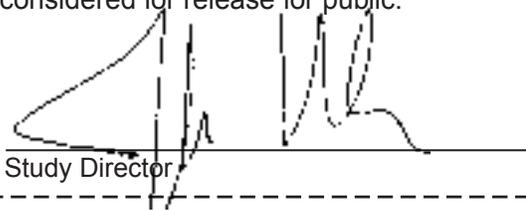


WEST KITIKMEOT / SLAVE STUDY SOCIETY

**Re: Spatial Organization and Habitat Selection Patterns of Barren-ground Grizzly Bears (*Ursus arctos*) in the Northwest Territories and Nunavut
Final Report**

STUDY DIRECTOR RELEASE FORM

The above publication is the result of a project conducted under the West Kitikmeot / Slave Study. I have reviewed the report and advise that it has fulfilled the requirements of the approved proposal and can be subjected to independent expert review and be considered for release for public.

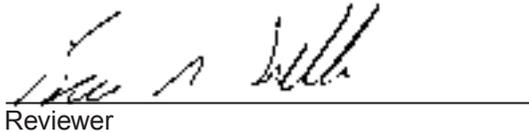

Study Director

January 19, 2000

Date

INDEPENDENT EXPERT REVIEW FORM

I have reviewed this publication for scientific content and scientific practices and find the report is acceptable given the specific purposes of this project and subject to the field conditions encountered.

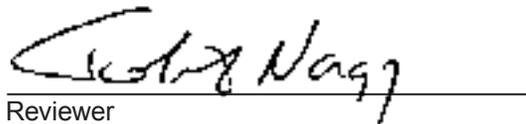

Reviewer

March 3, 2000

Date

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I have reviewed this publication for scientific content and scientific practices and find the report is acceptable given the specific purposes of this project and subject to the field conditions encountered.

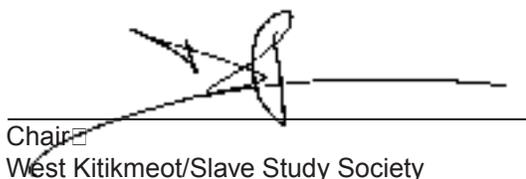

Reviewer

November 20, 2000

Date

BOARD RELEASE FORM

The Study Board is satisfied that this final report has been reviewed for scientific content and approves it for release to the public.


Chair
West Kitikmeot/Slave Study Society

November 20, 2000

Date

THE SPATIAL ORGANIZATION AND HABITAT SELECTION PATTERNS OF
BARREN-GROUND GRIZZLY BEARS (*URSUS ARCTOS*) IN THE NORTHWEST
TERRITORIES AND NUNAVUT: FINAL REPORT TO THE
WEST KITIKMEOT/SLAVE STUDY SOCIETY



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November 1999

SUMMARY

The main objective of this research project was to study the spatial organization and habitat selection patterns of barren-ground grizzly bears (*Ursus arctos*) inhabiting the low Arctic tundra of mainland Nunavut and the Northwest Territories, Canada. Specifically, this project focused on the population delineation, important habitats, movement patterns, denning habits, and spatial range of mining impacts to grizzly bears. To meet the study goals, an extensive satellite telemetry programme was conducted in a study area of approximately 200,000 km², centred 400 km northeast of the city of Yellowknife, Northwest Territories.

From May 1995 to June 1999, we captured 264 barren-ground barren-ground grizzly bears. Of the total number of captures, 152 different bears were identified. Of these 152 individuals, 39 were adult females and 36 were adult males. Among subadults (aged three to four years), 12 were females and 10 were males. We marked 30 cubs-of-the-year (16 female, 14 male), 16 yearling cubs (eight females, eight males), and nine two-year-old cubs (three females, six males). We placed 89 satellite radio-collars on 81 bears ($n = 42$ females, $n = 39$ males). For 23 bears (mostly females), break-away VHF radio-collars were fitted after satellite collars were removed.

Three populations of grizzly bears were identified in the study area using multivariate cluster analysis of movement data and home range analysis. We obtained independent clustering solutions that grouped both female

and male grizzly bears into the North Slave, Bathurst Inlet, and Kugluktuk regions of the study area. Although female population ranges were completely contained within established population unit boundaries, male population ranges demonstrated overlap with boundaries. High exchange among populations for both females and males suggest that identified grizzly bear populations cannot be managed independently from one another.

We examined habitat selection first at the level of the home range. Here, habitat use was determined by the proportional availability of habitat types contained within the home range of an animal and habitat availability was determined by the proportion of habitat types in the entire study area. Selection analysis indicated that there was no significant difference between the sexes with regard to habitat selection patterns (Wilk's Lambda Approx. $F_{11,11} = 1.27$, $P = 0.37$). That is, both males and females were practicing the same selection patterns when deciding where to place their home ranges in the study area. The general pattern was for bears to possess home ranges, relative to the study area, that contained preferential amounts of esker habitat, tussock/hummock successional tundra, lichen veneer, birch seep, and tall shrub riparian areas over other habitat types.

We also examined habitat selection at a finer level of selection, whereby habitat use was determined from individual satellite telemetry locations and compared to the availability of habitats within readily accessible portions of the home ranges of individual animals.

Selection patterns at this scale indicated that there were significant differences in habitat selection among sexes (Wilk's Lambda Approx. $F_{10,201} = 2.45$, $P = 0.009$), seasons (Wilk's Lambda Approx. $F_{30,591} = 2.75$, $P < 0.001$), and for an interaction between sex and season (Wilk's Lambda Approx. $F_{30,591} = 1.39$, $P = 0.08$). That is, habitat selection differed for males and females, and the extent of these differences were dependent upon the season of the year. Overall, esker habitat was the most preferred habitat type for females throughout the year. In addition, riparian tall shrub and birch seep habitat were generally highly ranked by females. Tall shrub habitat was also important to males, as was esker and tussock/hummock successional tundra at varying times during the year.

Annual ranges of radio-tracked animals (≥ 38 locations per year) were estimated using the 95% fixed kernel technique. The mean annual range for adult males was $6,685 \text{ km}^2$ ($SE = 1,351$, $n = 19$), which was significantly larger than for females ($\bar{X} = 2,074 \text{ km}^2$, $SE = 335$, $n = 35$). There was no difference in the annual ranges among females of differing family status. Because of smaller sample sizes, seasonal ranges were estimated using the 95% minimum convex polygon technique. There was a significant difference between the sexes with regard to the size of seasonal ranges. In addition, females possessed ranges that varied among seasons, increasing in size from spring to summer and decreasing in size from summer to autumn. Seasonal rates of movement (calculated from straight-line distances between successive

locations) were significantly higher for males than for females. Both sexes decreased movement rates from their highest rates in spring (males) and summer (females) to their lowest rates in autumn. Annual and seasonal ranges are the largest ranges reported for grizzly bears in North America. Large ranges may put individual bears in contact with humans even when developments are tens or even hundreds of kilometres from the core of the home range of an animal.

Bears entirely avoided denning in five of the 12 major habitat types available to them (wetlands, tussock/hummock successional tundra, lichen veneer, boulder fields and exposed bedrock). Esker habitat, which previously had been regarded as a major denning habitat for barren-ground grizzly bears, accounted for seven of 56 den sites. The remainder of the dens were located in typical heath tundra habitat (23/56), tall shrub riparian habitat (3/56), birch seep (5/56), spruce forest (5/56), heath tundra habitat with >30% boulder content (11/56), and heath tundra habitat with >30% bedrock content (1/56). One further den was located in a non-vegetated sand embankment adjacent to the Hood River. Compared to the proportional availability of habitat types in the study area, the selection of denning habitat by bears was determined to be significantly different from random ($\chi^2 = 381.6$, df 11, $P < 0.0001$).

All dens were located on well-drained slopes ($\bar{X} = 25.3^\circ$, SE = 1.2, n = 55). Choice of den aspect was decidedly non-random ($\chi^2 = 12.4$, df 3, $P < 0.01$), with the majority of dens facing south (25/56), followed by west (13/56),

east (10/56), and north (8/56). Almost all dens were constructed under the cover of tall shrub (>0.5 m) species (*Betula glandulosa* and *Salix* spp.), the root structures of which likely support the ceilings of dens. Most dens contained substantial amounts of bedding material, which was observed to be gathered by bears prior to den entrance. Bedding material was almost exclusively composed of mats of crowberry (*Empetrum nigrum*). The majority of bears emerged from their dens in the first week of May. Den entrance occurred primarily in the last two weeks of October.

ACKNOWLEDGEMENTS

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1.0 OBJECTIVES

Although most grizzly bear (*Ursus arctos*) populations in North America have undergone some degree of decline or range reduction since the arrival of Europeans, barren-ground grizzly bear populations in the Northwest Territories and Nunavut remain relatively undisturbed from human activity. Far removed from human habitation, barren-ground grizzly bears have not been subjected to the exploitation and habitat changes that led to the extirpation of grizzly bears from much of their former range. Barren-ground grizzly bears, however, are considered vulnerable to population decline (COSEWIC, 1996 list), especially in the light of increasing human activity in the central Arctic.

Barren-ground grizzly bears in the Northwest Territories and Nunavut may be at risk to population decline for several reasons, including: (1) they have limited continuity with other grizzly bear populations because they are near the northern- and easternmost limit of the species' North American range, (2) because of reduced cover, bears in tundra habitats are more likely to be displaced by nearby human activity than bears in forested areas (McLellan 1990), (3) populations of grizzly bears in tundra habitat exist at the lowest recorded densities of all extant North American grizzly bears (review in McLellan 1994), and (4) they likely have very large spatial requirements (see, e.g., Reynolds 1980; Nagy et al. 1983; Clarkson and Liepins 1989; Ballard et al. 1993), which would put individual bears in contact with

humans even when developments are at considerable distance from the core of the home range of an animal.

Of particular importance, concerns have been raised about barren-ground grizzly bears inhabiting the Slave Geological Province (SGP), an area of roughly 200,000 km² that straddles the mainland border of the Northwest Territories and Nunavut (Fig. 1). Here, recently discovered deposits of diamonds, gold, and other base metals have been targeted for large-scale mining operations. The governments of the Northwest Territories (GNWT) and Nunavut support exploration and mining as long as such activities do not unduly impact the environment or its wildlife populations. Agencies such as the Federal Department of Indian Affairs and Northern Development, Native groups, the World Wildlife Fund, and the Canadian Arctic Resources Committee have all recognized the need for a conservation strategy particular to barren-ground grizzly bears. In addition, mining companies (e.g., BHP Diamonds Inc., Diavik Diamonds Mines Inc.) have committed themselves to the concept of "sustainable development", thus supporting steps to mitigate the negative effects of resource exploration and extraction on barren-ground grizzly bear populations.

Although it is agreed that grizzly bears in the SGP must be protected, knowledge of the ecology of barren-ground grizzly bears is limited and currently impairs the development of management strategies that would achieve this goal (GNWT 1991). There is an urgent need to acquire ecological information on barren-ground grizzly

bears to ensure that resource development does not result in substantial impacts on the population. Specifically, the distribution, movement patterns, habitat requirements, and denning ecology of barren-ground grizzly bears must be studied in order to develop an effective management plan for the species.

In light of the need for ecological information on barren-ground grizzly bears, and the need to develop a scientifically-based management plan for bears in the SGP, the specific objectives of this research project were:

1. To identify population units based on long-term movements of barren-ground grizzly bears;
2. To define important habitats for barren-ground grizzly bears;
3. To describe annual and seasonal movement patterns of barren-ground grizzly bears;
4. To detail the denning habits of barren-ground grizzly bears;
5. To document the geographic extent of potential impacts of resource extraction activities with relation to the barren-ground grizzly bear.

2.0 DESCRIPTION

2.1 Study Area

The study area was located in the Slave Geological Province, which straddles the border separating the mainland portion of Nunavut from that of the Northwest

Territories, Canada (Fig. 1). The area encompassed approximately 200,000 km² of Low Arctic tundra, and was delineated, clockwise, by Kugluktuk (formerly Coppermine), the Kent Peninsula, Aylmer Lake, MacKay Lake, and Great Bear Lake. The region is characterized by short, cool summers and long, cold winters. Summer temperatures average 10°C and winter temperatures are commonly below -30°C; the area is semi-arid with annual precipitation around 300 mm, about half of which falls as snow (BHP Diamonds Inc., 1995, Ecological mapping: 1995 baseline study update, Yellowknife, Northwest Territories, Canada). Drainages support willow (*Salix* spp.) and dwarf birch (*Betula glandulosa*) shrubs as tall as 3 m, and birch shrublands (<0.5 m in height) dominate the uplands. Shrubs such as blueberry (*Vaccinium uliginosum*), cranberry (*Vaccinium vitis-idaea*), and crowberry (*Empetrum nigrum*) are also common and their berries are important foods to grizzly bears (Gau 1998). The Bathurst caribou (*Rangifer tarandus*) herd migrates annually through the study area. The herd leaves wintering grounds below the treeline in April, travels to calving grounds near Bathurst Inlet by early June, and disperses south in late summer and autumn. The herd was estimated at 349,000 ± 95,000 caribou >1 year of age in 1996 (Gunn et al. 1997). Muskox occur sporadically in the northern half of the study area. Much of the study area is part of a well-drained peneplain with lakes in the hollows and scattered depressions. Rounded rocky hills and glacio-fluvial features such as eskers, kames, drumlins, and raised beaches are often the only major relief features.

2.2 Animal Capture and Telemetry

We used satellite radio-telemetry (Service Argos Inc., Landover, Maryland, USA) to obtain movement data on barren-ground grizzly bears. Satellite telemetry provides continued and precise (± 0.5 km) information on bear movements with minimum disturbance to bears (Fancy et al. 1988; Harris et al. 1990). Satellite collars (Telonics, Mesa, Arizona, USA) were equipped with a VHF beacon to permit locations of radio-marked animals from an aircraft and, eventually, for the retrieval of collars. Most collars were designed to transmit approximately two to five latitude-longitude locations every two days (eight hour duty cycle) from 1 May-1 November. During other months collars were programmed to transmit locations every six days to minimize output of battery power.

Between May 1995 and June 1998 we used a Bell 206B or Hughes 500 helicopter to search for and capture bears. A two-seat, fixed-wing aircraft was sometimes used for more intensive searches of the study area. Most grizzly bears were captured in spring during the snow melt period (15 May-5 Jun) by following tracks in the snow. We immobilized each bear with an injection of titelamine hydrochloride and zolazepam hydrochloride (Telazol[®], Ayerst Laboratories Inc., Montreal, Quebec, Canada) from a projected dart. Immobilized animals were marked with identification numbers applied as ear tags and permanent lip tattoos. Bears were weighed using a load-cell scale

(Norac Systems International Inc., Saskatoon, Saskatchewan, Canada) while suspended in a cargo net from a helicopter. We measured heart girth, straight-line body length, skull length, and skull width with a tape measure and calipers, and extracted a premolar tooth for age determination (Craighead et al. 1970). Some bears were tested for nutritional condition using bioelectrical impedance analysis and blood sampling (Gau 1998). Only those bears weighing >110 kg (males) and >90 kg (females) were fitted with satellite radio-collars prior to release.

2.3 Population Delineation

To meet the first objective of the study, we planned to delineate sub-populations of barren-ground grizzly bears in the SGP by analyzing movement data using multivariate clustering techniques and methods of home range analysis (see Bethke et al. 1995). The population delineation method of Bethke et al. (1996) required that sampling of individuals for movement data be uniformly distributed throughout the study area. This was attempted here as much as possible.

2.3.1 Multivariate Cluster Analysis

In order to use satellite locations in a cluster analysis, the latitude-longitude coordinate system upon which locations are based must first be scaled to a common x-y grid (Bethke et al. 1996). A geographical information system (SPANS[®] Explorer[™] 7.0, Tydac Research Inc., Nepean, Ontario, Canada) was used to convert bear

locations to Lambert grid coordinates to yield a "meters easting" and "meters northing" coordinate system, and all other spatial analyses described herein. The x-y Lambert grid was based upon a Lambert Conformal Conic projection covering the entire study area. Location data obtained from satellite telemetry and used in multivariate cluster analysis were separated in time by a minimum of 24 hours.

For each grizzly bear, a median meters easting value and a median meters northing value for each of four seasons in a year were calculated from movement data, and placed in a data matrix (bear \times season) upon which cluster analysis could be performed. The data matrix was stratified by season to account for seasonal variations in range size and movement rates (McLoughlin et al. 1998, 1999). We defined seasons according to changes in the diet of barren-ground grizzly bears during the active period (adapted from Gau 1998), including: spring (den emergence–20 Jun), summer (21 Jun–31 Jul), late summer (1 Aug–9 Sep), and autumn (10 Sep–den entrance). Den emergence generally occurs in the last week of April and den entrance in the last week of October (McLoughlin et al. 1998). Only those individuals that transmitted in all seasons of the year were included for analysis; however, if an individual transmitted locations in three out of four seasons, and there was a location recorded within one week from one of the bracketing seasons, the closest location from the bracketing seasons was used as an observation for the missing season (Taylor et al. 1999). Animals with two or more years of consecutive seasons were treated as separate observations (i.e., bear-years were used as the sampling unit).

Because of known differences in the range requirements and seasonal movement rates between sexes (McLoughlin et al. 1999), separate cluster analyses were conducted for males and females. Previous analyses using the method of Bethke et al. (1996) were conducted only for female animals (e.g., Bethke et al. 1996, Taylor et al. 1999); however, the movement patterns of both males and females will determine the spatial continuity of a breeding population. Here, the clustering of both female and male movement patterns were used for the final interpretation of population continuity in the SGP.

For each sex agglomerative hierarchical cluster analysis was used to group objects (bears) according to similarity (Pielou 1984, Romesburg 1984). Analyses were performed using SPSS 9.0 for Windows (SPSS Inc., Chicago, Illinois, USA). The unstandardized matrix of objects (bears) and attributes (seasonal median x and y coordinates) were used to calculate the values of the Euclidean distance or resemblance coefficient. Here, Ward's minimum variance technique (Pielou 1984, Romesburg 1984) was used to process the values of the resemblance coefficient to create a dendrogram that shows the hierarchy of similarities among all pairs of objects (bears). The interpretation of clusters was based on a hierarchical separation of clusters into a small number of definable groups ($n = 3$).

2.3.2 Mapping Population Boundaries

Individuals were assigned to "populations" based upon cluster analysis results. For any given sex and population, bear locations were pooled and then used in a home range analysis to map the spatial distribution of the population. The x-y coordinate data were analyzed to detail the spatial distribution of populations using the fixed kernel technique with least squares cross-validating (LSCV) to determine bandwidths (Silverman 1986; Worton 1989a,b, 1995; Seaman and Powell 1996). Population ranges were calculated using the program "The Home Ranger", Version 1.1 (F. W. Hovey, British Columbia Forest Service, Research Branch, Columbia Forest District, P.O. Box 9158, R.P.O. No. 3, Revelstoke, BC V0E 3K0, Canada). Utilization distribution contours (90% and 70%) for population ranges were plotted in SPANS GIS. The contours were then used to guide placement of population boundaries. Where possible, a single boundary was used to delineate the population range of both male and female clusters. In areas where there was broad overlap in low-use areas (>70% contour level) several boundary lines were possible. Here, political boundaries were used to place population unit boundaries (Bethke et al. 1996).

2.3.3. Validating Population Boundaries

Validation of populations identified by cluster analysis and delineated using home range analysis was based on two criteria. We hoped to define resident breeding populations; thus, to validate population units, we first required that spatial clusters for male and female bears be similar enough in distribution so that both distinctive male and female components could be contained within identifiable population boundaries (70% contour level). Second, to ensure that population growth rates for identified populations would be determined largely by intrinsic rates of birth and death, and not immigration or emigration, we required that no more than one radiotracked animal of either sex could immigrate to or emigrate from a population unit annually. Even allowing one animal to immigrate to or emigrate from a population unit permitted a generous annual population exchange rate (between 2.1% and 4.3% of a given population sample per year). Immigration and emigration were determined by analyzing the movements of all independent bears captured in the study for each year in which a bear was observed. Exchange for an individual was considered to have taken place if an animal moved from the population in which it either emerged from its den or was captured in the early part of one year to another population as determined by where the bear emerged from its den in the following year. Here we considered data for each "bear-year"--the period from one spring to the next during which data for a bear were collected--to represent an independent sample. Annual exchange among populations was thus based on the entire collection of several different years of

bear movement data. By limiting the calculation of exchange rates to where individuals moved from the early part of one year to the next, we hoped to further define our populations as breeding populations. Grizzly bears in our study area generally breed from shortly after den emergence through early summer.

