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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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

<u>Program activities</u>

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.

<u>Field activities</u>

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.

<u>Analyses</u>

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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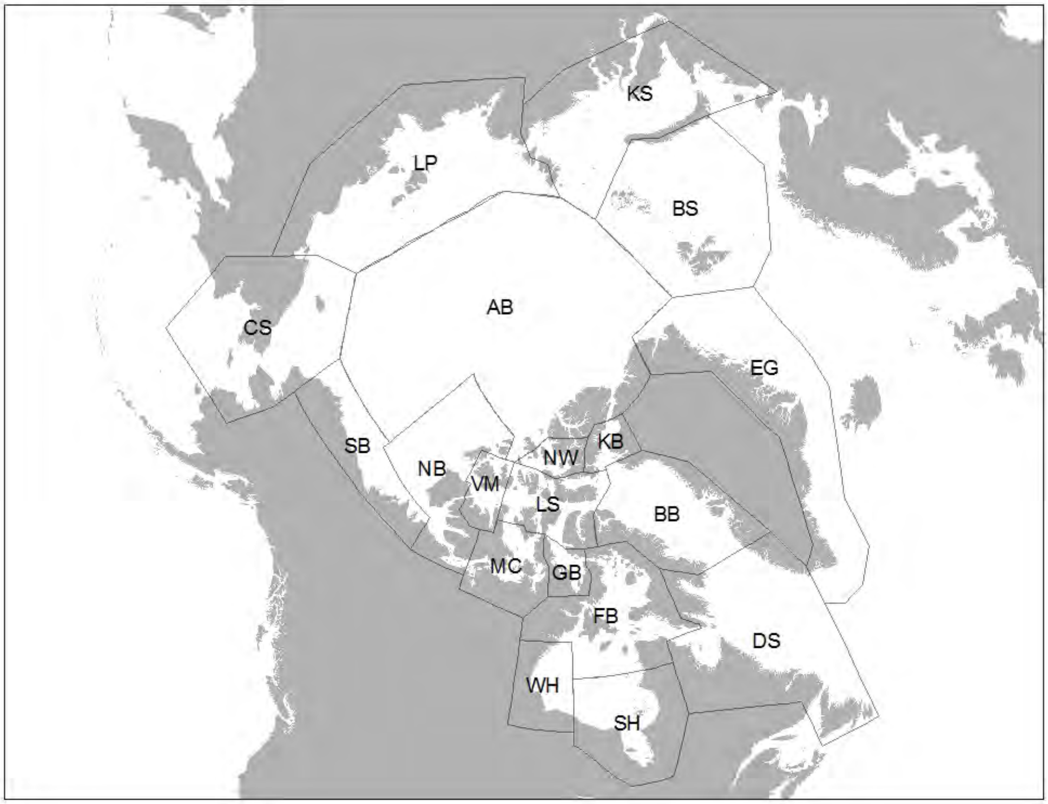

Figure 1.1. Map of the circumpolar Arctic showing the 19 subpopulations of polar bears, including Baffin Bay (BB) and Kane Basin (KB). Polar Bear subpopulations: Arctic Basin (AB), Baffin Bay, Barents Sea (BS), Chukchi Sea (CS), Davis Strait (DS), East Greenland (EG), Foxe Basin (FB), Gulf of Boothia (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.

<u>Genetics</u>

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.

<u>Basis for Comparison of the 1990s and 2000s BB Satellite Telemetry Data</u>

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.

<u>Overlap of Ranges between Decades</u>

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.

<u>Changes in Median Latitude from Telemetry</u>

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 (χ^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

<u>Genetics</u>

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).

			Movement to other subpopulation during tracking period				
Time period	**Subpopulation of origin**	**n**	**Arctic Basin**	**Baffin Bay**	**Davis Strait**	**Kane Basin**	**Lancaster Sound**
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.

			Movement to other subpopulation during tracking period				
Time period	**Subpopulation of origin**	**n**	**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.

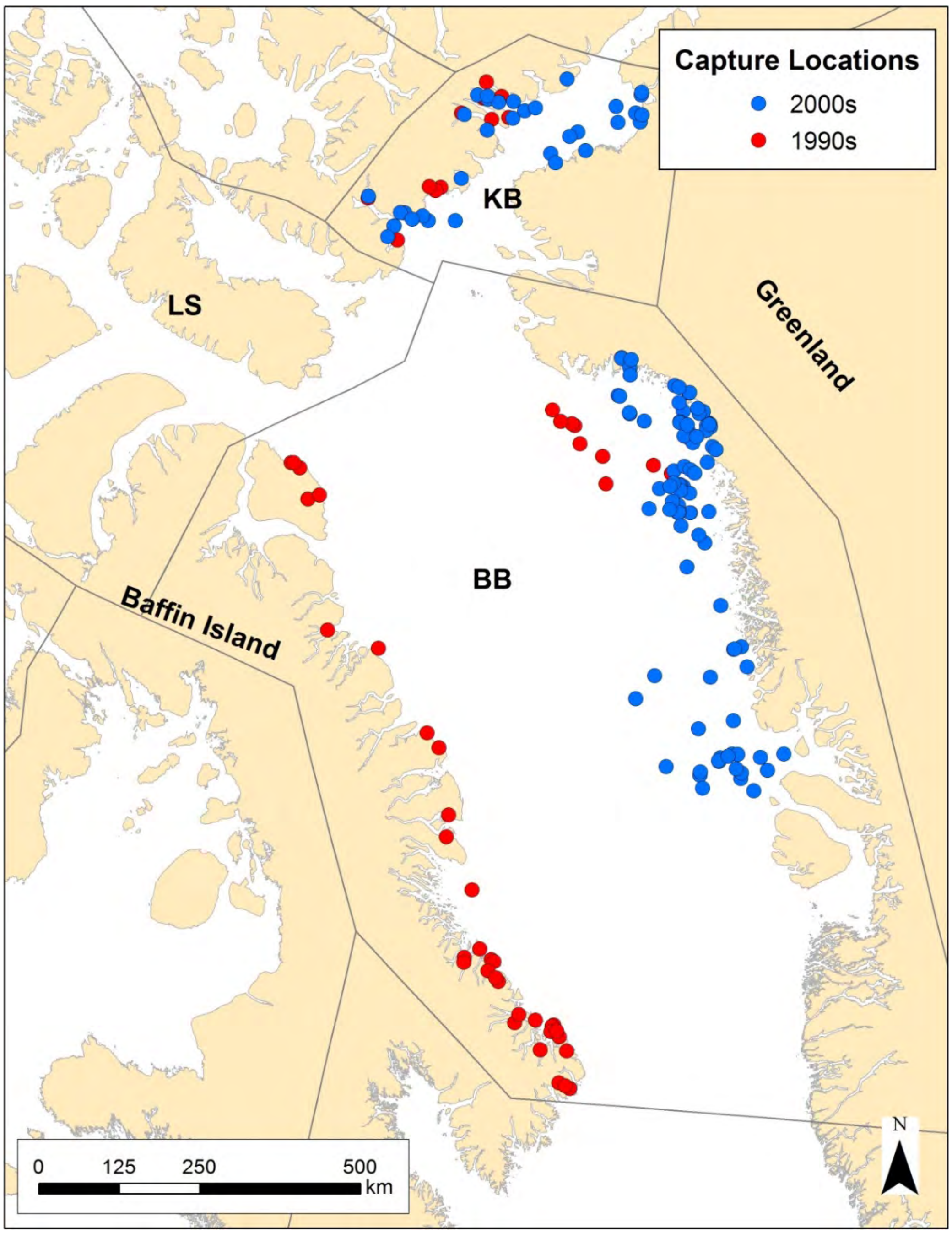


Figure 2.2. Distribution of ages and family groups of a total of 139 individual polar bears captured in spring in northwest Greenland, 2009-2013.

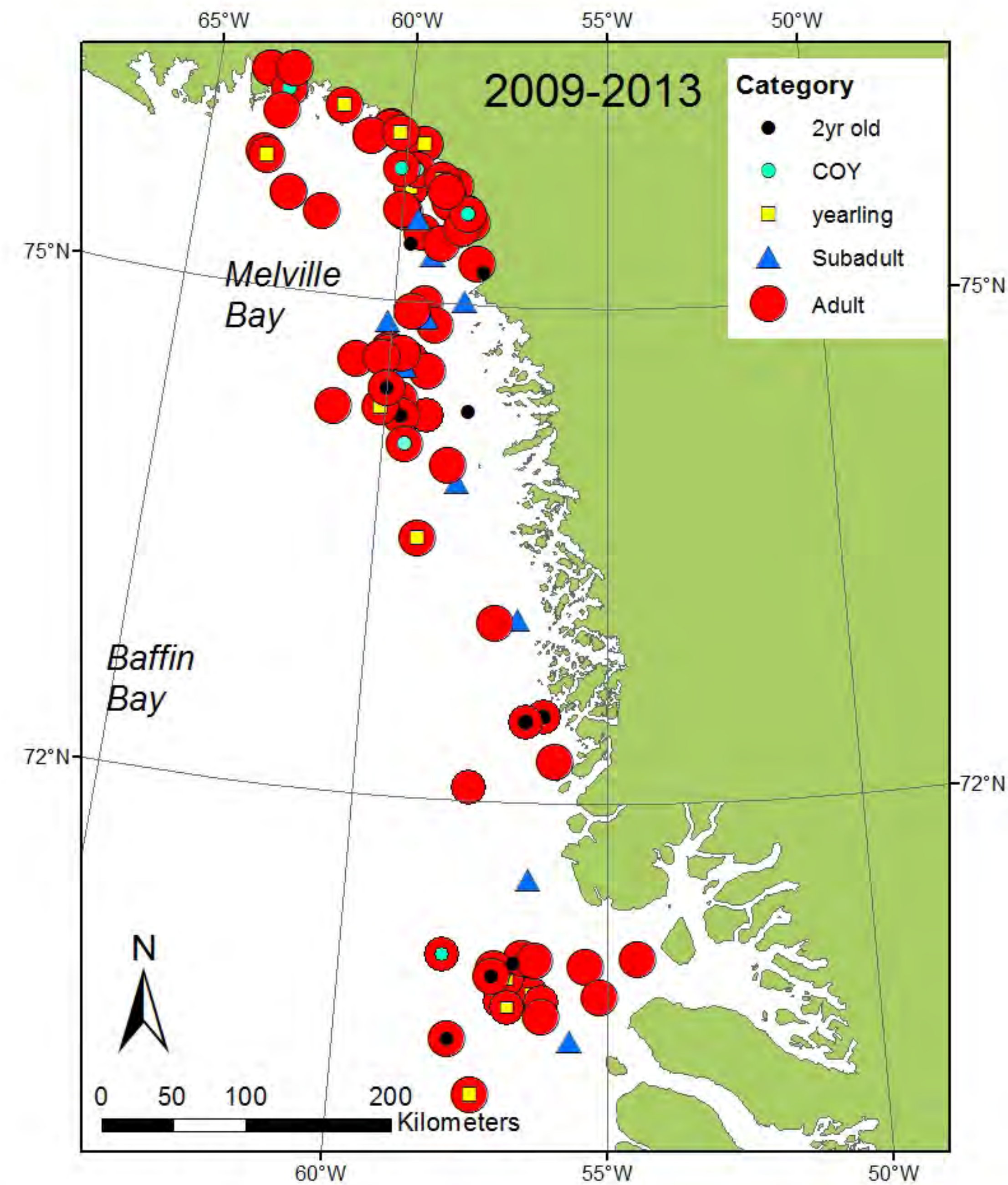


Figure 2.3. Tracklines from n=43 adult female polar bears satellite collared in the 1990s in BB.

Note the general absence of tracks on the fast ice in West and Northwest Greenland.

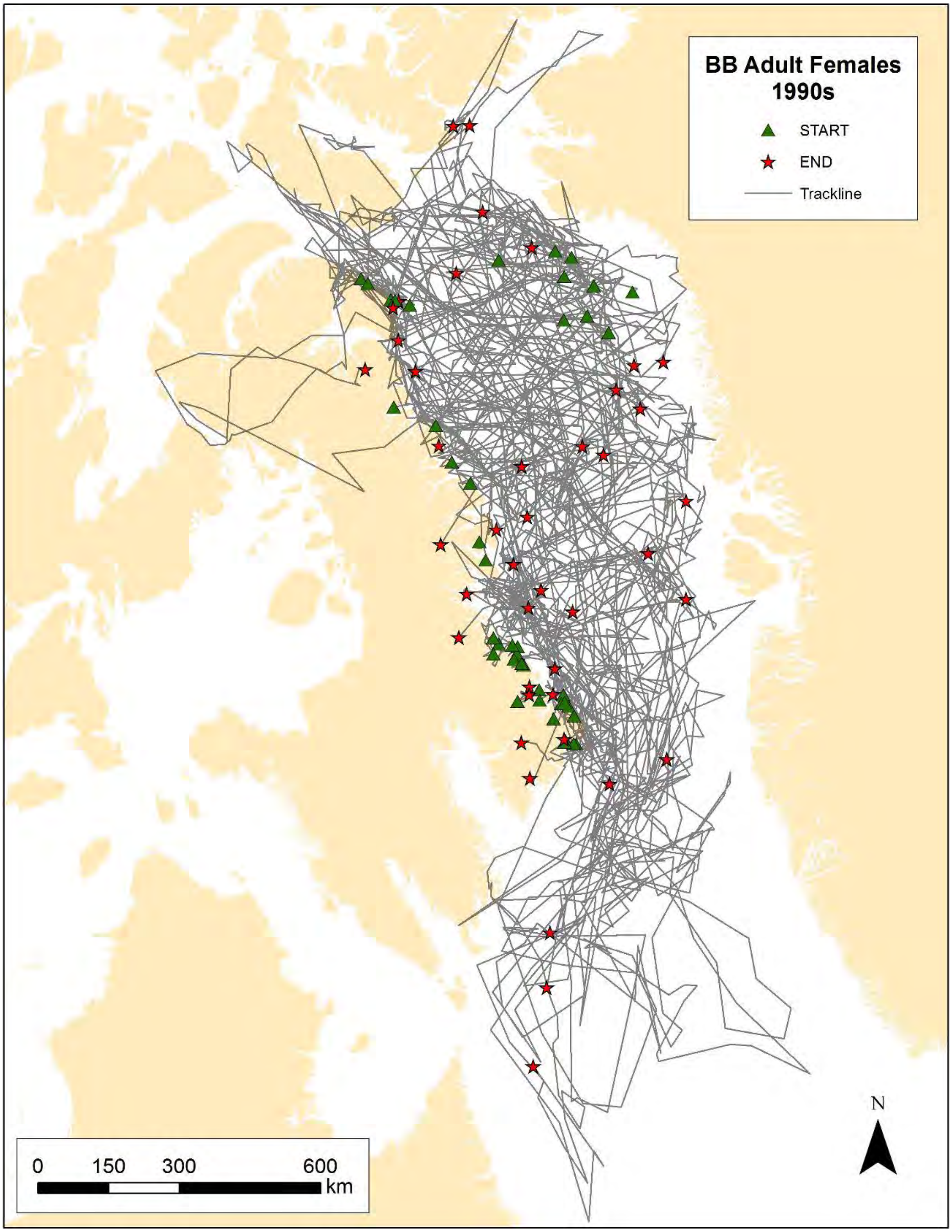


Figure 2.4. Tracklines from n=5 adult female polar bears satellite collared in 2009 in BB.

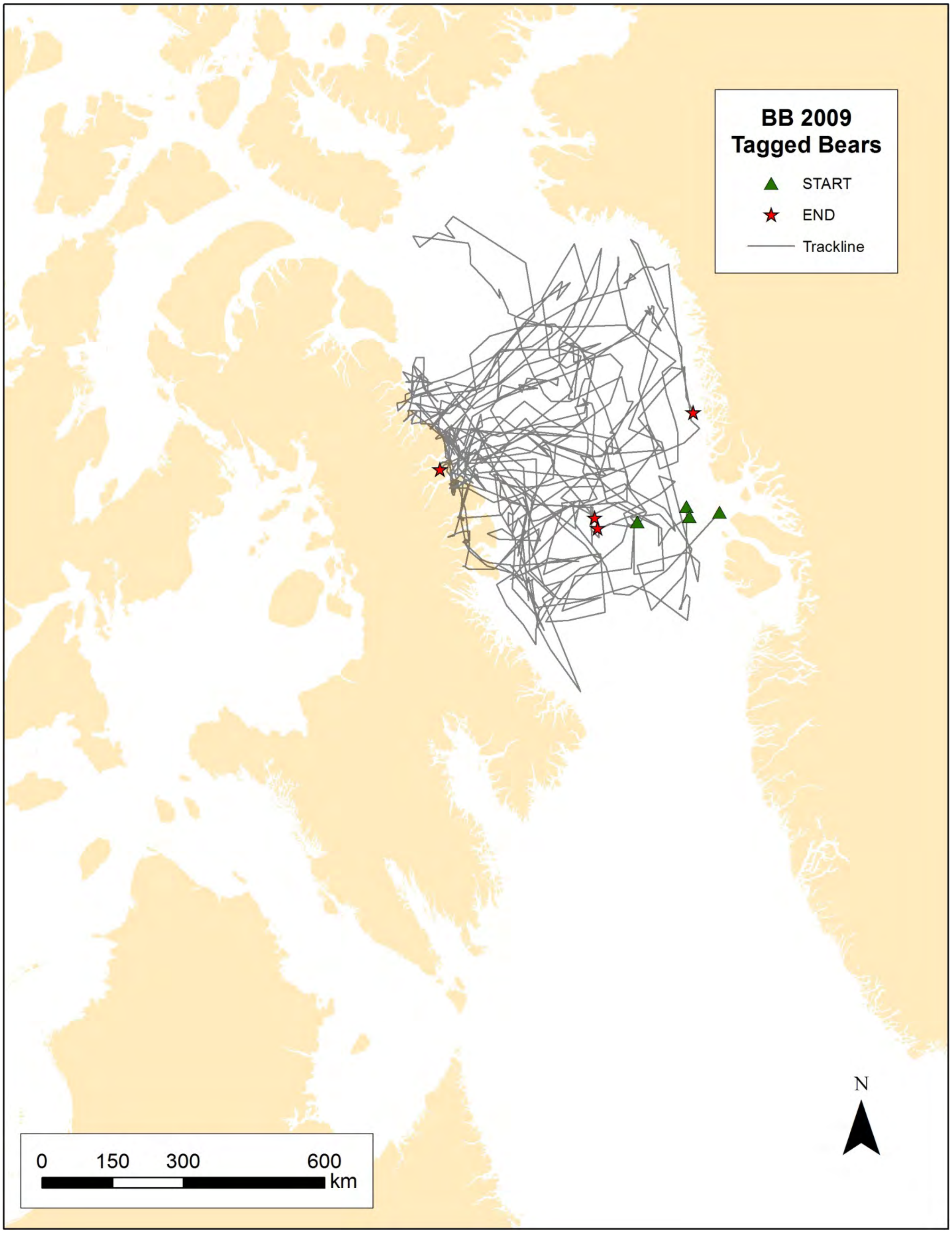


Figure 2.5. Tracklines from n=9 adult female polar bears satellite collared in 2010 in BB.

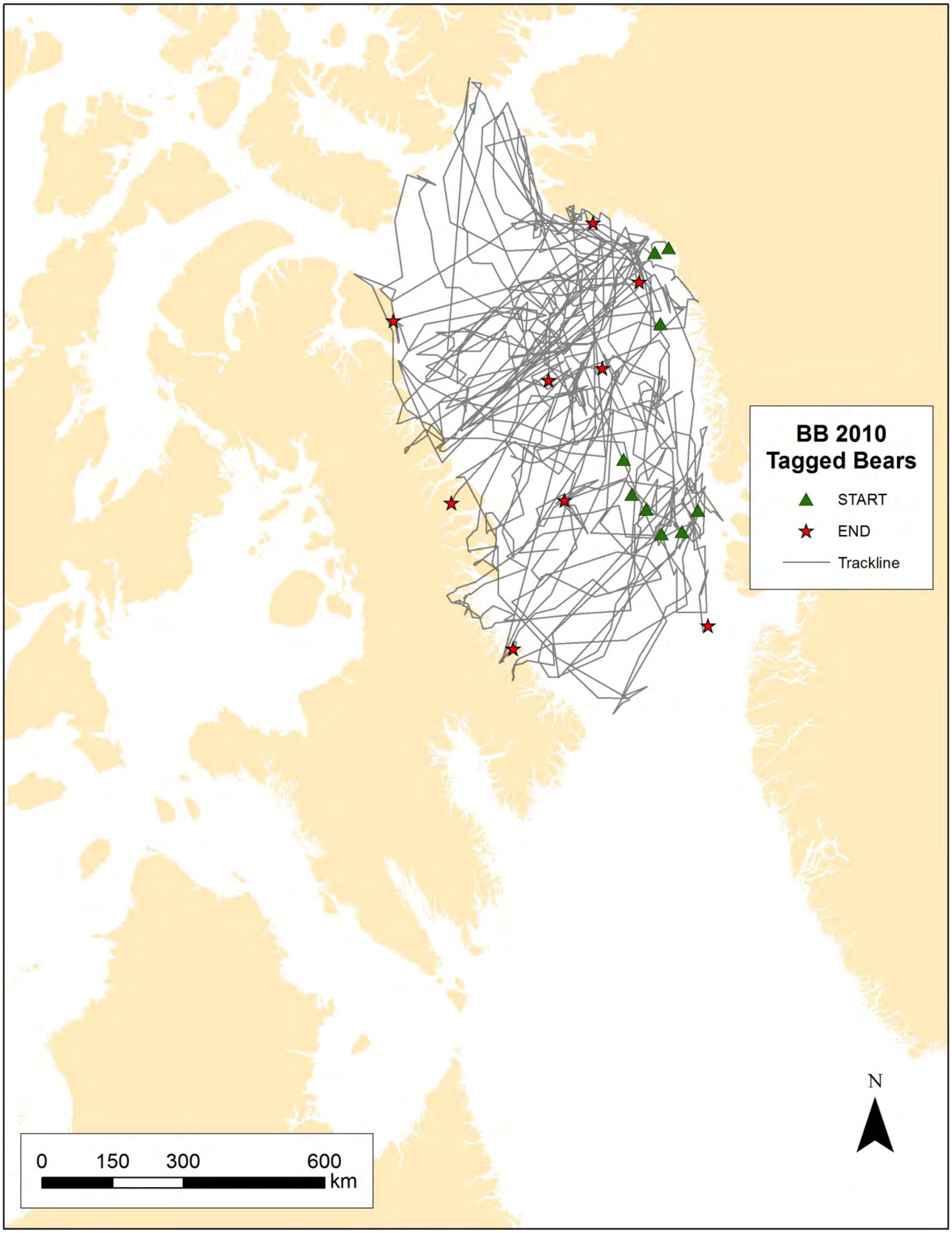


Figure 2.6. Tracklines from n=12 adult female polar bears satellite collared in 2011 in BB.

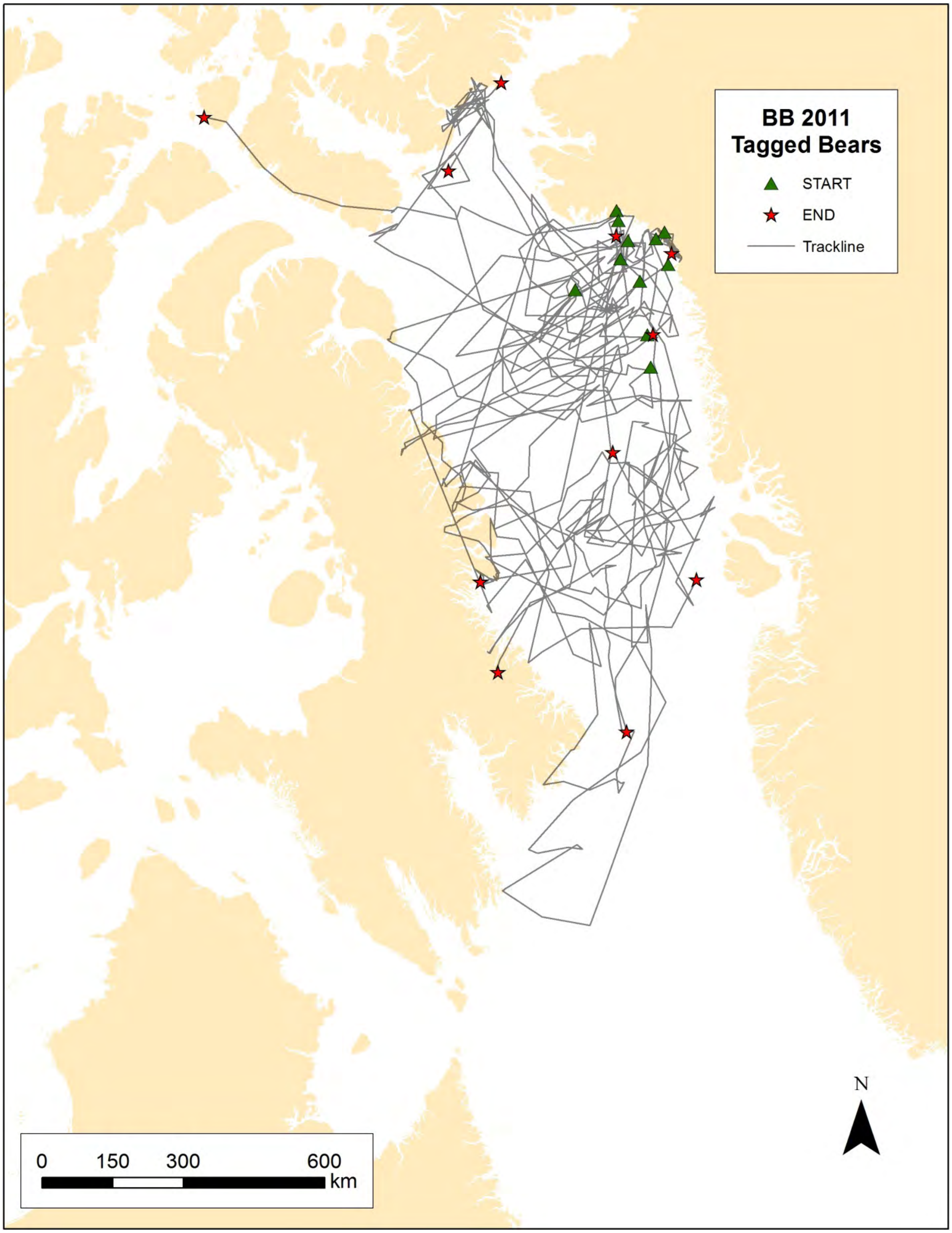


Figure 2.7. Tracklines from n=11 adult female polar bears satellite collared in 2012 in BB.

