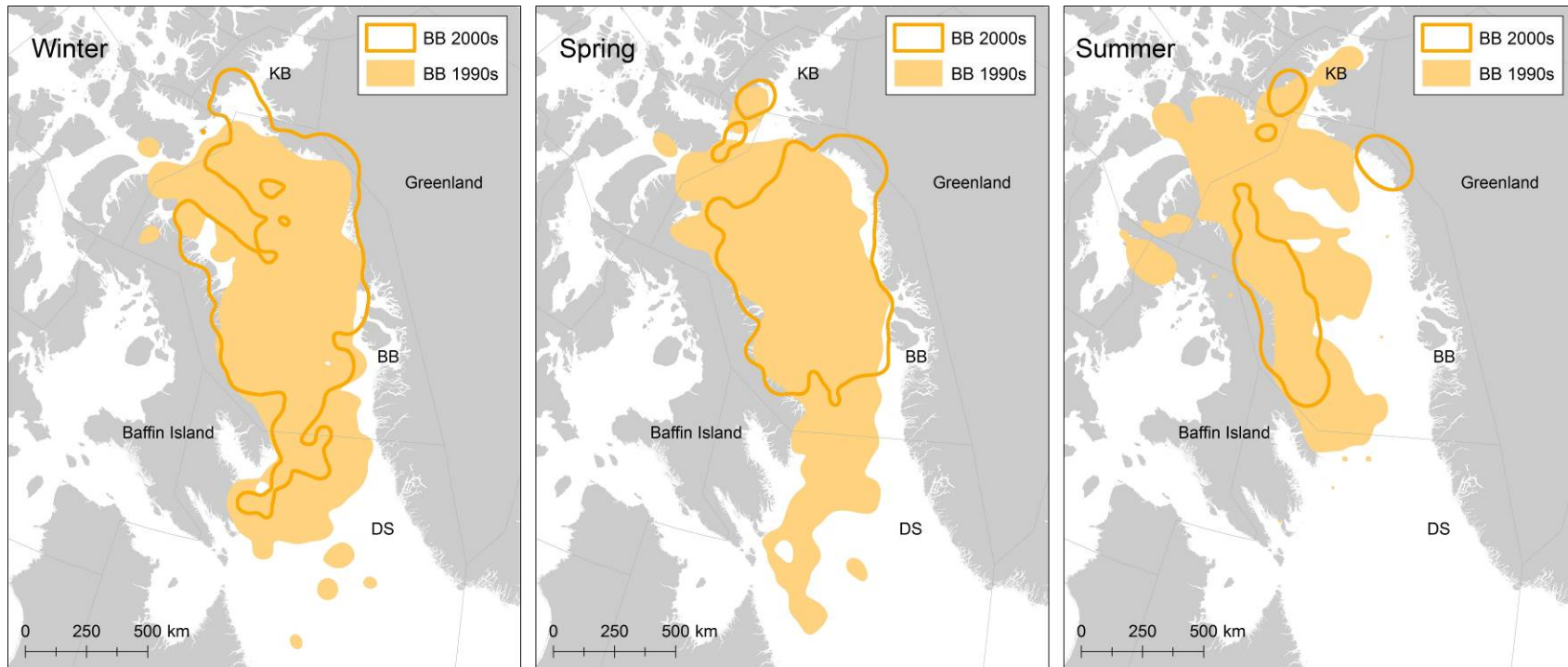
Figure 2.17. Matrix of home ranges shown by month in Baffin Bay for collared adult females in the 1990s and 2000s.

Figure 2.18. Home range sizes between decades for adult female polar bears in BB in the 1990s

(red, n=43) and 2000s (blue, n=38). Line represents the mean values by month and shaded area

+/- 2 SE. Graph excludes Melville Bay resident bears.