2.4 Habitat Analysis

In an earlier progress report (McLoughlin et al. 1998) we described the results of a habitat analysis for grizzly bears inhabiting the immediate area surrounding Lac De Gras (Fig. 1). The habitat analysis was conducted primarily to aid in the drafting of the Environmental Assessment Submission (EAS) for Diavik Diamond Mines Inc. (Strom and McLoughlin 1998); however, the project also presented itself as an opportunity for us to conduct a preliminary habitat analysis for the West Kitikmeot/Slave Study Society. The approach used to examine habitat selection patterns for grizzly bears involved comparing the use of habitats by collared grizzly bears to the relative availability of those habitat types. The methods presented in McLoughlin et al. (1998) and Strom and McLoughlin (1998), with some modifications, were used for the final habitat analysis for barren-ground grizzly bears in the SGP.

2.4.1 Habitat Maps

In our preliminary habitat analysis (McLoughlin et al. 1998; Strom and McLoughlin 1998) we used a 14,000 km² LANDSAT Thematic Mapper (TM) image to define eight

discrete habitat types available to grizzly bears. Here, we used a combination of three new LANDSAT TM scenes classified by the NWT Centre for Remote Sensing (covering approximately 75,000 km² in the SGP) to determine the availability of habitat types to grizzly bears (Epp and Matthews 1998). Twelve discrete habitat types excluding water and ice are represented in the new maps (Table I), including: esker habitat, wetlands, tussock/hummock successional tundra, lichen veneer, spruce forest, boulder fields, exposed bedrock, riparian tall shrub areas, birch seep, typical heath tundra, heath tundra with >30% boulder content, and heath tundra with >30% bedrock content (Epp and Matthews 1998). All spatial analyses described herein were conducted using SPANS[®] Explorer[™] 7.0 (Tydac Research Inc., Nepean, Ontario, Canada).

2.4.2 Habitat Analysis Background

Two analyses were conducted to examine habitat selection by barren-ground grizzly bears, each at a different spatial and temporal scale. For our first analysis, termed a "second order selection" analysis by Johnson (1980), we compared the availability of habitat types in the home ranges of study animals to the availability of habitat types in the entire study area. Second order selection analyses thus determine whether home ranges are placed randomly in the study area with respect to habitat content, or if animals place their home ranges in areas with greater than (or less than) expected amounts of one or more habitat types.

For our second analysis, termed a "third order selection" analysis by Johnson (1980), we examined the proportional use of habitat types within a bear's home range to the proportional availability of habitat types within available sections of the home range. Here, individual telemetry locations were used to determine the proportional use of habitat types. A third order selection analysis can therefore be said to describe habitat selection at a finer spatial and temporal scale than does a second order selection analysis. For example, the habitat selection patterns examined in a third order selection analysis may result from foraging decisions determined on a daily or hourly basis (i.e., where an animal chooses to forage in a day or hour), rather than on an annual or multiannual basis as might be the case for a second order selection analysis (i.e., where an animal chooses to forage over the course of a year or its lifetime). In a formal sense, our null hypotheses are that, at each scale of study, all habitat types have the same selective value to grizzly bears.

2.4.3 Second Order Selection

The first analysis (second order selection; Johnson 1980) was based on the methods of Manly et al. (1993), and considered the study area as available and each multiannual home range as the area used by study animals. Multiannual home ranges were determined for bears using the fixed-kernel technique with least-squares cross validating to determine bandwidths (see section 2.5.1). For both habitat availability and use we divided the area of each of the twelve habitat types (Table I) by the

total study area or multiannual range, respectively. The resulting sets of used and available habitat ratios, which always totalled 1.0, were used to calculate a resource selection index for each habitat type for each bear (Manly et al. 1993). The resource selection function (the set of b_i 's, the standardized resource selection indices; Manly et al. 1993) for an individual bear was considered to be the basic datum for subsequent statistical analyses.

2.4.4 Third Order Selection

For the second analysis (third order selection; Johnson 1980), methods were adapted from those presented by Arthur et al., whereby the areas available for habitat use by an animal from one location to the next (as determined from satellite telemetry) depends upon the amount of elapsed time between successive locations. In addition, here we used buffers placed around satellite telemetry points to determine the use of habitat types, rather than simply assigning habitat classes to points according to the habitat types in which they fell (McLoughlin et al. 1998; Strom and McLoughlin 1998; Rettie and Messier 1999). The use of buffers around points ensured a high probability of the true habitat type being included when habitat use was measured. Although this method reduces the power of statistical tests of selection if point locations are exact in their accuracy (Rettie and McLoughlin 1999), we felt that for our satellite telemetry data it would be more appropriate to treat locations not as points, but rather as areas of

use, because of known errors associated with satellite telemetry data*.

We determined the radii for measuring availability for each satellite location observation according to a function derived from the 95th percentile of distances moved over hourly periods for grizzly bears in this study (bounded by the limits of the multiannual home range of an animal). We defined habitat used as the contents of a circle 1.0 km in radius, centred on the telemetry location. To maintain accuracy in our analysis, buffers were calculated only for locations of Service Argos* classes two and three.

Here, each buffer of use may be thought to conform to the average area used by a bear within a period of less than one hour (after one hour but less than two hours the average distance traversed by a bear from a previous location is approximately 2.1 km). Specifying a use radius of 1.0 km allowed us to employ successive satellite locations with temporal differences of as little as one hour, because after one hour grizzly bears, on average, have moved greater than two km away from any given point location. Also note that because we are estimating availability separately for each buffer of

*Locations are categorized by Service Argos to indicate accuracy on a scale of 3, 2, 1, 0, A, B, and Z, with 3 being the highest quality location. Only classes 1, 2, and 3 are given error estimates. Reported accuracies for locations are: class 1, 68% of locations are accurate within 1000 m; class 2, 68% of locations are accurate within 350 m; class 3, 68% of locations are accurate within 150 m. Location accuracy can be influenced by the stability of a transmitter's oscillator, the elevation of the transmitter, ionospheric propagation errors, and errors in satellite orbital data.

use, we are eliminating problems associated autocorrelated observations that may be an issue with other methods used to estimate habitat selection (Arthur et al. 1996).

For both use and availability we divided the area of each habitat type within a buffer by the total area of the buffer. The resulting sets of used or available habitat ratios totalled 1.0 for each telemetry location. Data were processed with a program written in C⁺⁺ to determine the resource selection probability function (RSPF, the set of H resource selection indices (b_i) where $i = 1$ to H and H is the number of habitat types) according to the formulae in Arthur et al. (1996).

In contrast to the first analysis, the second analysis was conducted on a seasonal basis. Four seasons were defined for the analysis by referring to temporal changes in the diet of barren-ground grizzly bears (obtained from scat analyses of study animals; Gau 1998), which include: spring (den emergence-June 20); summer (June 21-July 31); late summer (August 1-September 9); and autumn (September 10-denning).

The RSPF for a single animal season was considered the basic datum for subsequent analyses at the third order of selection. For this level of analysis, the spruce forest habitat type (Table I) was eliminated for both use and availability, as it was only found in the southern reaches of the study area (and outside several multiannual ranges of study animals). A habitat type must be greater than zero in availability for RSPFs to be

calculated (otherwise there is a problem of division by zero). Including spruce forest in the seasonal analysis would have prevented RSPFs from being calculated for those bears that did not have access to spruce forest in their multiannual ranges.

2.4.5 Statistical Analyses

For both second and third order selection analyses, all values of b_i were rank-transformed (Conover and Iman 1981) prior to statistical analysis to enable the use of parametric methods with decidedly non-parametric data. Following the methods of Arthur et al. (1996) the selection indices for each bear or bear season were used to create

$H - 1$ synthetic variables based on differences in adjacent pairs of ranked b_i values. We employed the synthetic variables to conduct multivariate analyses of variance (MANOVA) with the objective of examining the effects of sex and season (third order selection only) on habitat selection patterns (SPSS Inc., Chicago, Illinois, USA). The MANOVA procedure employed is analogous to a multivariate repeated-measures ANOVA design (Johnson and Wichern 1982; SPSS Inc. 1993). For the MANOVA and subsequent post-hoc analyses, we decided to weigh each observation (either bear or bear season, depending on order of selection analyzed) by the sample size used to determine RSPFs using a weighted least-squares (WLS) regression model (SPSS Inc. 1993).

All post-hoc multiple comparisons were conducted using the Welsch step-up procedure (Welsch 1977; Sokal and

Rohlf 1995: 252-254) on ranks of b_i -values. An experimentwise alpha value of 0.10 was used to test for significance in all tests.

2.5 Home Ranges and Movements

2.5.1 Annual Ranges

From satellite telemetry locations we estimated annual ranges for grizzly bears using the fixed kernel technique with least squares cross-validating (LSCV) to determine bandwidths (Silverman 1986; Worton 1989a,b, 1995), as this was the least biased method available (Seaman and Powell 1996, Seaman et al. 1999). We chose the 95% isopleth to measure annual ranges, but exclude occasional sallies. We calculated annual ranges using "The Home Ranger", Version 1.0 (F.W. Hovey, British Columbia Forest Service, Research Branch, Columbia Forest District, P.O. Box 9158, R.P.O. No. 3, Revelstoke, BC V0E 3K0, Canada). Radio locations used in all of our analyses were a minimum of 48 hours apart. Most satellite collars in the study were designed to last for two years; hence, for some animals we obtained two annual range estimates. With these cases, to avoid sample pseudo-replication, we chose only a single annual range for inclusion in our analyses (the estimate with the most locations), unless the animal underwent a change in family status between the two years (i.e., cases where females gained or lost cubs, or cubs aged). We included only those annual ranges comprised of ≥ 38 locations for analysis, as kernel techniques tend to overestimate range size with smaller sample sizes (Seaman et al. 1999). Also, annual ranges

were not calculated for subadult males. Subadult male grizzly bears may wander extensively in search for a home region, and during this period they are not considered to possess a home range (Burt 1943).

2.5.2 Seasonal Ranges

Seasonal ranges were calculated only for those animals which transmitted ≥ 8 locations per season in every season of the year. Seasons were defined as in section 2.4.4. Because sample sizes for seasonal ranges were always < 38 , the 95% minimum convex polygon (MCP) method was used to estimate seasonal ranges (Tracker, Version 1.1, Camponotus AB, Solna, Sweden). When the number of fixes is low, the MCP is more robust than other techniques (Harris et al. 1990).

2.5.3 Seasonal Movement Rates

Seasonal rates of movement were calculated for the same data set that was used to estimate seasonal ranges, but data from four subadult males were added for comparison. Rates of movement were calculated using the Tracker program by examining straight-line distances between successive locations.

2.5.4 Statistical Analyses

Range and movement rate estimates were \log_{10} -transformed prior to analyses to meet assumptions of normality and equal variance among groups of data (Sokal and Rohlf

1995). The annual ranges of adult males and females were compared using a one-way analysis of variance (ANOVA). A preliminary one-way ANOVA was performed to determine whether family status of females (i.e., females without accompanying offspring, with cubs of the year, with yearlings, or with two-year olds) influenced annual ranges. Estimates of seasonal ranges and movement rates for each grizzly bear across a single year were related through time; hence, to compare seasonal ranges and rates of movement between males and females and among seasons, a two-way repeated-measures ANOVA was performed (SigmaStat, Version 2.0, Jandel Corporation, San Rafael, California, USA). Following significant ANOVAs, Tukey's HSD test (Zar 1984) was used to compare individual means.

2.6 Denning Habits

2.6.1 Den Investigations

We investigated habitat characteristics of dens located by satellite telemetry with help from aerial tracking. We measured den characteristics where possible (i.e., cavity height, width, length, entrance width and height). We recorded the percentage cover of plant species in the immediate surroundings of den entrances (1 m radius), and collected a soil sample from the excavation pile for soil-typing of the denning habitat. We recorded the aspect of den entrances using a compass with an adjusted declination of 35° east, which is the average declination from true north for the study area. Aspect of den entrances were coded into one of four categories: north (315°-45°), east (45°-135°), south (135°-225°), and west

(225°-315°). A clinometer was used to measure the slope (°) of the immediate area in which dens were excavated.

2.6.2 Dates of Den Entrance and Emergence

General dates of den entry and den emergence for study animals were described from dates on which collar transmissions to satellites ceased to be received in autumn (a result of signal blockage from the den structure) and the dates on which satellites resumed receiving transmissions in spring.

2.6.3 Statistical Analyses

Use of habitats for denning was compared to the proportional availability of habitats in the study area (as determined from maps described in Section 2.4.1) using a log-likelihood ratio goodness of fit test (Zar 1984: 52-53). Only those habitats in which dens occurred were included for analyses, as zero values in frequency of use cannot be used in a log-likelihood ratio test. Thus, the null hypothesis tested here was one of no preference for those habitats in which dens were found to occur. For habitats in which dens were not known to occur, avoidance of those habitats for denning was assumed. Following rejection of the null hypothesis, 90% Bonferroni confidence intervals were constructed for the proportion of times animals denned in each available habitat type (Neu et al. 1974). Comparison of overlap of confidence intervals to habitat availabilities was used to determine which habitat types were being preferred

and/or avoided for denning (Neu et al. 1974; Byers et al. 1984; White and Garrot 1990).

The frequencies obtained for the aspect of den entrances were compared to what was expected from random using a Chi-square Goodness of Fit Test (Zar 1984; Sokal and Rohlf 1995).

2.7 Potential Impact of Mining on Grizzly Bears

Telemetry data and den work has allowed for the drawing of conclusions as to the potential effects of mining developments on grizzly bears.

3.0 ACTIVITIES FOR THE YEAR

In May, 1998, we deployed the last of the satellite radio-collars for the grizzly bear project. Capture operations were directed mainly east and north of Contwoyto Lake, including east of Bathurst Inlet. Satellite radio-collars were deployed on 10 adult males and seven females. Further, during the capture operation five grizzly bears were captured for the purpose of removing satellite radio-collars. Two of these five animals were fitted with break-away VHF collars to aid in the finding of dens during the winter of 1998-99.

In September, 1998, a recapture operation was launched to recover 16 satellite radio-collars. During this operation, the satellite radio-collars of six females were replaced with break-away VHF collars. These collars were deployed to aid in the finding of dens during the

1998-99 winter. The collars also helped us determine the reproductive and survival status of the females and their accompanying offspring in May, 1999.

Also in September, 1998, we investigated the dens of 19 grizzly bears based on where telemetry flights in March, 1998, determined the den sites of satellite radio-collared grizzly bears.

In May and June, 1999, we captured 47 bears (eight adult males, 16 adult females, two male yearlings, one female yearling, 10 male cubs-of-the-year, and 10 female cubs-of-the-year) and removed all remaining transmitting satellite radio-collars from study animals ($n = 11$). We also removed 12 VHF break-away collars. These were the final capture operations of the project.

In August, 1999, 21 dens that were identified from collared animals in March, 1999, were investigated. This was the final field operation for the grizzly bear project.

4.0 RESULTS

4.1 Animal Capture and Telemetry

From May 1995 to June 1999, we captured 264 barren-ground grizzly bears. Many of these bears were recaptures as we replaced and removed radio-collars or investigated the body condition of bears. Of the total number of captures, 152 different bears were identified. Of these 152 individuals, 39 were adult females and 36 were adult

males. Among subadults (aged three to four years), 11 were females and nine were males. We marked 30 cubs-of-the year (16 female, 14 male), 16 yearling cubs (eight females, eight males), and nine two-year-old cubs (three females, six males). We also marked two three-year-old bears (one female, one male) that were still with their mother. All age classes noted above were at the time of first capture.

Since May 1995 we have placed 89 satellite radio-collars on 81 bears ($n = 42$ females, $n = 39$ males)(Fig. 2). Some bears received a second satellite radio-collar after the first one was removed. For 23 bears (mostly females), a break-away VHF radio-collar was fitted after the satellite collar was removed. The number of locations obtained from satellite telemetry with at least one hour of elapsed time between successive locations totalled 18,256. With at least 24 hours of elapsed time between successive locations, the number of locations obtained totalled 8,461.

4.2 Population Delineation

4.2.1 Multivariate Cluster Analysis

A total of 8,054 locations ($n = 4,370$ female, $n = 3,684$ male) and 96 bear-years of data ($n = 55$ female, $n = 41$ male) were available for evaluating the existence of sub-populations of grizzly bears in the SGP by multivariate cluster analysis. All locations were separated in time by a minimum of 24 hours. Movement patterns for males and females are indicated in Figs. 3 and 4. Individual

annual ranges averaged ~2,100 km² for adult females and ~6,700km² for adult males (see section 4.4.1). Subadult males ranged from ~10,000 km² to ~40,000 km² in a single year.

The dendrogram (clustering solution) obtained for females indicated the separation of bears into approximately three clusters (Fig. 5): a cluster in the North Slave area, Bathurst Inlet area, and Kugluktuk area (Fig. 6). The utilization distribution contours indicated marginal overlap of population ranges (Fig. 6).

Like the analysis for females, the dendrogram obtained for males indicated a separation of bears into approximately three clusters (Fig. 7). The three identified populations were located in similar areas as were female population ranges: the North Slave area, Bathurst Inlet area, and Kugluktuk region (Fig. 8). However, unlike for females population ranges for male grizzly bears indicated higher overlap (Fig. 8), even at the 70% utilization contour level.

4.2.2 Mapping Population Boundaries

Population boundaries were set based on the 70% utilization contours for female and male clusters. Identified populations included the North Slave unit, Bathurst Inlet unit, and Kugluktuk unit (Fig. 9). The political border separating Nunavut from the Northwest Territories was used to separate the North Slave unit from the Kugluktuk and Bathurst Inlet units, as at the 70% contour level no overlap among female clusters

occurred when this unit boundary was selected; however, marginal overlap of the male population clusters occurred at the 70% contour level. The Nunavut/Northwest Territories border was also used to enclose the western perimeter of the Kugluktuk unit, separating that unit from the Sahtu region of the Northwest Territories (Fig. 9).

4.2.3 Validating Population Boundaries

Movement data (1995-98) from a total of 102 bear-years ($n = 61$ female, $n = 41$ male) were analyzed to determine expected annual exchange among identified populations (Fig. 9). After one year, we observed one of 17 adult female bears that originated in the Kugluktuk area move into the North Slave unit. Another female from the Kugluktuk unit emigrated across the Nunavut/Northwest Territories border into the Sahtu region of the Northwest Territories. We recorded movements of this same female back into the Kugluktuk unit a year later. And, after one year, we observed two of 14 male bears emigrate from the Kugluktuk unit to the North Slave unit. From the Kugluktuk unit a further two males emigrated to the Bathurst Inlet unit, and another male emigrated across the Nunavut/Northwest Territories border into the Sahtu. Also, after one year, two of 18 males emigrated from the North Slave area to the Kugluktuk unit. Another male of the North Slave population unit moved to the Bathurst Inlet unit. No bears were observed to emigrate from the Bathurst Inlet population unit, although three males immigrated to this region.

4.3 Habitat Analysis

4.3.1 Second Order Selection

Multivariate analysis of variance indicated that there was no significant difference between the sexes with regard to habitat selection patterns at the second order of selection (Wilk's Lambda Approx. $F_{11,11} = 1.27$, $P = 0.37$). That is, both males and females were practicing the same selection patterns when deciding where to place their home ranges in the study area.

Mean ranks of selection index values and significant differences among habitat types as determined from multiple comparison tests on ranks of habitat selection indices (both sexes combined) are presented in Fig. 10. The most preferred habitat relative other habitats was esker habitat. That is, when compared to the habitats available in the study area, the home ranges of study animals contained preferentially more esker habitat when compared to other habitats. Next, relative to other habitats, bears preferentially selected for tussock/hummock successional tundra, lichen veneer, and birch seep. Selection for these three habitat types was followed by preferential selection for tall shrub riparian areas, bedrock regions, spruce forests, heath/boulder, and heath tundra. The mean rank for wetlands was significantly less preferred when compared to these previous habitats. Boulder fields were significantly less preferred when compared to all other habitat types, including wetlands.