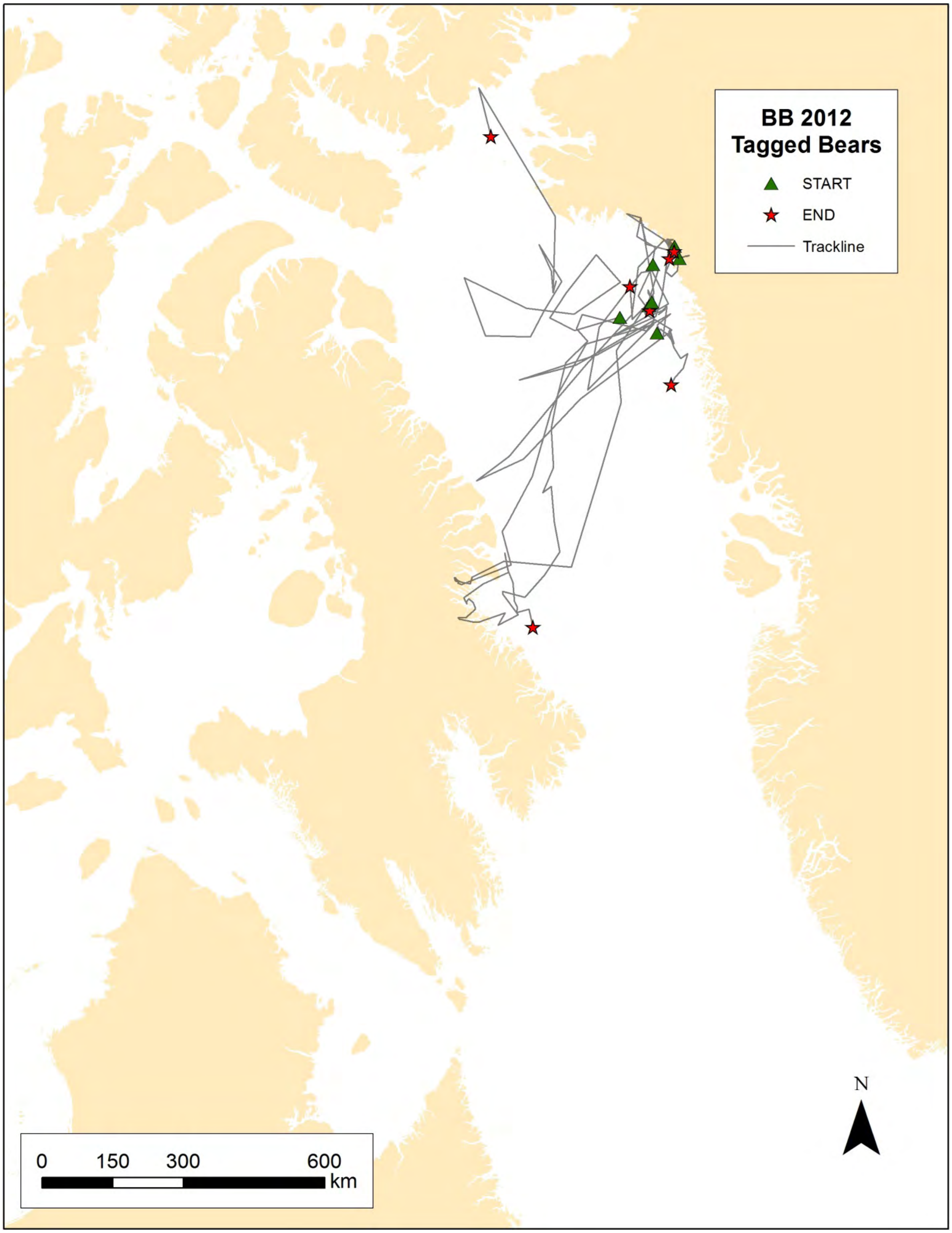


Figure 2.8. Tracklines from n=9 adult female polar bears satellite collared in 2013 in BB.

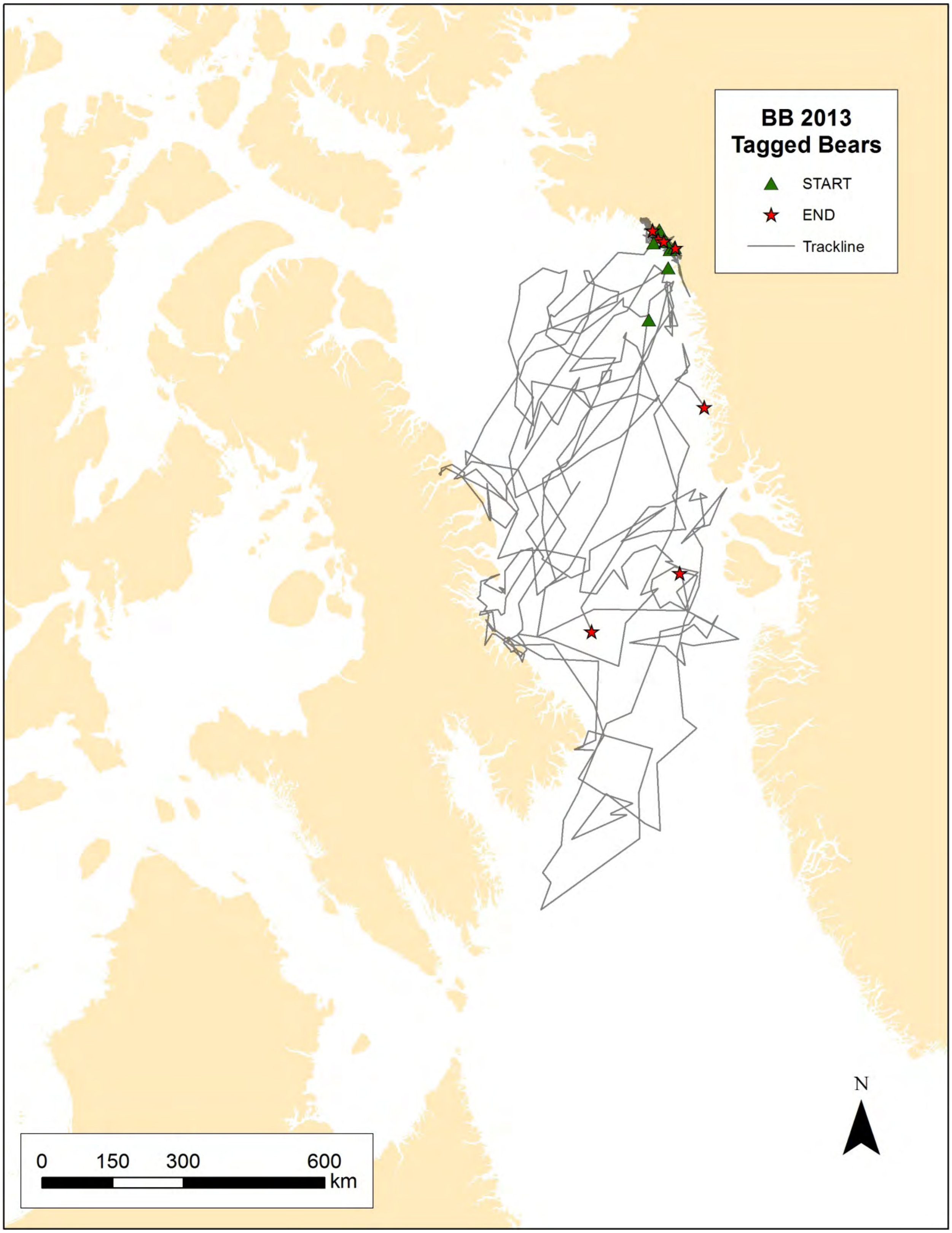


Figure 2.9. Tracklines from all adult female bears (n=38) collared between 2009 and 2013 shown together through April 2015, excluding bears where collars failed after a few days.

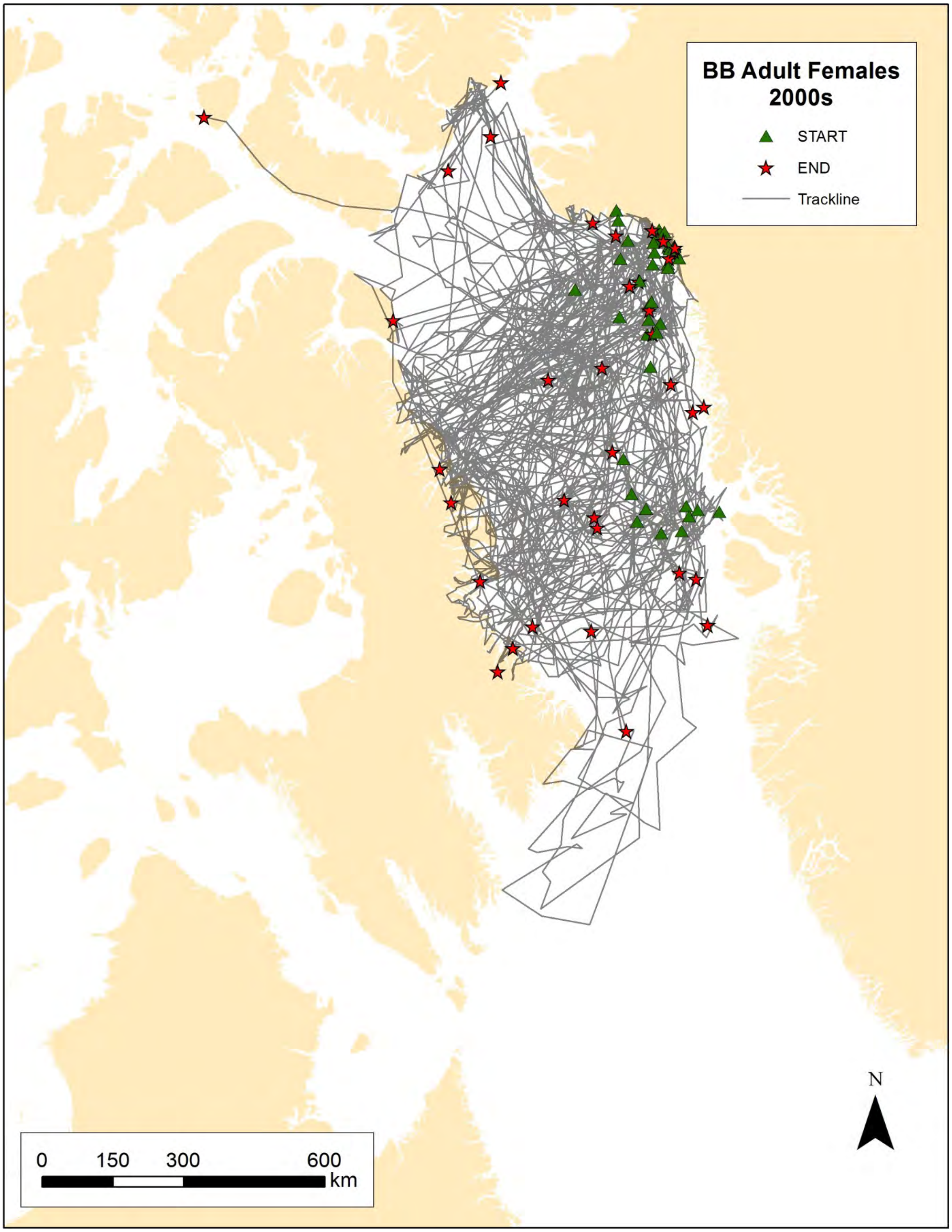


Figure 2.10. Tracklines from n=32 adult male bears tagged with ear transmitters between 2009-2013.

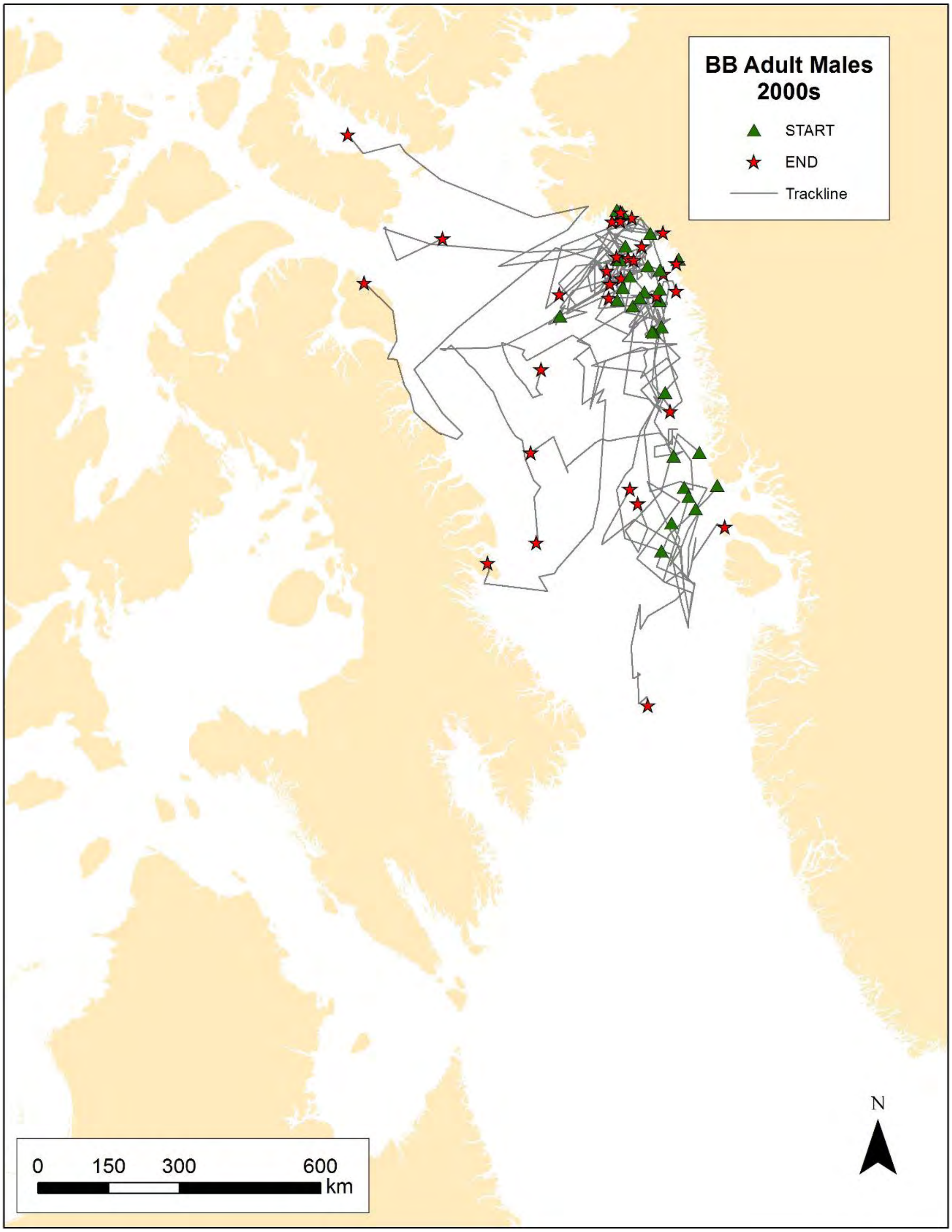


Figure 2.11. Tracklines from n=12 adult female polar bears satellite collared in the 1990s in KB.

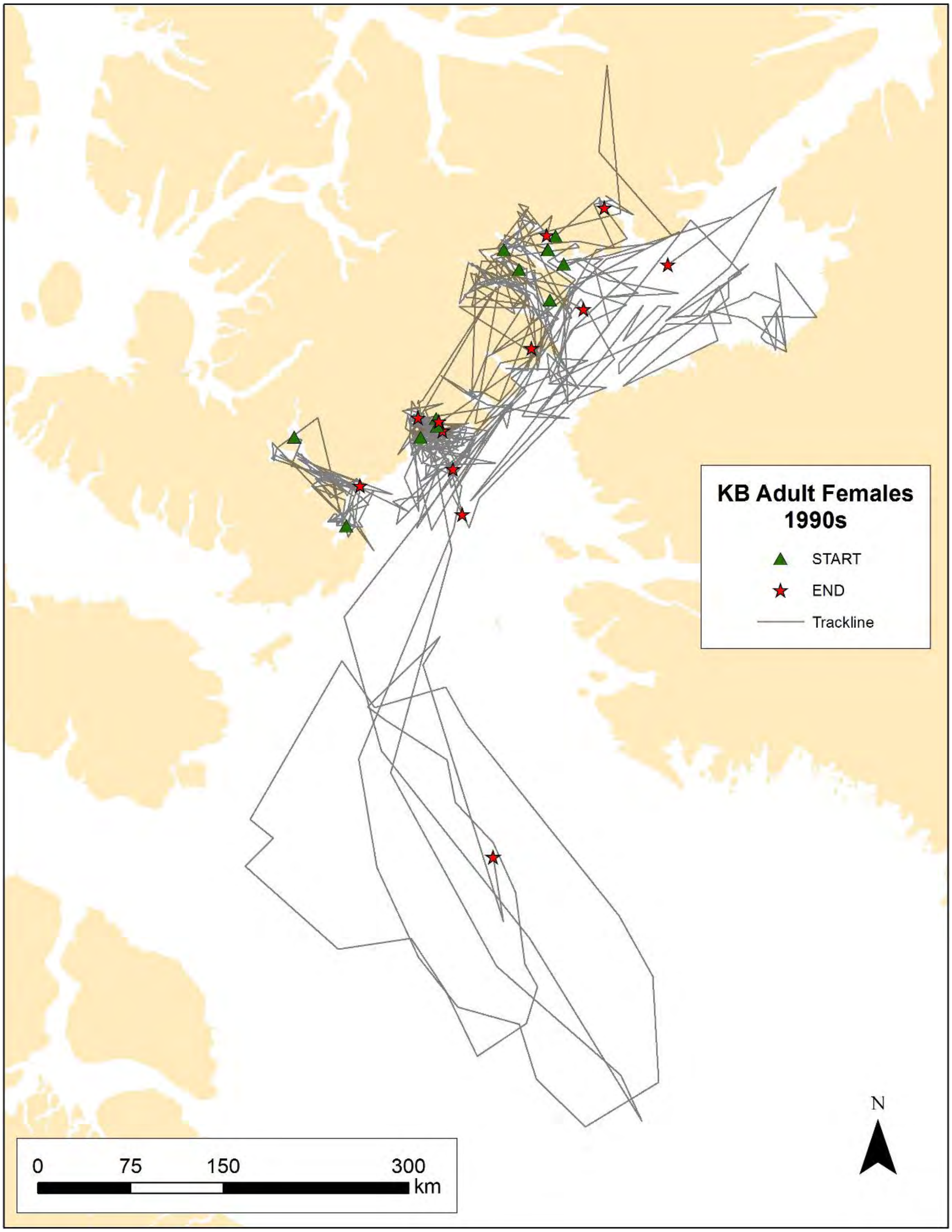


Figure 2.12. Tracklines from n=9 adult female polar bears satellite collared in 2012 in KB.

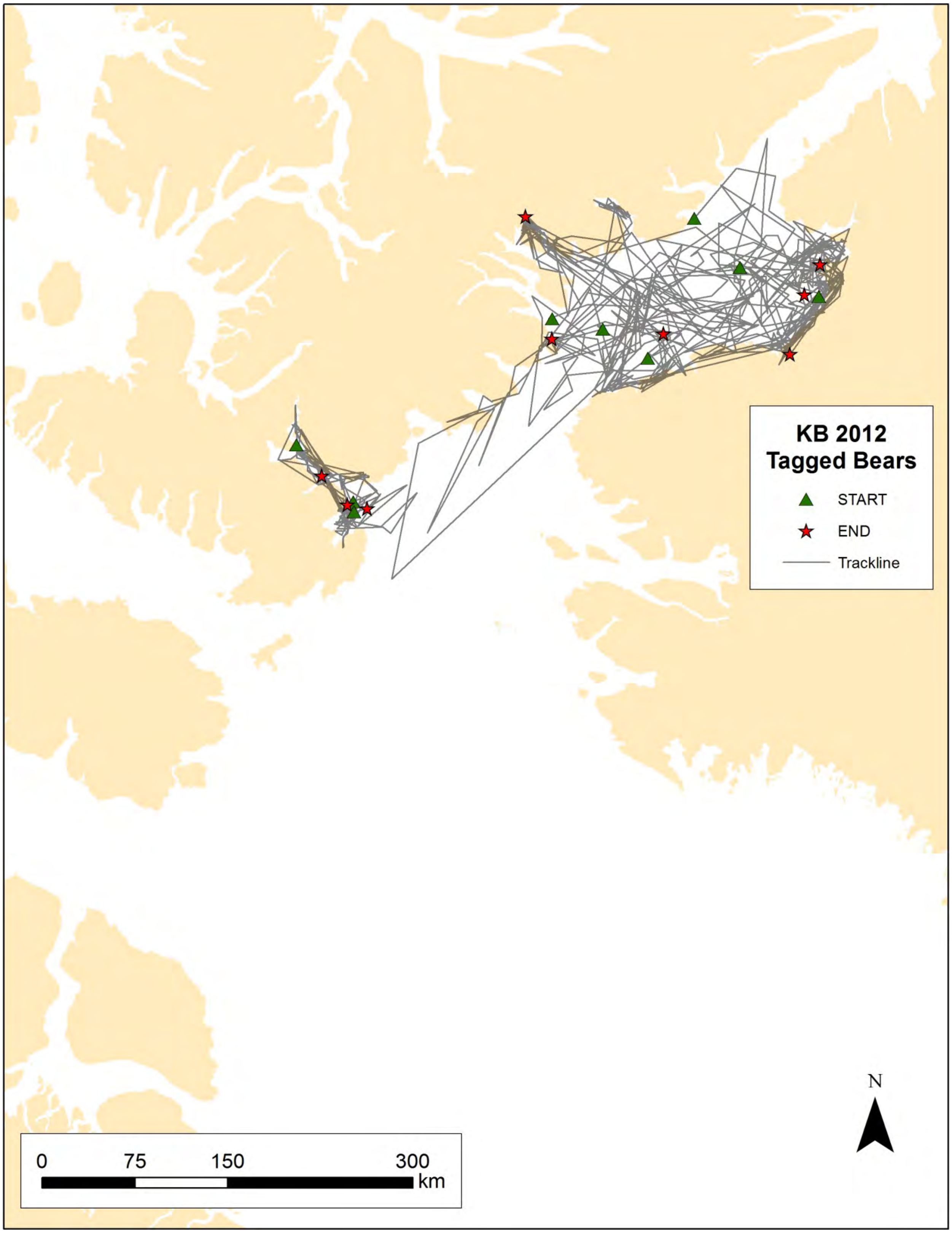


Figure 2.13. Tracklines from n=11 adult female polar bears satellite collared in 2013 in KB.

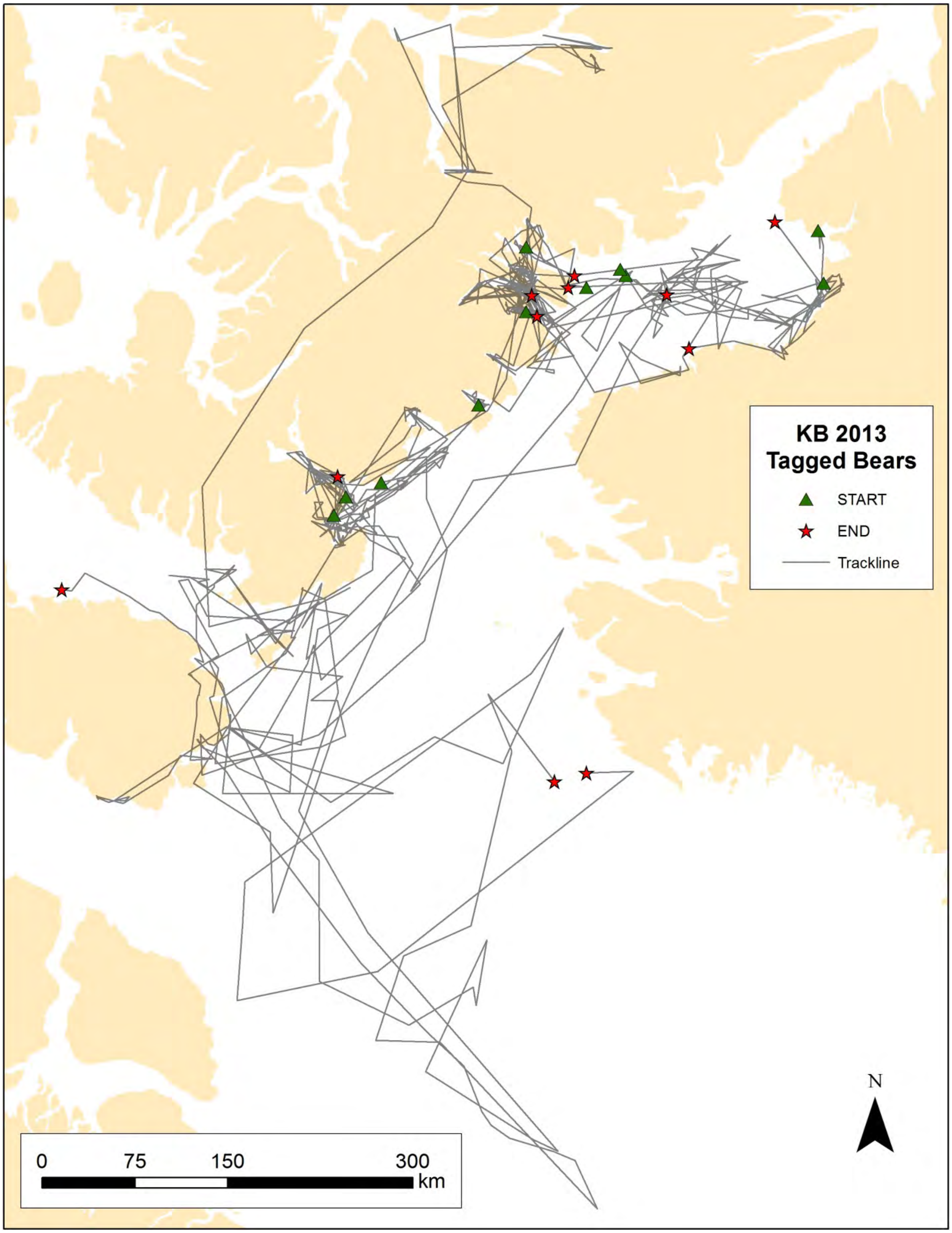


Figure 2.14. Tracklines from n=20 adult female polar bears satellite collared in 2012 and 2013 shown through April 2015 in KB. Inset shows n=1 bear that moved to Russia, excluded from analyses.