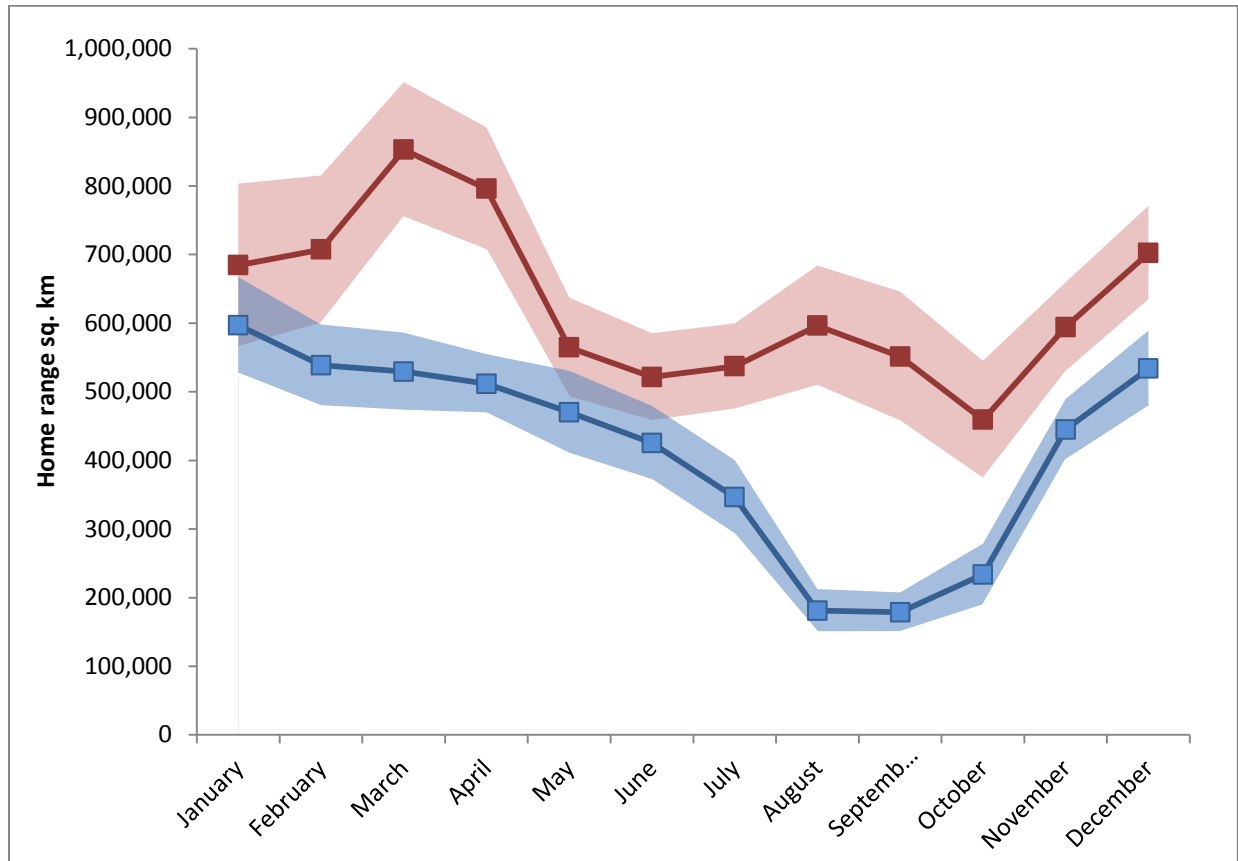
Figure 2.19. 95% kernel ranges for adult female bears captured in 1990s and 2000s in KB by season (winter, spring and summer).

See Table 2.4 for areas, overlap and test for significance between decades.
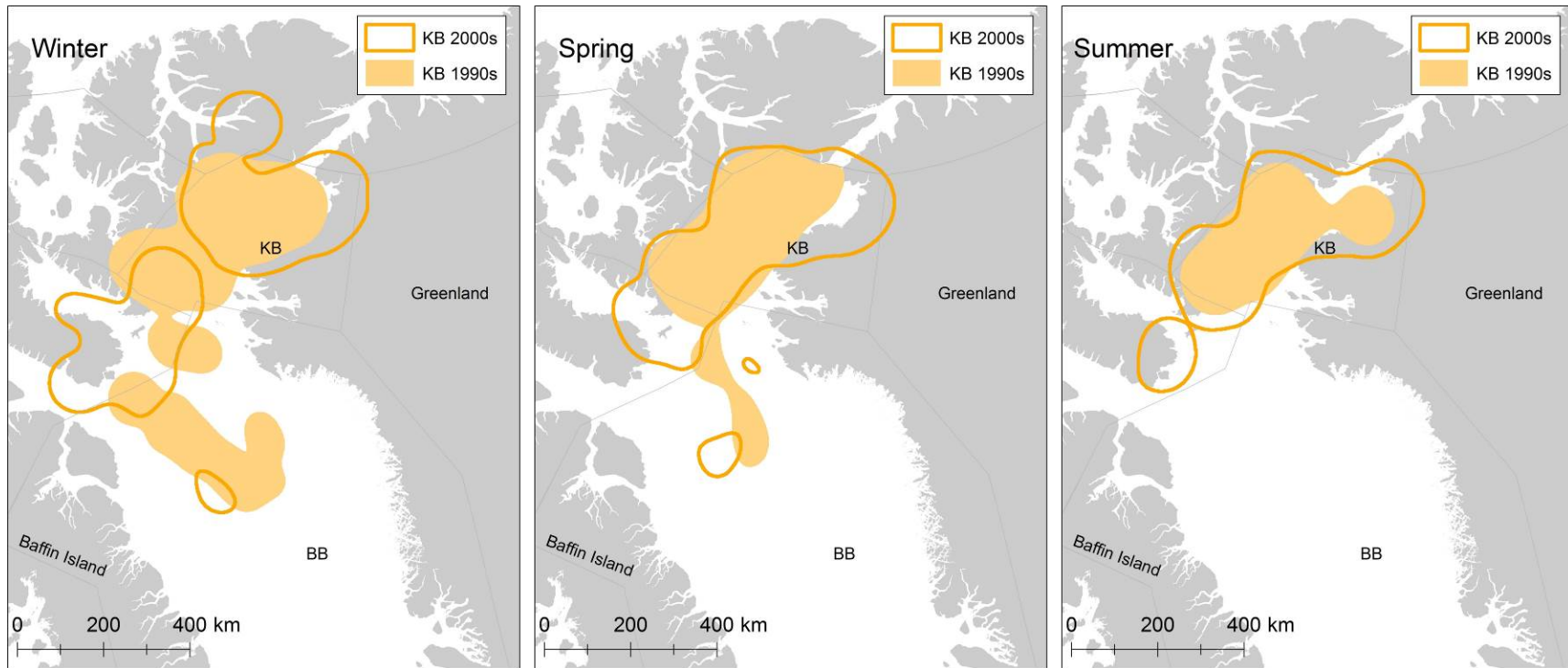
Figure 2.20. Matrix of home ranges shown by month for adult female polar bears in Kane Basin

in the 1990s and 2000s.