4.3.2 Third Order Selection

Multivariate analysis of variance indicated that there were significant differences in habitat selection among sexes (Wilk's Lambda Approx. $F_{10,201} = 2.45, P = 0.009$), seasons (Wilk's Lambda Approx. $F_{30,591} = 2.75, P < 0.001$), and for an interaction between sex and season (Wilk's Lambda Approx. $F_{30,591} = 1.39, P = 0.08$). That is, at the third order of selection, habitat selection differed for males and females, and the extent of these differences were dependent upon the season of the year.

Mean ranks of selection indices and significant differences among habitat types as determined from multiple comparison tests on ranks of habitat selection indices are presented for each sex for each season in Figs. 11 (spring), 12 (summer), 13 (late summer), and 14 (autumn). In spring, both males and females showed greatest preference relative other habitats for esker habitat and bedrock habitat. Males also showed high preference relative other habitats for the tussock/hummock successional tundra. In summer, males continued to show high preference for tussock/hummock successional tundra, while females demonstrated highest preference for tall shrub riparian habitat and eskers. Tall shrub was also ranked highly for males, as was birch seep for females. The pattern of selection for birch seep was opposite from males, which significantly avoided birch seep habitat relative to all other habitat types. In late summer, eskers again presented themselves as one of the most preferred habitat types for both males and

females, but females also showed high preference for boulder fields and birch seep (which are sometimes found to coexist; Table I). Females and males continued to demonstrate striking differences with respect to their positive and negative preferences for birch seep, respectively. In autumn, there was a demonstrated preference by males for tall shrub habitat, heath tundra, heath boulder, and birch seep. Females also showed high preference for tall shrub and heath tundra habitat, but most preferred esker habitat.

Overall, esker habitat was the most preferred habitat type for females throughout the year. In addition, riparian tall shrub and birch seep habitat were generally highly ranked by females. Tall shrub habitat was also important to males, as was esker and tussock/hummock successional tundra at varying times during the year.

4.4 Home Ranges and Movement Data

4.4.1 Annual Ranges

Home range and movement rates were calculated for 64 bears collared in the study. Annual ranges were calculated for 19 adult males, 18 lone females, four females with cubs of the year, six females with yearlings, and seven females with two-year olds. The annual ranges of females with different family status did not vary ($F_{3,31} = 0.99$, $P = 0.42$). Female annual ranges were subsequently pooled across family status for comparison with adult males. The mean annual range of adult males was 6,685 km² (SE = 1,351, $n = 19$); the mean

annual range of females was 2,074 km² (SE = 335, n = 35). Male annual ranges were significantly larger than female annual ranges ($F_{1,52} = 20.2, P < 0.001$). Movement maps for individual animals in the last full year of the study (1998) can be found in Appendices I (males) and II (females).

4.4.2 Seasonal Ranges

Nineteen and 11 bear-years of seasonal ranges were obtained from adult males and females, respectively. Seasonal ranges of males were larger than the seasonal ranges of females ($F_{1,84} = 23.78, P < 0.001$) (Fig. 15), and a probable season effect was detected ($F_{3,84} = 2.52, P = 0.06$). After reducing the full ANOVA model by sex, females ($F_{3,54} = 3.69, P = 0.02$), but not males ($F_{3,30} = 0.52, P = 0.60$), possessed ranges that significantly varied in size across seasons; however, ranges of males varied similarly among seasons as ranges of females (Fig. 15). Mean range size for females increased from spring to summer (Tukey's HSD test, $P < 0.05$) and decreased from summer to autumn (Tukey's HSD test, $P < 0.05$).

4.4.3 Seasonal Movement Rates

Seasonal movement rates from 15 male and 19 female bear-years were calculated. A sex effect ($F_{1,96} = 34.88, P < 0.001$), season effect ($F_{3,96} = 3.38, P < 0.05$), and sex by season interaction ($F_{3,96} = 4.73, P < 0.005$) were detected (Fig. 16). The full model was reduced by sex, and both females ($F_{3,54} = 4.79, P = 0.005$) and males ($F_{3,42} = 3.35, P$

< 0.05) continued to reveal season effects. Females were shown to increase movement rates from spring to summer (Tukey's HSD test, $P < 0.05$), followed by a decrease from summer to autumn (Tukey's HSD test, $P < 0.05$). Males showed a significant decrease in rate of movement between spring and autumn (Tukey's HSD test, $P < 0.05$). A general trend from a high rate of movement in spring (males) and summer (females) to lower rates in autumn was clear (Fig. 16).

4.5 Denning Habits

4.5.1 Den Investigations

Bears entirely avoided denning in five of the 12 major habitat types available to them (wetlands, tussock/hummock successional tundra, lichen veneer, boulder fields and exposed bedrock). Esker habitat, which previously had been regarded as a major denning habitat for barren-ground grizzly bears (Mueller 1995), accounted for seven of 56 den sites. The remainder of the dens were located in typical heath tundra habitat (23/56), tall shrub riparian habitat (3/56), birch seep (5/56), spruce forest (5/56), heath tundra habitat with >30% boulder content (11/56), and heath tundra habitat with >30% bedrock content (1/56). One further den was located in a non-vegetated sand embankment adjacent to the Hood River. Compared to the proportional availability of habitat types in the three LANDSAT TM images used in the habitat analysis (Table II), the selection of denning habitat by bears was determined to be significantly different from random ($G = 127.67$, $df 6$,

$P < 0.0001$). Comparison of Bonferroni confidence intervals indicated that esker habitat was selected more than expected from chance ($0.10 > P > 0.05$). In addition to those habitats in which no dens were found, heath tundra with >30% bedrock content was avoided for denning ($P < 0.05$).

All dens were located on well-drained slopes ($\bar{X} = 25.3^\circ$, $SE = 1.2$, $n = 55$). Choice of den aspect was decidedly non-random ($\chi^2 = 12.4$, $df 3$, $P < 0.01$), with the majority of dens facing south (25/56), followed by west (13/56), east (10/56), and north (8/56).

Almost all dens were constructed under the cover of tall shrub (>0.5 m) species (*Betula glandulosa* and *Salix* spp.), the root structures of which likely support the ceilings of dens. Most dens contained substantial amounts of bedding material, which was observed to be gathered by bears prior to den entrance. Bedding material was almost exclusively composed of mats of crowberry (*Empetrum nigrum*).

4.5.2 Dates of Den Entrance and Emergence

The majority of bears emerged from their dens in the first week of May. Den entrance occurred primarily in the last two weeks of October.

4.6 Potential Impact of Mining on Grizzly Bears

Results are based on home range data, den work, and habitat analyses. Conclusions with regard to the potential effects of mining on grizzly bears are discussed below.

5.0 DISCUSSION/CONCLUSIONS

5.1 Population Delineation

If geographic bounds for a population can be clearly established, population size, demographic rates, and life-history parameters may be estimated with greater reliability from accurate estimates of immigration and emigration rates. Further, an increased number of methods are available to enumerate a closed (where births, deaths, immigration, and emigration are assumed to be zero), rather than open (no assumptions of demographic rates), population (Krebs 1999). If geographic bounds for a population cannot be established, then estimates of demographic rates must be obtained with discretion, and techniques of abundance estimation must be restricted. For example, the Cormack-Jolly-Seber technique (see Krebs 1999) is the only mark-recapture method available to enumerate open populations; several other enumeration techniques are available if rates of immigration and emigration can be assumed to be zero (e.g., Lincoln-Peterson, Schnabel methods; Otis et al. 1978, Krebs 1999). The degree of connectivity within a population or among two or more identified populations will also have important ramifications for how a given

population is best managed. For example, if harvest rates are set for a population that is continuous with a neighbouring population or management unit, animals from both areas of management may be affected jointly. This could pose a conservation problem if population connectivity is not recognized, particularly if the two areas of management are isolated through politics (e.g., divided by the borders of two countries, states, provinces, or territories).

We tested the connectivity of the barren-ground grizzly bear population in the SGP, an area bisected by a territorial border. Here, for identified population units to be valid, we required that population units contain both distinctive male and female components as determined by the independent clustering of male and female bears in the study area. Further, we required negligible exchange of individuals among identified population units. The latter criteria was to ensure that spatial closure of population units was such that demographic processes within a unit would be mainly a function of intrinsic birth and death rates, and not immigration or emigration rates (i.e., that population units likely represented independent demographic units).

Our first validation rule was at least partially satisfied. We obtained independent clustering solutions that grouped both male and female grizzly bears into three relatively distinct areas: the North Slave region, Bathurst Inlet region, and Kugluktuk region. Spatial clusters for male and female bears appeared similar enough in distribution so that distinctive male and

female components could be contained within common population boundaries. Matches between male and female ranges for a population unit were not perfect, however. Although female population ranges were completely contained within established population unit boundaries at the 70% contour level, male population ranges demonstrated a higher degree of overlap. Due to this overlap, no population range for males could be completely contained within a designated population boundary. From these results it was anticipated that population closure would be less than that needed to designate population units as independent demographic units.

Indeed, exchange rates among population units implied poor population closure. And, not surprisingly, this was more evident for the male, rather than the female constituent of identified population units. In any given year, 35% of the males in the Kugluktuk area could be expected to emigrate annually from the population unit (14% each to the North Slave and Bathurst Inlet units, 7% to the Sahtu). Immigration to the Kugluktuk unit may be as high as 14%. Also, after one year, 22% of the males in the North Slave unit could potentially move out of the population unit (11% each to the Kugluktuk and Bathurst Inlet units). Immigration of males may be as high as 11%. No males were observed to emigrate from the Bathurst Inlet population unit, but immigration to the region could be as high as 18% annually.

Although not generally as high as for males, females also demonstrated population exchange. The fact that female

exchange occurred among population units is important. In a polygonous species such as the grizzly bear, provided there are enough males to mate all receptive females in a population, the intrinsic rate of increase of females will likely determine the population's intrinsic rate of increase. Population growth rates may thus be affected more by female exchange than male exchange. Here, female immigration to the Kugluktuk unit may be as high as 7%/year, and emigration from the Kugluktuk unit may be as high as 13%/year. Female immigration to the North Slave unit may reach 3.4% annually. Considering data from both sexes, but especially from females, leads us to conclude that exchange among units was higher than that required to identify any of the three populations as independent demographic units.

In addition to the above, several males and females spent long periods of time (>2 weeks) in population units other than those from where they originated, but returned to their population of origin to den. During these periods it was possible for several of these animals to mate (we have seen matings as late in the year as July 25); however, exchange for these bears was not calculated. These findings further imply an open (continuous), rather than closed, population of barren-ground grizzly bears in the SGP.

The data also suggest that the Nunavut portion of the Kugluktuk cluster is continuous with the Sahtu region immediately west of the Nunavut/Northwest Territories border and north of the North Slave population unit. We documented three cases of exchange across this border

(two female, one male). Further, one female that clustered in the Kugluktuk area was captured in and dened exclusively in the Sahtu. Although this female did not demonstrate emigration as defined in the methods of this study, she did, however, spend large amounts of time (>1 month/year) on the Kugluktuk side of the territorial border. We could not test whether bears of the Bathurst Inlet area were continuous with those bears ranging east to Hudson's Bay, or whether bears of the North Slave unit were continuous with those bears that range south and west of the treeline. Based on the results obtained for bears within the SGP, however, it is likely that bears in the North Slave and Bathurst Inlet units are continuous with adjacent bear populations located outside the study area.

The grizzly bear population in the SGP should be treated as an open (continuous) population. The study area may still be divided and managed along the population boundaries identified herein for logistical and political reasons; however, it must be realized that management practices implemented in one identified unit will likely affect adjacent units. In addition, the bear population in the study area is likely continuous with bear populations located adjacent to and outside the study area. Techniques of estimating population abundance demographic rates for grizzly bears in the SGP should be restricted to those that do not assume population closure (e.g., Cormack-Jolly-Seber method; Krebs 1999).

5.2 Habitat Analysis

Rettie and Messier (1999) point out that selection patterns for animals should permit them to avoid the effects of the factor(s) most able to limit individual fitness, and selection patterns that allow for this should be strongest at the coarsest (largest) scales. For example, caribou may select habitats at higher orders of selection to minimize wolf predation, or exposure to the lethal meningeal worm (Rettie and Messier 1999). Only at finer scales would foraging decisions determine habitat selection patterns.

Grizzly bears, especially those found in the SGP, are likely not limited by predation (including human hunting) or disease. Therefore, we predicted that the patterns of selection observed by barren-ground grizzly bears at the coarser scale (second order selection) examined in this study would likely correspond to factors such as food abundance or food availability in time and space (i.e., grizzly bears in the SGP are likely food-limited). We also predicted that patterns of selection for barren-ground grizzly bears at the finer scale of study (third order selection) would focus on vegetation communities identified at the coarser scale. These predictions appear to have been borne out.

Our results document highly selective behaviour of certain habitat types by the animals in our study. Selection was demonstrated at both spatial scales examined, and at both temporal scales. The habitats selected at the second order (coarser scale) were largely

selected at the third order (finer scale) as well. The general pattern was for bears to preferentially select esker habitat, tall shrub riparian habitat, tussock/hummock successional tundra, and birch seep areas relative to other habitat types for both orders of selection examined. However, relative preference for these habitat types did vary between the sexes at the third order of selection.

Males and females may be preferring to use esker habitat and exposed bedrock habitat relative to other habitat types during the spring season because these habitats are likely the first to become snow-free, thus providing the easiest access to the previous year's berry crop. Eskers may be preferentially selected throughout the entire year, however, because they may act as easy and convenient travel routes, or they may provide cover for hunting (or contain more abundant game than other habitat types). Grizzly bears in the study area are decidedly carnivorous, moreso than bears found in other parts of North America (Gau 1998). Arctic ground squirrels, an important component of the grizzly bear's diet in autumn (Gau 1998), may be found more easily or captured more easily in esker habitat. Soils in eskers are less compacted than those found in typical glacial till, which may allow for easier excavation of ground squirrel burrows.

Tall shrub riparian habitat and birch seep may be important during summer and autumn for several reasons, including: overhead hiding cover, thermal cover during hot days, and access to tall shrub-specific foods such as

horsetail, willow buds, and some sedges. Tussock/hummock successional tundra may provide for cool bedding habitat in summer and late summer, as well as hunting habitat for ground squirrels. Lichen veneer may attract caribou, which are specialist foragers of lichens, and thus offer hunting habitat for grizzly bears throughout the year. Highest use of lichen veneer occurred during spring when caribou are migrating through most of the home ranges of grizzly bears in this study.

Females are not generally exhibiting the same patterns of selection throughout the summer, late summer, and autumn as males. This may be a strategy to avoid males, which have been noted to prey on females and their cubs (e.g., Jonkel 1987; McLellan 1994; in the Kugluktuk area, Case and Buckland 1998). The majority of grizzly bear matings are expected to occur in spring, which may account for less of a distinction between male and female habitat selection patterns during this season.

Rettie and McLoughlin (1999) suggest that the results of selection studies that consider habitat use as areas, rather than points, may be largely insensitive to the radius of circular areas considered for use. Here, we considered areas of use (1.0 km in radius) that were probably only suitable for class two and three locations, given the larger area radius associated with less precise class one locations. Future examination of the data presented here will involve analyzing habitat selection for grizzly bears using larger areas of use (up to 2.0 km in radius), which would allow for inclusion of class one locations (and hence considerably larger sample sizes).

Further, we may consider examining habitat selection using smaller areas of use than what was examined here. Such analyses may provide insight into the effect of buffer radius on the results of habitat selection studies.

5.3 Home Ranges and Movements

Annual and seasonal ranges, and movement rates for barren-ground grizzly bears in the SGP, were always greater for males than for females. Gau (1998) determined that male grizzly bears in the SGP have higher daily energy requirements than females. Generally, a larger energy demand will necessitate a larger area for food gathering, unless food exists in superabundance (McNab 1963). Male grizzly bears also tend to wander more in search of mates, which would further increase male ranges and movement rates.

We failed to detect differences among females of differing family status with regard to annual ranges. Very few studies have compared ranges and movement rates among female grizzly bears of differing family status. Pearson (1975) indicated that female ranges in southern Yukon contracted when sows had cubs of the year but expanded when young reached yearling status, although this was not tested statistically. A trend of increasing range size as cubs age or are lost has also been observed among female grizzly bears by Blanchard and Knight (1991) in Yellowstone National Park, Nagy et al. (1983) on the Tuktoyaktuk Peninsula, Northwest Territories, and MacHutchon (1996) in Ivvavik National Park, northern

Yukon. Non-significant differences in ranges of females with cubs and females without cubs have been obtained from brown bears in southcentral Alaska (Ballard et al. 1982), on Kodiak Island (summer ranges compared only; Barnes 1990), and in the Khutzeymateen Valley of British Columbia (MacHutchon et al. 1993). Real differences between ranges of female grizzly bears of differing family status likely do exist, but the differences may be of short duration (e.g., occurring only during the first few seasons after cubs of the year leave dens), and hence difficult to test with the sample sizes of most telemetry studies.

Seasonal trends in ranges and movement rates for barren-ground grizzly bears likely reflect seasonal changes in behaviour. For example, male barren-ground grizzly bears travel at their highest speeds during spring, when mate-searching behaviour is at its greatest. The increase in female seasonal ranges from spring to summer and the high rates of movement exhibited by both sexes at that time probably results from low summer food availability, which may predispose bears to wander more in search of food. Fat stores reach annual lows in the summer, when female caribou aggregate on calving grounds beyond the ranges of most study animals and prior to the ripening of blueberries, cranberries, and crowberries (Gau 1998). The subsequent decrease in female ranges and movement rates by both sexes as the summer progresses likely reflects increased food availability. By late summer, caribou return to the central study area (where the majority of bears in this study were collared) and berries peak in abundance. Annual and seasonal ranges of

bears likely decrease in size when food supply increases, and vice versa. For example, an inverse relationship between range size and annual hard mast (acorns, hickory nuts, hazel nuts) production was documented for female black bears in North Carolina (Powell et al. 1997). Following the closure of garbage dumps in Yellowstone National Park (1968-1970), the mean annual ranges of male and female grizzly bears increased five-fold before apparently levelling off in the mid-1980's (Craighead et al. 1995).

Although male barren-ground grizzly bears varied the size of their ranges with seasons in a manner that mirrored females, mean seasonal ranges for males were not found to significantly differ. The strength of the relationship between food supply and male range size has been shown to be less than that of females in several mammalian species (for review see Powell et al. 1997:104), which may account for the observed variation in male seasonal ranges. Factors other than food availability, such as mate-searching behaviour, may weaken the relationship between seasonal food availability and range size in male barren-ground grizzly bears.

5.4 Denning Habits

Although dens were constructed in eskers only seven of 56 times, compared to the availability of esker habitat in the environment it is clear that esker habitat was selected for denning more than what was predicted by chance. Typical heath tundra, heath tundra with >30% boulder content, spruce forest, tall shrub riparian

areas, and birch seep areas were used in a manner consistent with what could have been expected from random habitat use. It should be noted that due to the small pooled sample size of dens ($n = 55$), power for the Bonferroni confidence intervals was low ($1 - \beta < 0.80$). Due to their large contributions to the G -statistic, however, bears are also likely preferring these three habitat types for denning but the statistical power needed to demonstrate this is lacking in our post-hoc analysis.

Not surprisingly, no dens were observed in tussock/hummock meadows, wetlands, or boulder and bedrock fields, likely because of poor digging substrate and/or poorly drained soils. Heath tundra with >30% bedrock may have been avoided as denning habitat due to shallow digging substrate.

Previous studies (e.g., Mueller 1995; Banci 1996) suggested that large glacio-fluvial deposits such as eskers were extremely important for grizzly bear denning habitat. For example, Mueller (1995) reported that 29 of 32 bear dens encountered (91%) were located in eskers, when esker habitat was expected to make up 1.5% of the surrounding landscape. Such exclusive use of esker habitat for denning is not supported by data obtained from radio-collared grizzly bears. Although bears are denning in eskers or esker-like materials, and they are doing so to an extent greater than what we would have predicted from chance alone, the use of eskers in this study is considerably less than what has been reported in prior studies of grizzly bear denning habits in the SGP.

Previous studies which implied that eskers were extremely important for grizzly bear denning relied heavily on aerial survey data. However, dens in eskers are much more visible from the air (and ground) than are dens in more common tundra habitats. Furthermore, some studies of grizzly bear denning habitat in the SGP were biased towards searching eskers more than other tundra habitat types (e.g., Mueller 1995). Following collared barren-ground grizzly bears to determine denning habitat selection patterns eliminates both of these biases.