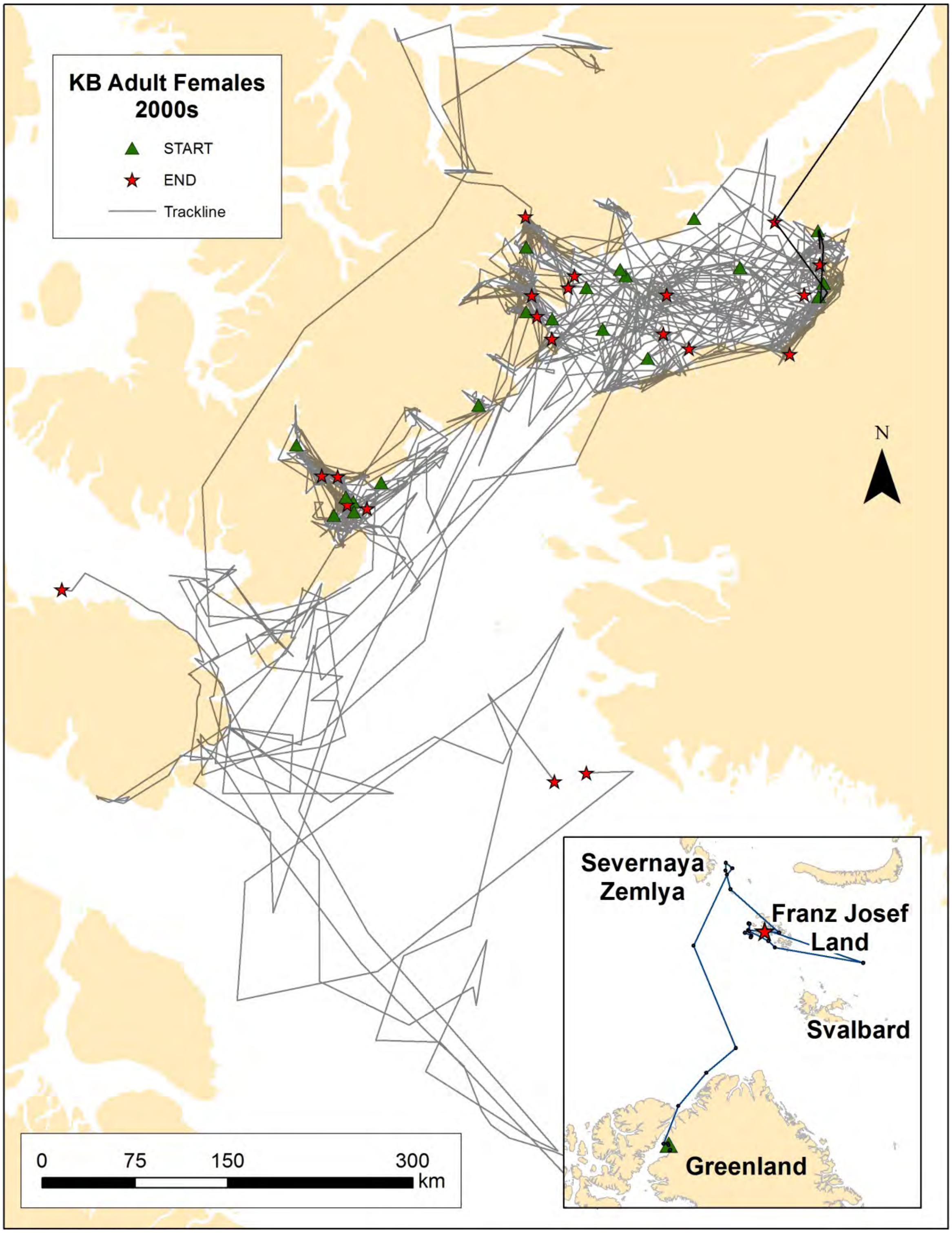


Figure 2.15. Tracklines from n=9 adult male polar bears satellite tagged with ear tags in 2012 and 2013 in KB.

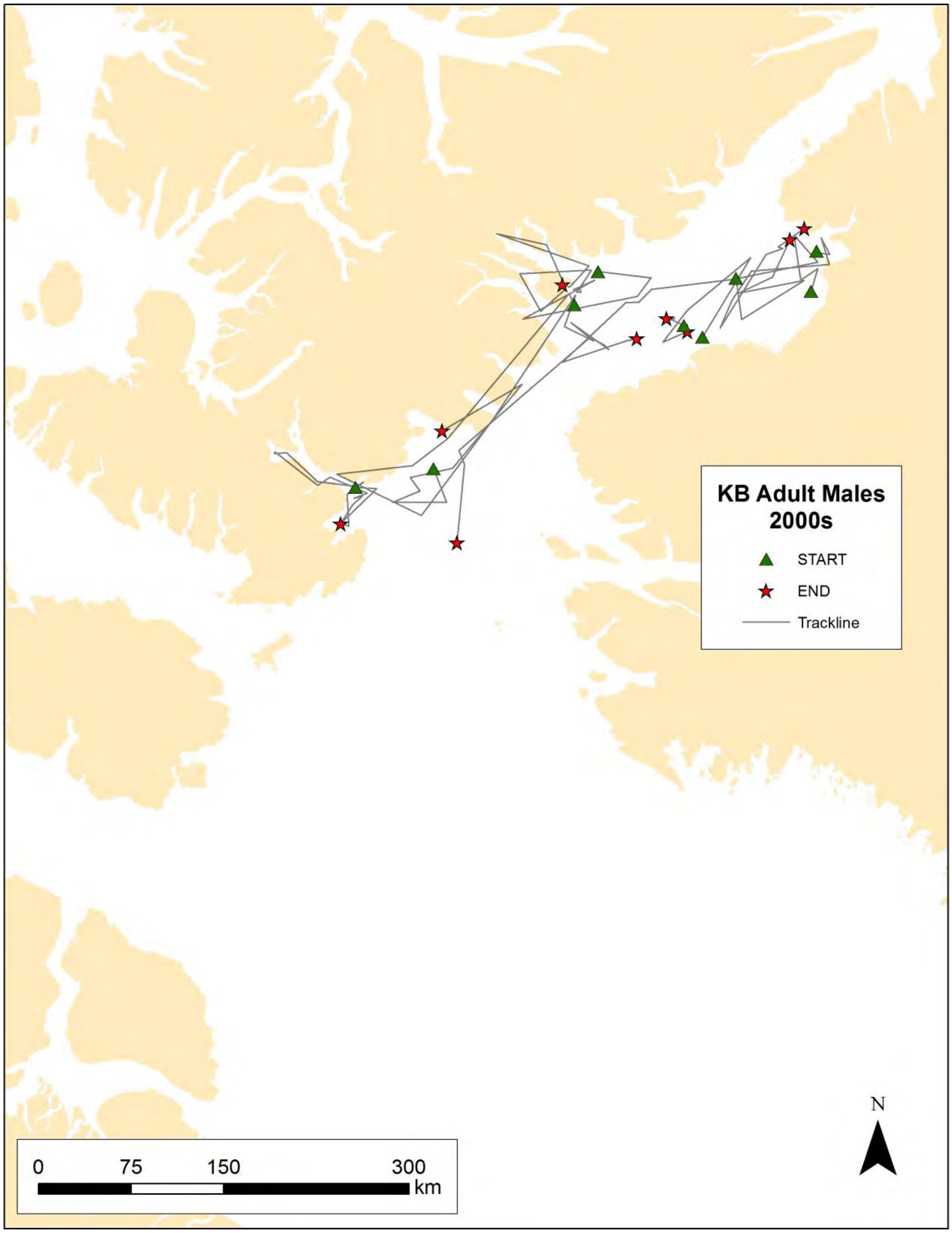


Figure 2.16. 95% kernel ranges for bears captured in 1990s and 2000s in BB by season (winter, spring and summer). See Table 2.4 for areas, overlap and tests for significance between decades.

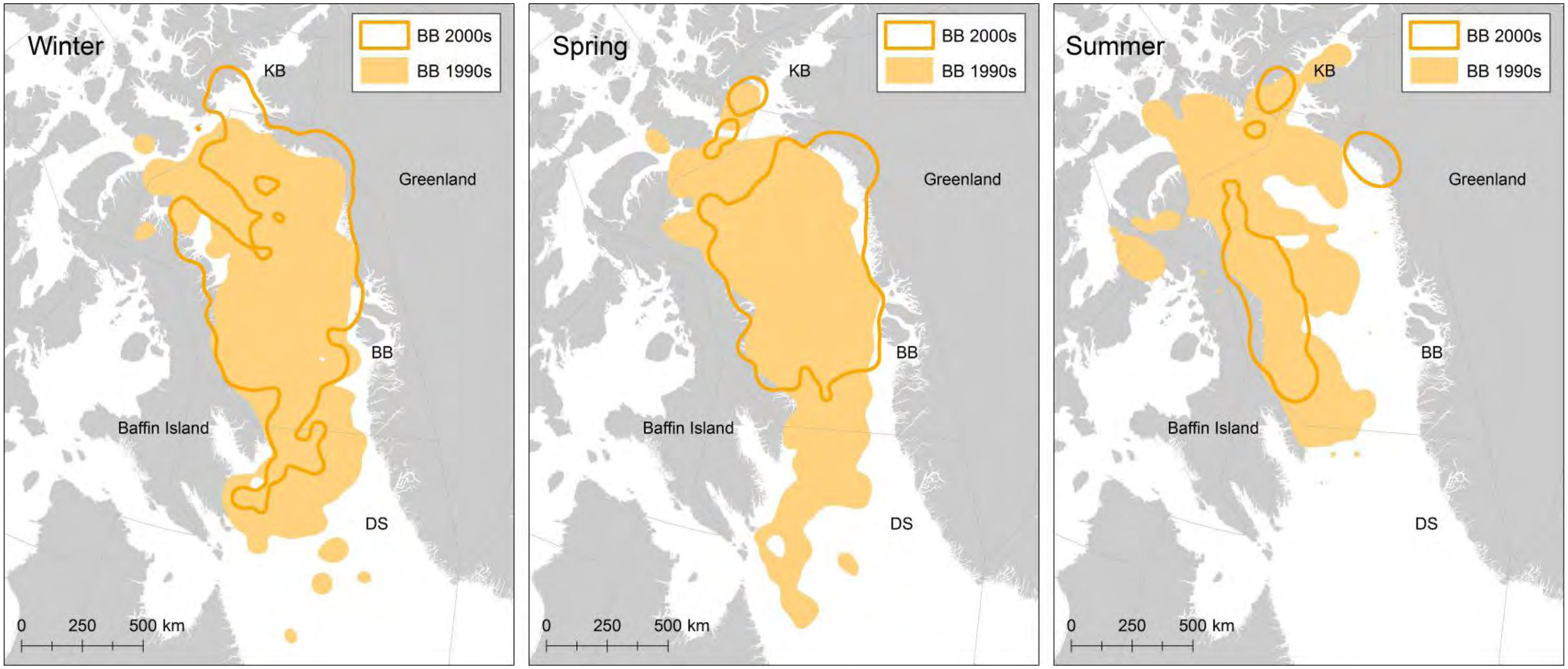


Figure 2.17. Matrix of home ranges shown by month in Baffin Bay for collared adult females in the 1990s and 2000s.

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.

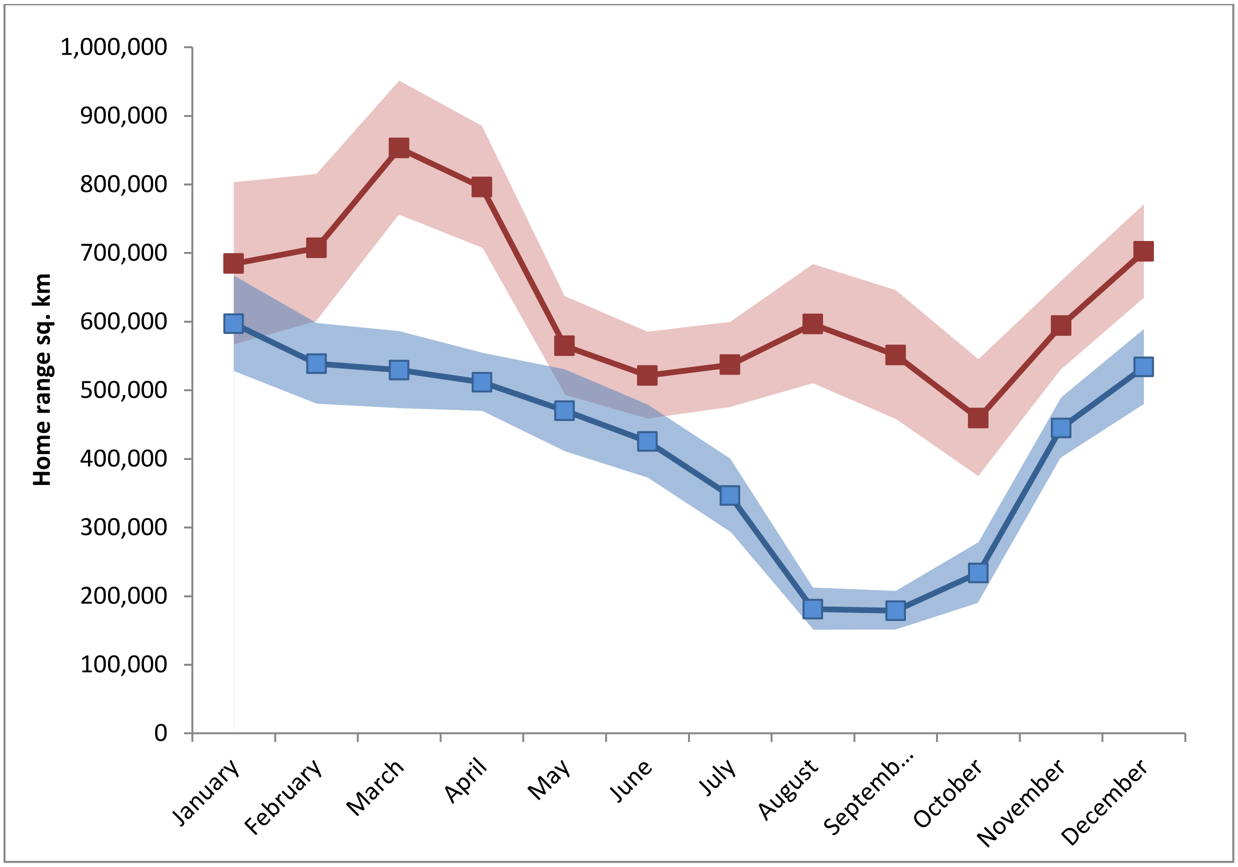


Figure 2.19. 95% kernel ranges for adult female bears captured in 1990s and 2000s in KB by season (winter, spring and summer).

See Table 2.4 for areas, overlap and test for significance between decades.

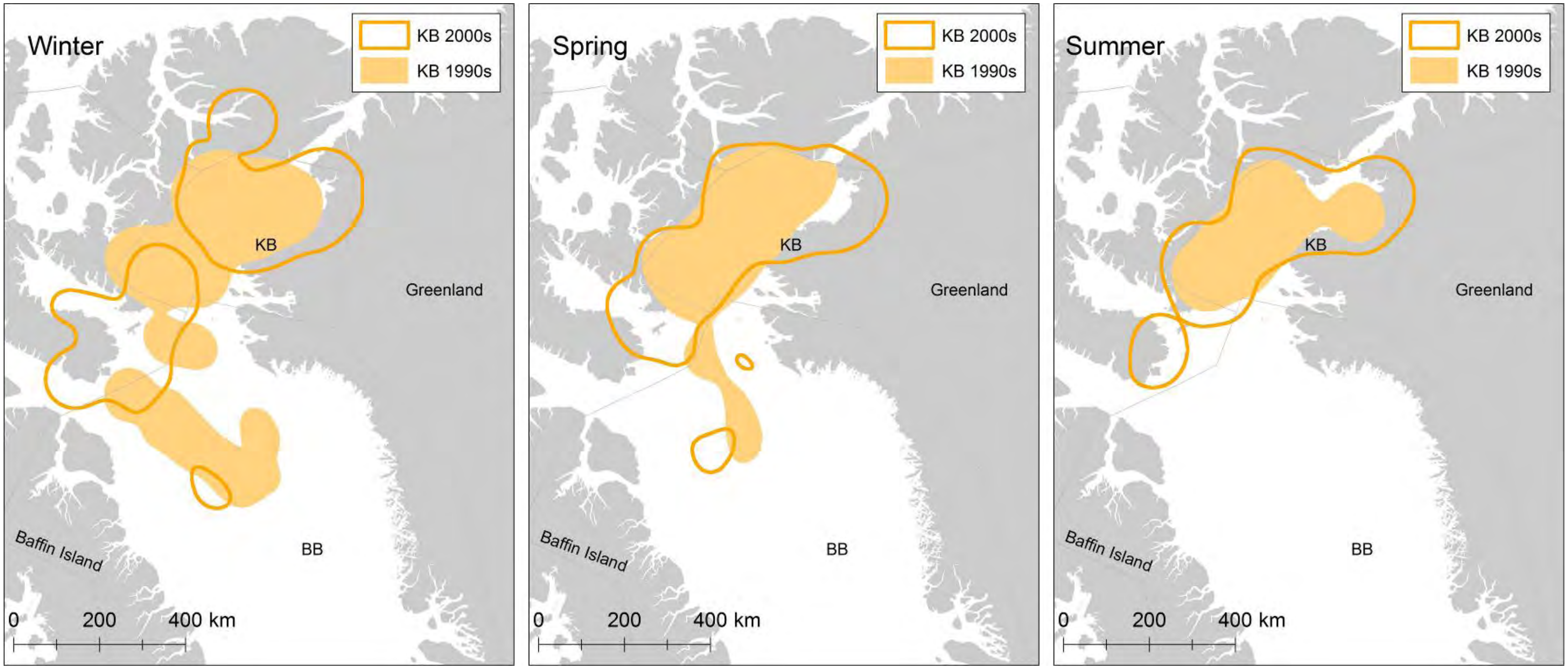


Figure 2.20. Matrix of home ranges shown by month for adult female polar bears in Kane Basin in the 1990s and 2000s.

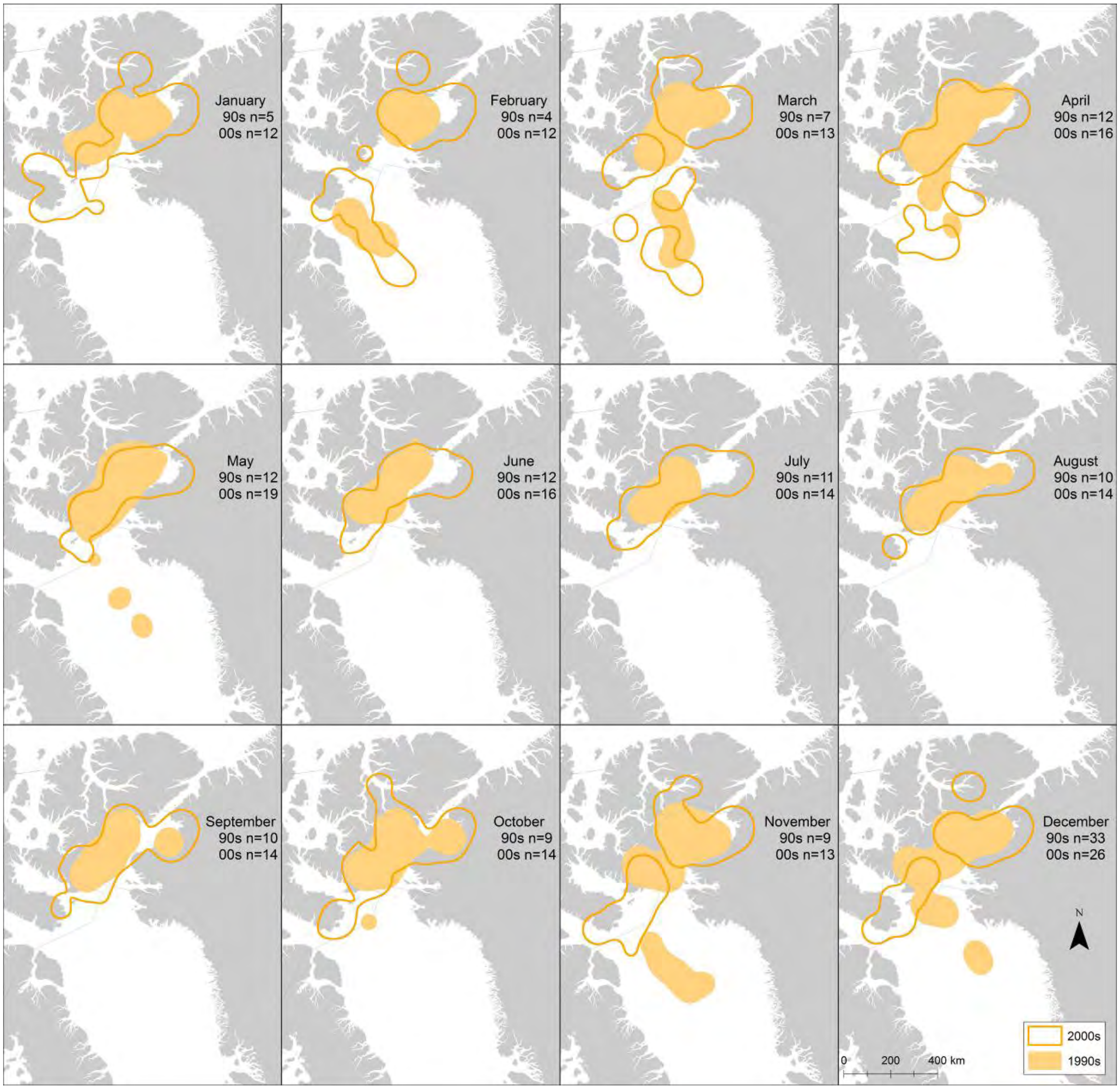


Figure 2.21. Home range sizes between decades for adult female polar bears in KB in the 1990s (red, n=12) and 2000s (blue, n=20). Line represents the mean values by month and shaded area +/- 2 SE.

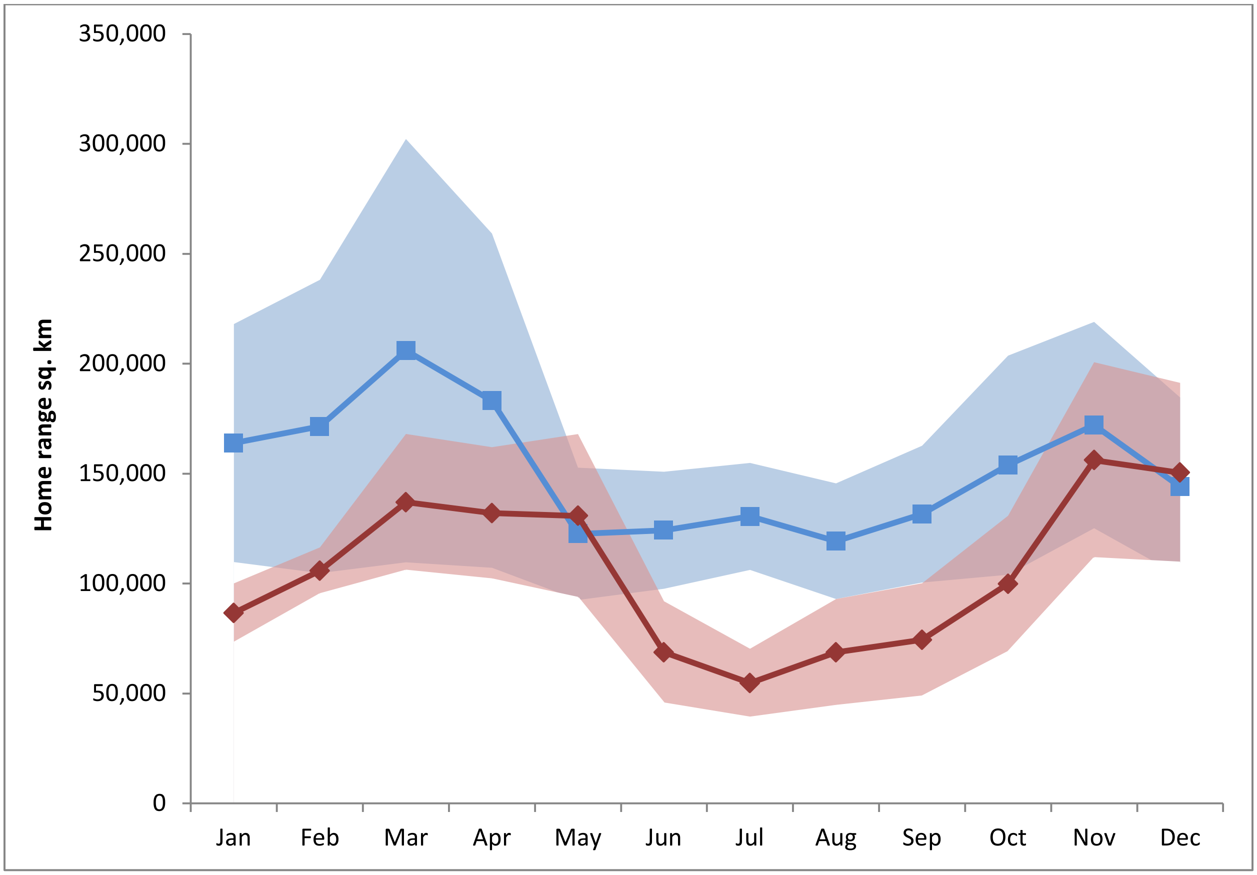


Figure 2.22. Box plots shown by season of median latitude for adult female polar bears in BB in the 1990s (n=43) and 2000s (n=38). Plot excludes the bears that are resident in Melville Bay though inclusion of these bears did not change the significance of the results.

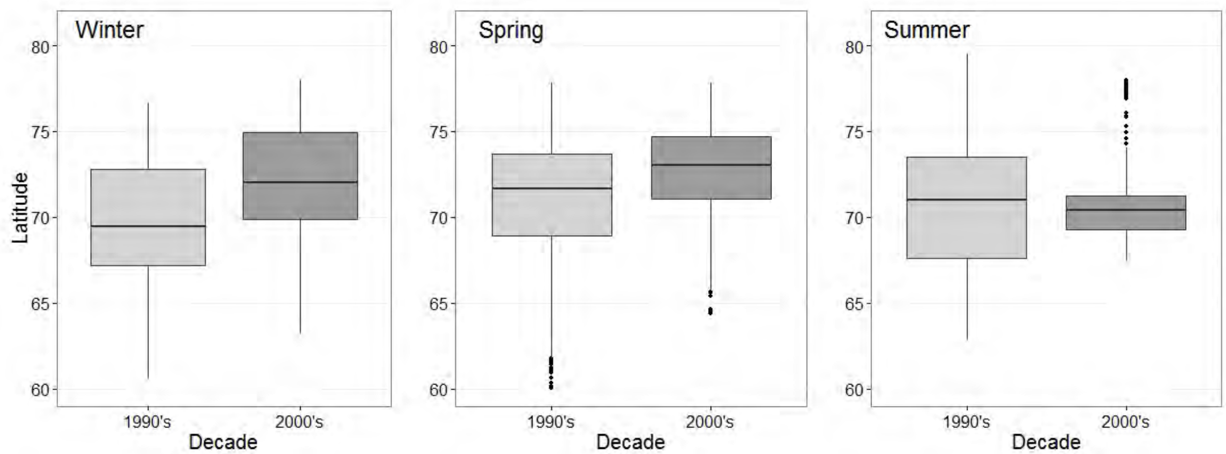


Figure 2.23. Box plots by season of median latitude for AF bears in KB in the 1990s (n=12) and 2000s (n=20).