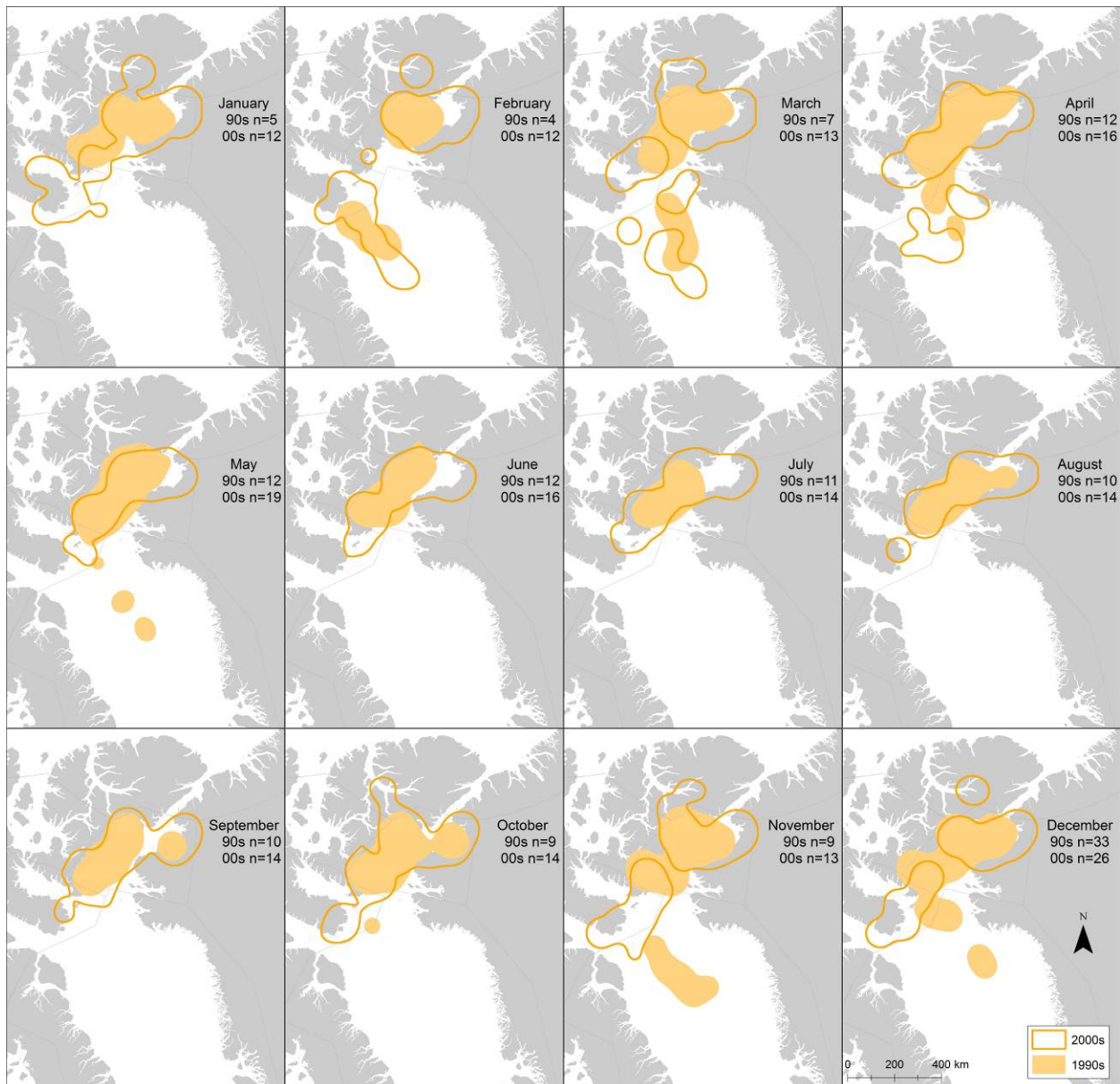
Figure 2.21. Home range sizes between decades for adult female polar bears in KB in the 1990s (red, n=12) and 2000s (blue, n=20). Line represents the mean values by month and shaded area +/- 2 SE.