The generally southern aspect of den entrances observed in this study agree with the results of previous accounts of the aspect of grizzly bear dens in tundra habitat (e.g., Mueller 1995). A southern aspect to den entrances may take advantage of northerly prevailing winds during winter, which can produce large snow banks on lee (southern) slopes. Large snowbanks covering den entrances likely help protect and insulate dens from the very cold temperatures experienced in the study area during winter.

The average slope into which dens were excavated was steep (>25%). Although dens may be easier to dig in steep slopes, steepness in slope may further help to trap windblown snow. In addition, steep, southerly-facing slopes often produce well developed patches of dwarf birch and willow, the roots of which may add to the soundness of den cavity ceilings.

The duration of the denning season in the study area is long compared to other grizzly bear populations in North America. In all likelihood this is due to the brevity of the snow-free period on the tundra, relative more western and southern ecosystems.

5.5 Potential Impact of Mining on Grizzly Bears

Grizzly bears in the SGP have large spatial requirements. This agrees with results of other studies of barren-ground grizzly bears (e.g., Reynolds 1980; Nagy et al. 1983; Clarkson and Liepins 1989; Ballard et al. 1993), although ranges in this study are much larger than any previously reported range estimates for grizzly bears. Large ranges may put individual bears in contact with humans even when camps or mine sites are of considerable distance from the core of the home range of an animal. Individual ranges could encompass several camps that are tens or even hundreds of kilometres apart. Furthermore, due to the connectivity of the population in the SGP, localized sources of bear mortality in the SGP may in actuality affect the demographics of grizzly bears in the entire region. The barren-ground grizzly bear population in the SGP is thus likely to be highly susceptible to human activity. Management of bears in the SGP should focus on maintaining low levels of human-caused mortality, with the realization that communities, hunting camps, and mining/exploration camps may impact bears from more than just the general vicinity. Estimates of bear population status and trends should be monitored for the region to ensure that the cumulative effects of human

activity on bears, including mortality, are within sustainable limits.

Den investigations have revealed that eskers may not be as important for denning as what was once thought. Nevertheless, results indicate that eskers are still used for denning (preferentially so) and are important habitat for grizzly bears throughout most of the year. Cautionary use of esker materials for roadbuilding, etc., is thus still warranted.

Future analysis of the impact of industrial developments on bear movements will likely come from the external wildlife monitoring programmes required by mine developers in the region (e.g., BHP NWT Diamonds Project, Diavik Diamonds Project).

6.0 LINKS WITH PARALLEL STUDIES

The research project has had synergistic effects with at least four other research initiatives. First, the study has proven to be important within the context of the Environmental Impact Statements required by resource extraction companies that are or will be operating in the SGP. The satellite telemetry programme has already proven to be useful to the grizzly bear monitoring programmes initiated at the BHP Diamond Mine and the Diavik site (e.g., Diavik Diamonds Project Environmental Assessment Submission). Second, this project was intimately related to a study on the nutritional ecology of barren-ground grizzly bears that was recently

completed by the Government of the Northwest Territories and the University of Saskatchewan (Gau 1998). Third, there was a need to develop a broad habitat classification for the SGP. This project was intimately involved in the development of such a classification. Fourth, this project has provided the groundwork for a possible future study on the demography and sustainable harvest barren-ground grizzly bears in the central NWT.

7.0 TRAINING ACTIVITIES AND RESULTS

This project provided Philip D. McLoughlin the opportunity to study at the Ph.D. level (University of Saskatchewan), and Robert J. Gau to successfully complete his M.Sc. degree (University of Saskatchewan). For many capture operations we encouraged local inhabitants (mainly HTA members) to help in the finding and handling of barren-ground grizzly bears. Local involvement in capture operations was quite beneficial to the project.

8.0 EXPENDITURES AND SOURCE OF FUNDS

Please see the financial statement submitted independently (Interim Report, May, 1999).

9.0 SCHEDULE AND ANY CHANGES

All field work for the grizzly bear project has now been completed. Although this report will serve as the final report for the project to the West Kitikmeot/Slave Study Society, the authors are committed to the dissemination of information contained in this report to the scientific

community. As such, each of the four major sections of this report (i.e., population delineation, habitat selection, home ranges and movement rates, and denning habits) has or will be submitted individually for possible publication in peer-reviewed, scientific journals. For example, the section on home ranges and movement rates has already been accepted for publication in the peer-reviewed journal *Ursus* (McLoughlin et al. 1999). By May, 2000, we anticipate that all sections of this report will be submitted for possible publication in peer-reviewed journals.

REFERENCES

- Arthur, S.M., Manly, B.F.J., McDonald, L.L., and Garner, G.W. 1996. Assessing habitat selection when availability changes. *Ecology* 77:215-227.
- Banci, V. 1996. Wildlife Studies. BHP Diamonds Inc., *Unpublished report*.
- Ballard, W.B., Miller, S.D., and Spraker, T.H. 1982. Home range, daily movements, and reproductive biology of brown bear in southcentral Alaska. *Canadian Field-Naturalist* 96:1-5.
- Ballard, W.B., Ayres, L.A., Reed, D.J., Fancy, S.G., and Roney, K.E. 1993. Demography of grizzly bears in relation to hunting and mining development in northwestern Alaska. Scientific Monograph NPS/NRRO/NRSM-93/23. U.S. Department of the Interior, National Park Service, Denver, Colorado, USA.
- Barnes, V.J., Jr. 1990. The influence of salmon availability on movements and range of brown bears on southwest Kodiak Island. *International Conference on Bear Research and Management* 8:305-313.
- Bethke, R., Taylor, M., Amstrup, S., and Messier, F. 1995. Population delineation of polar bears using satellite collar data. *Ecological Applications* 6: 311-317.
- Blanchard, B.M., and Knight, R.R. 1991. Movements of Yellowstone grizzly bears. *Biological Conservation* 58:41-67.
- Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. *Journal of Mammalogy* 24:356-352.
- Byers, C.R., Steinhorst, R.K., and Krausman, P.R. 1984. Clarification of a technique for analysis of utilization-availability data. *Journal of Wildlife Management* 48:1050-1053.

- Case, R.L., and Buckland, L. 1998. Reproductive characteristics of grizzly bears in the Kugluktuk area, Northwest Territories, Canada. *Ursus* 1:41-47.
- Clarkson, P.L., and Liepins, I.S. 1989. Inuvialuit wildlife studies: grizzly bear research progress report 1987-1988. Technical Report No. 3. Wildlife Management Advisory Council, Inuvik, Northwest Territories, Canada.
- Clarkson, P.L., and I.S. Liepins. 1994. Grizzly bear population estimate and characteristics in the Anderson and Horton Rivers area, Northwest Territories, 1987-89. *Int. Conf. Bear Res. Manage.* 9:213-221.
- Conover, W.J., and Iman, R.L. 1981. Rank transformations as a bridge between parametric and nonparametric procedures. *The American Statistician* 35:124-129.
- Craighead, J.J., Craighead, F.C., and McCutchen, H.E. 1970. Age determination of grizzly bears from fourth premolar tooth sections. *Journal of Wildlife Management* 34: 353-363.
- Craighead, J.J., Sumner, J.S., and Mitchell, J.A. 1995. *The grizzly bears of Yellowstone*. Island Press, Washington D.C., USA.
- Epp, H., and Matthews, S. 1998. Habitat/vegetation classification for the West Kitikmeot/Slave Study region. Yellowknife, Northwest Territories, Canada.
- Fancy, S.G., Pank, L.F., Douglas, D.C., Curby, C.H., Garner, G.W., Amstrup, S.C., and Regelin, W.L. 1988. Satellite telemetry: a new tool for wildlife research and management. *U.S. Fish Wildl. Serv., Resour. Publ.* 172. 55 pp.
- Gau, R.J. 1998. Food habits, body condition, and habitat of the barren-ground grizzly bear. M.Sc. thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- GNWT. 1991. Discussion paper towards the development of a Northwest Territories barren-ground grizzly bear management plan. GNWT, Unpubl. Report. 16 pp.

- Gunn, A., Dragon, J., and Nishi, J. 1997. Bathurst calving ground survey, 1996. Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada.
- Harris, R.B., Fancy, S.G., Douglas, D.C., Garner, G.W., Amstrup, S.C., McCabe, T.R., and Pank, L.F. 1990. Tracking wildlife by satellite: current systems and performance. U.S. Fish Wildl. Serv., Fish Wildl. Tech. Rep. 30. 52 pp.
- Harris, S., Cresswell, W.J., Forde, P.G., Trehwella, W.J., Woollard, T., and Wray, S. 1990. Home-range analysis using radio-tracking data—a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* 20:97-123.
- Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluations of resource preference. *Ecology* 61:65-71.
- Johnson, R.A., and Wichern, D.W. 1982. Applied multivariate statistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey, USA.
- Jonkel, C. 1987. Brown bear. Pages 457-473 in M. Novak, J.A. Baker, M.E. Obbard, and B. Malloch, editors. Wild furbearer management and conservation in North America. Ontario Ministry of Natural Resources, Toronto, Ontario, Canada.
- Krebs, C.J. 1999. Ecological methodology (2nd ed.). Addison-Welsey Educational Publishers, Inc., Menlo Park, California, USA.
- MacHutchon, A.G. 1996. Grizzly bear habitat use study, Ivvavik National Park, Yukon. Final Report. Western Arctic District, Parks Canada, Inuvik, Northwest Territories, Canada.
- MacHutchon, A.G., Himmer, S., and Bryden, C.A. 1993. Khutzeymateen Valley grizzly bear study. Final report. Wildlife Report No. R-25, Wildlife Habitat Research Report No. 31. Ministry of Forests Research Program, Victoria, British Columbia, Canada.

- Manly, B.F.J., McDonald, L.L., and Thomas, D.L. 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman and Hall, London, England. 177 pp.
- McLellan, B. 1990. Relationships between human industrial activity and grizzly bears. International Conference on Bear Research and Management 8:57-64.
- McLellan, B. 1994. Density-dependent population regulation of brown bears. Pages 3-34 in M. Taylor, editor. Density-dependent population regulation in black, brown, and polar bears. International Conference on Bear Research and Management Monograph Series No. 3.
- McLoughlin, P.D., Messier, F., Case, R., Mulders, R., and Cluff, H.D. 1998. The spatial characteristics of barren-ground grizzly bears (*Ursus arctos*) in the central Northwest Territories: a progress report to the West Kitikmeot/Slave Study Society. Yellowknife, Northwest Territories, Canada.
- McLoughlin, P.D., Case, R.L., Gau, R.J., Ferguson, S.H., and Messier, F. 1999. Annual and seasonal movement patterns of barren-ground grizzly bears in the central Northwest Territories. *Ursus* In press.
- McNab, B.K. 1963. Bioenergetics and the determination of home range size. *American Naturalist* 97:133-140.
- Mueller, F.P. 1995. Tundra esker systems and denning by grizzly bears, wolves, foxes, and ground squirrels in the central arctic, Northwest Territories. Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada.
- Nagy, J.A., Russell, R.H., Pearson, A.M., Kingsley, M.C., and Larsen, C.B. 1983. A study of grizzly bears on the barren grounds of Tuktoyaktuk Peninsula and Richards Island, Northwest Territories, 1974-1978. *Can. Wildl. Ser.* 104 pp.
- Neu, C.W., Byers, C.R., Peek, J.M., and Boy, V. 1974. A technique for analysis of utilization-availability data. *Journal of Wildlife Management* 38:541-545.

- Otis, D.L., Burnham, K.P., White, G.C., and Anderson, D.R. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monographs* 62: 1-135.
- Pearson, A.M. 1975. The northern interior grizzly bear (*Ursus arctos* L.). Canadian Wildlife Service Report Series No. 34, Ottawa, Ontario, Canada.
- Pielou, E.C. 1984. The interpretation of ecological data. John Wiley and Sons, Toronto, Ontario, Canada.
- Powell, R.A., Zimmerman, J.W., and Seaman, D.E. 1997. Ecology and behaviour of North American black bears. Chapman and Hall Wildlife Ecology and Behaviour Series 4. Chapman and Hall, New York, New York, USA.
- Rettie, W.J., and McLoughlin, P.D. 1999. Overcoming radiotelemetry bias in habitat-selection studies. *Canadian Journal of Zoology* 77:1175-1184.
- Rettie, W.J., and Messier, F. 1999. Hierarchical habitat selection by woodland caribou: its relationship to limiting factors. *Submitted*.
- Reynolds, H.V. 1980. North slope grizzly bear studies. Alaska Department of Fish and Game, Juneau, Alaska, USA.
- Romesburg, H.C. 1981. Wildlife science: gaining reliable knowledge. *Journal of Wildlife Management* 45: 293-313.
- Seaman, D.E., and Powell, R.A. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology* 77:2075-2085.
- Seaman, D.E., Millspaugh, J.J., Kernohan, B.J., Brundige, G.C., Raedeke, K.J., and Gitzen, R.A. 1999. Effects of sample size on kernel home range estimates. *Journal of Wildlife Management* 63:739-747.
- Taylor, M., Cluff, D., Born, E., Aqqaloo, R., Ferguson, S., Stirling, I., Andriashak, D., Barber, W., and Messier, F. 1999. Delineation of six Canadian and Greenland polar bear populations using cluster analysis of movements. *Submitted*.

- Silverman, B.W. 1986. Density estimation for statistics and data analysis. Chapman & Hall, London, England.
- Sokal, R.R., and F.J. Rohlf. 1995. Biometry. W. H. Freeman and Company, New York, New York, USA.
- SPSS Inc. 1993. SPSS for Windows: Advanced Statistics User Guide, Release 9.0. Chicago, Illinois, USA.
- Strom, K.B., and McLoughlin, P.D. 1998. Habitat effectiveness model for grizzly bears in the Lac de Gras region, Northwest Territories, Canada. Technical report for the Diavik Diamonds Project Environmental Effects Report for Wildlife. Calgary, Alberta.
- Welsch, R.E. 1977. Stepwise multiple comparison procedures. Journal of the American Statistical Association 72:566-575.
- White, G.C., and Garrot, R.A. 1990. Analysis of wildlife radio-tracking data. Academic Press, Toronto, Canada.
- Worton, B.J. 1989a. Kernel methods for estimating the utilization distribution in home range studies. Ecology 70:164-168.
- Worton, B.J. 1989b. Optimal smoothing parameters for multivariate fixed and adaptive kernel methods. Journal of Statistical Computation and Simulation 32:45-57.
- Worton, B.J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59:794-800.
- Zar, J.H. 1984. Biometry. Prentice Hall, Englewood Cliffs, New Jersey, USA.

TABLES

Table I. Land habitat types identified in the three
LANDSAT

TM images by the NWT Centre for Remote Sensing and used
in the analysis of habitat selection by grizzly bears
(adapted from Epp and Matthews 1998).

Lichen Veneer This ecosystem unit characterizes areas covered with continuous mats of lichen that appears as a "veneer". These sites are windswept and dry, allowing for little other plant growth. Lichen veneer consists mainly of Iceland moss, several species of Certraria, green and black hair lichens, grey mealy lichen, worm lichens, and others. Saxifrages and heath plants become more common in sites where growing conditions are more favourable.

Esker Complex Esker complexes include all communities occurring on esker landforms. Esker tops are usually sparsely vegetated; common species include three-toothed saxifrage and moss-campion with lesser amounts of crowberry and bearberry. Lee slopes support bands of dwarf birch and willow that may reach heights of 1 m.

Wetland This ecosystem unit is made up of sedge meadows, and occasionally sedge fens and emergent plant communities.

Tussock/Hummock This ecosystem unit occurs on moist to sub-hygric lower slopes and depressions where tussocks (and hummocks) form. Tussocks are composed primarily of mounds of sheathed cotton-grass; later stage hummocks are typified by dwarf birch. Labrador tea, cloudberry, and Labrador lousewort are also common.

Heath Tundra This ecosystem unit delineates the typical mesic tundra habitat. Boulder and bedrock content is below 30%. Vegetation is dominated by a well-developed mat of low shrubs including dwarf birch, Arctic willow, northern Labrador teat, crowberry, cranberry, black and read bearberry, and blueberry. Herb and moss layers are not well developed.

Heath Bedrock Heath tundra in which boulder content ranges from 30-80% coverage.

Heath Boulder Heath tundra in which exposed bedrock content ranges from 30-80% coverage.

Spruce Forest Localized to the southern part of the study area, where the transition between boreal forest and tundra is more pronounced. Species include white spruce, jack pine, and white birch. Where conditions are more favourable, spruce-lichen woodlands exists.

Tall Shrub Riparian This ecosystem unit occurs in active stream channels on fluvial veneers of fine-textured materials overlying boulders. The productive soil medium and constant availability of flowing water supports a tall shrub community (up to 4 m in height) of dwarf birch, diamond-leafed willow, green alder, and occasionally white or black spruce (in southern portions of the study area). The herb layer is also well developed with bluejoint, dwarf raspberry, dwarf march-violet, and horsetail as common species.

Cont...

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Birch seep This ecosystem unit occurs in areas of active seepage through boulder fields. Typical vegetation is relatively well-developed dwarf birch (1 to 3 m tall) with a herb layer of bluejoint. Fine-textured fluvial deposits may occur in boulder crevices but rooting is primarily in the flowing water.

Bedrock Field Exposed bedrock with a coverage in excess of 80%.

Boulder Field Boulder fields with a coverage in excess of 80%. Boulders support a community of rock lichens of Umbicullaria and other species.

Table II. Observed and expected number of dens in each habitat type for barren-ground grizzly bears.

Habitat of den	Proportion of habitat in study area (p_i)	Observed # dens in habitat ($n = 55$)	Expected # dens in habitat ($p_i \times 55$)
Lichen veneer*	0.0243	0	1.34
Esker habitat	0.0077	7	0.42
Wetland *	0.0790	0	4.35
Tussock/hummock *	0.0946	0	5.20
Heath tundra	0.3200	23	17.60
Spruce forest	0.0025	5	0.14
Bedrock*	0.0352	0	1.94
Riparian tall shrub	0.0031	3	0.17
Birch seep	0.0108	5	0.59
Heath/boulder	0.1574	11	8.66
Heath/bedrock	0.1114	1	6.13
Boulder field*	0.1540	0	8.47

*Not included for statistical analysis as observed values of use are zero (see text).

FIGURES

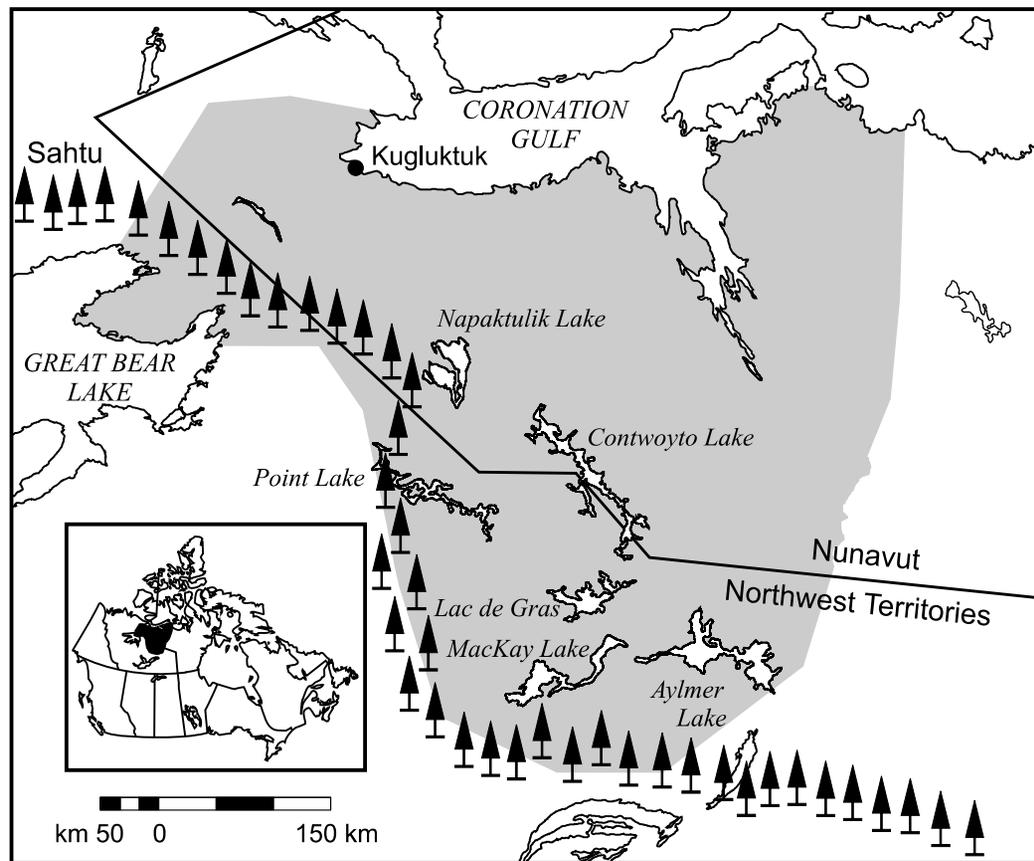


Fig. 1. Study area in the Slave Geological Province, central Northwest Territories. The treeline indicates the northern extent of trees in the region.