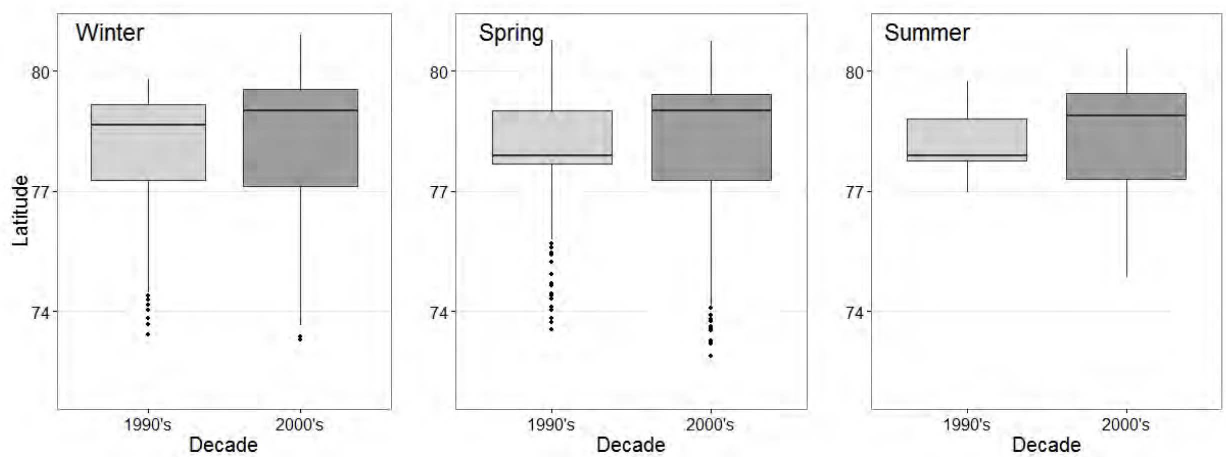


Figure 2.24. Plot of departure timing from region of origin for BB and KB bears in the 1990s and 2000s where departures of any length (min 4 days) were considered. See Table 2.3 for sample sizes.

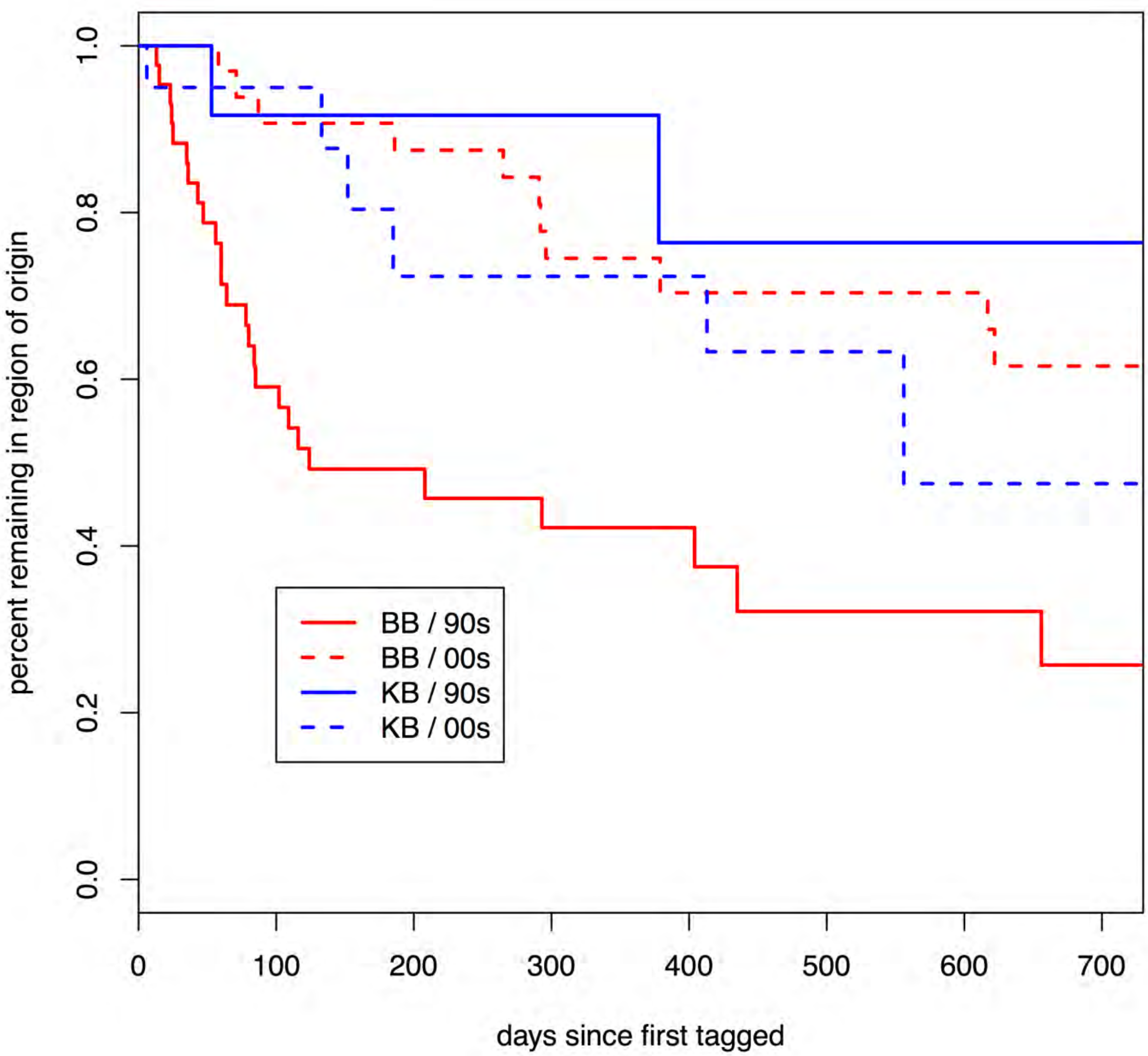


Figure 2.25. Plot of departure timing from region of origin for BB and KB bears in the 1990s and 2000s where only departures 30 days or greater were considered. See Table 2.3 for sample sizes.

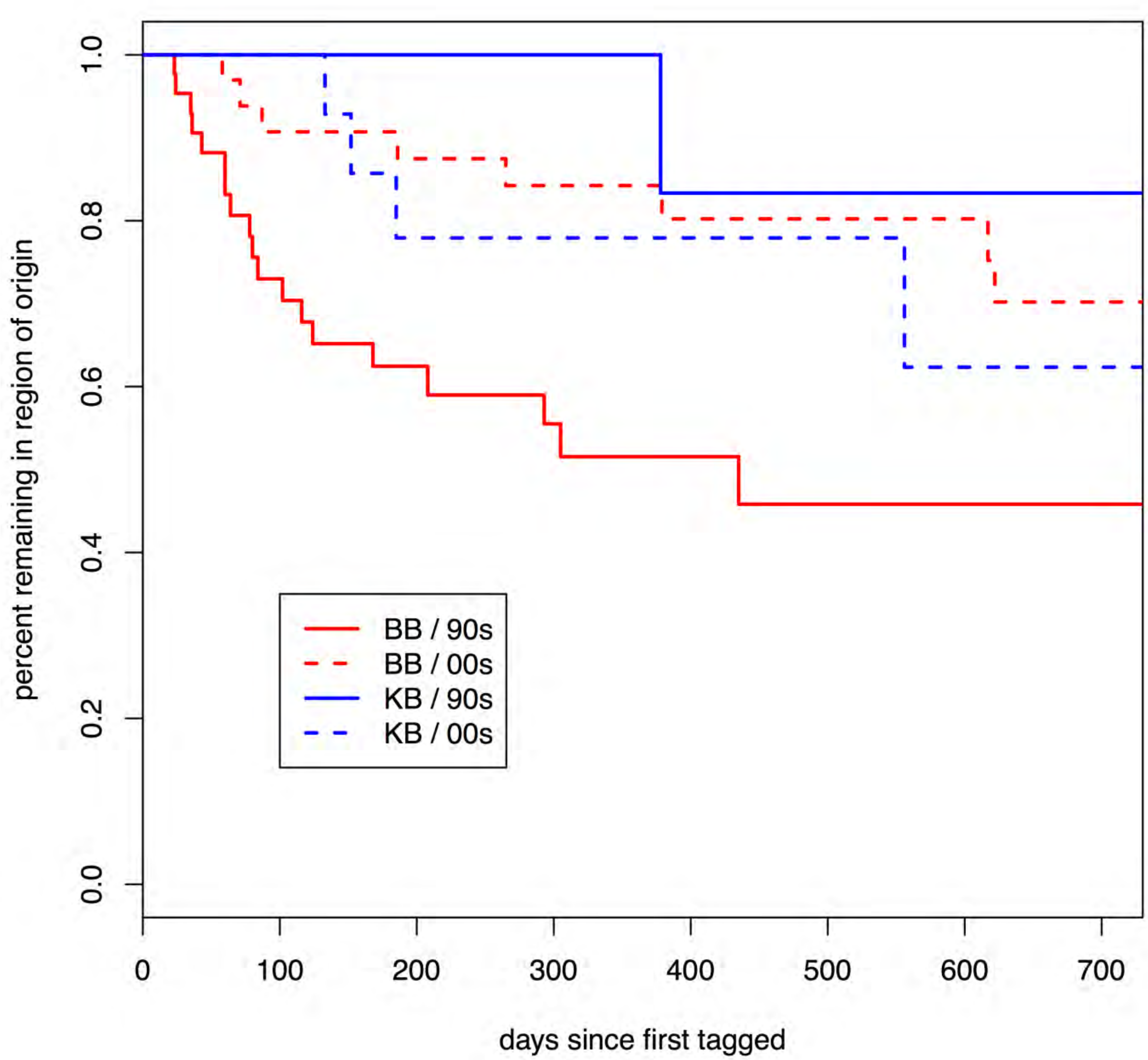


Figure 2.26. Distances (km) between mark and recapture locations of polar bears in Baffin Bay, 2011-2013. Adult females (AF), adult males (AM), cub-of-the-year (CO=COY), subadults (SA), yearlings (YR). Median distance is represented by the black line within each box. Box represents the interquartile range. Whiskers represent maximum and minimum values. Symbols denote significant differences between groups (Bonferonni correction for multiple comparisons, alpha = 0.05).

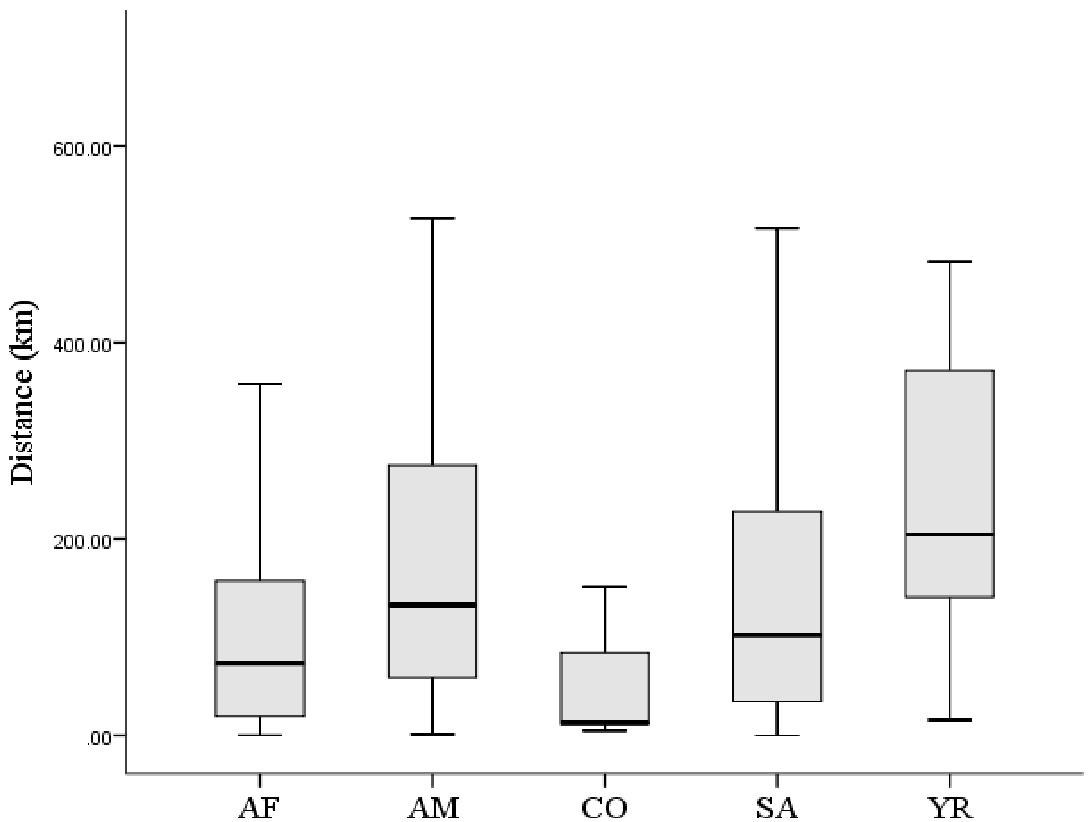


Figure 2.27. Relationship between capture-recapture interval and straight line displacement distance for 29 bears that moved between Baffin Bay and Davis Strait as detected by capture and recapture. Median distance is represented by the black line within each box. Box represents the interquartile range. Whiskers represent maximum and minimum values.

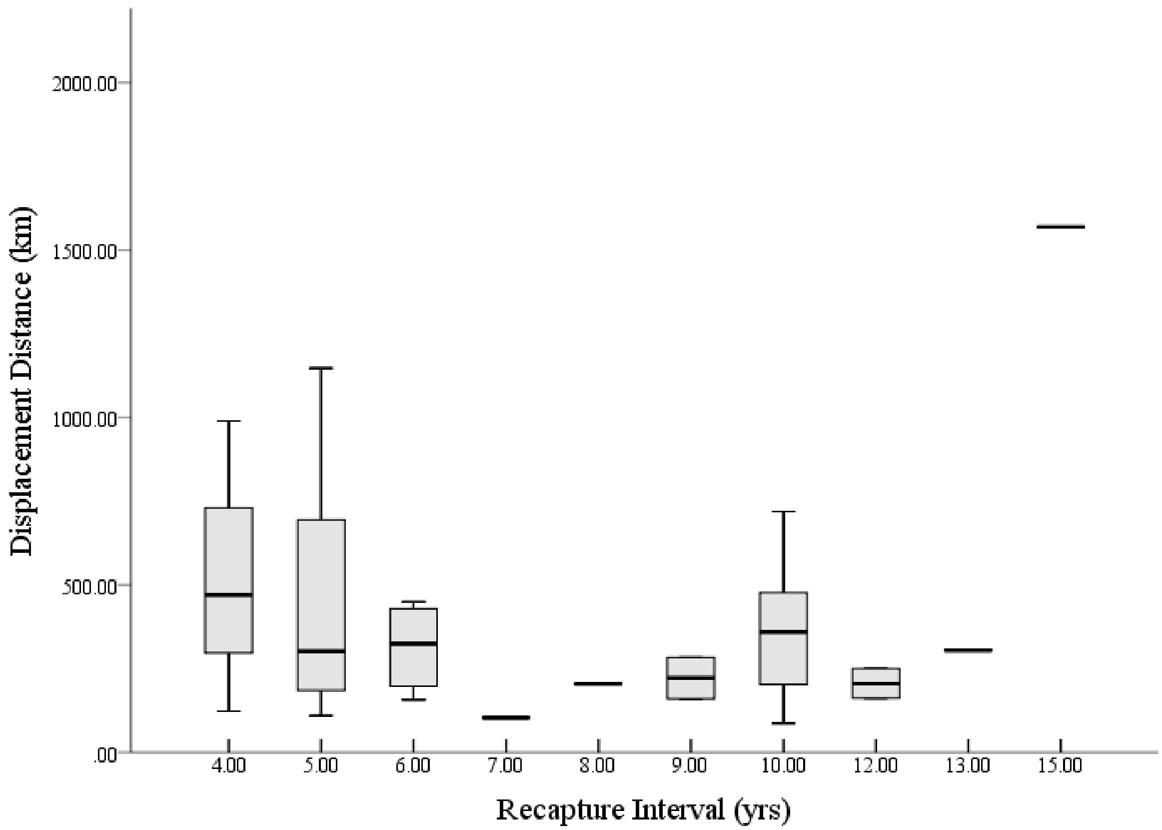


Figure 2.28. Frequency distribution of the distance between capture location and the boundary of the Baffin Bay (BB) and Davis Strait (DS) polar bear subpopulations for 29 individuals that made inter-subpopulation movements as detected by capture and recapture (grey bars), 1991-2013. Distances between 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.

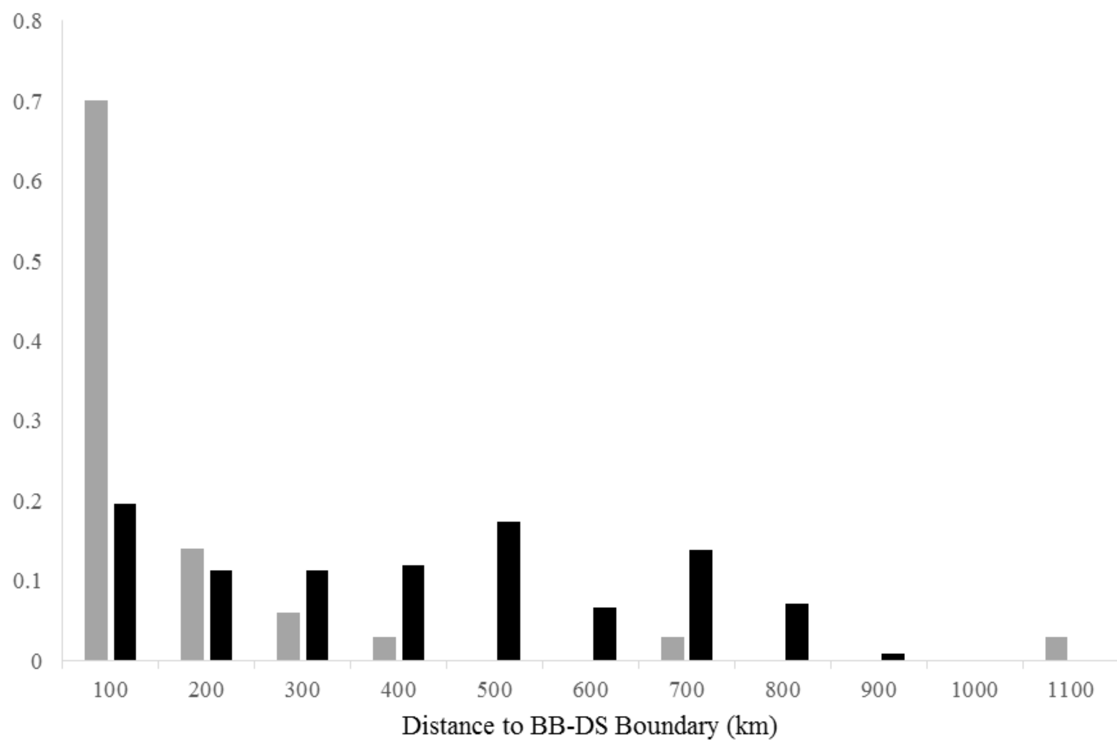
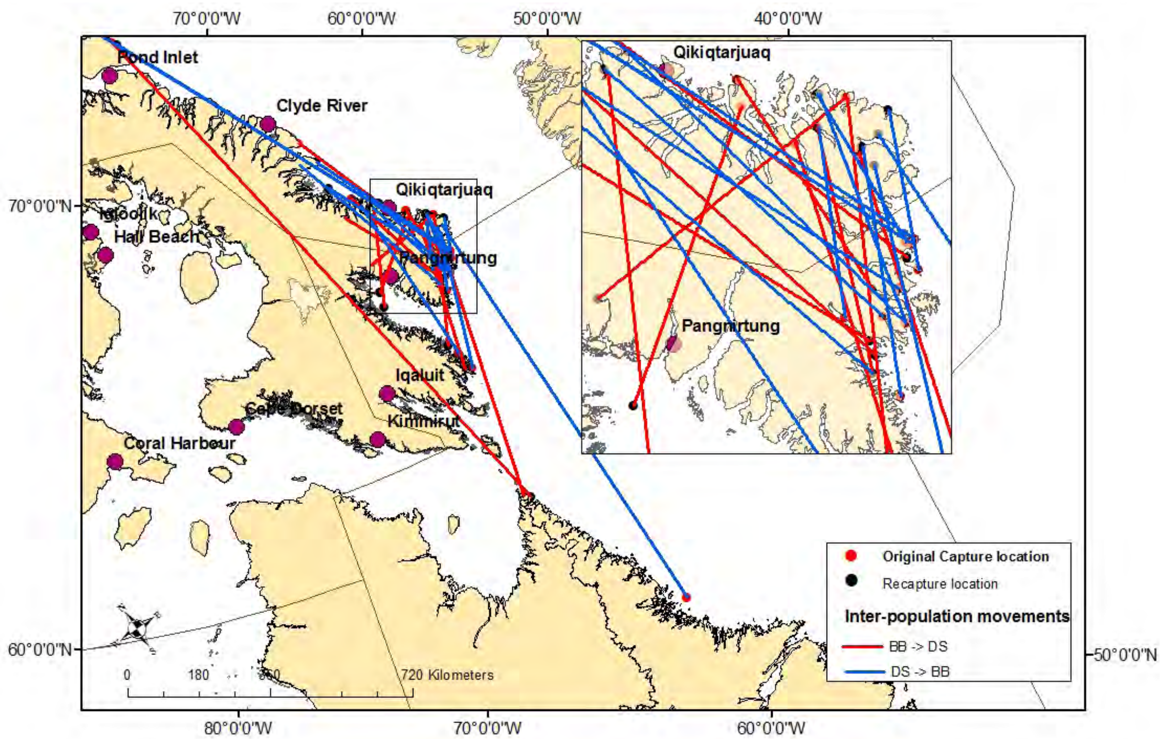


Figure 2.29. Capture and recapture locations of bears known to have made inter-subpopulation movements between mark-recapture sampling sessions in Baffin Bay (BB) (1990-97), Davis Strait (DS) (2005-07), and Baffin Bay (2009-2013).



CHAPTER 3

REASSESSING THE 1990S BAFFIN BAY DATA FOR BIAS AND COMPATIBILITY WITH THE 2010S DATA

KEY FINDINGS

- This chapter evaluates patterns in the 1990s physical MR data, including non-random and incomplete sampling, and the resulting potential for bias in estimates of demographic parameters.

- The 1990s MR sample size was small (average 229 total captures per sampling year), relative to the 2010s (average 470 total biopsies per sampling year), and the number of recaptures in the 1990s was low. There were few dead recoveries during the period between MR sampling studies (1998-2010), particularly in the latter years. Small sample sizes make it difficult to estimate demographic parameters and assess subpopulation trend, limiting both the strength of inference that can be drawn from the 1990s data and our ability to quantify and reduce bias in estimates of demographic parameters.

- The spatial distribution of polar bear physical captures and biopsy samples for the MR studies in the 1990s and 2010s was significantly different. In the 2010s, a larger fraction of bears were captured inland from the coastline, and inside fjords along Baffin Island.

- The difference in distribution of captures between sampling periods was not due to changes in habitat use. Analyses of satellite telemetry data from adult females, providing an unbiased assessment of land use between decades, showed no differences in distance inland or elevation for onshore bears between the 1990s and 2010s. Thus, the difference in capture distributions were a function of different sampling effort, with less effort expended away from coastlines and inside fjords in the 1990s.

- Consistent with the differences in sampling effort and temporary emigration between the 1990s and 2010s, there were significant differences in the composition of the MR samples (e.g., the proportion of bears within each age-sex class) between these two periods. Specifically, adult females were under-represented in the 1990s samples.

- The spatially-defined sampling area (km^2) in Nunavut encompassed the capture and biopsy locations in both decades and represented a minimum area sampled. The sampling area in the 1990s survey was less than ½ of that sampling in the 2010s. The 2010s sampling area encompassed most fjords along the coast and more inland habitat. To evaluate potential biases associated with the smaller sampling area of the 1990s, MR analyses and estimated parameters were compared from two datasets: (1) all 2010s MR data, and (2) a geographic subset of the 2010s MR data that was comparable to the sampling area in the 1990s (Chapter 5).

- In the 1990s there was likely a high degree of temporary emigration from the sampling area on the Baffin Island coast because bears used sea ice offshore in Baffin Bay or in the archipelago in summer. Significantly less sea ice was available in the 2010s and temporary emigration was lower. In the 1990s, ≤30% of radio-collared female bears were inside the sampling area during the MR sampling periods, compared to 70-80% in the 2010s. This suggests that a potentially significant proportion of bears were not available for capture each year during the 1990s, though sample sizes for analysis were small. Completely random temporary emigration from the sampling area should not result in biased demographic parameters. However, the degree of temporary emigration in the 1990s appeared variable and dependent on environmental conditions; and small samples sizes made it difficult to rule out significant bias.

- Additional sources of temporary emigration in the 1990s were non-random and linked to the reproductive cycle of females. Adult females in reproductive classes that were likely pregnant in fall moved farther inland on Baffin Island (e.g., to find suitable denning habitat), compared to non-pregnant females, which likely contributed to the under-sampling of adult females in some years in the 1990s because of the lack of inland sampling.

- There also were technical challenges with the 1990s MR data. Within the 1990s MR data there was uncertainty in identifying bears that were located with the aid of radio-telemetry vs. those located by standard search (i.e., random encounter). Original capture records could not be located and were inferred by comparing available information to the capture history files compiled for the 1990s BB demographic analysis. This uncertainty could result in bias, because knowing which bears were located by telemetry was important in the most-supported MR models for the 1990s data.

- Relative to the 2010s data, the 1990s data were characterized by relatively small sample sizes, incomplete geographic sampling, a likely higher degree of temporary emigration for bears that remained on sea ice during the summer, and potential non-random temporary emigration for adult females that moved farther inland to den. These issues led to an increased potential for bias in estimates of survival and abundance from the 1990s data. As a result, demographic parameters estimated from 1990s and 2010s BB data are not directly comparable and there is a limited ability to evaluate subpopulation trends.

3.1. Background

Accurate knowledge of demographic parameters (e.g., survival, abundance) is important for wildlife management decisions such as determining sustainable harvest levels and evaluating subpopulation viability. Mark-recapture (MR) studies are used to estimate demographic parameters because it is generally not feasible to monitor every individual in a subpopulation.

The results from MR studies can be biased by several factors, including heterogeneity in recapture probability (p) that is not accounted for through the choice of sampling design or modeling approach (Williams et al. 2002). The magnitude of bias is generally largest for abundance (Pollock et al. 1990) although estimates of survival probability can have meaningful bias as well (Devineau et al. 2006). Estimating accurate and unbiased demographic parameters for polar bears is particularly challenging. First, sample sizes are relatively small due to challenging environmental and logistical conditions, and the high cost of Arctic fieldwork. Second, polar bears are often distributed across large landscapes at low densities. Only a fraction of the study subpopulation may be accessible to researchers, and this fraction may change from year to year based on environmental conditions and logistical constraints. This limits sample sizes, leads to difficulty in delineating subpopulation boundaries, and means that the effective study subpopulation may be different than the biological population of interest. Third, the high mobility of polar bears and inter-annual variability of their sea-ice habitat can lead to nonrandom movements (i.e., temporary emigration) with respect to the sampling area. Fourth, female bears may be less-observable or unobservable for several months when pregnant or associated with maternal dens, leading to an 'unobservable state'. Fifth, the three-year reproductive cycle of polar bears makes it difficult to estimate reproductive rates and their relationships with environmental conditions. Finally, relatively long-term datasets are required because of the long life span of polar bears and high inter-annual variability in the Arctic environment.