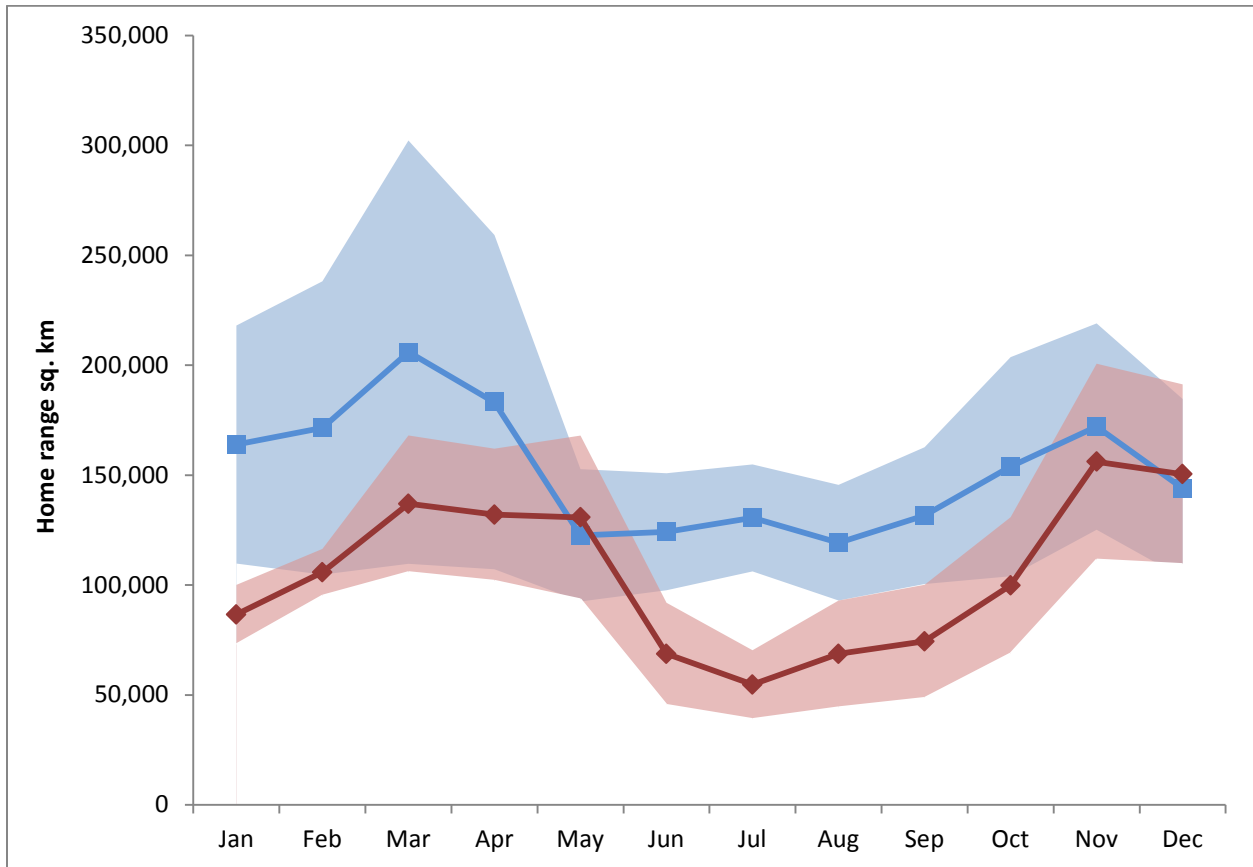
Figure 2.22. Box plots shown by season of median latitude for adult female polar bears in BB in the 1990s (n=43) and 2000s (n=38). Plot excludes the bears that are resident in Melville Bay though inclusion of these bears did not change the significance of the results.
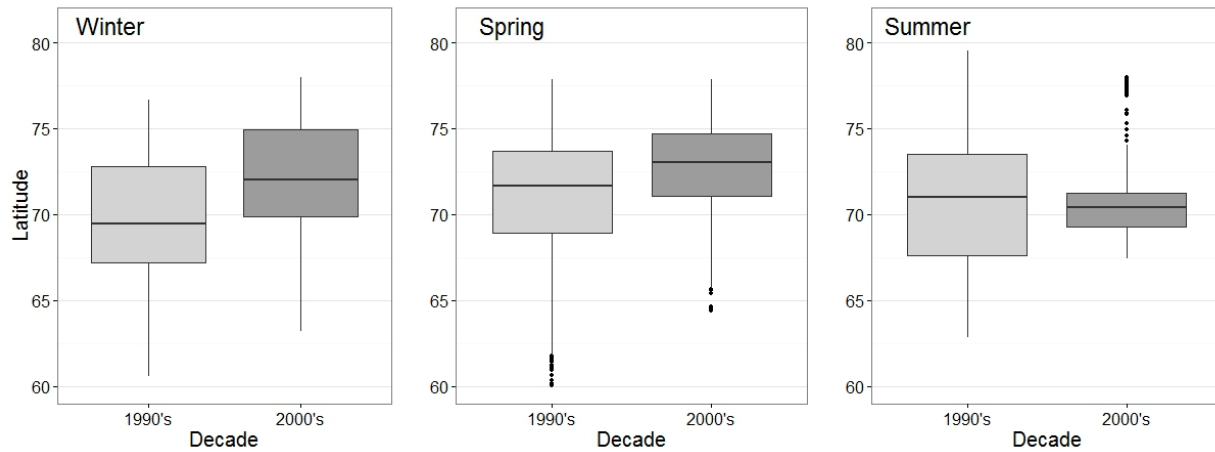
Figure 2.23. Box plots by season of median latitude for AF bears in KB in the 1990s (n=12) and 2000s (n=20).