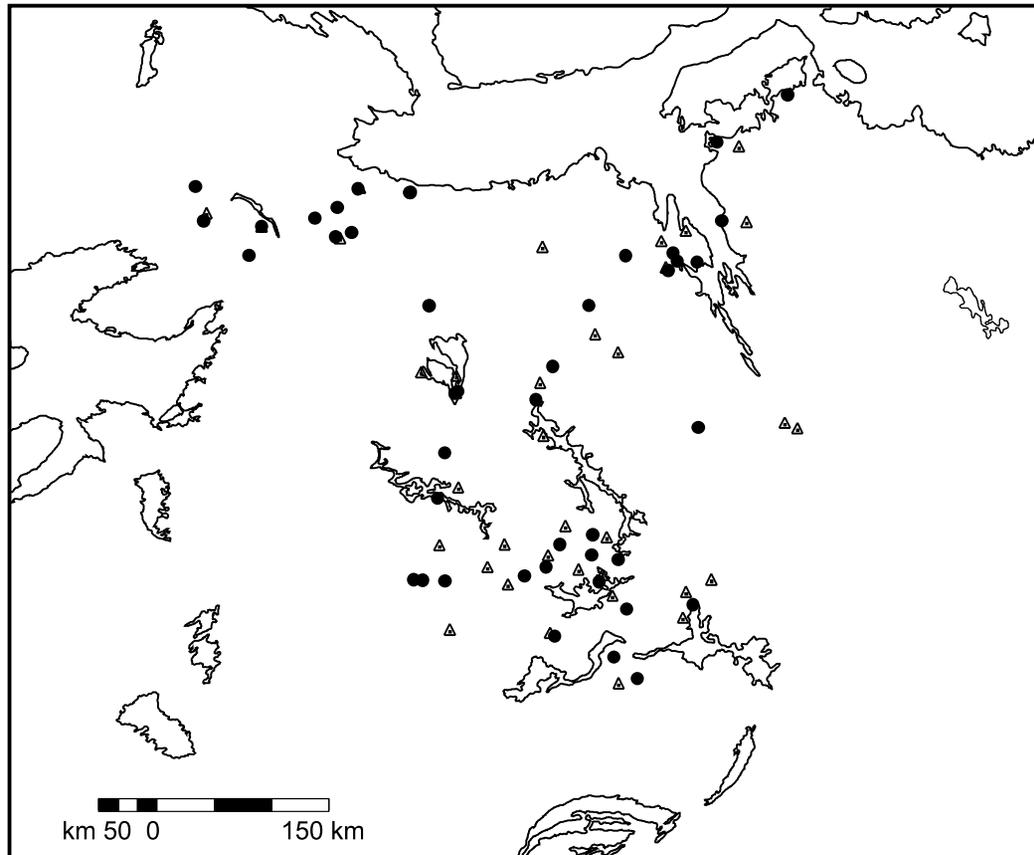


Fig. 2. Capture locations for male (triangles) and female (circles) barren-ground grizzly bears in the Slave Geological Province, 1995-1998.

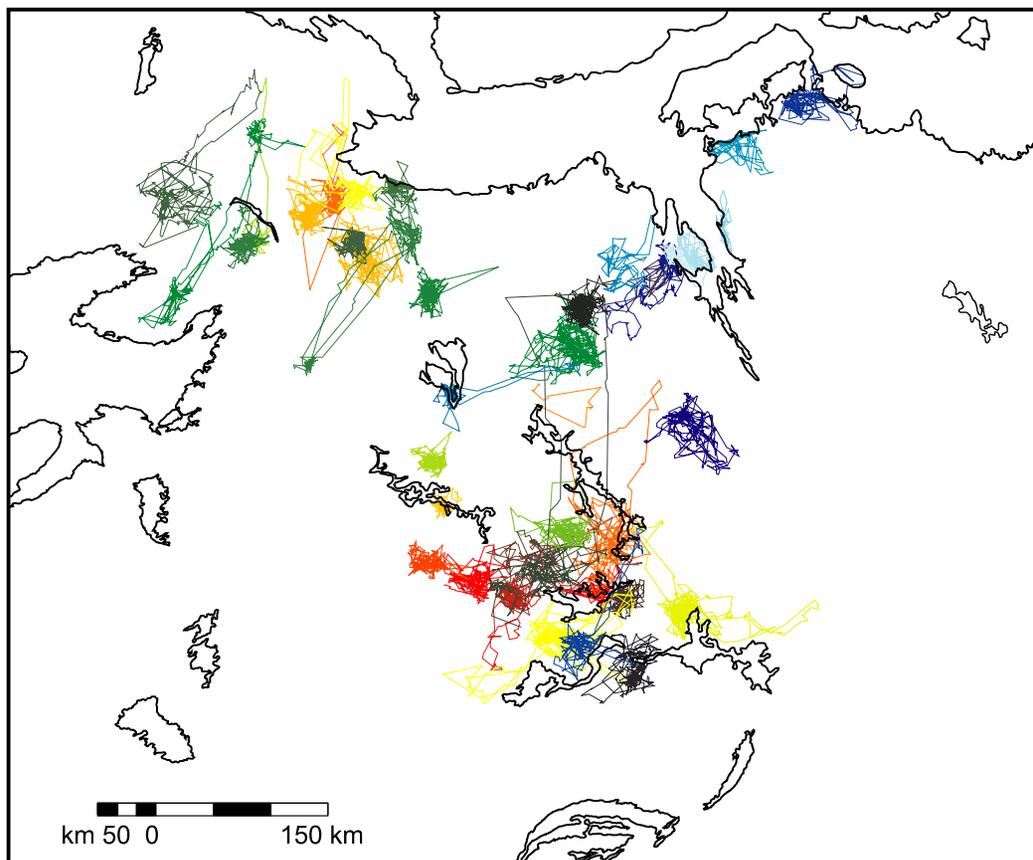


Fig. 3. Multi-annual movements of female barren-ground grizzly bears in the Slave Geological Province, 1995-1998.

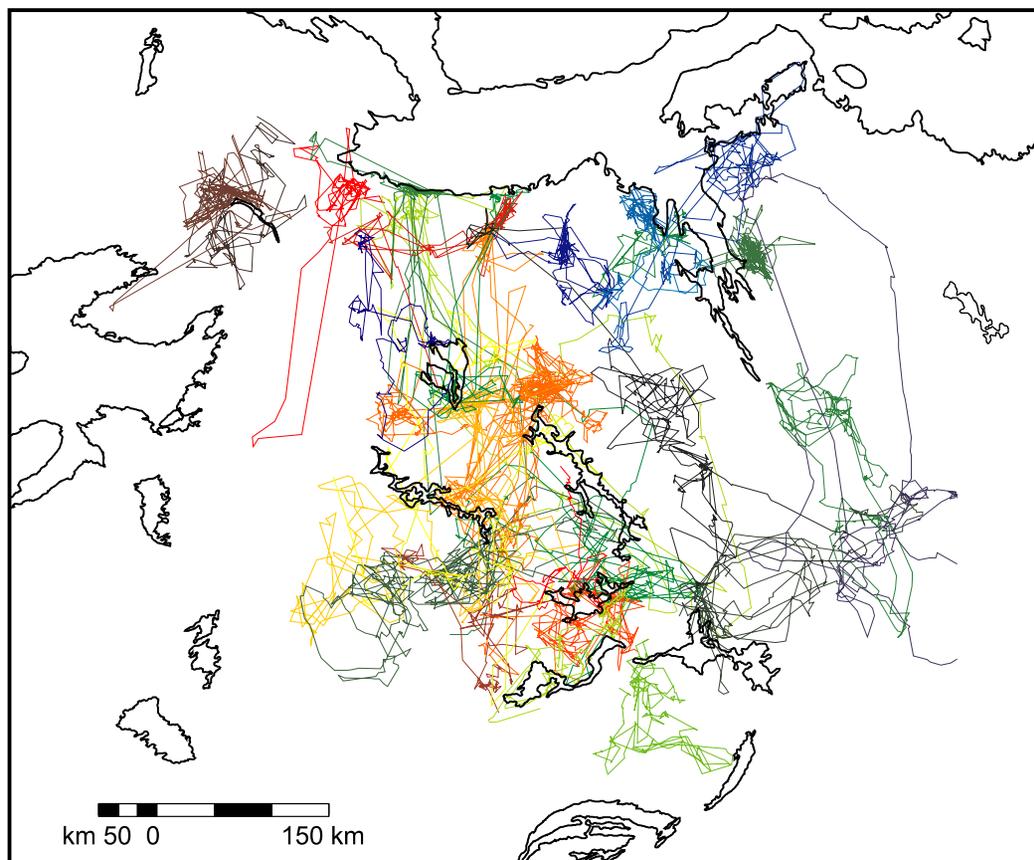


Fig. 4. Multi-annual movements of male barren-ground grizzly bears in the Slave Geological Province, 1995-1998.

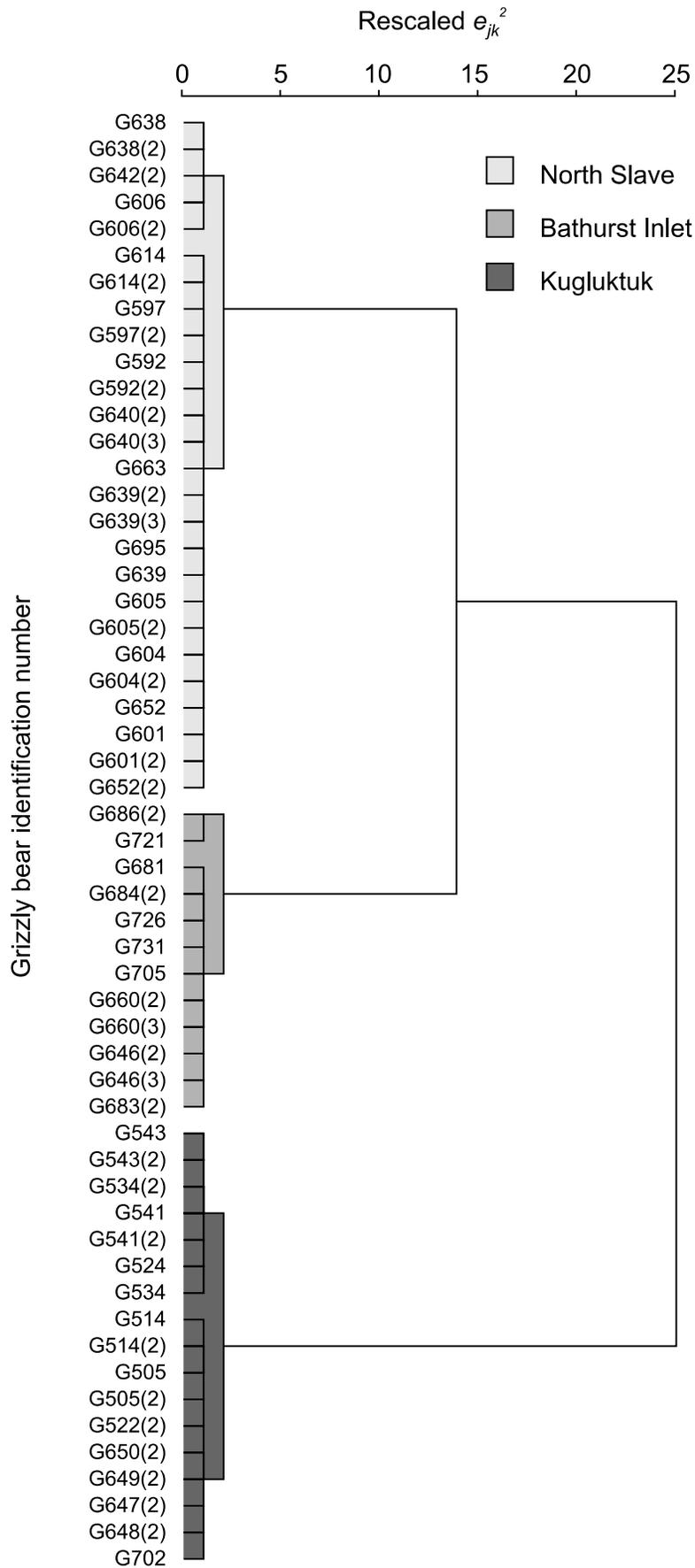


Fig. 5. Dendrogram showing spatial clusters of female bears in the Slave Geological Province, 1995-1998. Objects (bears) are based on one bear-year of data.

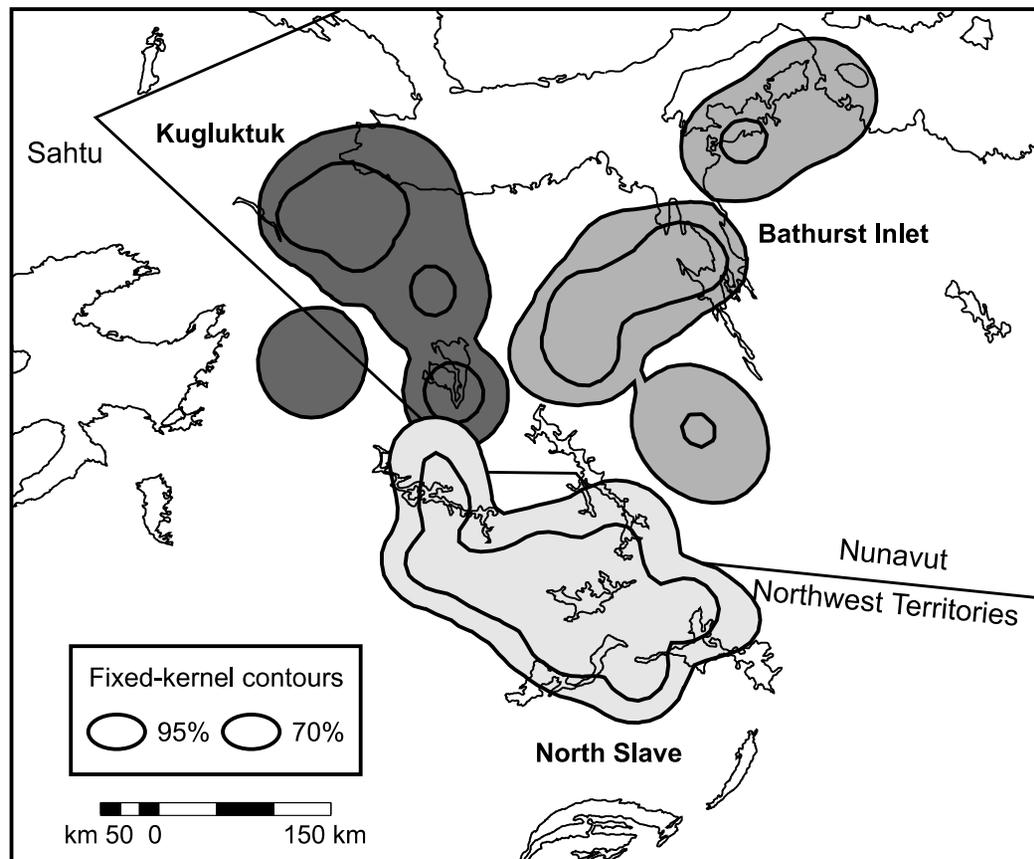


Fig. 6. The utilization distributions for the Kugluktuk, Bathurst Inlet and Lac de Gras clusters for female bears. Contours correspond to the 95% and 70% utilization distributions.

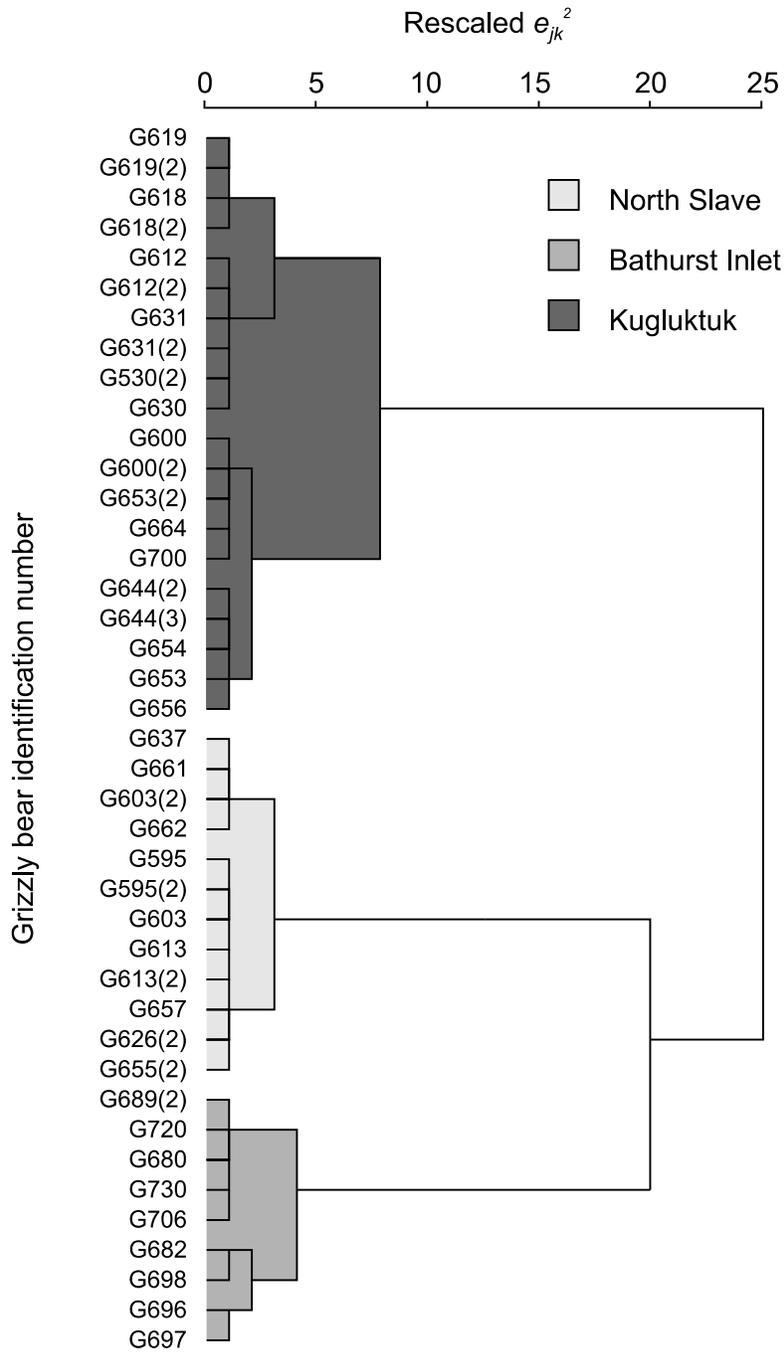


Fig. 7. Dendrogram showing spatial clusters of male bears in the Slave Geological Province, 1995-1998. Objects (bears) are based on one bear-year of data.