In recent years, methodological advances have led to an increased ability to detect, quantify, and mitigate bias in demographic parameters from MR studies arising from the challenges listed above. Advances include noninvasive genetic methods to increase sample size

(Lukacs and Burnham 2005); multiple sampling occasions per year under a "robust design" (Kendall et al. 1997); spatially-explicit models to account for heterogeneity in recapture probability as a function of site fidelity (Royle et al. 2014); models with "unobservable states" to account for temporary emigration (Schaub et al. 2004); and models that integrate data from multiple sources (Peñaloza et al. 2014). Some of these methods have been employed for polar bears, whereas others have not been used due to lack of familiarity or practical limits on the types of sampling that can be conducted.

The MR study of the Baffin Bay subpopulation 2011-2013 incorporated noninvasive genetic sampling and modelled live-recapture and dead-recovery data in the same analytical framework. Both of these approaches increased sample sizes and reduced susceptibility to some types of bias. Nonetheless, there remained major challenges to the application of MR models to the Baffin Bay data, and in this chapter we evaluate sampling and biological issues that have the potential to introduce bias in estimates of survival and abundance. Similar investigations of bias have become a standard part of MR studies for polar bears (e.g., Regehr et al. 2010), and are necessary to understand the strength of inference that can be drawn from MR studies. In this chapter we focus on reassessing the 1990s BB data because, compared to the 2010s data, the 1990s data had smaller sample sizes, reduced geographic coverage, and other uncertainties and limitations. This assessment directly informs our ability to compare results from the 1990s and 2010s data and evaluate trends in polar bear survival and abundance between sampling periods.

Distribution of Mark-Recapture Sampling on Baffin Island

Prior to the 2011-2013 survey of the Baffin Bay subpopulation, MR sampling occurred during several periods. Initial sampling was conducted during the 1970s (northern Baffin Island

and Bylot Island, near Lancaster Sound), early 1980s (east-central Baffin Island), and late 1980s to early 1990s (Canada and Greenland, as part of movement studies; Figure 5.2; Taylor et al. 2005). Early sampling efforts were generally restricted to spring-time and primarily occurred on landfast and nearshore pack ice. These studies documented that an unknown but likely large proportion of the subpopulation was on sea ice farther offshore during the spring and therefore unavailable for capture. We excluded these early data from present analyses (*cf*. Taylor et al. 2005, in which these early data were included) because the early sampling occurred in a different season (i.e., spring) and was spatially variable and restricted. Additionally, lack of tissue samples from early sampling precluded genetic identification for use in the present study.

In 1993 –1995 and 1997, more systematic sampling occurred during fall ice-free seasons (during September and October) on Baffin and Bylot islands (Figure 3.1). There was no fall sampling in 1996 due to logistical and resource constraints. These data formed the core of the study reported by Taylor et al. (2005) who estimated the number of polar bears in Baffin Bay at 2,074 (95% confidence interval: 1544-2604) in 1998. Taylor et al. (2001) indicated that a large majority of polar bears were onshore in summer retreat areas on Bylot and Baffin islands during the autumn. Taylor et al. (2005) reported that search effort during the 1990s was uniform and systematic across the coastal regions, islands, and inland reaches of Baffin Island. Consequently, Taylor et al. (2005) suggested that the autumn onshore sampling in 1993-1995 and 1997 provided improved coverage of the subpopulation and more reliable abundance estimates compared to those derived from the 1980s BB data, which Taylor et al. (2005) suggested were biased low.

In 2011-2013 we completed a second fall-time MR sampling study (August – October) on the coasts of Baffin Island (Figure 3.1). Data from West Greenland were also collected (see

Chapter 5, Figure 5.8). During this study, new data on movements and spatial distribution of bears were also obtained via satellite telemetry in BB and KB. This information was used to assess subpopulation boundaries (Chapter 2) and habitat use relative to the 1990s (Chapter 4), but also to improve MR study design (i.e., stratify the study site; Chapter 5) with the objectives of reducing heterogeneity in capture probabilities and more efficiently allocating survey effort. The 2011-2013 study (see Chapter 5) was largely modeled after Taylor et al. (2005) in that bears were targeted during the ice-free season, to obtain estimates of abundance and vital rates that might be comparable to Taylor et al. (2005) therefore useful for assessing trend.

Here we compare the spatial and temporal distribution of physical captures and biopsy sampling on Baffin Island for sampling 1993-1995 and 1997 vs. sampling during 2011-2013 (referred to as the "2010s"). The goal is to evaluate whether there were important differences in sampling, which could lead to different biases or different definitions of the effective study subpopulations (e.g., if a large group of bears was systematically missed in one study period, then the effective study subpopulation for that period would be smaller). Field records (e.g., Global Positioning System helicopter logs, navigation maps) delineating survey effort 1993-1995 and 1997 were unavailable. Therefore, we plotted sighting data from Taylor et al. (2005) in a Geographic Information System (GIS; ArcMap 10.2, ESRI, Redlands, California, USA) to examine the spatial distribution of captures compared to the 2010s. We also used historic and current radio telemetry data to identify whether potential differences in capture locations were influenced by changes in the onshore movements and habitat use of polar bears.

Methods – Maps of physical capture and biopsy sampling locations (hereafter collectively referred to as "captures") on Baffin Island suggested that captures in the 1990s were more limited to coastal areas, whereas captures in the 2010s included bears located farther from the coast and deep inside fjords, including higher altitudes (Figure 3.1). We examined the hypothesis that the discrepancy in capture locations across periods reflects differences in sampling effort rather than a shift in the onshore distribution of bears. We calculated the distance to the nearest coastline and the distance to the smoothed outer Baffin Island coastline for each capture location in the 1990s and 2010s. The smoothed coastline followed the contour of the true physical coastline of Baffin Island, but was smoothed across fjords with a straight segment orthogonal to the fjord direction. We smoothed fjords only when the distance across the mouth of the fjord was ≤ 7 km using an Azimuthal Equidistant projection (WGS84 datum). We calculated the distance to both coastlines (original and smoothed) for all captures of independent bears (i.e., age 2 or older) that were located on mainland Baffin and Bylot islands (i.e., not on offshore islands) and were successfully genotyped.

We compared the distance-to-coast results to locations of radio-collared bears onshore during the 1990s and 2010s to evaluate whether differences in capture locations reflected differences in sampling effort or differences in the distribution of bears. Given that recent analyses of movement data suggest significant changes in sea-ice habitat use and onshore timing (Chapter 4), we considered the possibility that bears had also changed their behavior and habitat use while on land. First, we verified that the sample of 1990s bears collared in the fall on Baffin Island were comparable to the sample of 2010s bears collared in the spring in West Greenland, by assessing what fraction of spring-collared bears used the area on Baffin Island where bears were collared in the fall (see details in Chapter 2). Overall, 92% of the 2010s spring-captured bears used the fall collaring area. This suggests that, although radio-collaring occurred in different seasons and areas across the two time periods, the collared bears exhibited similar movement and habitat use patterns, and therefore provided comparable data for evaluating onshore habitat use across time periods.

Using satellite telemetry data, we calculated the distance inland from the smoothed coastline and Digital Elevation Model (DEM) elevation (m) for all locations of collared female bears during summer months (August-October). We used land covariates derived from the 22 m^2 ASTER GDEM for all positions in Canada (http://www.jspacesystems.or.jp/ersdac/GDEM/E/4.html). We only used adult female bears on Baffin Island and calculations excluded resident bears that remained year-round on the Melville Bay glacier ice.

We also examined distance to the smoothed Baffin Island coastline for adult females as a function of reproductive status (captured alone, as mating pairs; or with COY, yearlings, 2-year old cubs) to evaluate whether this factor may have influenced temporary emigration with respect to the sampling area (particularly the nearer-shore sampling area in the 1990s). For this specific analysis (reproductive state examination) we only examined adult females in the year of collar deployment because their reproductive status was known at the time of capture in spring, thus could be assumed in fall. We excluded bears on sea ice during August-October.

Results – The mean distance of captures to the smoothed coastline was smaller in the 1990s ($\bar{x}$= 5.1 km, SD = 7.2, n = 438) compared to the 2010s ($\bar{x}$= 8.6, SD = 11.9, n = 766, Mann-Whitney U test: z = 3.4, P < 0.001). Detailed results are provided in Table 3.2. Furthermore, a greater proportion of independent bears were captured near the smoothed coastline during the 1990s than the 2010s (Figure 3.2). For example, 84% of captures occurred within 10 km of the smoothed coastline during 1993 – 1997, compared to 72% of captures during 2011 – 2013. Similarly, one independent bear was captured > 35 km from the smoothed coastline during the 1990s sampling, whereas 28 independent bears were sampled > 35 km from the smoothed coastline during the 2010s. The corresponding analysis using satellite telemetry found no significant differences in the distance of adult females from the smoothed Baffin Island coastline between the 1990s and 2010s; adult female bears on average in the 1990s were about a mean 17 km from the smoothed coast in August and September, where as in the 2000s they were about 13 km in those months, however standard errors were overlapping (Figure 3.4). Also, there were no differences in the mean monthly elevation used by adult females on Baffin Island between the 1990s and 2010s (Figures 3.4 and 3.5).

Satellite telemetry analyses further documented differences in the inland distance of adult females on Baffin Island as a function of reproductive status. Females that were most likely available to breed and become pregnant in spring (e.g., those captured alone, with 2 year old cubs, or as mating pairs in spring) were significantly farther inland in fall than adult females captured with COYs or yearling cubs (Table 3.2). This was especially pronounced for adult females captured in mating pairs (on average 27-35 km inland).

In contrast to analyses based on distance to the smoothed coastline, the distance of captures to the true coastline (not smoothed) was consistent between sampling periods (Figure 3.3), averaging 1.8 km (SD = 2.8) in the 1990s and 1.5 km (SD = 2.5) in the 2010s. This suggests that the difference in capture locations between the two sampling periods was largely due to less effort spent searching and capturing bears in the inland portions of fjords in the 1990s compared to the 2010s. For adult females, mean distances to the true coastline were 6.4 km (SD: 8.0) and 10.2 km (SD: 12.6) during the 1990s and 2010s, respectively (Figures 3.2 and 3.3).

Summary – The distribution of polar bear captures on Baffin Island differed significantly between sampling in the 1990s and 2010s. Specifically, the capture data indicate an under-representation of bears in fjords and inland regions during the 1990s (see also Chapter 5). Satellite telemetry location data, which were collected from independent bears over several years and were not influenced by which areas were searched in any given year, did not suggest a shift in the onshore distribution of polar bears. Given that no changes in adult female use of land habitats was detected (also see Chapter 4 terrestrial resource selection), the differences in capture distribution can be attributed to differences in sampling. During the 1990s, capture effort was concentrated on islands, along the outer coastline, and near the mouths of fjords (Figures 3.2 and 3.4). During the 2010s, these areas were searched as well as the inland portions of fjords. This is particularly prominent in central and northern Baffin Island, where no captures were recorded beyond the mouths of fjords during the 1990s. In contrast to the southern parts of Baffin Island the central and northern parts have a higher and more mountainous terrain. Finally, satellite telemetry data also indicate that adult females in different reproductive status show a non-random pattern of moving farther inland, likely in search of locations to construct maternal dens. These findings suggest a non-random probability of being a temporary emigrant as a function of the multi-year reproductive state. Taken together, these findings suggest that restricted geographic sampling in the 1990s likely led to higher probabilities of temporary emigration from the sampling area during that time period, compared to the 2010s. Furthermore, the probability of being a temporary emigrant appears non-random. Variable and non-random temporary emigration is known to introduce bias into estimates of survival and abundance under some conditions (Peñaloza et al. 2014).

<u>Size of the Mark-Recapture Sampling Area on Baffin Island</u>

Following from the previous section, we calculated the sizes of the effective MR sampling areas on Baffin Island in the 1990s and 2010s.

Methods – We delineated the sampling areas based on the spatial distribution of capture locations. We first used ArcGIS to create 99% kernel density contour around all capture locations in each time period. We then adjusted this contour on a point-by-point basis to ensure that the final estimated sampling area was within 1 km of the outermost capture locations. The sampling area did not extend offshore, except in a few cases in the 1990s where there were offshore points, in which case the boundary was kept within 1 km of those points. When capture locations occurred inside a fjord, it was assumed that sampling effort occurred everywhere from the mouth of that fjord to the capture location.

Results – The size of the MR sampling areas differed significantly between the 1990s and 2010s. The estimated sampling area was ~28,700 km^2 in the 1990s and ~60,200 km^2 in the 2010s. The 2010s sampling area included most fjords along the Baffin Island coast and reached farther inland than the 1990s (Figures 3.6 and 3.7). Furthermore, the 1990s sampled area was almost entirely contained within the 2010s sampling area (Figure 3.8). This made it possible to subsample the 2010s capture data, using the restricted 1990s sampling area, for the purpose of evaluating the influence of the size of sampling area on estimates of abundance from the two time periods (see Chapter 5).

<u>Temporary Emigration Related to the Availability of Sea ice</u>

Previous sections in this chapter documented a smaller onshore sampling area in the 1990s, which likely resulted in higher and potentially non-random temporary emigration from the sampling area in the 1990s. Here we evaluate temporary emigration related to the availability of sea ice, which declined between the two study periods in all months of the year, including the summer when sampling on Baffin Island occurred. We used satellite telemetry data to assess the fraction of adult females that were located in the sampling area vs. out of the sampling area (including on the sea ice) in the 1990s compared to the 2010s.

Methods – For each year of sampling in the 1990s and 2010s, we used the specific date range when sampling occurred (Table 3.3) to calculate the proportion of independent collared bears located inside the sampling area, as well as the proportion of locations from each individual bear that were inside the sampling area. First, we identified independent adult females that were wearing functional radio-collars during the sampling period. To ensure that location data were independent, we did not include locations from the same sampling period on which an adult female was captured and fitted with a radio-collar. For example, if a bear was captured and collared on October 1, 1993, locations from that individual through October 8, 1993 were not used (Table 3.3). However, locations from that individual in 1994 and 1995 were considered independent and included in analyses. If a bear was captured in spring of a given year, her location data were considered independent by fall of that year. We considered a bear to be located inside the sampling area if that bear had 1 (or more) telemetry location inside the sampling area.

We evaluated average sea-ice conditions in Baffin Bay during each sampling period for the 1990s and 2010s to determine whether bears that were located outside of the sampling area, were located on sea ice. For each sampling period, we mapped mean sea-ice concentration during the week that encompassed the mid-point of the sampling period, using the Passive Microwave data (SMMR/SSMI) sea-ice concentration dataset from the National Snow and Ice Data Center (see Chapter 4). We then superimposed independent bear locations on the sea-ice concentration map, and visually examined whether bears located outside of the sampled area were in an area with a substantial concentration of sea ice and therefore likely using the sea ice.

Results – Table 3.3 shows the date range of MR sampling in each year. There were a maximum of 13 independent adult female bears transmitting with satellite collars during the 1990s sampling periods. The number of individuals declined over the course of the 1990s study because most collars were deployed at the beginning of the study and some collars failed (Table 3.4). The largest number of transmitting independent bears occurred in 1993, and by 1997 there were none. There were also a maximum of 13 transmitting independent bears during a given sampling period in the 2010s, although sample sizes remained higher through the 2010s due to longer collar attachment periods (Table 3.4). We found large differences in the proportion of transmitting independent bears using the sampling areas between 1990s and 2010s. In the 1990s, 0-20% of females occurred within the sampling area during the MR sampling period (Table 3.4, Figure 3.9 - 3.11). In the 2010s, 67-80% of females occurred within the sampling area during the MR sampling period (Table 3.4, Figure 3.12 - 3.14).

Sea-ice availability in Baffin Bay declined between the 1990s and 2010s. In the 1990s, a substantial amount of sea ice was available in offshore central Baffin Bay; within the Canadian archipelago, including around Devon Island; and in Lancaster Sound and Kane Basin (Figures 3.15-3.21). In 1993, when the largest proportion of independent bears was offshore during the sample period (Figure 3.15), there was a persistent area of sea ice available in central Baffin Bay. In other years in the 1990s, some bears were located on the advancing sea ice forming in northern Baffin Bay (Figures 3.15-3.17). In contrast, in the 2010s all bears (excluding resident bears in Melville Bay) were distributed on land on Baffin Island or in Kane Basin (Figures 3.18-3.20) during the sampling periods. There were no bears on offshore ice in the 2010s, because sea ice had melted completely in central Baffin Bay by July (see Chapter 4). The differences in sea-ice conditions between the 1990s and 2010s can been seen clearly using juxtaposed sea-ice concentration maps (Figure 3.21).

In addition to relatively fewer adult females being present in the sampling area during the 1990s, most bears with >1 location in the sampling area did not spend the entire sampling period there, but rather were passing through (Table 3.5). In the 1990s, approximately 44% of locations received for bears that used the sampling area, were located inside the sampled area (see Chapter 1 for information on location filtering and subsampling). In the 2010s, approximately 94% of locations received for bears that used the sampling area, were located inside the sampled area. Although sample sizes were small and unevenly distributed across years, the higher probability of bears in the 1990s being located outside the sampling area appeared largely due to the presence of sea ice, whereas in the 2010s sea ice was absent and bears exhibited reduced summertime movement rates (see Chapter 4).

Summary – Temporary emigration from the sampling area during the autumn sampling period has the potential to introduce bias into estimates of demographic parameters from this study. Our analyses suggest that the proportion of adult females (and presumably other sex and age classes) in the sampling area was likely lower in the 1990s compared to the 2010s, for two reasons. First, some bears located inland in the 1990s were not available to capture teams because there was apparently limited inland search effort, and in particularly bears were not captured in the deep inland portions of fjords. Furthermore, the location of bears from the coast—and therefore the susceptibility of bears to capture—appeared related to reproductive status, in which case the probability of being a temporary emigrant may have been nonrandom. Second, a proportion of radio-collared polar bears used offshore ice in the 1990s, whereas sea ice was less available in the 2010s and therefore a substantially higher proportion of bears were likely inside the sampling area. Because of small sample sizes that varied across years, we were unable to calculate precise estimates of temporary emigration rates or to evaluate the magnitude and direction nonrandom patterns (e.g., Markovian dependence) in a statistically rigorous manner. Nonetheless, multiple lines of evidence indicate higher temporary emigration in the 1990s, compared to the 2010s. The most likely effect of temporary emigration is an unknown but potentially meaningful negative bias in estimates of survival and abundance (Schaub et al. 2004, Devineau et al. 2006, Peñaloza et al. 2014).

Additional sampling considerations

Small sample sizes lead to multiple challenges into MR studies, including high variance in estimated parameters, small-sample bias, susceptibility to bias due to violation of modeling assumptions (e.g., un-modeled heterogeneity in recapture probability), and limited options for quantifying or mitigating bias (Williams et al. 2002). Compared to the 2010s data, sample sizes in the 1990s were small and had a low proportion of recaptures (Table 3.1). For example, the entire dataset for adult females (F2+ age group) included only 5 animals recaptured by standard search in 1995, and 14 animals recaptured by standard search in 1997 (note that numbers in Table 3.1 are higher, because they include "likely" recaptures and re-sightings of bears located by radio telemetry; see below). Furthermore, there were relatively few dead recoveries during the interim period when no sampling occurred (1998-2010), particularly in the later years. For example, an average of 1.3 research-marked females per year were recovered in the harvest, from 1998-2010. Conceptually, it is apparent that the small number of live recaptures during 1990s live-encounter sampling, the gap years between 1990s and 2010s sampling, and the small number of dead recoveries during the gap years contain a limited amount of information and will lead to estimates of demographic parameters that have substantial uncertainty and low resolution (i.e., that few demographic parameters can be estimated, requiring the estimation of "average" parameters over years or groups of animals).

There were significant differences in the composition of the MR samples (i.e., the proportion of bears within each age-sex class, based on initial captures) between the 1990s and 2010s in Baffin Bay (Table 3.1). There were more adult and sub-adult male captures in the 1990s, whereas there were more sub-adult and adult female captures in the 2010s. The proportion of total female captures in the1990s was less than the 2010s (mean annual proportion of age 2+ female captures : total 2+ captures, 1990s: 0.42; 2010s: 0.53; Table 3.1). Given the spatial segregation of bears by sex and age-classes and reproductive states (see section Distribution of Mark-recapture Sampling on Baffin Island), the apparent under-representation of females in the 1990s samples likely reflects at least in part the coastal-focused sampling protocols during that period, rather than true differences in the composition of the subpopulation (although we cannot rule out progressive depletion of males through the 2010s due to high harvest).

Development of an Individual Covariate to Explain Inland Habitat Use

Given the apparent differences in sampling effort between the 1990s and 2010s, the spatial segregation of bears by sex and age class, and differences in the composition of capture samples, we hypothesized that proximity to the coastline may explain variation in recapture probabilities. We also wanted to explore whether proximity to the coastline for an individual bear was nonrandom across years (e.g., whether bears captured inland were more likely to be recaptured inland). We assigned capture locations to either coastal or inland categories, using a threshold of 2 km from true and smoothed coastlines, and compiled contingency tables for individuals captured in multiple sampling periods. For individuals captured three or more times, we used only an individual's first two capture events and included only those bears initially captured as independent animals, since the locations of cubs-of-the-year and yearlings were dependent on the location of their mothers.

Use of inland areas appeared nonrandom. Individual polar bears initially captured inland from the true coastline were more likely to be recaptured inland in subsequent years (all data: $\chi^2 = 10.4$, $P = 0.0012$; 1990s only: Fisher's exact test $P = 0.10$; 2010s only: Fisher's exact test $P = 0.02$). Similarly, bears initially captured inland of the smoothed coastline were more likely to be recaptured inland (all data $\chi^2 = 18.1$, $P < 0.0001$), a pattern which was driven largely by the 2010s (Fisher's exact test $P < 0.0001$; 2010s only: Fisher's exact test $P = 0.21$; 1990s only). As such, we incorporated a proximity to coastline covariate for modeling recapture probability in demographic analyses (see Chapter 5).

<u>Challenges with Using the 1990s Radio Telemetry Data</u>

Some aspects of the 1990s radio-telemetry data were uncertain or unavailable, presenting challenges to the use of these data in the current analysis. As part of a study examining subpopulation delineation and spatial ecology (Ferguson et al. 1997, Taylor et al. 2001), a sample of adult female polar bears was fitted with satellite radio-collars in Baffin Bay (from both Canada and Greenland) during the 1990s. Some of these bears ($n = 14$) were captured on Baffin and Bylot Islands during autumn 1993 – 1997. Taylor et al. (2005) report that collared bears and their dependent young were often relocated using VHF during the 1990s study period. The probability of locating and recapturing a bear with a collar is likely higher than the probability of recapturing a bear without a collar. Therefore, a radio telemetry covariate, describing whether a bear was wearing a functional radio-collar that could have allowed it to be located by telemetry, was important for explaining variation in recapture probabilities; and all of the most-supported models in the 1990s included a radio telemetry covariate (Taylor et al. 2005). Taylor et al. (2005:209) reported that "The probability of autumn recapture was lower for females and yearling cubs than for adult males and sub-adults, except for radio-collared females and their young" which indicates that radio-collared females were recaptured using radio-location data. Unfortunately, the data archives did not include complete information on which bears were wearing functional radio-collars and located using VHF. Furthermore, in some cases where records could be located, there were inconsistencies among databases and historical hard-copy files. This presented a challenge to MR modeling because the live-capture data in the 1990s were sparse, particularly for adult females, and we anticipated that the additional records for bears likely recaptured using VHF would be important for explaining patterns in survival and recapture probability (see Taylor et al. 2005). To address this issue, we manually reviewed capture histories and covariates compiled for the previous Baffin Bay analysis. We compared these historical files with our available records to identify events in which a bear was likely located via VHF (see also Chapter 5). Based on this, we added 7 recapture events of 5 age 2+ individuals previously in the dataset, and 6 capture events of 5 age 2+ individuals not previously included in the dataset. We believe that this protocol accurately incorporated most of the data for polar bears captured by VHF in the 1990s, although some uncertainty remains given that the original data were not available.

Ramifications of Issues with the 1990s Baffin Bay Data

It is difficult to estimate demographic parameters and detect trends in parameters, for long-lived animals using short time-series of live-encounter data, especially when recapture rates are low, environmental variation is high, and the entire study subpopulation is not exposed to sampling effort on each occasion (Williams et al. 2002). The analyses described above identify specific challenges with 1990s Baffin Bay MR data that arise from both sampling issues and environmental factors. These challenges may lead to bias in estimates of survival and abundance, and ambiguity in the definitions of parameters being estimated (e.g., whether a model is estimating apparent survival, which reflects emigration from the study subpopulation, or true survival).

Survival – A statistical assessment of trends in polar bear survival between the 1990s and 2010s is not possible due to the short duration of live-encounter sampling periods, the large gap between 1990s and 2010s live-encounter sampling, low recapture probabilities, low numbers of dead recoveries, changes in the sampling area between the 1990s and 2010s, and evidence for changes in polar bear movements with respect to the sampling area. This conclusion was supported by computer simulations (T. Arnold, University of Minnesota, unpubl data) in Program MARK to generate datasets that resembled the actual Baffin Bay data but included a known effect (e.g., large reduction in survival), and evaluating the power of MR model to detect such effects (T. Arnold, University of Minnesota, unpublished data). In the context of small and variable sample sizes, a primary challenge for estimating survival is the difficulty of delineating temporary vs. permanent emigration from the study area, and the effects of emigration on estimates of survival. MR modeling was performed using Burnham models, which assume that emigration from the study subpopulation is permanent. Burnham models directly estimate the probability of permanent emigration (*F*) based on patterns in live-encounter data in conjunction with harvest data collected from an area that is larger than the MR sampling area. Under the Burnham model, the survival parameter (S) is technically defined as true survival (i.e., does not include an emigration component). However, research-marked bears that are harvested outside the sampling area may be temporary rather than permanent emigrants (i.e., the bears could have returned to the sampling area in future years, if they had not been killed), and the short duration of the study, small sample sizes, and likely high interannual variability in the probability of being a temporary emigrant (e.g., as related to sea-ice availability) make it difficult to delineate temporary vs. permanent emigration. Simulations suggested that the Baffin Bay data were too sparse to fit Barker models, which relax the assumption that emigration is permanent, and are capable of estimating temporary emigration rates, including non-random temporary emigration. The consequence of using Burnham models either with *F* estimated or with *F* fixed = 1 (i.e., assuming no permanent emigration if *F* is estimated), is that variation across individuals and sampling occasions in the probability of being a temporary emigrant is not explicitly accounted for, and therefore exists as variation in recapture probabilities. Heterogeneity in recapture probabilities has the potential to introduce bias into estimates of S (Schaub et al. 2004). The directionality of bias is often negative and its magnitude tends to increase in the final years of a study (Devineau et al. 2006). Furthermore, non-random patterns in temporary emigration are known to cause bias in estimates of survival (Kendall et al. 1997), and the availability of adult females for capture in the 1990s was related to their multi-year reproductive cycle. Interpretation of trends in survival between the 1990s and 2010s is further complicated because radio-telemetry data suggest changes in fidelity to the MR sampling study area between the epochs, and because the geographic extent of the MR study area itself changed. We conclude that estimates of survival from the current MR analysis of Baffin Bay data must be interpreted with caution. Although estimates of survival provide the basis for discussion and ecological interpretation, they are unlikely to be directly comparable between the 1990s and 2010s, and will require further analysis (e.g., regarding different assumptions about movements between epochs) if used in matrix-type models for subpopulation projections.