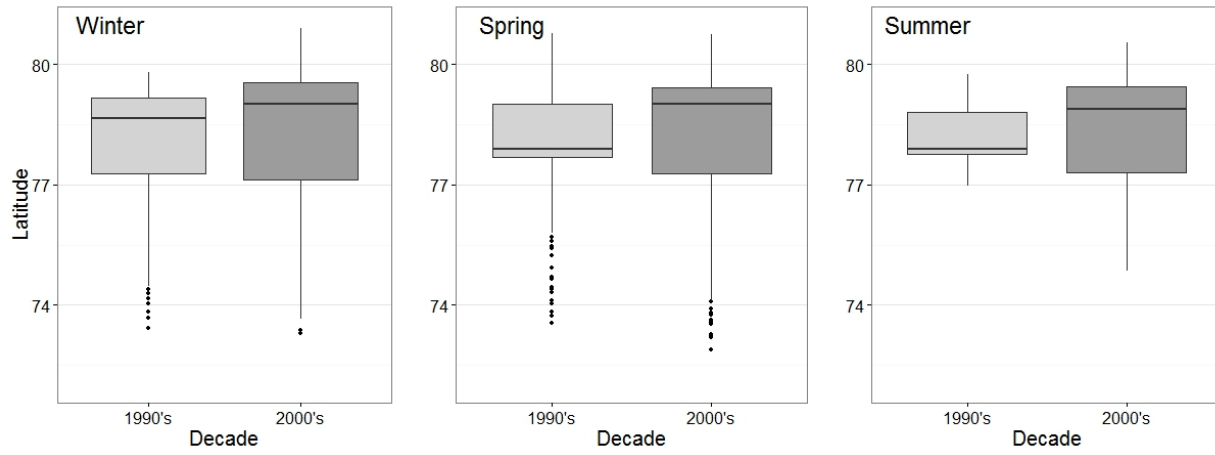
Figure 2.24. Plot of departure timing from region of origin for BB and KB bears in the 1990s and 2000s where departures of any length (min 4 days) were considered. See Table 2.3 for sample sizes.
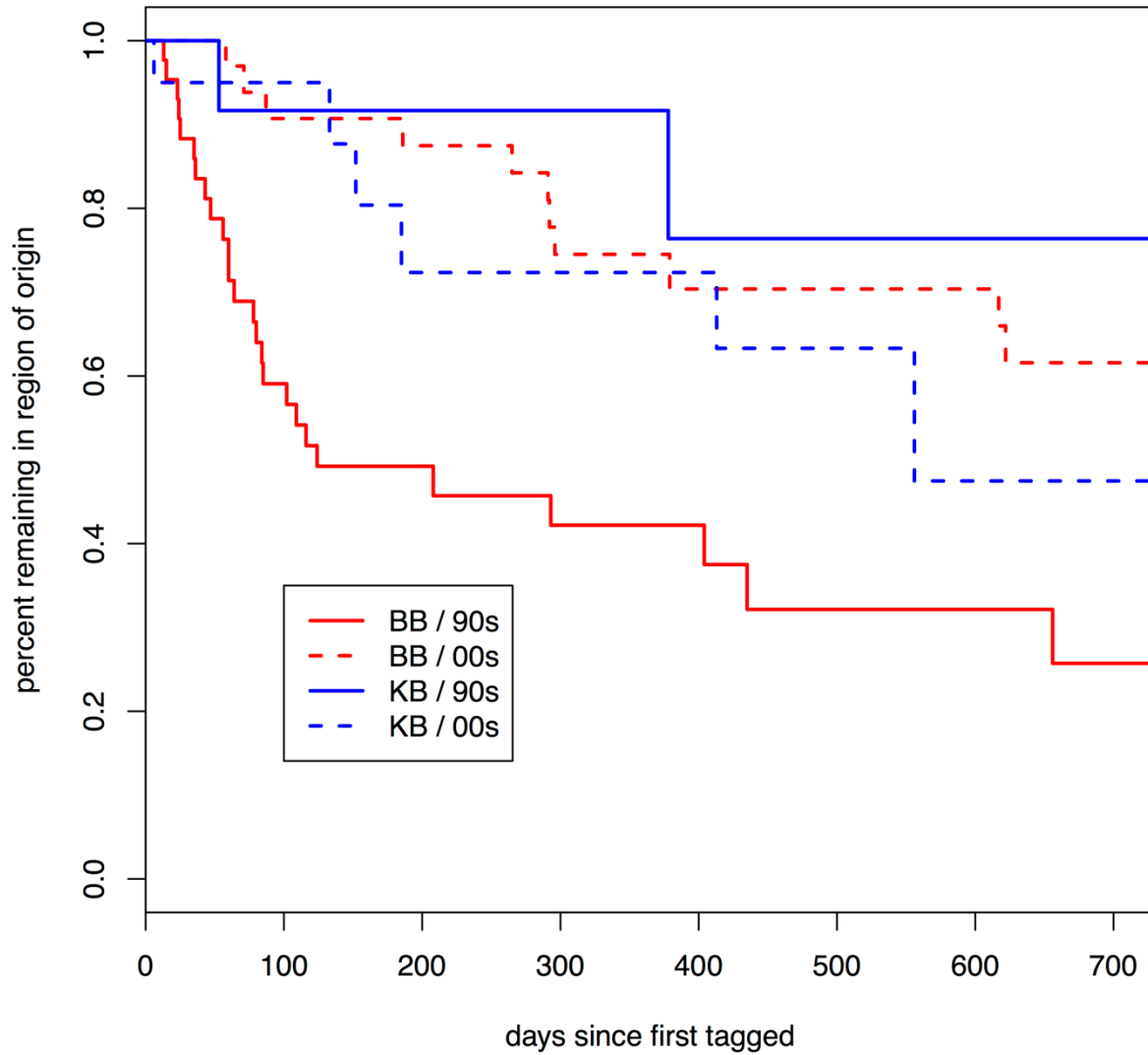
Figure 2.25. Plot of departure timing from region of origin for BB and KB bears in the 1990s and 2000s where only departures 30 days or greater were considered. See Table 2.3 for sample sizes.