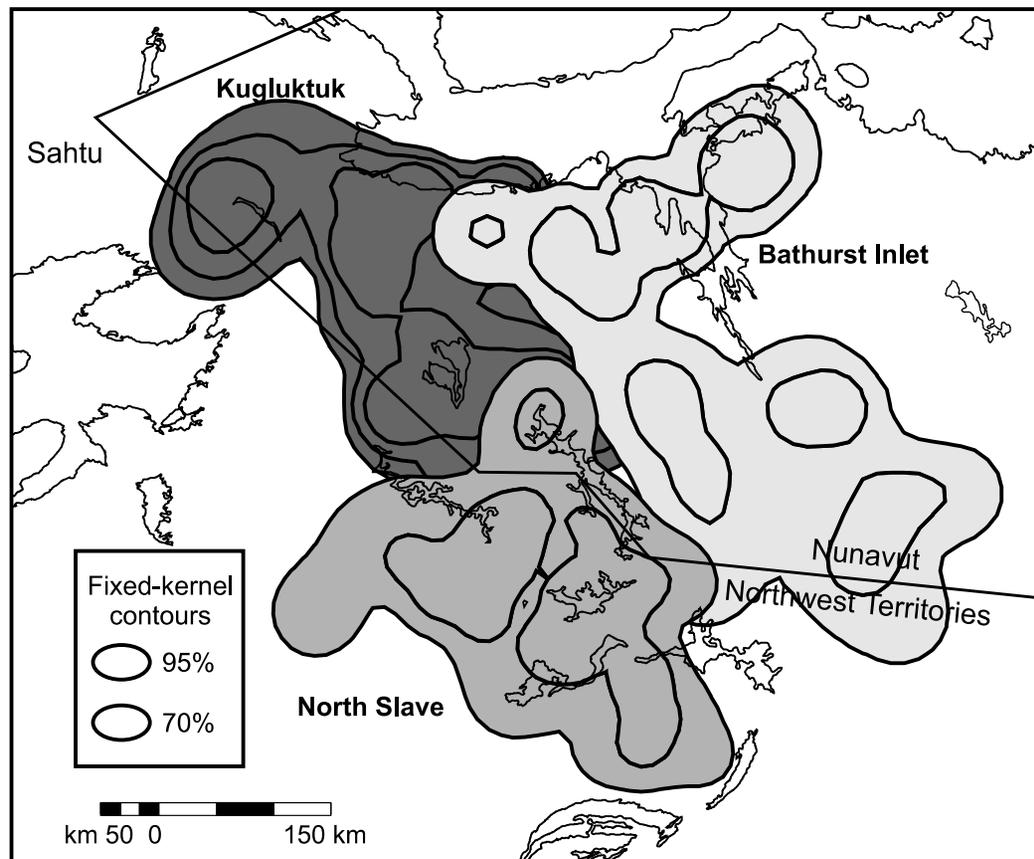


Fig. 8. The utilization distributions for the Kugluktuk, Bathurst Inlet and Lac de Gras clusters for male bears. Contours correspond to the 95% and 70% utilization distributions.

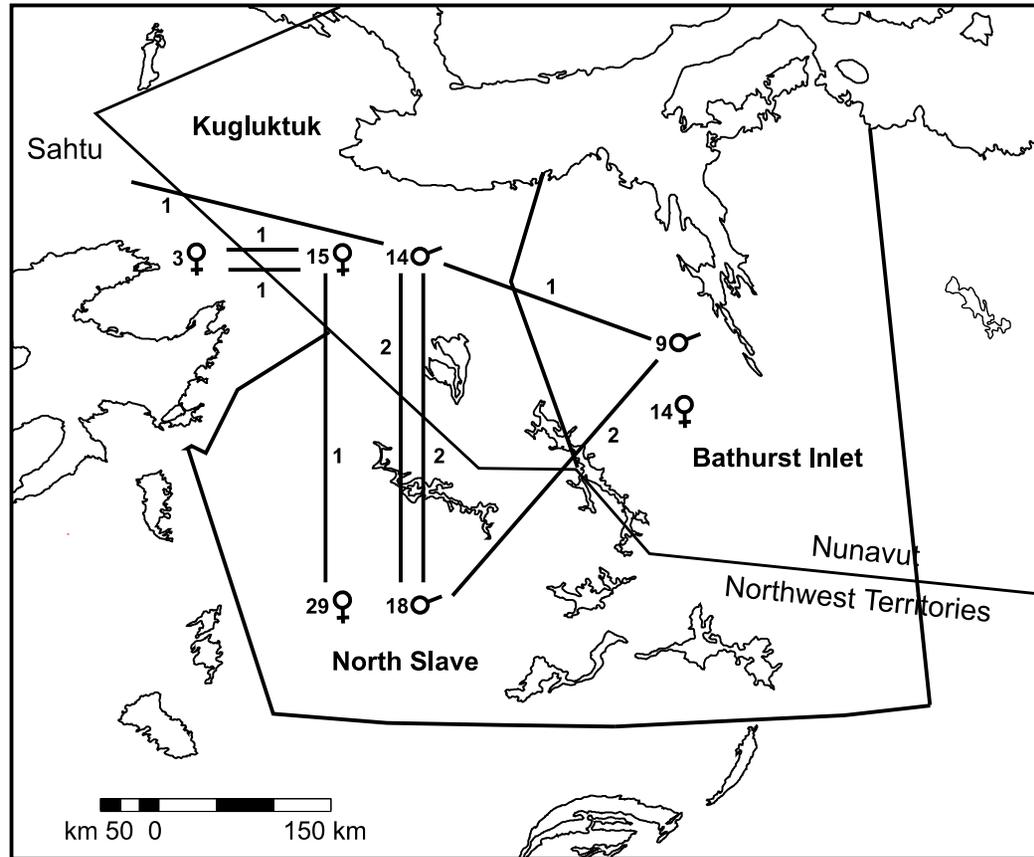


Fig. 9. Final population unit boundaries for the North Slave, Bathurst Inlet, and Kugluktuk clusters in the Slave Geological Province. Boundaries were based on the 70% utilization distributions (fixed kernel) for male and female population clusters. Immigration and emigration after one bear-year of data (see text) are indicated for the female and male components of each population unit. Arrows indicate direction of exchange and number of animals immigrating or emigrating.

Habitat	Boulder Field	Wetland	Heath Bedrock	Heath Tundra	Heath Boulder	Spruce Forest	Bedrock	Tall Shrub	Birch Seep	Lichen Veneer	Tussock Hummock	Esker
Mean Rank	2.29	4.23	5.17	6.29	6.63	6.94	7.00	7.17	7.54	8.14	8.17	8.37
Homogeneous Subsets												

Figure 10. Mean ranks of habitat selection indices (b_i) for the second order of selection. Homogeneous subsets of data are indicated for mean ranks which are not significantly different (experimentwise $\alpha = 0.10$; Welsch's multiple range test).

A.

Habitat	Heath Bedrock	Birch Seep	Heath Boulder	Tall Shrub	Tussock Hummock	Boulder	Heath Tundra	Wetland	Lichen Veneer	Esker	Bedrock
Mean Rank	4.12	4.90	5.20	5.67	5.80	6.01	6.05	6.24	6.99	7.30	7.79
Homogeneous Subsets											

B.

Habitat	Birch Seep	Heath Boulder	Heath Bedrock	Tall Shrub	Wetland	Boulder	Heath Tundra	Lichen Veneer	Bedrock	Tussock Hummock	Esker
Mean Rank	3.67	4.77	4.87	5.31	5.80	6.07	6.49	6.72	7.14	7.18	8.00
Homogeneous Subsets											

Figure 11. Mean ranks of habitat selection indices (b_i) for the third order of selection in spring (A. Females, B. Males). Homogeneous subsets of data are indicated for mean ranks which are not significantly different (experimentwise $\alpha = 0.10$; Welsch's multiple range test).

A.

Habitat	Heath Bedrock	Heath Boulder	Boulder	Tussock Hummock	Lichen Veneer	Heath Tundra	Bedrock	Wetland	Birch Seep	Esker	Tall Shrub
Mean Rank	3.70	4.97	5.51	5.61	5.82	5.93	6.45	6.60	6.93	7.02	7.48
Homogeneous Subsets											

B.

Habitat	Birch Seep	Boulder	Heath Bedrock	Bedrock	Lichen Veneer	Heath Boulder	Esker	Wetland	Tall Shrub	Heath Tundra	Tussock Hummock
Mean Rank	4.74	4.94	5.50	5.72	5.73	5.95	6.24	6.44	6.65	6.70	7.41
Homogeneous Subsets											

Figure 12. Mean ranks of habitat selection indices (b_i) for the third order of selection in summer (A. Females, B. Males). Homogeneous subsets of data are indicated for mean ranks which are not significantly different (experimentwise $\alpha = 0.10$; Welsch's multiple range test).

A.

Habitat	Heath Boulder	Lichen Veneer	Wetland	Heath Tundra	Tussock Hum-mock	Tall Shrub	Heath Bedrock	Bedrock	Birch Seep	Esker	Boulder
Mean Rank	4.83	4.85	5.31	5.78	5.81	5.83	6.26	6.56	6.63	7.02	7.12
Homogeneous Subsets	<hr/> <hr/>										

B.

Habitat	Heath Bedrock	Birch Seep	Lichen Veneer	Bedrock	Wetland	Tall Shrub	Tussock Hum-mock	Heath Boulder	Boulder	Heath Tundra	Esker
Mean Rank	4.44	4.81	5.19	5.70	5.81	6.36	6.37	6.44	6.53	6.94	7.41
Homogeneous Subsets	<hr/> <hr/>										

Figure 13. Mean ranks of habitat selection indices (b_i) for the third order of selection in late summer (A. Females, B. Males). Homogeneous subsets of data are indicated for mean ranks which are not significantly different (experimentwise $\alpha = 0.10$; Welsch's multiple range test).

A.

Habitat	Heath Bedrock	Boulder	Wetland	Heath Boulder	Birch Seep	Lichen Veneer	Tussock Hummock	Bedrock	Tall Shrub	Heath Tundra	Esker
Mean Rank	3.83	3.85	4.05	5.70	5.83	6.68	6.72	6.75	7.32	7.55	7.71
Homogeneous Subsets	<hr/> <hr/>										

B.

Habitat	Esker	Boulder	Wetland	Lichen	Heath Bedrock	Tussock Hummock	Bedrock	Birch Seep	Heath Boulder	Heath Tundra	Tall Shrub
Mean Rank	4.20	4.44	5.17	5.21	5.46	5.55	5.61	6.67	7.32	7.96	8.41
Homogeneous Subsets	<hr/> <hr/>										

Figure 14. Mean ranks of habitat selection indices (b_i) for the third order of selection in autumn (A. Females, B. Males). Homogeneous subsets of data are indicated for mean ranks which are not significantly different (experimentwise $\alpha = 0.10$; Welsch's multiple range test).

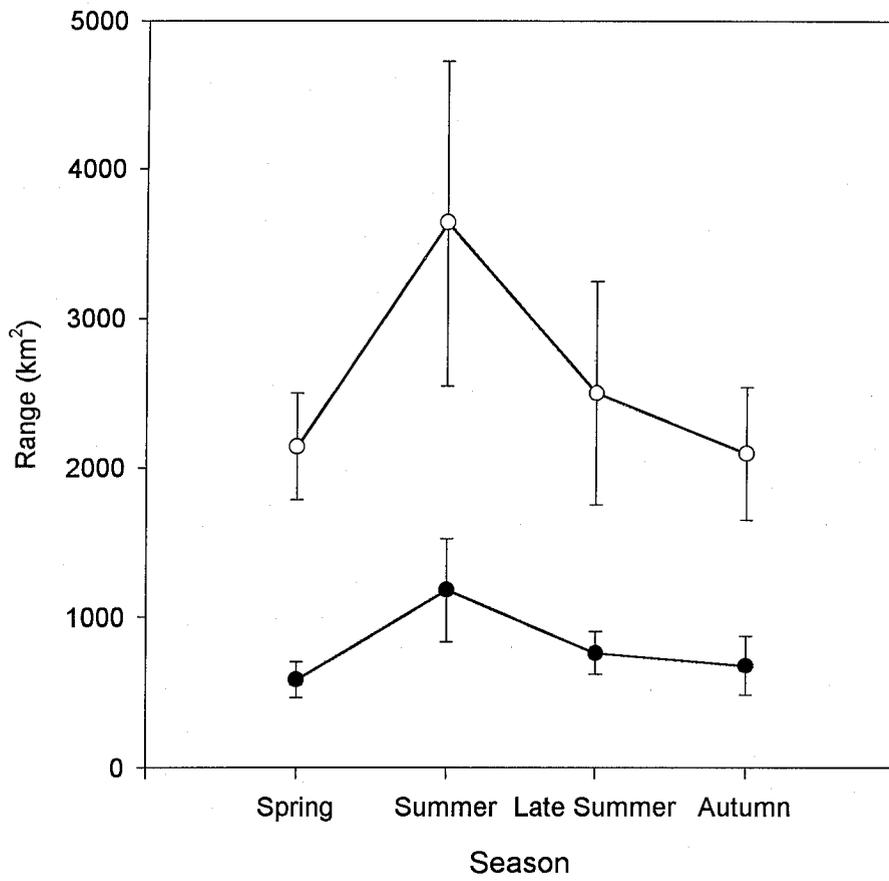


Fig. 15. Seasonal ranges for male (open circles) and female (closed circles) barren-ground grizzly bears in the Slave Geological Province, 1995-1997.

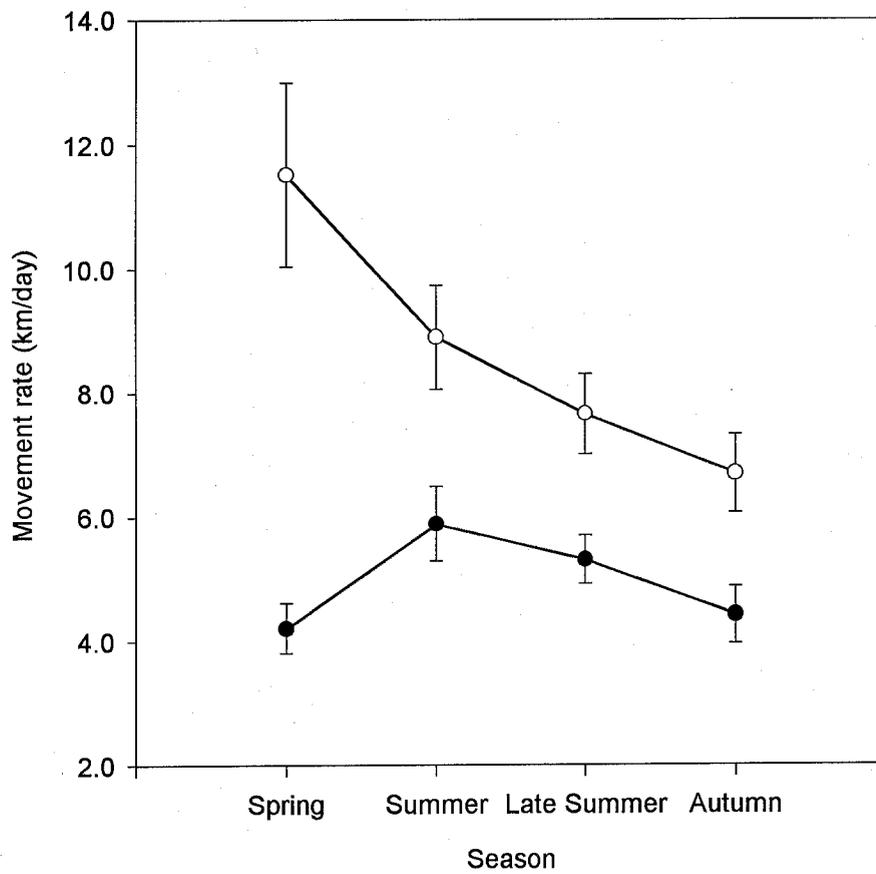
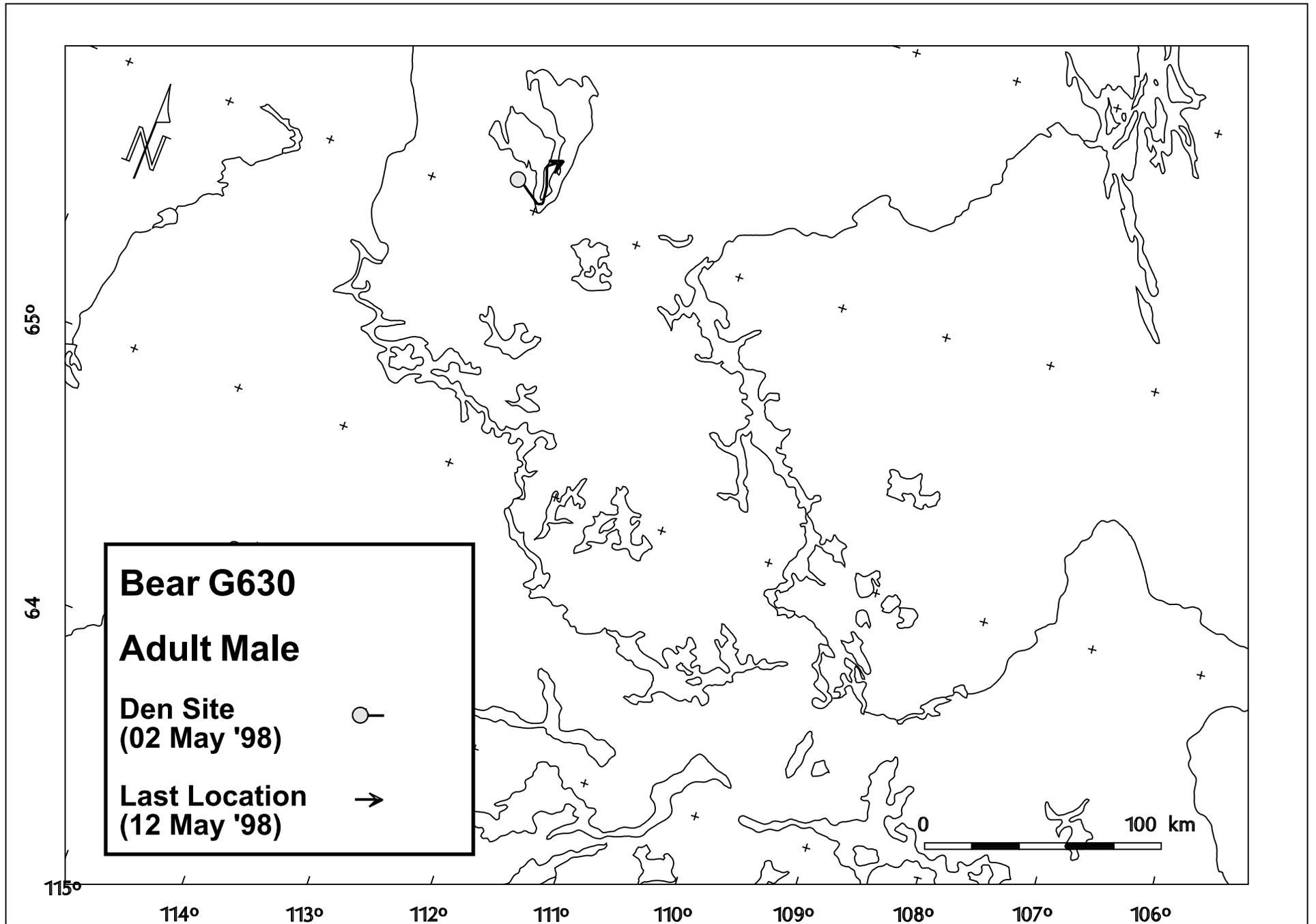
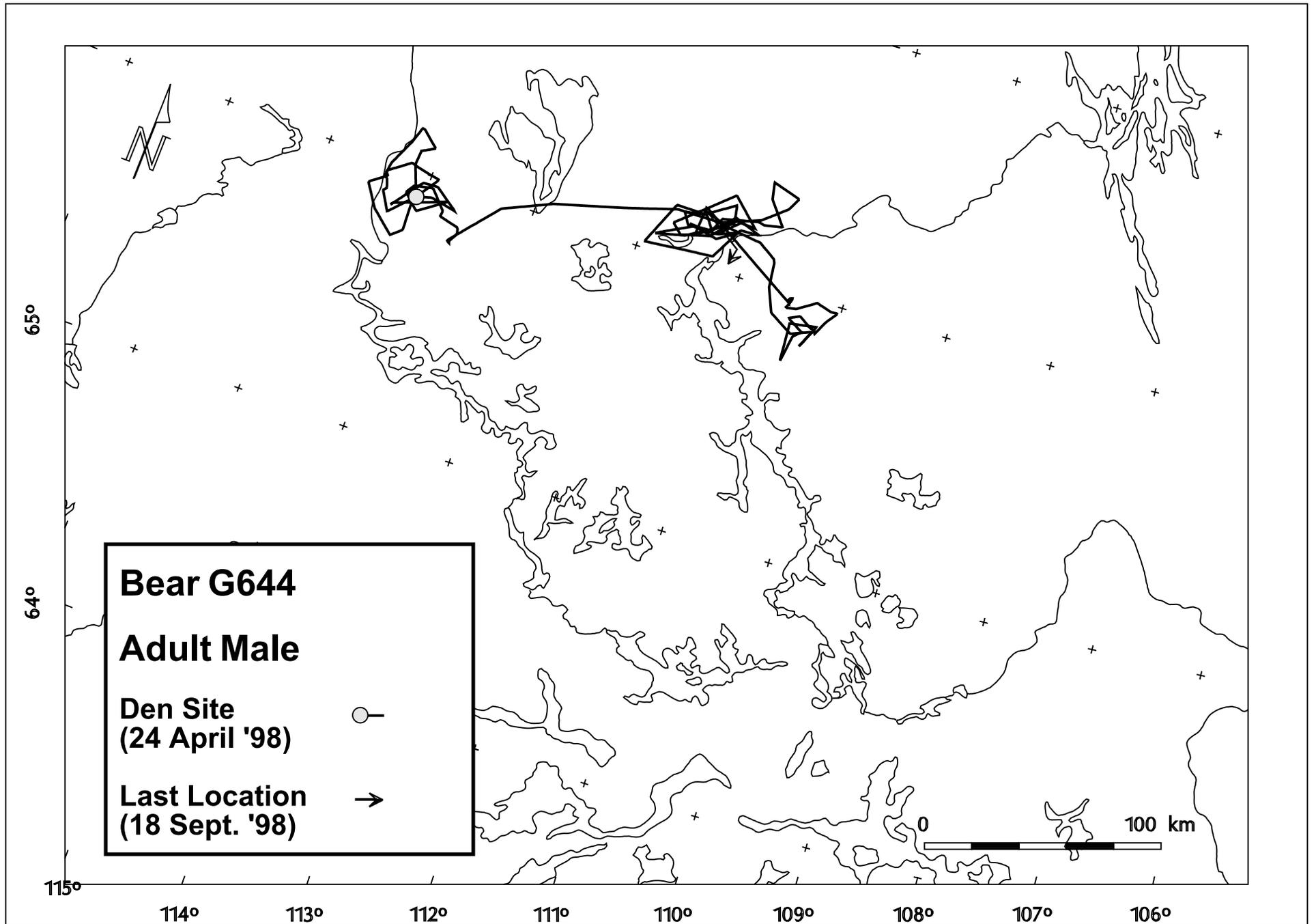