Abundance – Estimating abundance is one of the more difficult challenges in wildlife management (Williams et al. 2002). Deriving accurate estimates of abundance and evaluating trends in abundance over time require an appropriate study design and, especially, consistent distribution of sampling effort in time and space. In the current study, the difference between the distributions of captures in the 1990s and 2010s suggest that the sampling area on Baffin Island expanded substantially from the 1990s to the 2010s. Specifically, sampling was spatially restricted to a portion of the subpopulation's fall range during the 1990s, thus excluding bears with seasonal fidelity to inland areas. Furthermore, an unknown but potentially significant portion of the Baffin Bay subpopulation may not have been exposed to sampling in the 1990s due to the higher presence of sea ice, which some bears used throughout the year rather than coming onto land. We conclude that the abundance estimate in the 2010s, based on MR data from the entire sampling area, is not directly comparable to the previous 1990s abundance estimate. To investigate the extent to which differences in sampling affected abundance estimates from the 1990s and 2010s, we used the 1990s sampling area to create a subset of the 2010s data, and subsequently derived a 2010s abundance estimate based on this restricted subset of the data. We included only those 2011 – 2013 capture events that were located within the estimated 1990s sampling frame and completed supplemental demographic analyses (see Chapter 5). This analysis helped evaluate the potential biases associated with the more restricted area of onshore sampling on Baffin Island in the 1990s. However, it did not address the potential effects of polar bears using the sea ice in the 1990s. When there is temporary emigration from the sampling area, estimates of abundance from Burnham models represent the "superpopulation" (defined as all animals with a probability of moving through the sampling area, even if not every animal was actually in the sampling area on every sampling occasion). If temporary emigration from the sampling area is completely random, it will not introduce bias into estimates of abundance. However, nonrandom temporary emigration (e.g., if some individuals are often or always temporary emigrants) has a similar effect on estimates of demographic parameters from MR models as un-modeled heterogeneity in recapture probability, and generally introduces negative bias into estimates of abundance (Kendall et al. 1997).

MR model covariates – 1990s sampling bias may also impact the individual, geographic fidelity covariate (proximity to smoothed coastline). Analyses did not suggest a significant relationship between initial and subsequent capture locations in the 1990s, but this may be due to sampling (e.g., not enough effort was expended inland, to identify animals with fidelity to inland areas). The relationship is driven by the 2010s data. Also, the radio telemetry covariate may be biased in some unknown direction due to the uncertainty as to whether the subsequent capture of a collared bear was facilitated by the radio tracking. Sensitivity analyses outlined above may help better understand potential biases. Given the differences between the 1990s and 2010s, including epoch effects for the binary 'proximity to smoothed coastline' is important.

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Table 3.1. Summary table of live captures and dead recoveries during the mark-recapture study of the Baffin Bay polar bear subpopulation in Nunavut, Canada, and Greenland, 1993 – 2010. Shaded cells indicate that data were not possible due to an absence of marking or recapture.

	Initial captures						**Live recaptures**				**Dead recoveries**					
	Females			*Males*			*Females*		*Males*		*Females*			*Males*		
	Coy	**Yrl**	**2+**	**Coy**	**Yrl**	**2+**	**Yrl**	**2+**	**Yrl**	**2+**	**Coy**	**Yrl**	**2+**	**Coy**	**Yrl**	**2+**
1993	14	8	53	12	8	61					0	0	1	0	0	0
1994	26	13	65	16	9	77	0	5	0	14	0	0	3	0	0	7
1995	15	11	62	19	11	85	4	11	4	23	0	2	6	1	0	8
1996												1	8		0	7
1997	22	10	60	19	13	113		20		31	0	0	6	0	1	9
1998												0	3		0	11
1999													3			9
2000													0			8
2001													2			8
2002													0			11
2003													0			7
2004													1			7
2005													2			3
2006													3			6
2007													1			2
2008													2			4

2009													2			0
2010													0			1
2011	2	23	163	1	20	148		5		5	0	0	4	0	0	20
2012	40	30	221	35	30	192	3	41	0	54	0	0	8	0	2	14
2013	28	15	121	16	15	90	4	48	5	55	0	1	8	1	0	20
Totals	**147**	**110**	**745**	**118**	**106**	**766**	**11**	**130**	**9**	**182**	**0**	**4**	**63**	**2**	**3**	**162**

Table 3.2. Metrics for adult females satellite collared in the 1990s (fall) and 2010s (spring) for the distance inland from the outer Baffin Island coast. Distance is reported in km.

		August			**September**			**October**		
Adult Female Accompanied by	**N**	**Mean distance inland**	**SD**	**Count of locations**	**Mean distance inland**	**SD**	**Count of locations**	**Mean distance inland**	**SD**	**Count of locations**
1990s										
2YR	1							5.6	4.4	3
AM	0									
COY	15	10.8	14.2	10	19.7	15.1	13	9.6	5.9	46
YRL	12	6.0	5.6	3	18.0	17.8	25	8.4	5.8	41
ALONE	5				8.8	9.4	6	13.4	11.8	8
2010s										
2YR	5	13.5	9.3	25	27.0	8.3	20	16.2	13.5	11
AM -in spring	2	27.1	10.2	9	32.6	12.0	5	35.1	9.3	4
COY	2	5.5	4.8	3	7.5	4.3	13	3.6	4.3	11
YRL	7	3.5	5.0	20	6.8	6.2	33	6.2	7.3	27
ALONE	6	11.9	10.8	25	16.3	7.6	22	14.4	7.8	18

Table 3.3. Time periods when the BB fall sampling period occurred in each decade. These dates were used to asses if independent bears were in or out of the sampled area.

Year of sampling	Start	End
1993	23 August	8 October
1994	7 September	19 October
1995	17 September	19 October
1996	n/a	n/a
1997	21 September	29 October
2011	4 September	14 October
2012	26 August	29 September
2013	20 August	11 October

Table 3.4. The overall fraction of independent collared adult female (AF) bears found in the sampling range by year.

Year of sampling	n independent collared bears	n independent AF bears in the sampled area (minimum of n=1 location during date range)	% independent AF bears in the sampled area for each decade
1993	13	3	23
1994	5	1	20
1995	1	0	0
1997	0		
2011	12	8	67
2012	13	11	85
2013	6	4	67

Table 3.5. Independent BB adult female bears with satellite collars transmitting during the MR sample periods. Bears listed are only those that used the sampled area on Baffin Island for each decade. The fraction of locations inside the sampled area is shown for each bear.

YEAR + capture season	ID (PTT + Year)	Start Date	End Date	n independent bears during this year	n independent bears in the sampled area	Fraction of total locations inside sampled area during the sampling dates	Proportion of locations
1993		**23-Aug**	**8-Oct**	**13**	**3**		
fall	199111062	27-Aug	16-Sep			1/4	0.25
spring	19922718	24-Aug	7-Oct			1/8	0.13
fall	19922700	25-Aug	25-Aug			1/1	1.00
1994		**7-Sep**	**19-Oct**	**5**	**1**		
spring	19922701	8-Sep	6-Oct			2/6	0.33
2011		**4-Sep**	**14-Oct**	**12**	**8**		
spring	201068010	6-Sep	8-Oct			8/9	0.89
spring	2011105814	24-Sep	10-Oct			4/4	1.00
spring	201074768	6-Sep	12-Oct			8/8	1.00
spring	2011105809	6-Oct	6-Oct			1/1	1.00
spring	200974767	6-Sep	12-Oct			10/10	1.00
spring	2011105817	4-Sep	14-Oct			10/10	1.00
spring	2011105816	4-Sep	14-Oct			5/5	1.00

spring	200968005	6-Sep	12-Oct			10/10	1.00
2012		**26-Aug**	**29-Sep**	**13**	**11**		
spring	201074774	29-Aug	26-Sep			6/7	0.86
spring	2012105829	29-Aug	26-Sep			5/7	0.71
spring	201068010	12-Sep	24-Sep			2/3	0.67
spring	2011105814	29-Aug	26-Sep			5/7	0.71
spring	201074768	27-Aug	28-Sep			7/8	0.88
spring	2011105808	29-Aug	26-Sep			7/8	0.88
spring	2011105809	6-Sep	6-Sep			1/1	1.00
spring	200974767	27-Aug	28-Sep			1/9	1.90
spring	200974771	29-Aug	26-Sep			8/8	1.00
spring	2011105813	29-Aug	22-Sep			2/6	0.33
spring	200968005	27-Aug	27-Aug			1/1	1.00
2013		**20-Aug**	**11-Oct**	**6**	**4**		
spring	2013105818	20-Aug	11-Oct			12/12	1.00
spring	2013128265	20-Aug	11-Oct			14/14	1.00

Figure 3.1. Locations of polar bears sampled in Baffin Bay during the 1990s (August – October, 1993 – 1995, 1997, red) and 2010s (August – October, 2011 – 2013, blue). Sampling in Greenland in the 2010s occurred near Melville Bay but is not shown. Note the absence of captures in fjords on Baffin Island during the 1990s in the inset.

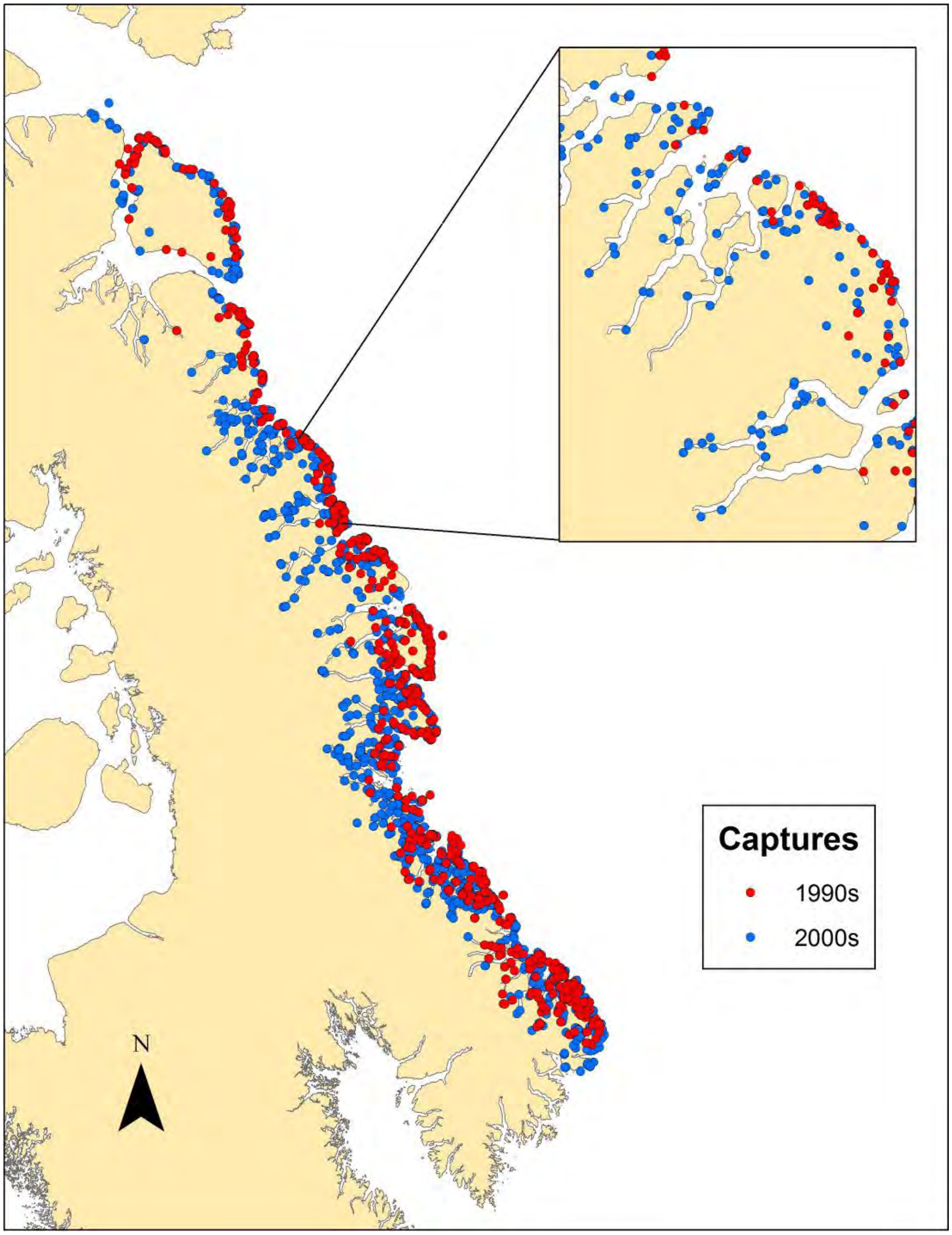

Figure 3.2. Distances independent bears were captured from the smoothed coastlines of Baffin and Bylot Islands during fall-time sampling in the Baffin Bay subpopulation, 1993 – 1997 and 2011 – 2013.

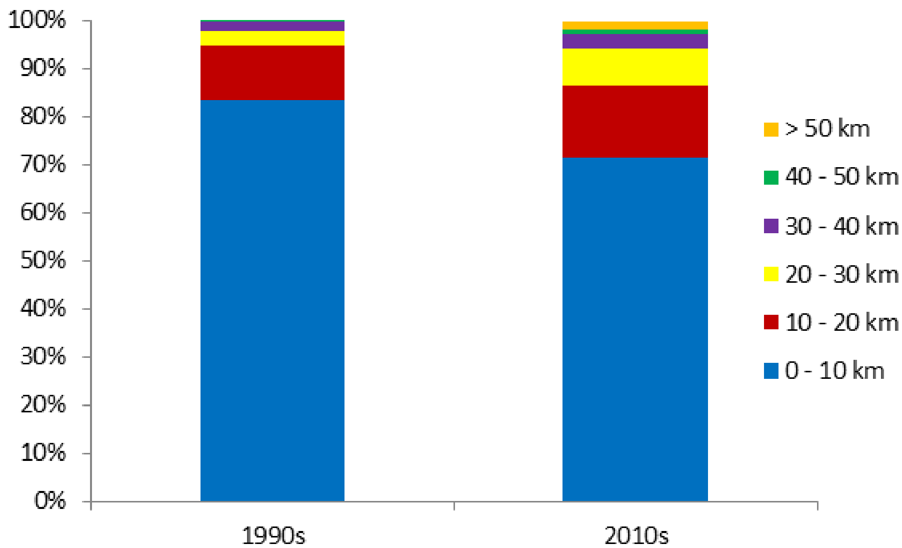

Figure 3.3. Distances independent bears were captured from the true coastlines of Baffin and Bylot Islands during fall-time sampling in the Baffin Bay subpopulation, 1993 – 1997 and 2011 – 2013.

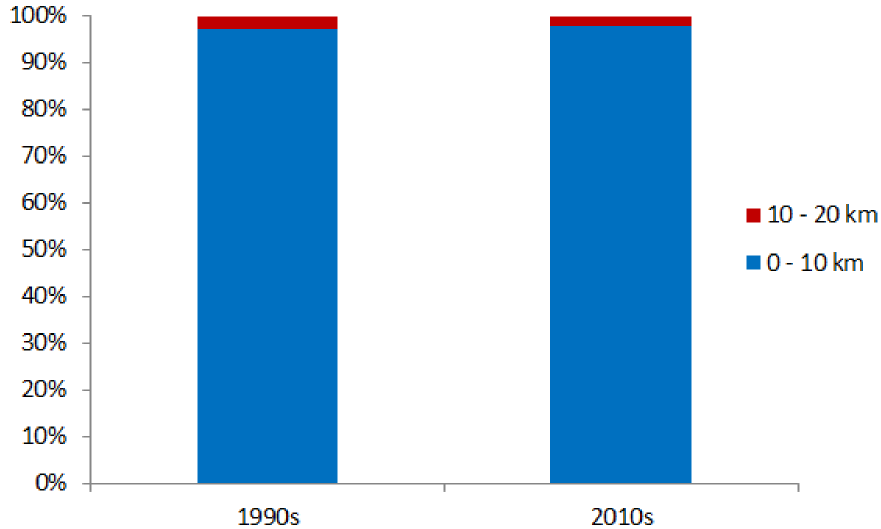

Figure 3.4. Distance to smoothed Baffin Island coastline shown in all summer months using satellite telemetry data from adult females in the 1990s (red) and 2010s (blue) located on Baffin Island. Shaded regions represent 2 SE from the mean. Numbers above represent numbers of telemetry locations for each month. There was no difference in distance inland (or distance to the outer Baffin Island coast) between decades.

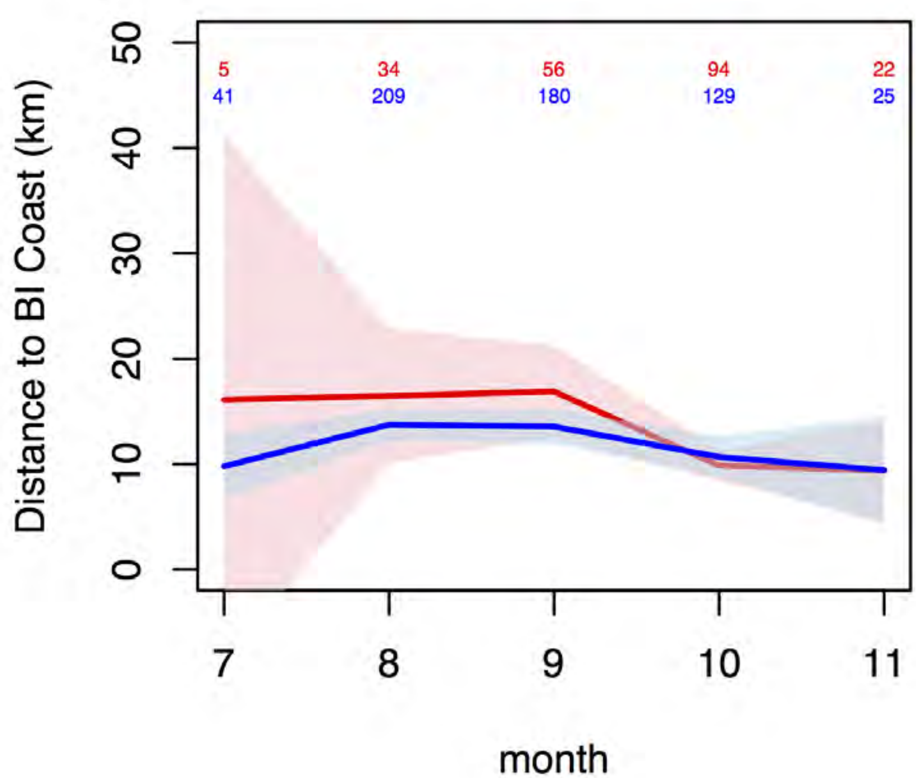

Figure 3.5. Elevation of adult female polar bears on Baffin Island shown in all summer months using satellite telemetry data from the 1990s (red) and 2010s (blue). Shaded regions represent 2 SE from the mean. Numbers above represent numbers of telemetry locations for each month. There was no difference in elevations used by polar bears across months between decades.

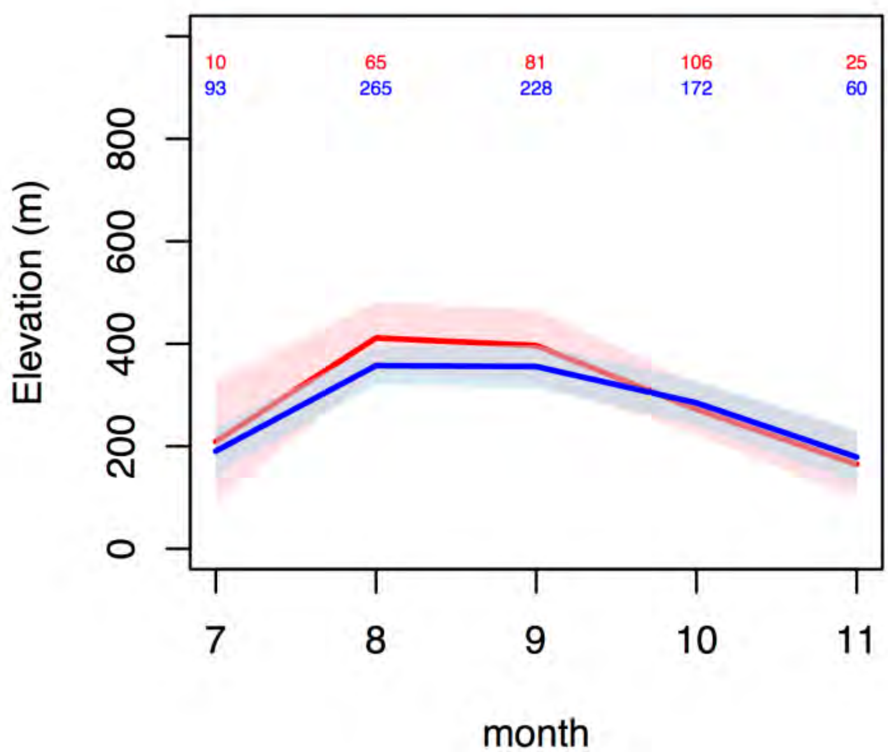

Figure 3.6. The delineation of the sampled area shown with a red outline for the 1990s with capture locations collected during the MR sampling.

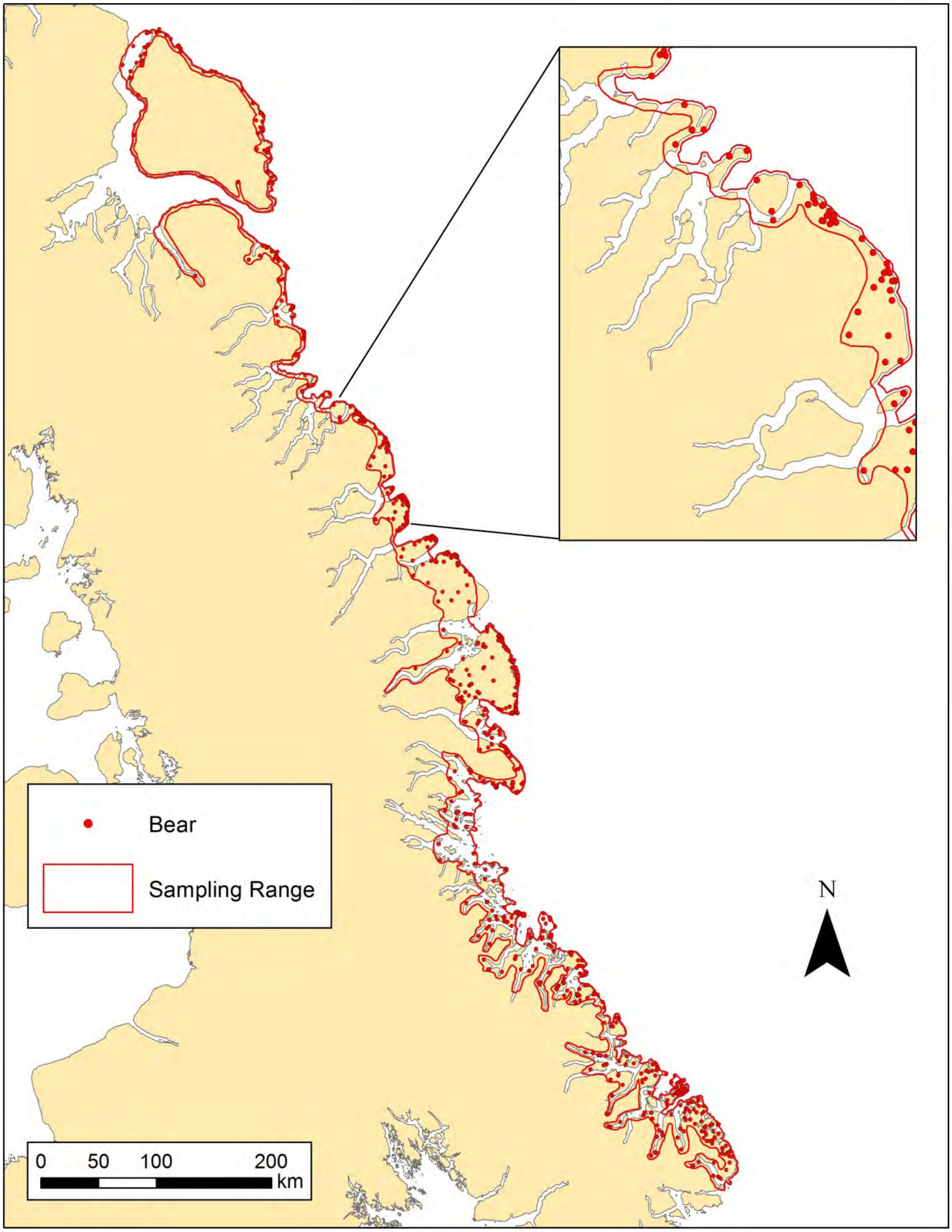

Figure 3.7. The delineation of the sampled area shown with a red outline for the 2010s with biopsy locations collected during the MR sampling (2011-2013).