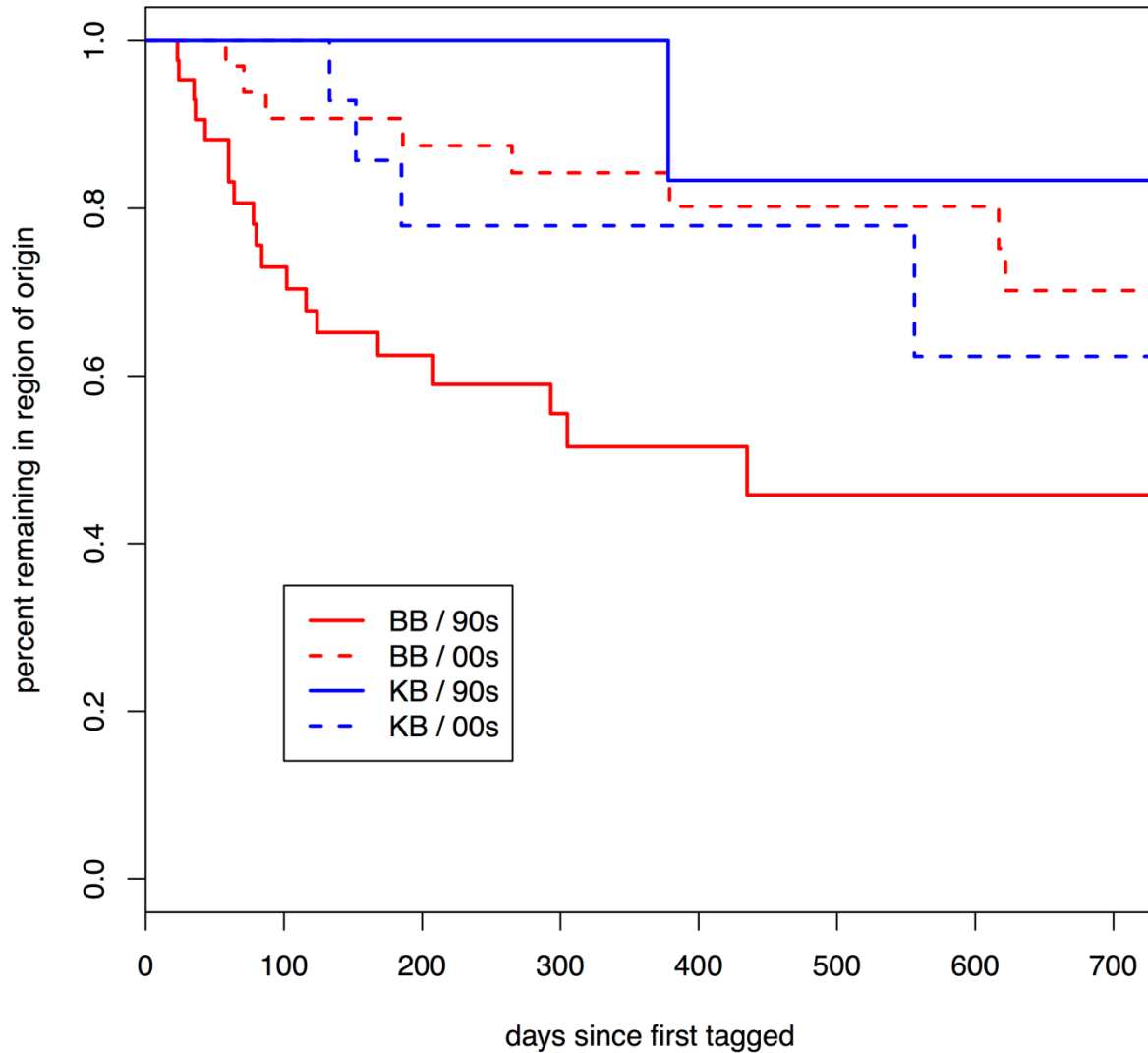
Figure 2.26. Distances (km) between mark and recapture locations of polar bears in Baffin Bay, 2011-2013. Adult females (AF), adult males (AM), cub-of-the-year (CO=COY), subadults (SA), yearlings (YR). Median distance is represented by the black line within each box. Box represents the interquartile range. Whiskers represent maximum and minimum values. Symbols denote significant differences between groups (Bonferonni correction for multiple comparisons, alpha = 0.05).