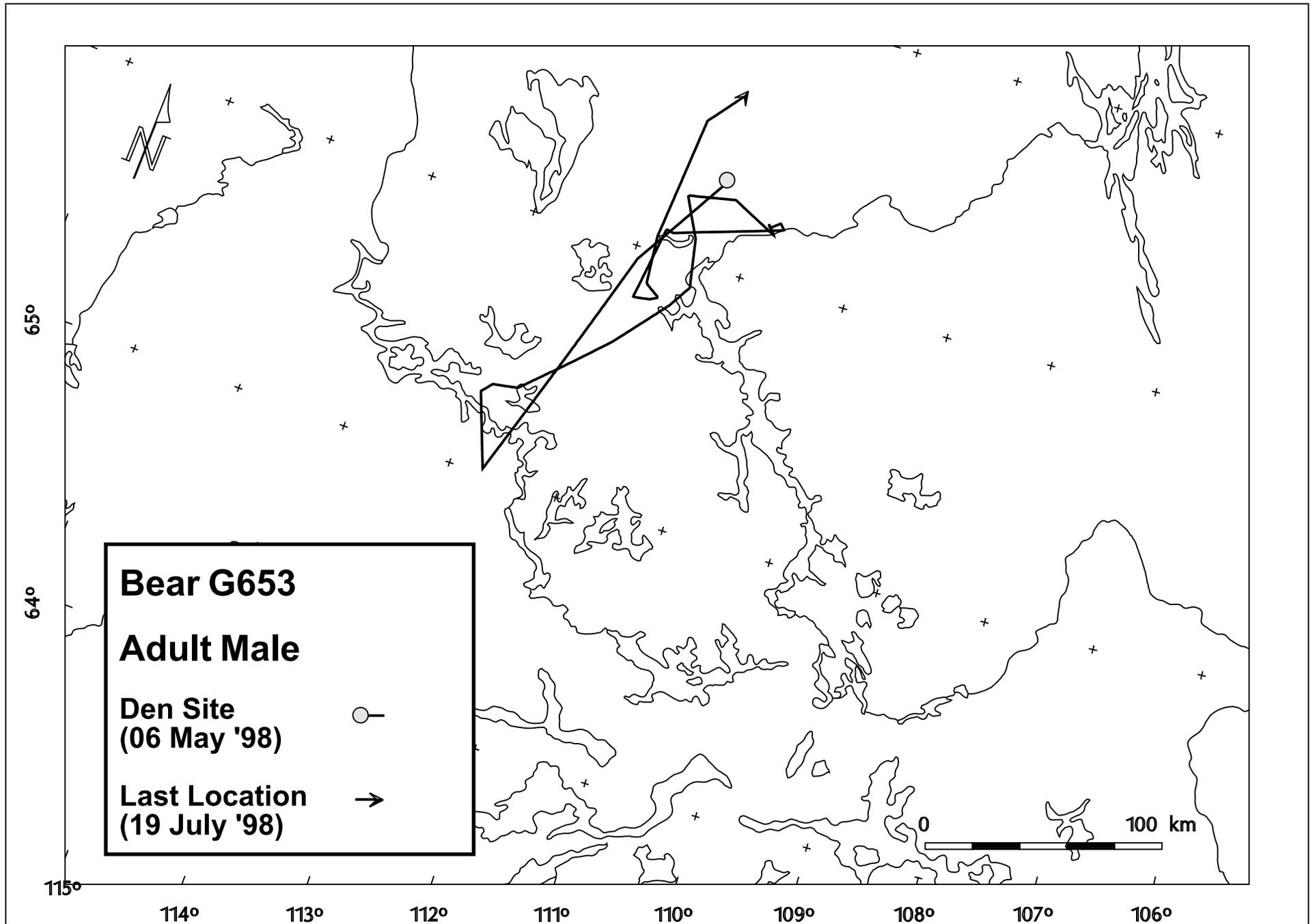
Fig. 16. Seasonal movement rates for male (open circles) and female (closed circles) barren-ground grizzly bears in the Slave Geological Province, 1995-1997.

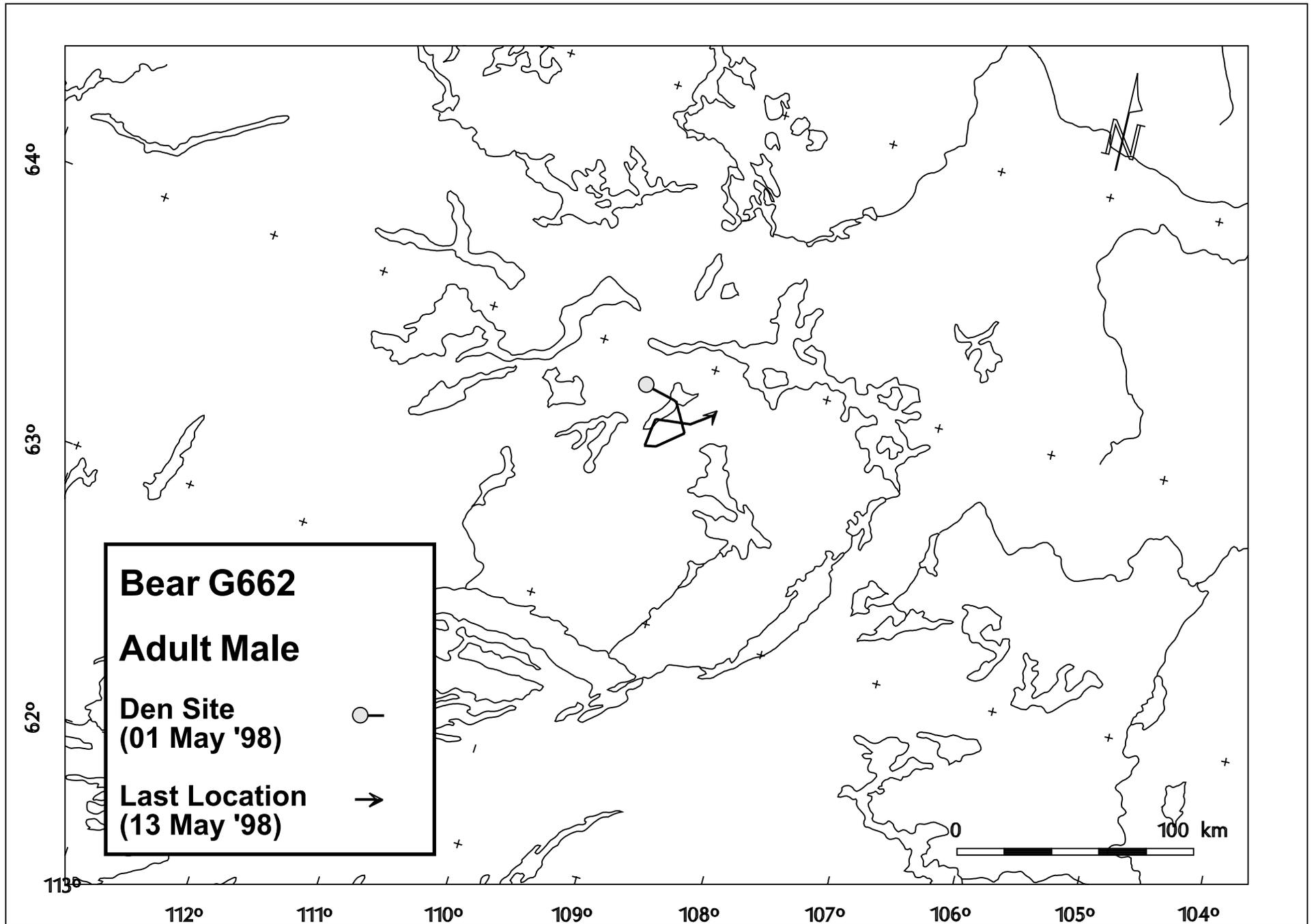
APPENDIX I

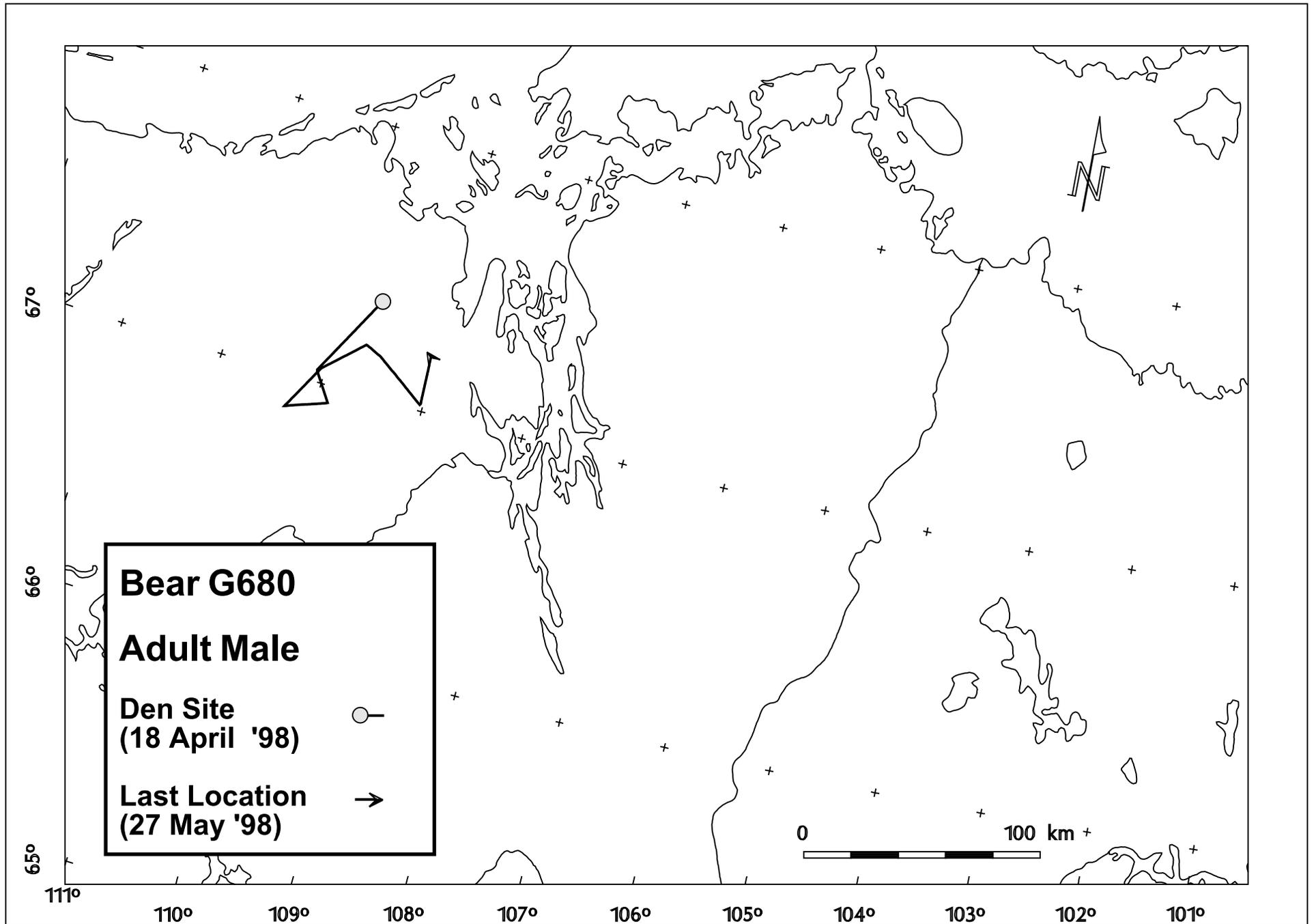
Movements of male barren-ground grizzly bears in the Slave
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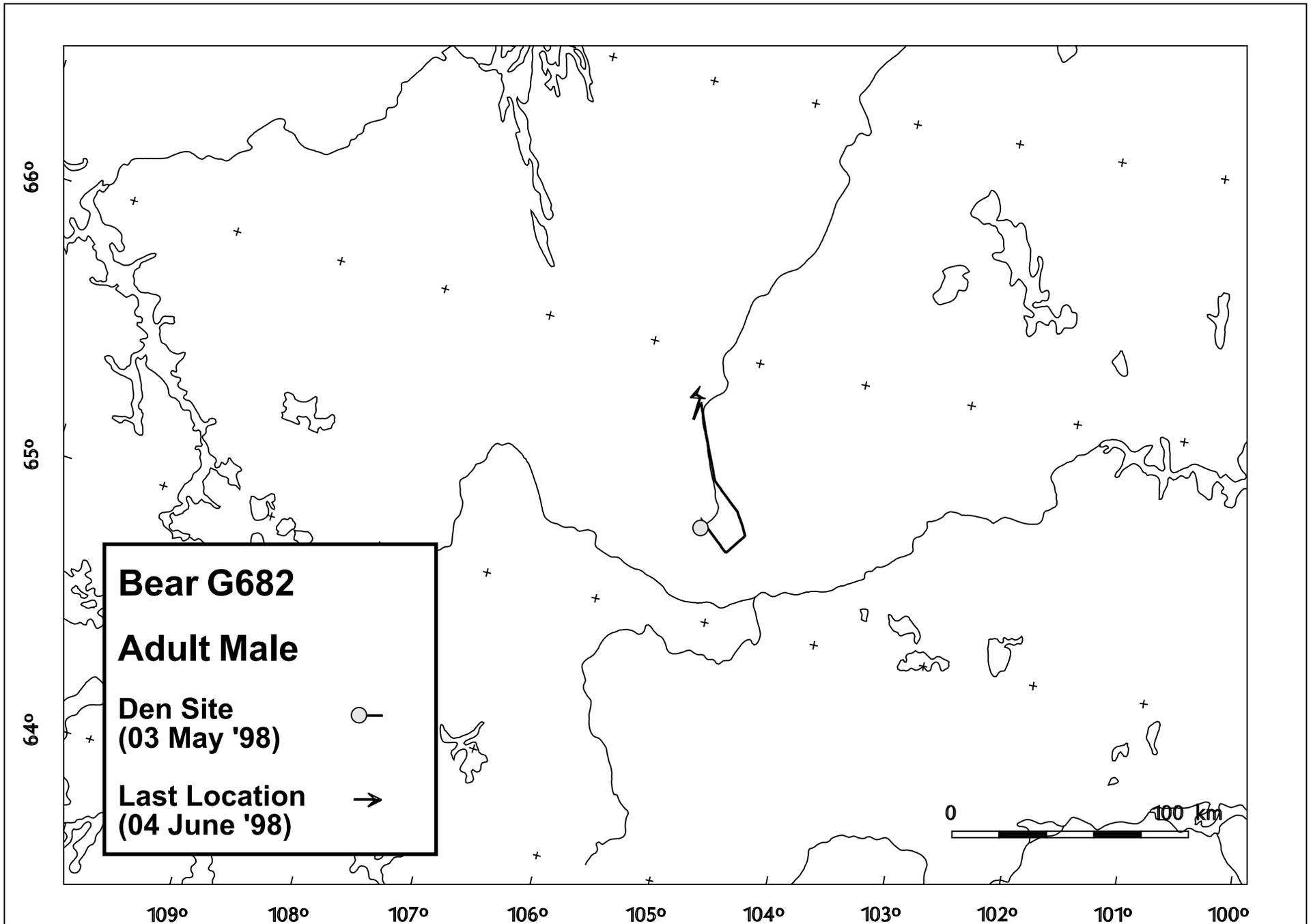