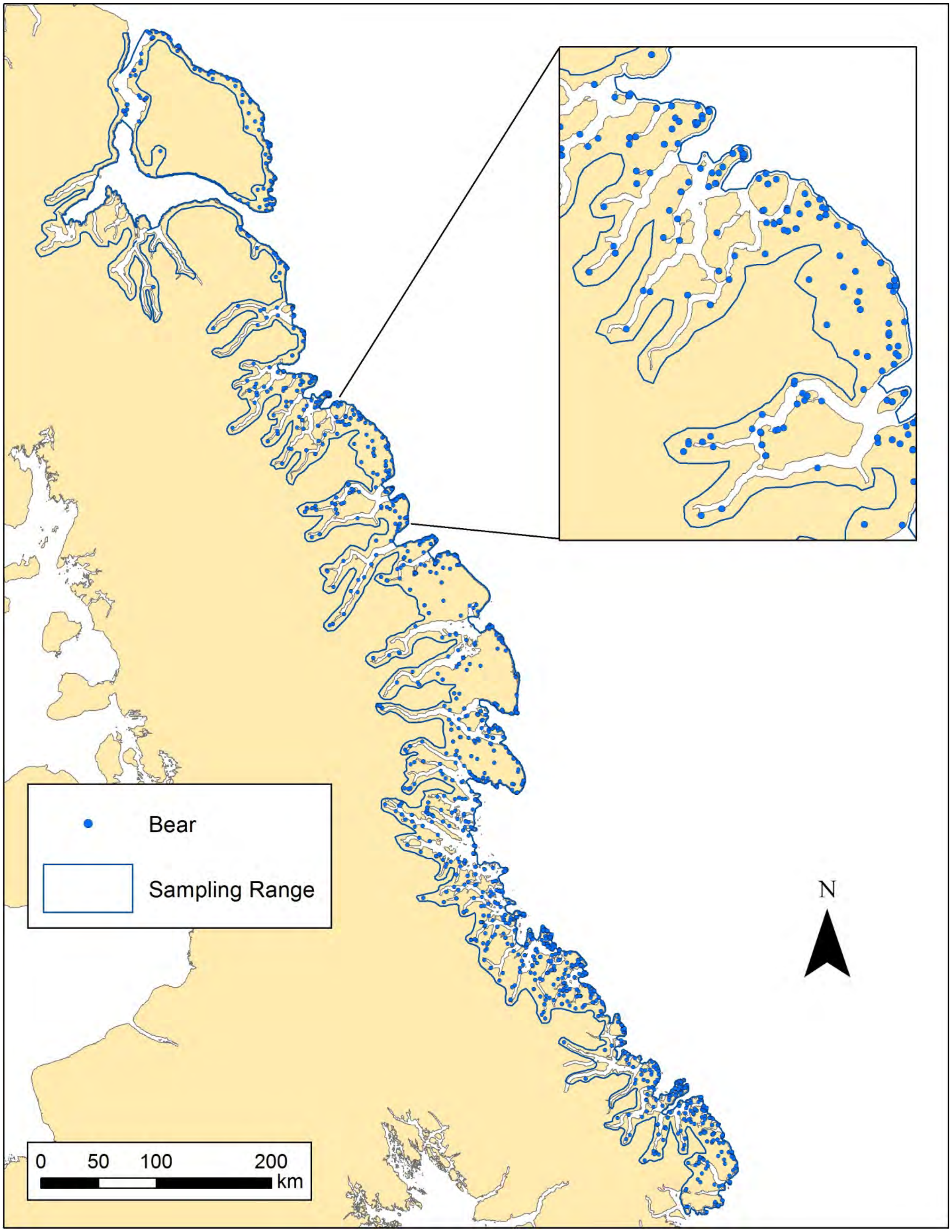

Figure 3.8. Geographic sampling ranges for the MR in the 1990s and 2010s.

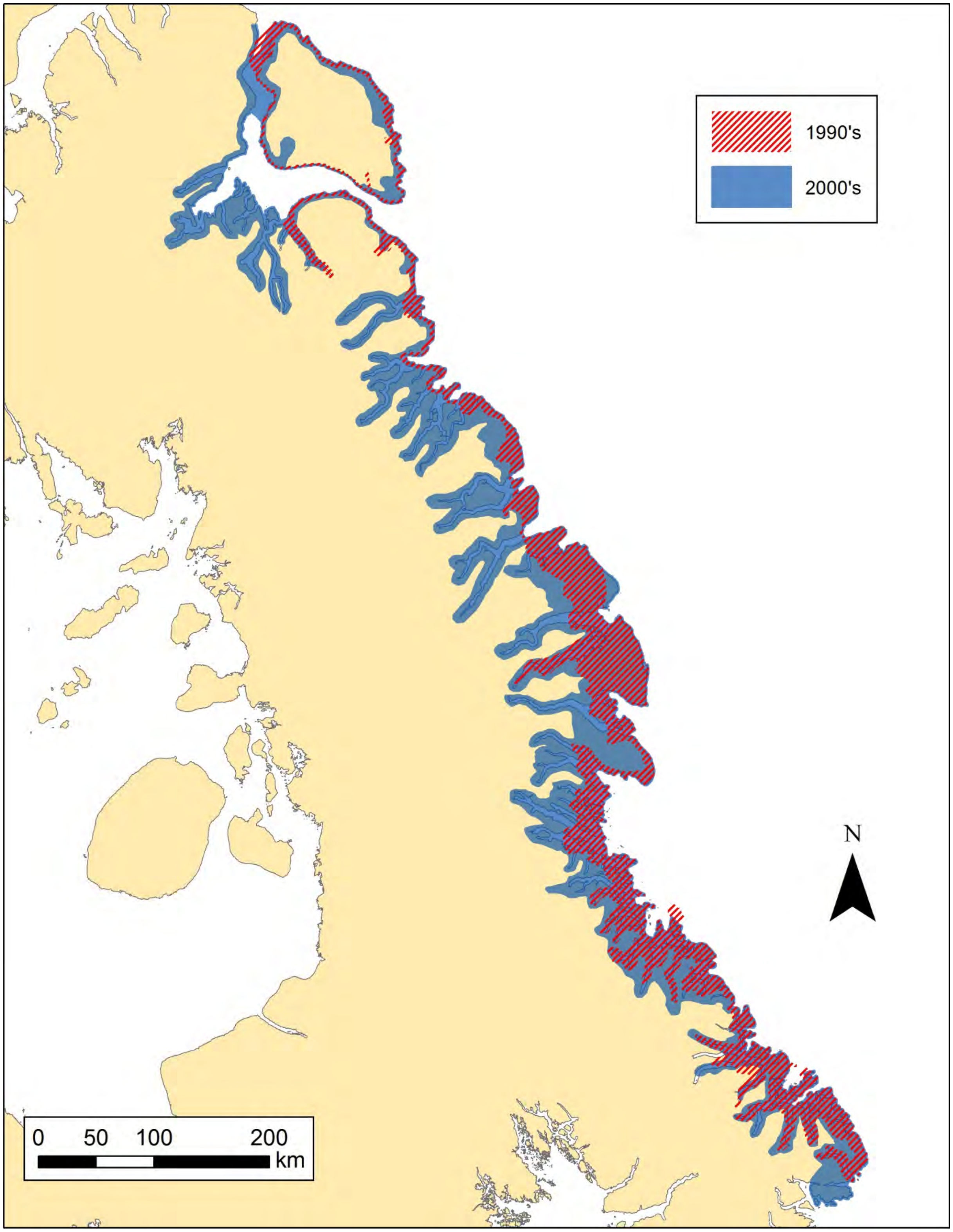

Figure 3.9. All telemetry locations from independent adult female bears with satellite collars transmitting during the 1993 sampling period dates (See Table 3.3). The 1990s sampled area for the MR study is shown in the red outline. Bears in central BB are on sea ice (Figure 3.15).

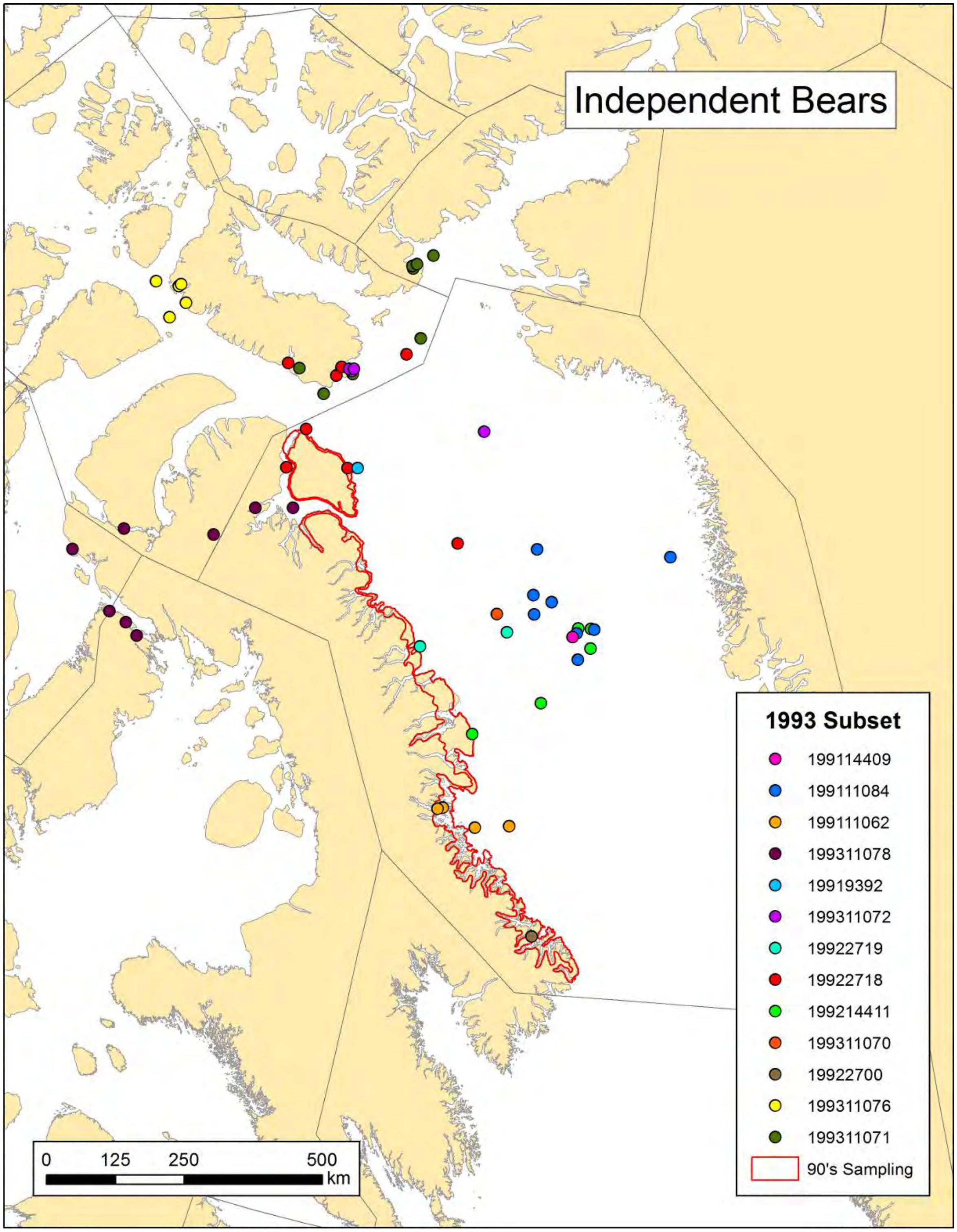

Figure 3.10. All telemetry locations from independent adult female bears with satellite collars transmitting during the 1994 sampling period dates (See Table 3.3). The 1990s sampled area for the MR study is shown in the red outline.

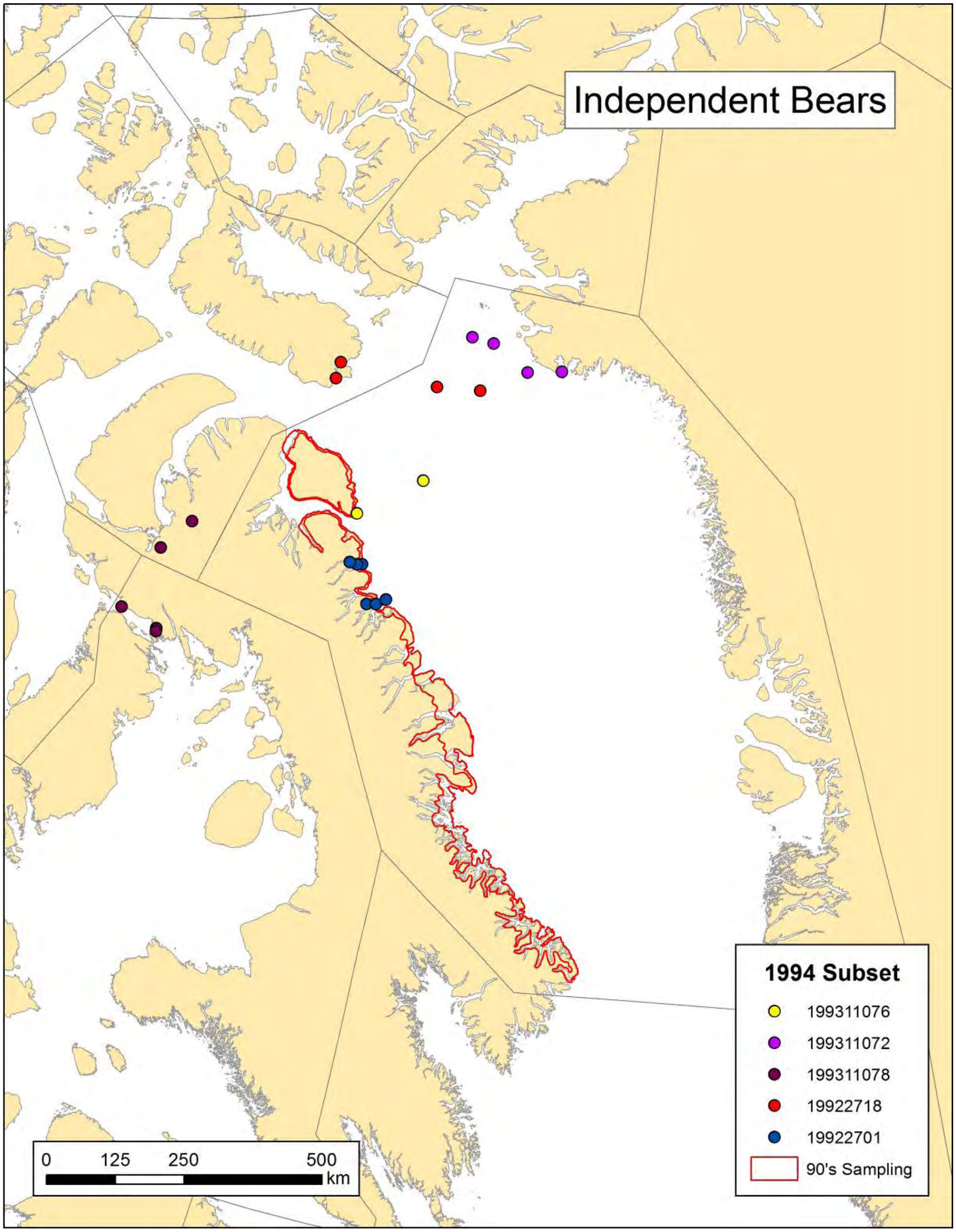

Figure 3.11. All telemetry locations from independent adult female bears with satellite collars transmitting during the 1995 sampling period dates (See Table 3.3). The 1990s sampled area for the MR study is shown in the red outline.

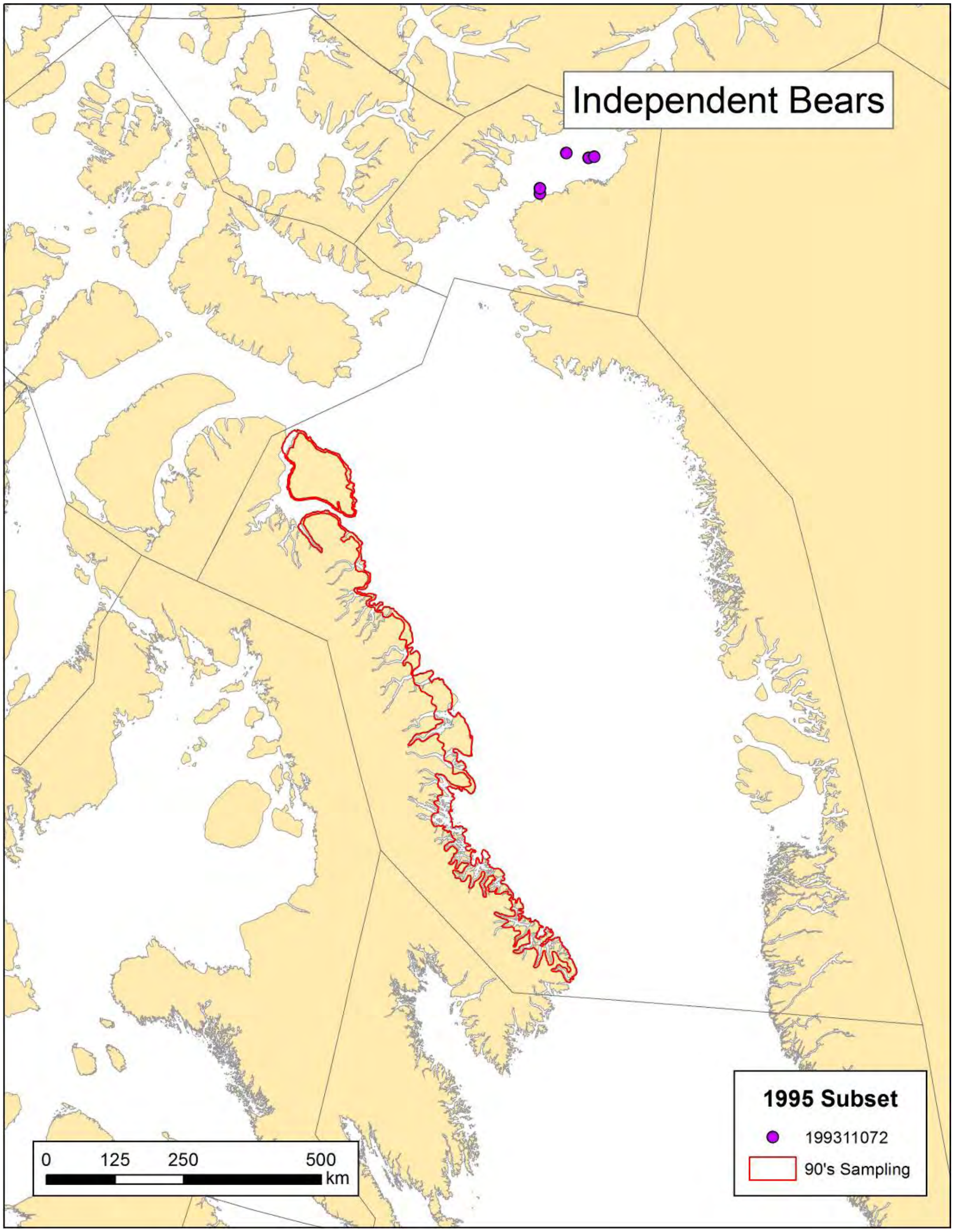

Figure 3.12. All telemetry locations from independent adult female bears with satellite collars transmitting during the 2011 sampling period dates (See Table 3.3). The 2010s sampled area for the MR study is shown in the blue outline.

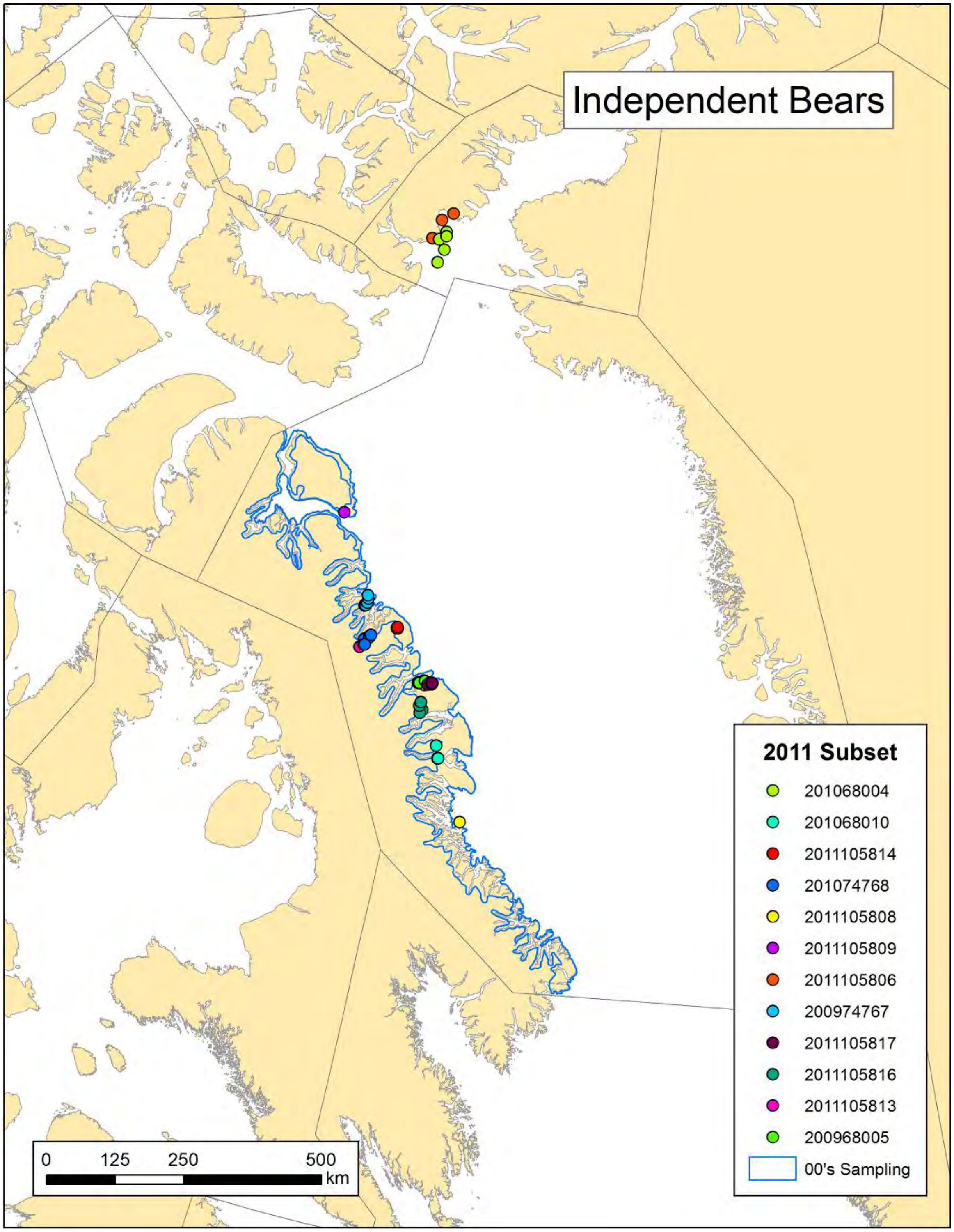

Figure 3.13. All telemetry locations from independent adult female bears with satellite collars transmitting during the 2012 sampling period dates (See Table 3.3). The 2010s sampled area for the MR study is shown in the blue outline.

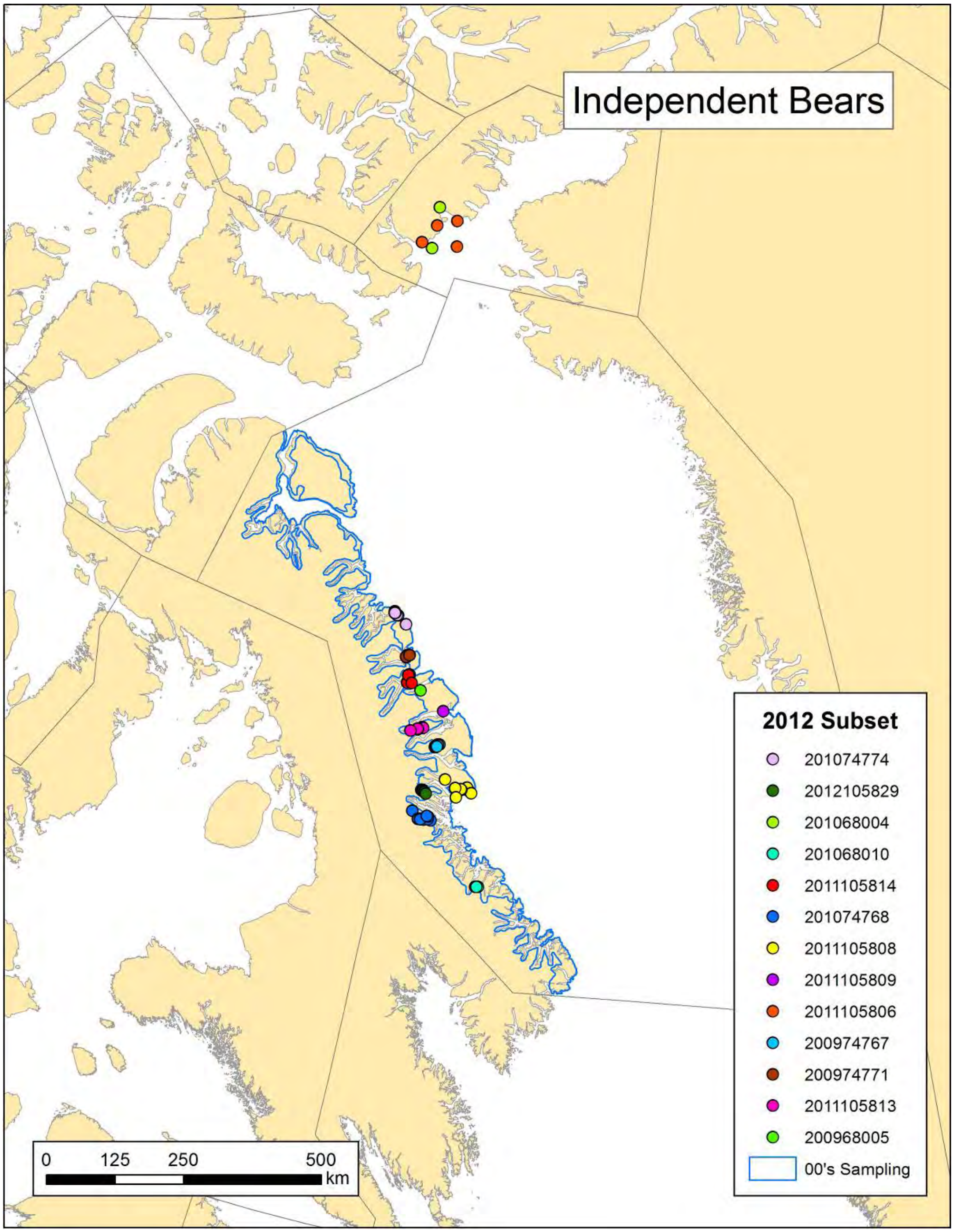

Figure 3.14. All telemetry locations from independent adult female bears with satellite collars transmitting during the 2013 sampling dates (See Table 3.3). The 2010s sampled area for the MR study is shown in the blue outline.