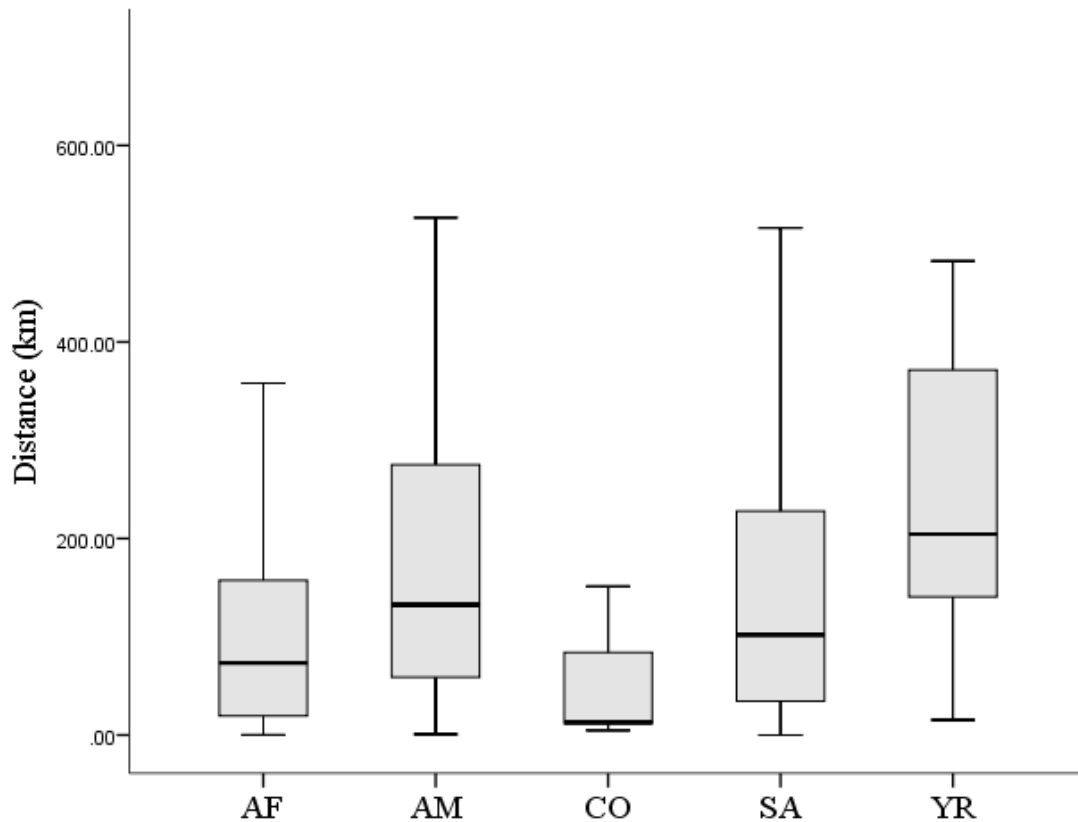
Figure 2.27. Relationship between capture-recapture interval and straight line displacement distance for 29 bears that moved between Baffin Bay and Davis Strait as detected by capture and recapture. Median distance is represented by the black line within each box. Box represents the interquartile range. Whiskers represent maximum and minimum values.
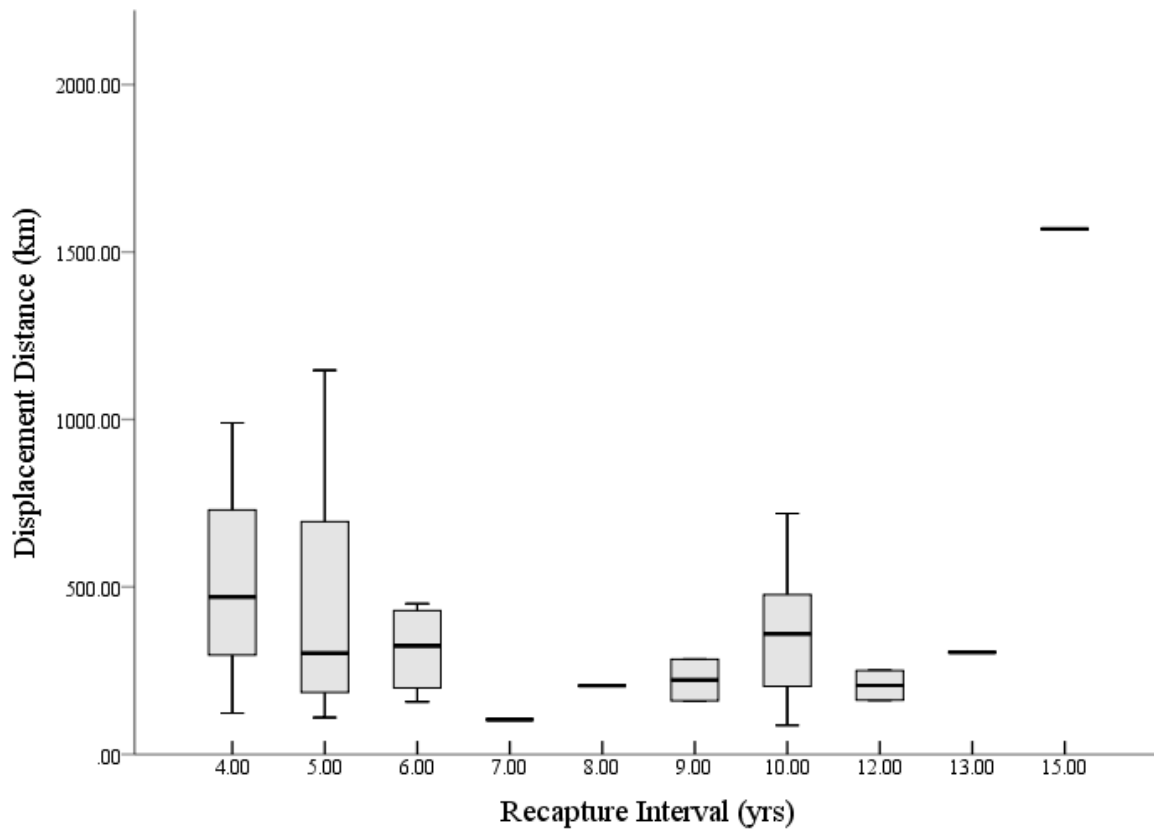
Figure 2.28. Frequency distribution of the distance between capture location and the boundary of the Baffin Bay (BB) and Davis Strait (DS) polar bear subpopulations for 29 individuals that made inter-subpopulation movements as detected by capture and recapture (grey bars), 1991-2013. Distances between capture locations and the BB-DS boundary for all bears (n = 2,771) marked in BB and DS are also shown (black bars). Bars represent proportion of captures occurring within each distance bin.
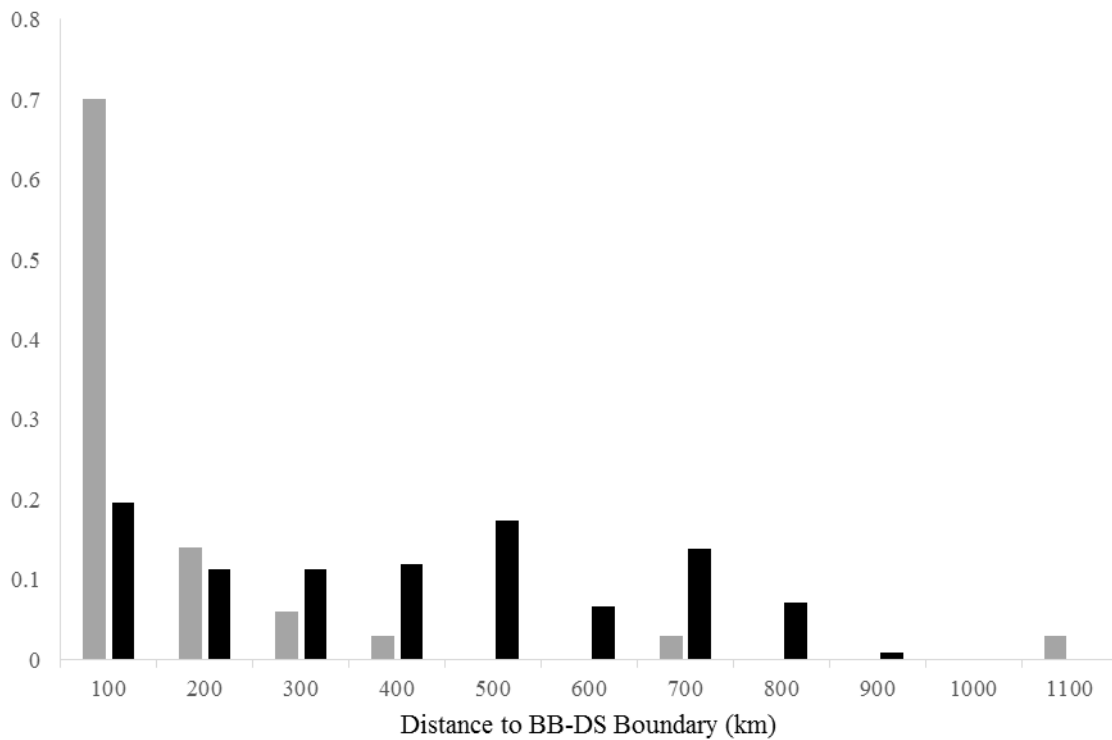
Figure 2.29. Capture and recapture locations of bears known to have made inter-subpopulation movements between mark-recapture sampling sessions in Baffin Bay (BB) (1990-97), Davis Strait (DS) (2005-07), and Baffin Bay (2009-2013).