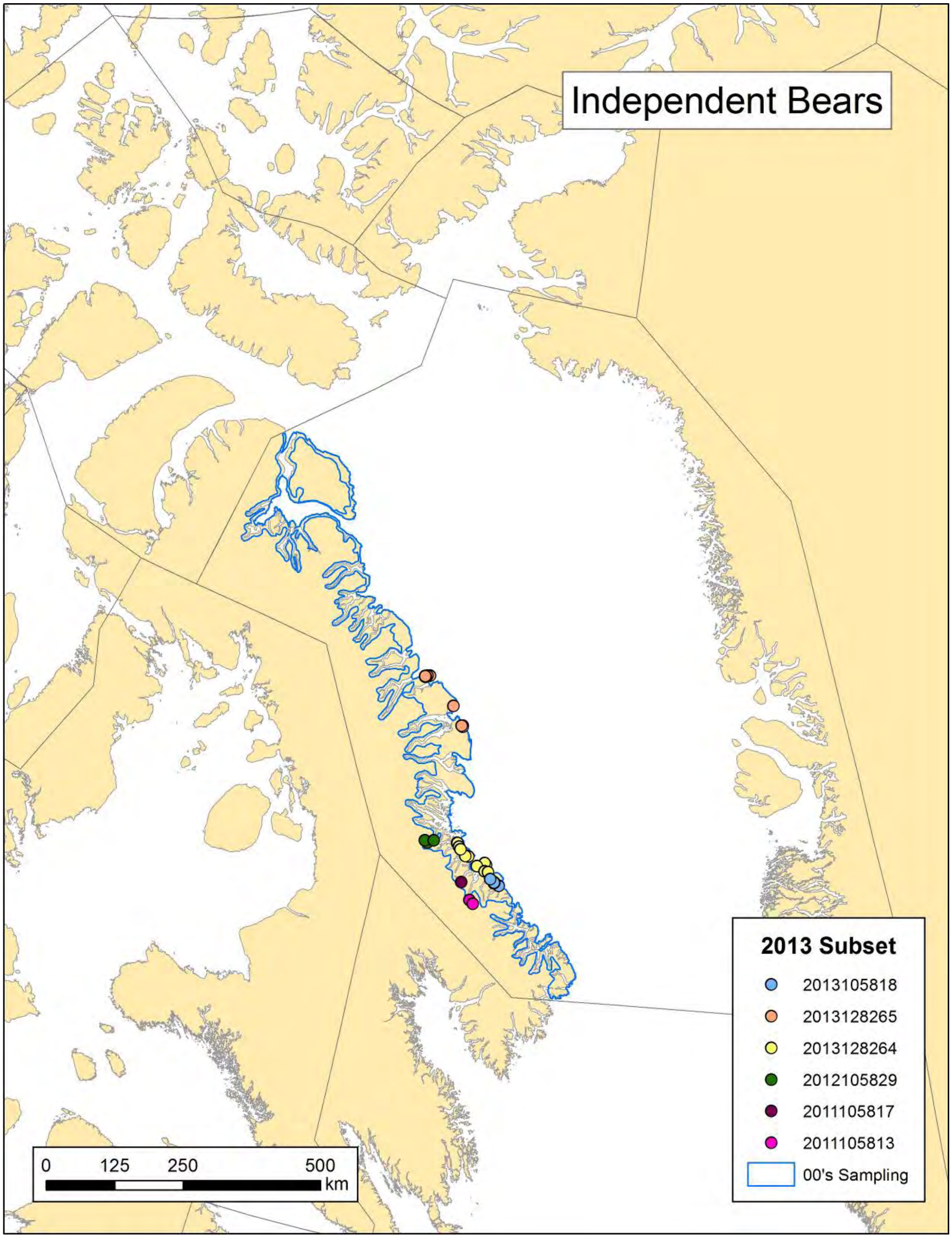

Figure 3.15. Distribution of weekly mean sea-ice concentrations (SSMI) during the mid-point of the sampling period in 1993 (August week 4). Sea ice is shown in 25 km^2 pixels. Locations of independent AF bears during the 1993 sampling period are shown.

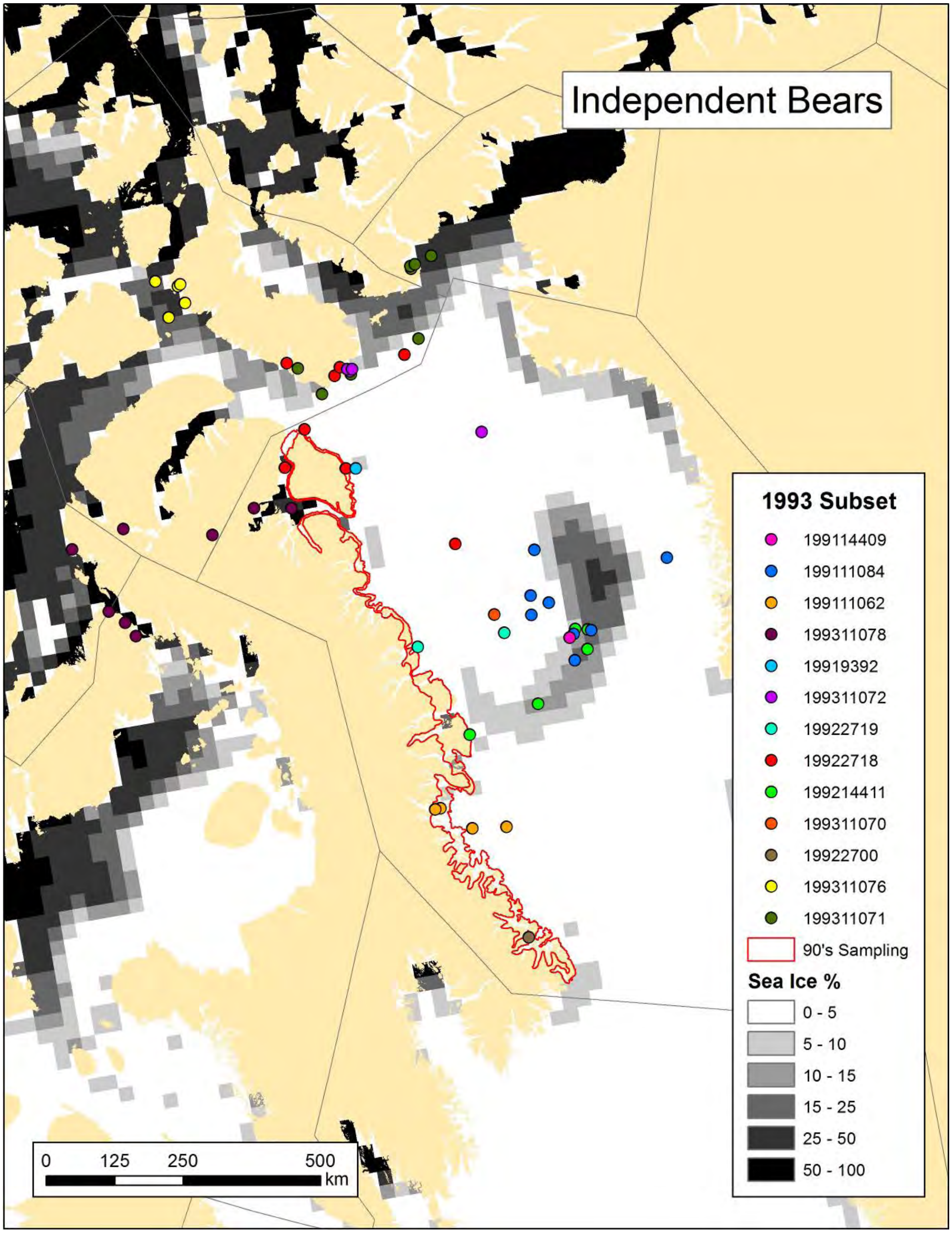

Figure 3.16. Distribution of weekly mean sea ice concentrations (SSMI) during the mid-point of the sampling period in 1994 (October week 1). Sea ice is shown in 25 km^2 pixels. Locations of independent AF bears during the 1994 sampling period are shown.

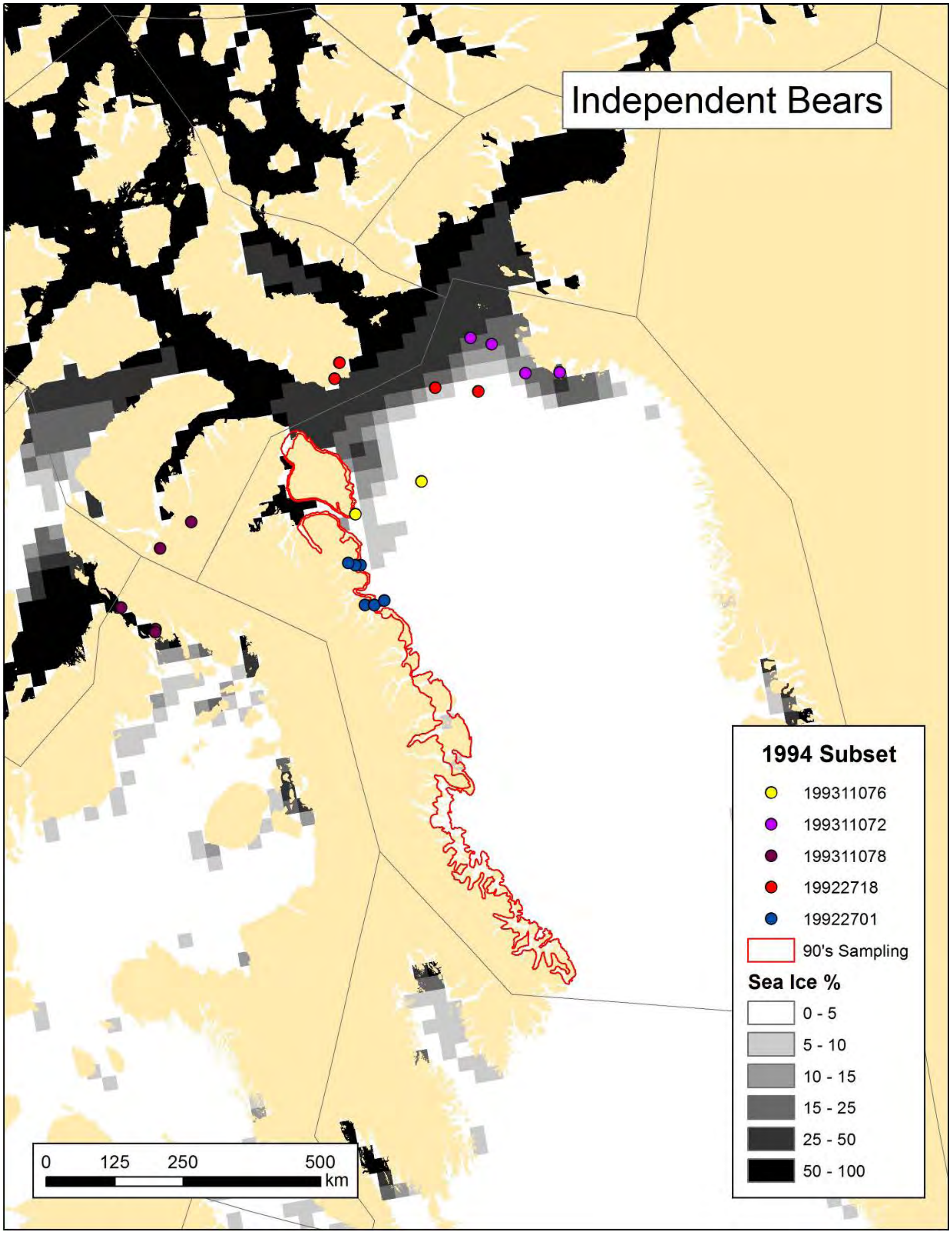

Figure 3.17. Distribution of weekly mean sea-ice concentrations (SSMI) during the mid-point of the sampling period in 1995 (October week 2). Sea ice is shown in 25 km^2 pixels. Locations of independent AF bears during the 1995 sampling period are shown.

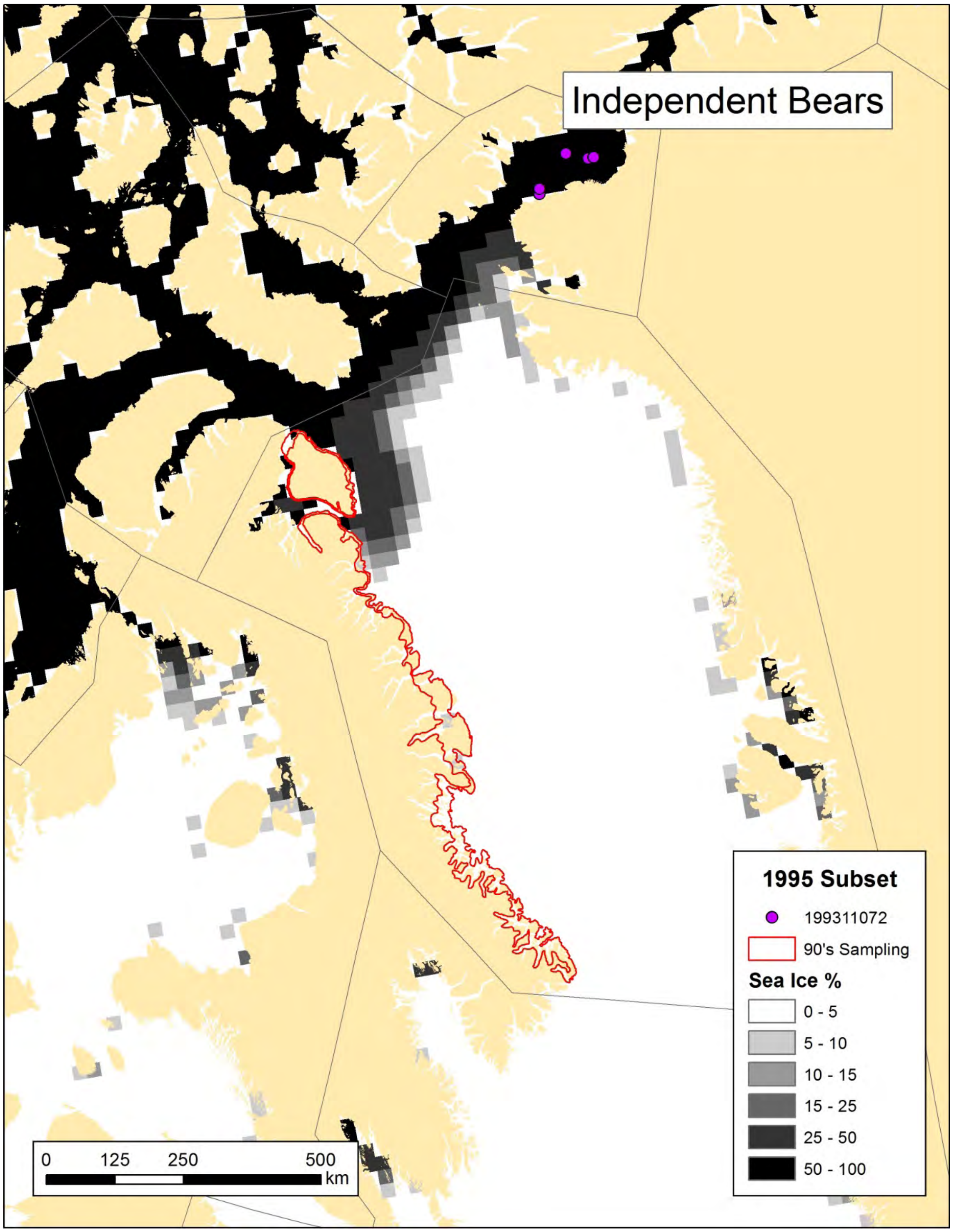

Figure 3.18. Distribution of weekly mean sea-ice concentrations (SSMI) during the mid-point of the sampling period in 2011 (September week 3). Sea ice is shown in 25 km^2 pixels. Locations of independent AF bears during the 2011 sampling period are shown.

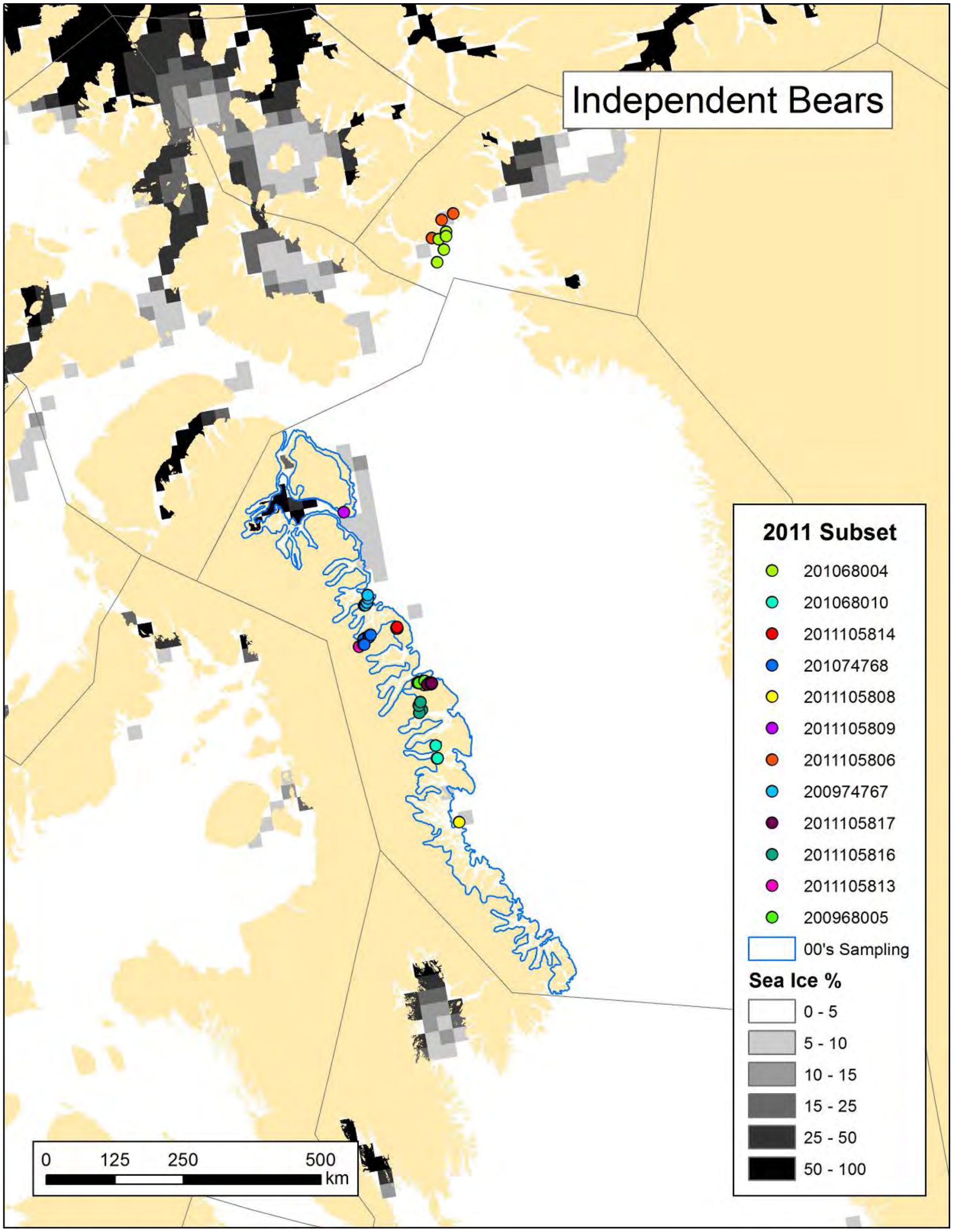

Figure 3.19. Distribution of weekly mean sea-ice concentrations (SSMI) during the mid-point of the sampling period in 2012 (September week 2). Sea ice is shown in 25 km^2 pixels. Locations of independent AF bears during the 2012 sampling period are shown.

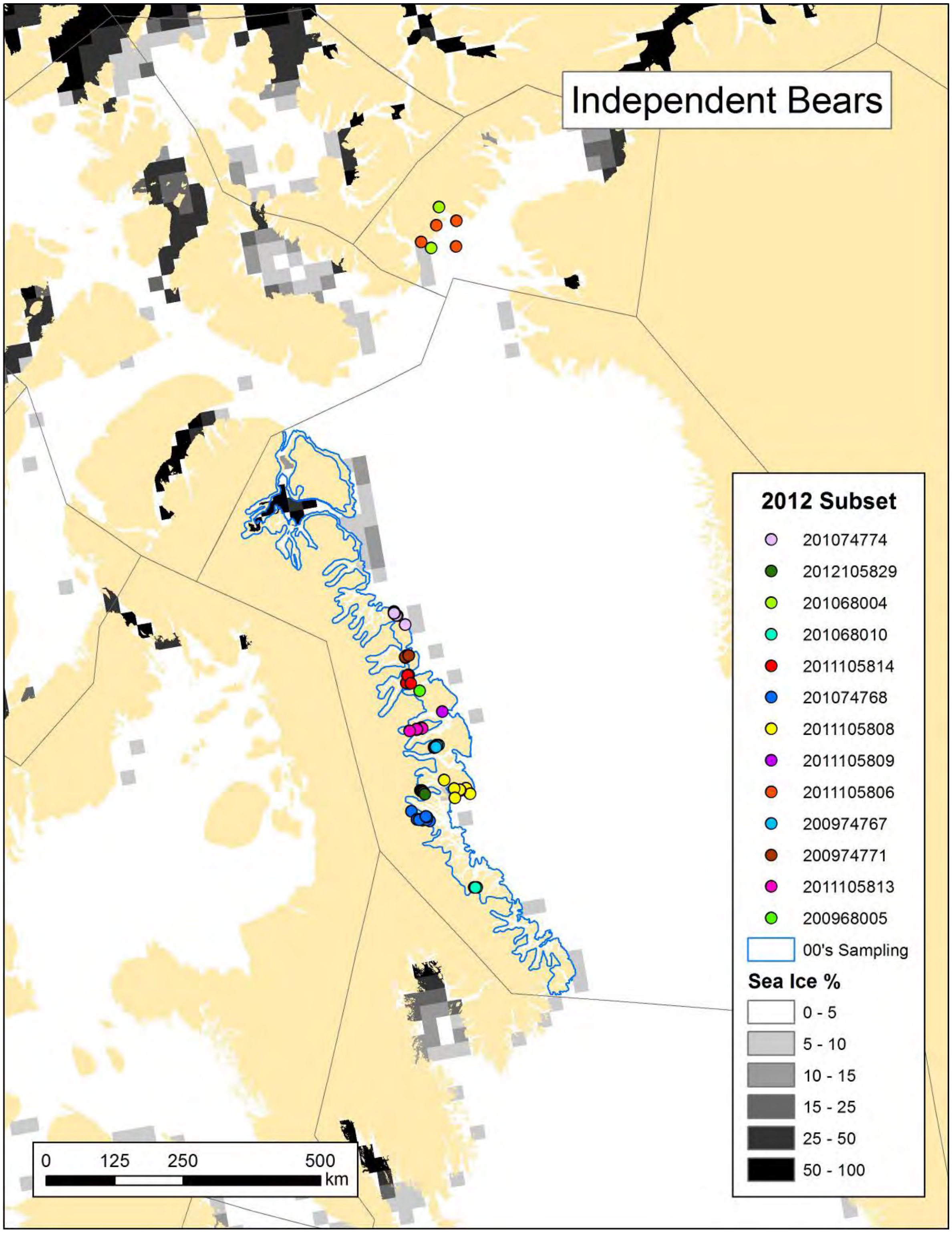

Figure 3.20. Distribution of weekly mean sea-ice concentrations (SSMI) during the mid-point of the sampling period in 2013 (September week 3). Sea ice is shown in 25 km^2 pixels. Locations of independent AF bears during the 2013 sampling period are shown.

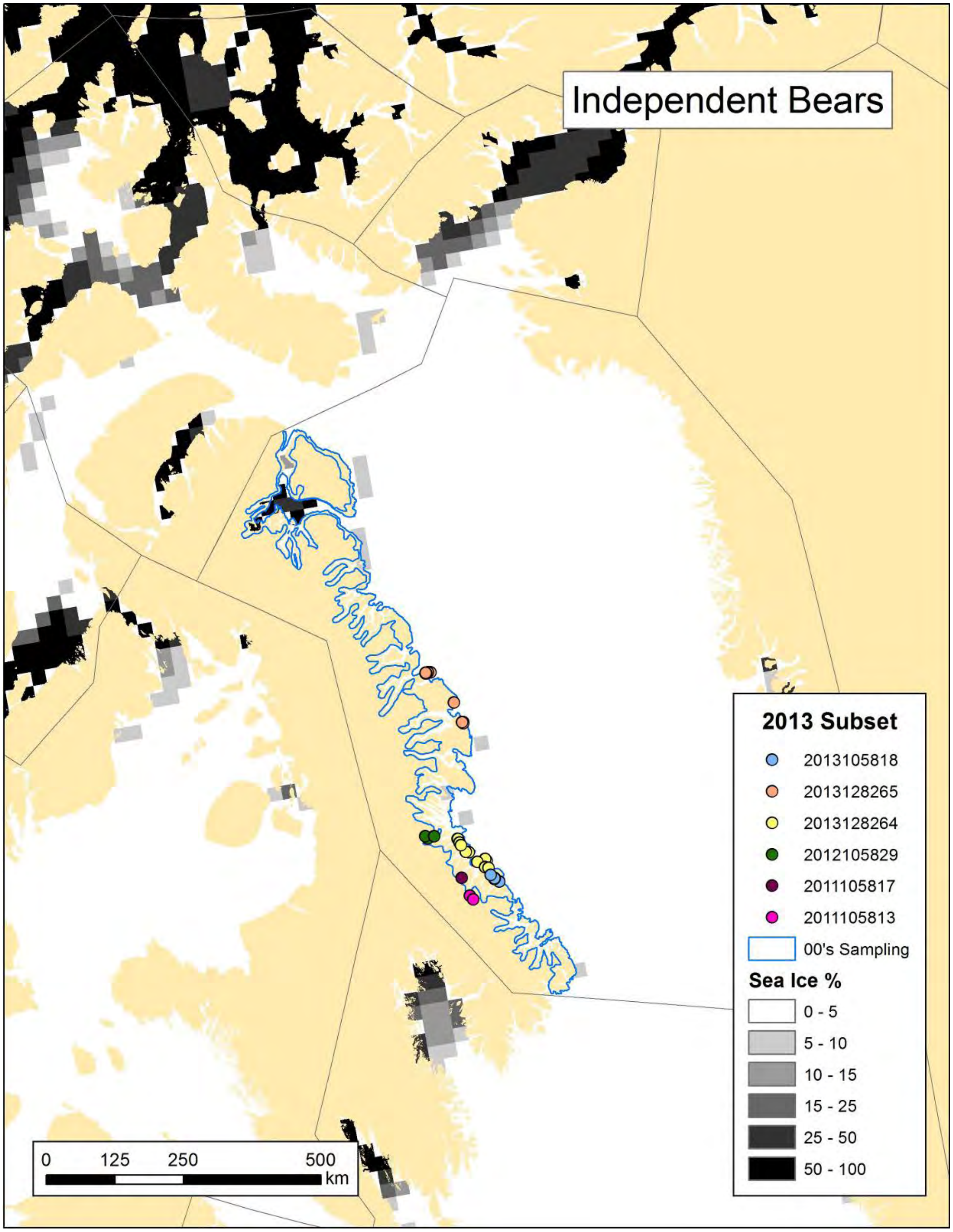

Figure 3.21. Distribution of sea-ice conditions (SSMI) during 1990s MR (top left to right 1993, 1994 and 1997) and 2010s MR (bottom left to right 2011, 2012, and 2013). Independent bears transmitting during the sampling are shown for reference. Note sampling occurred in 1997 but there were no independent collared bears for assessment of presence in the sampling area.