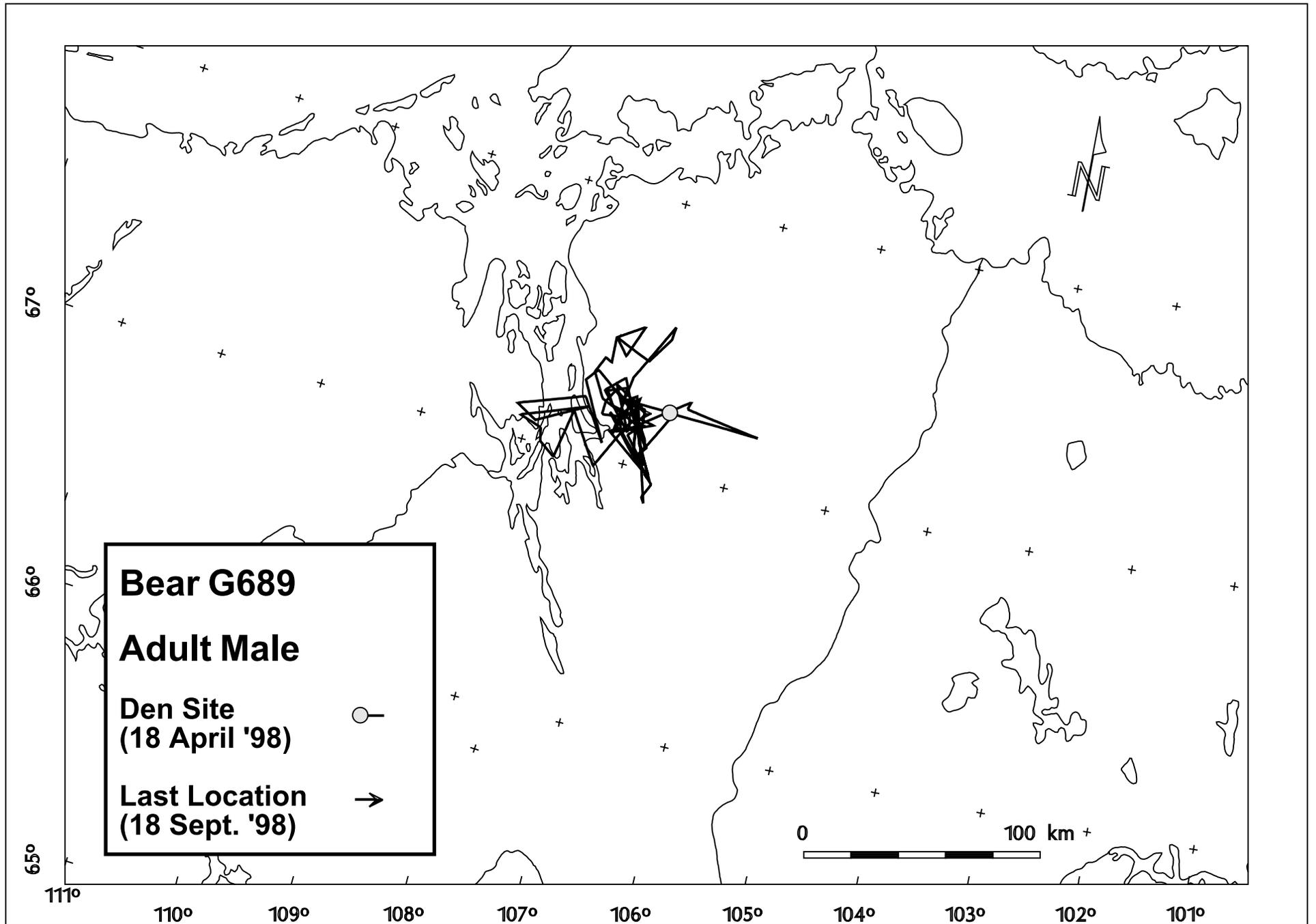


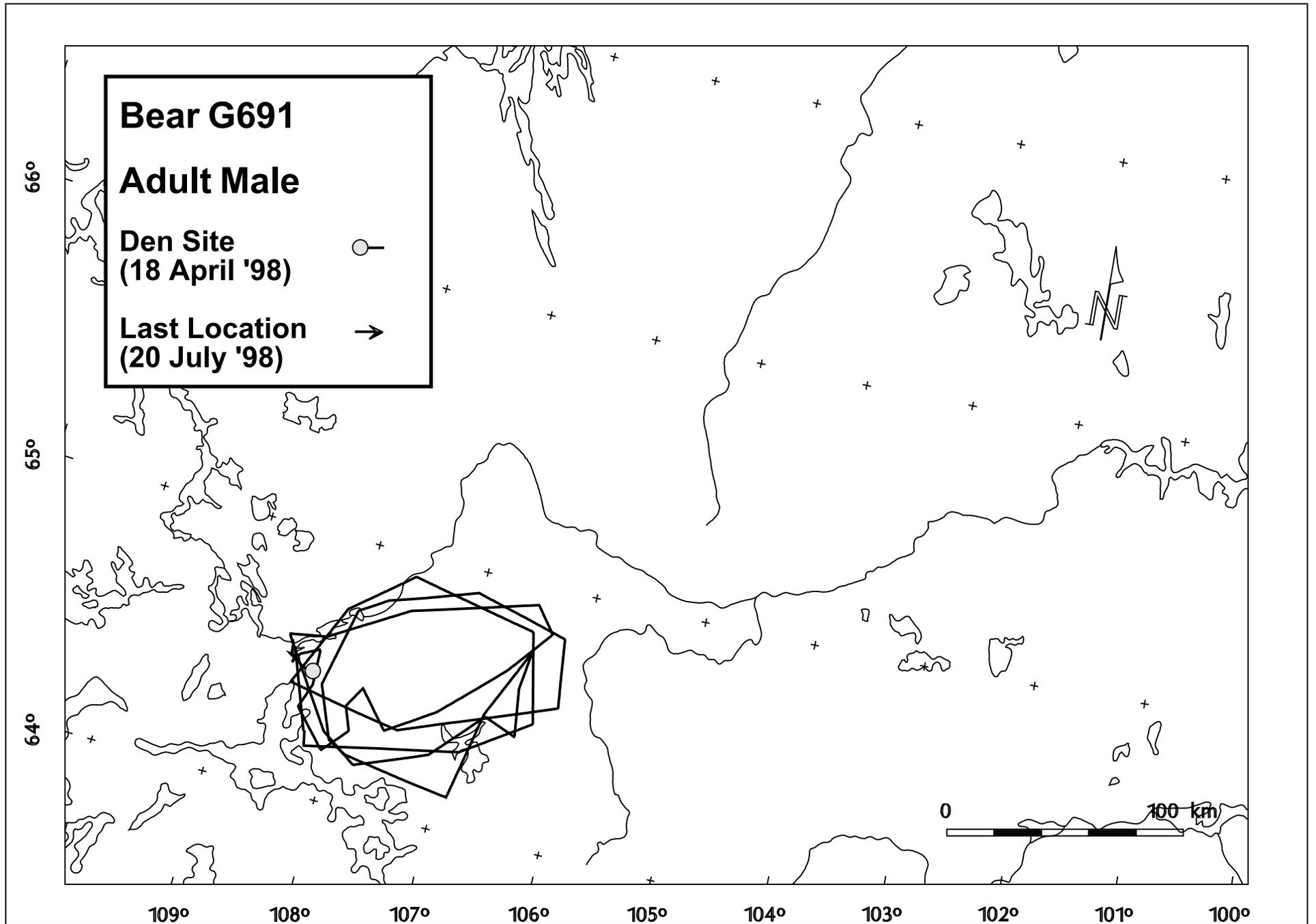


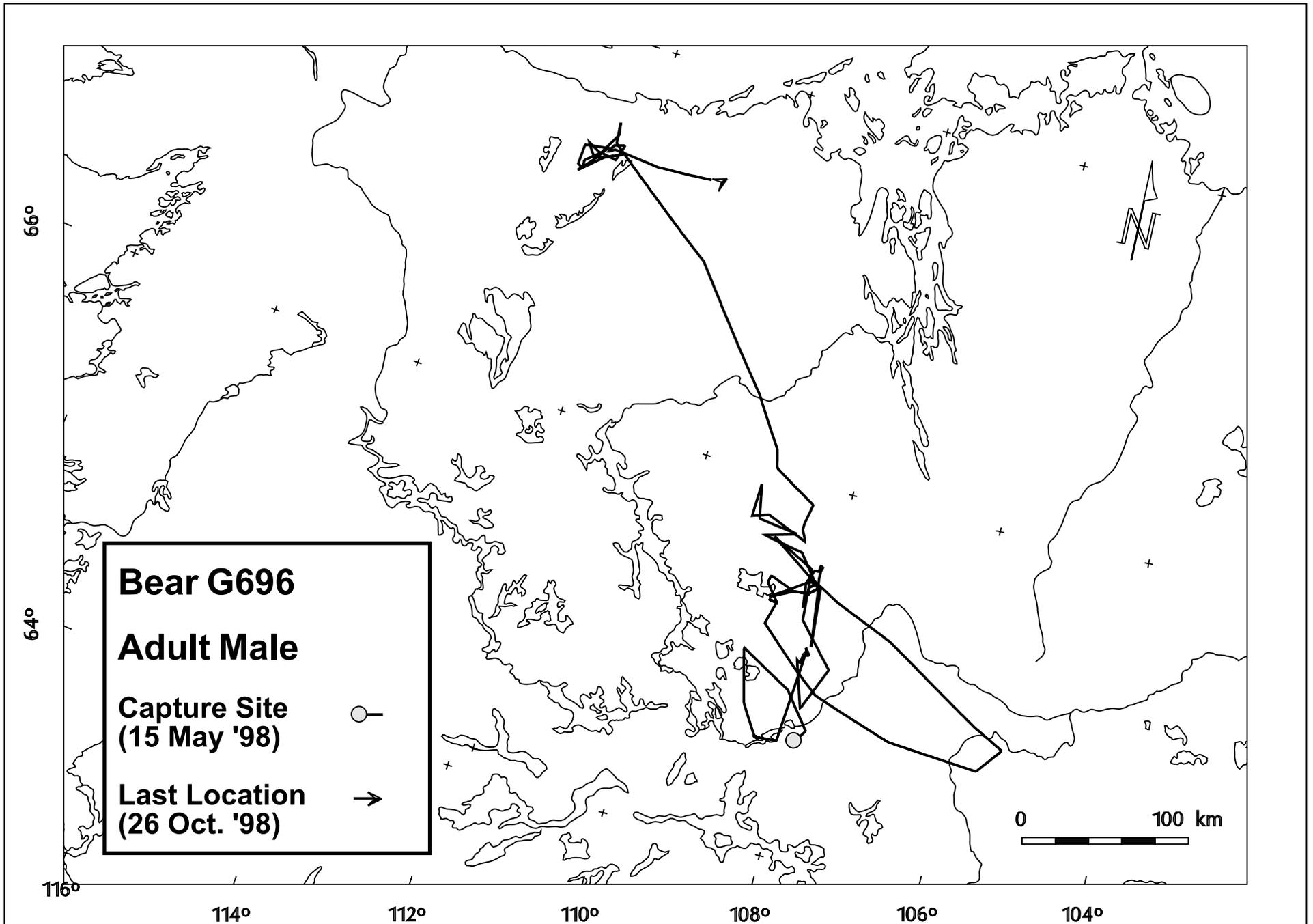


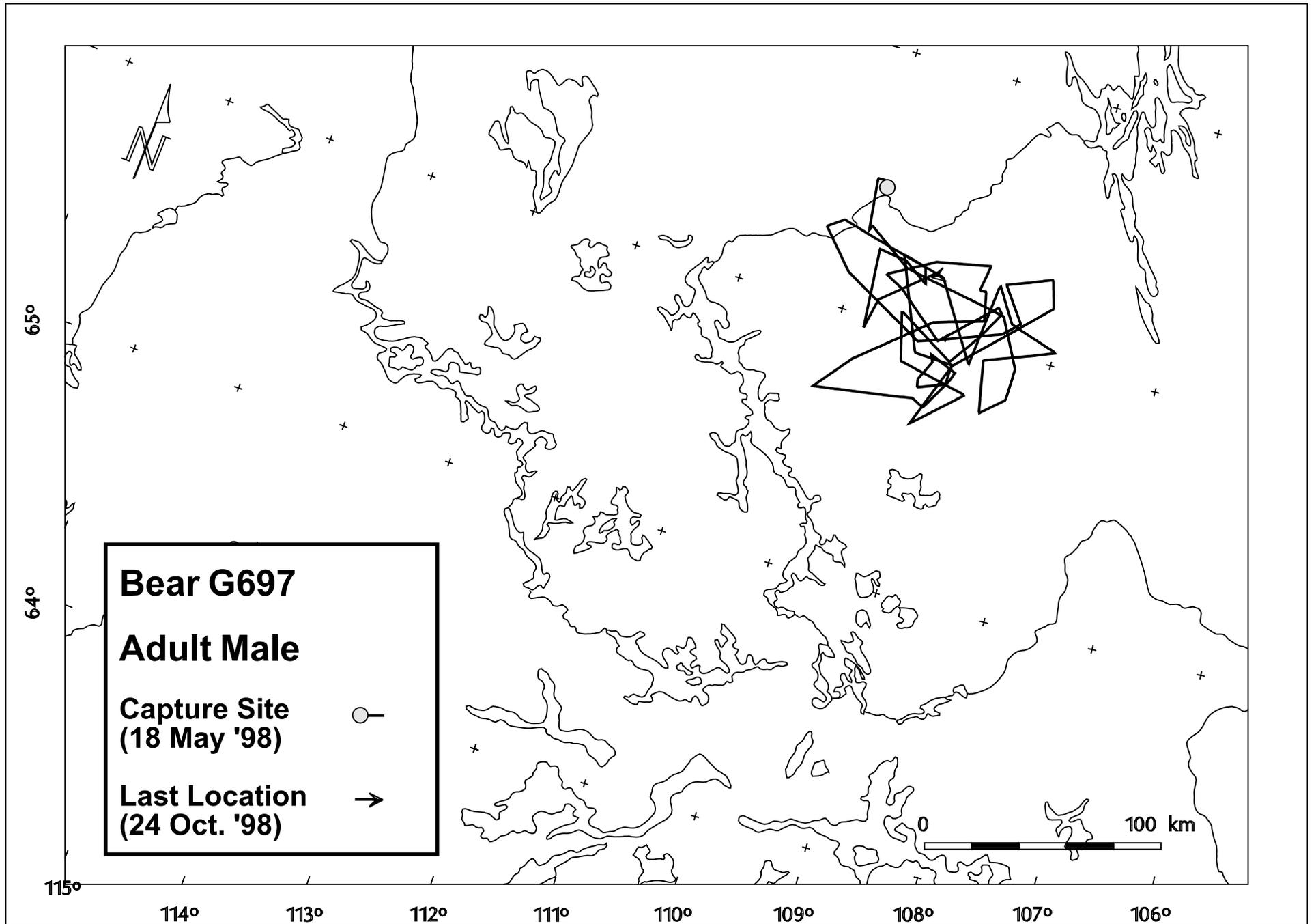


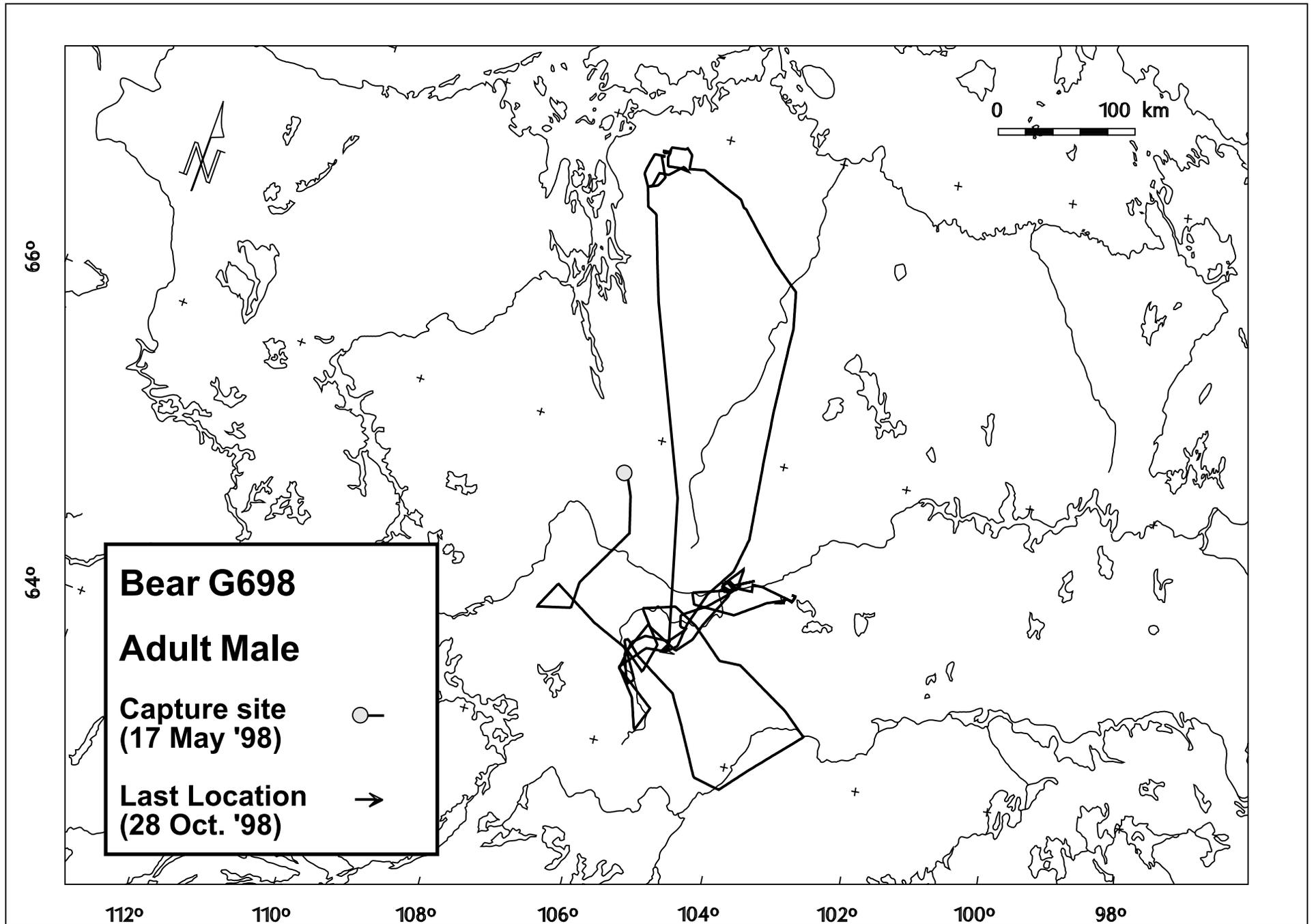


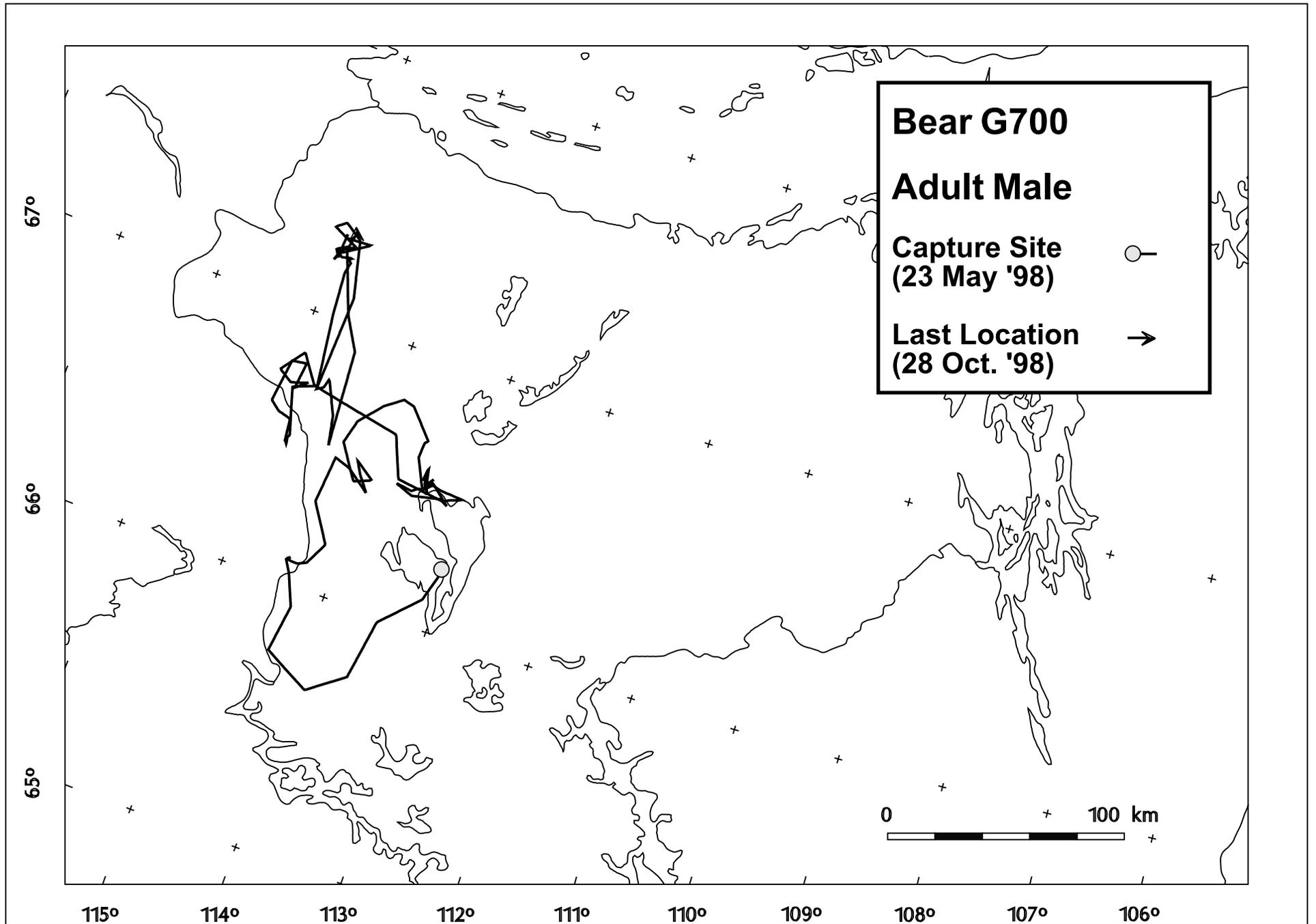


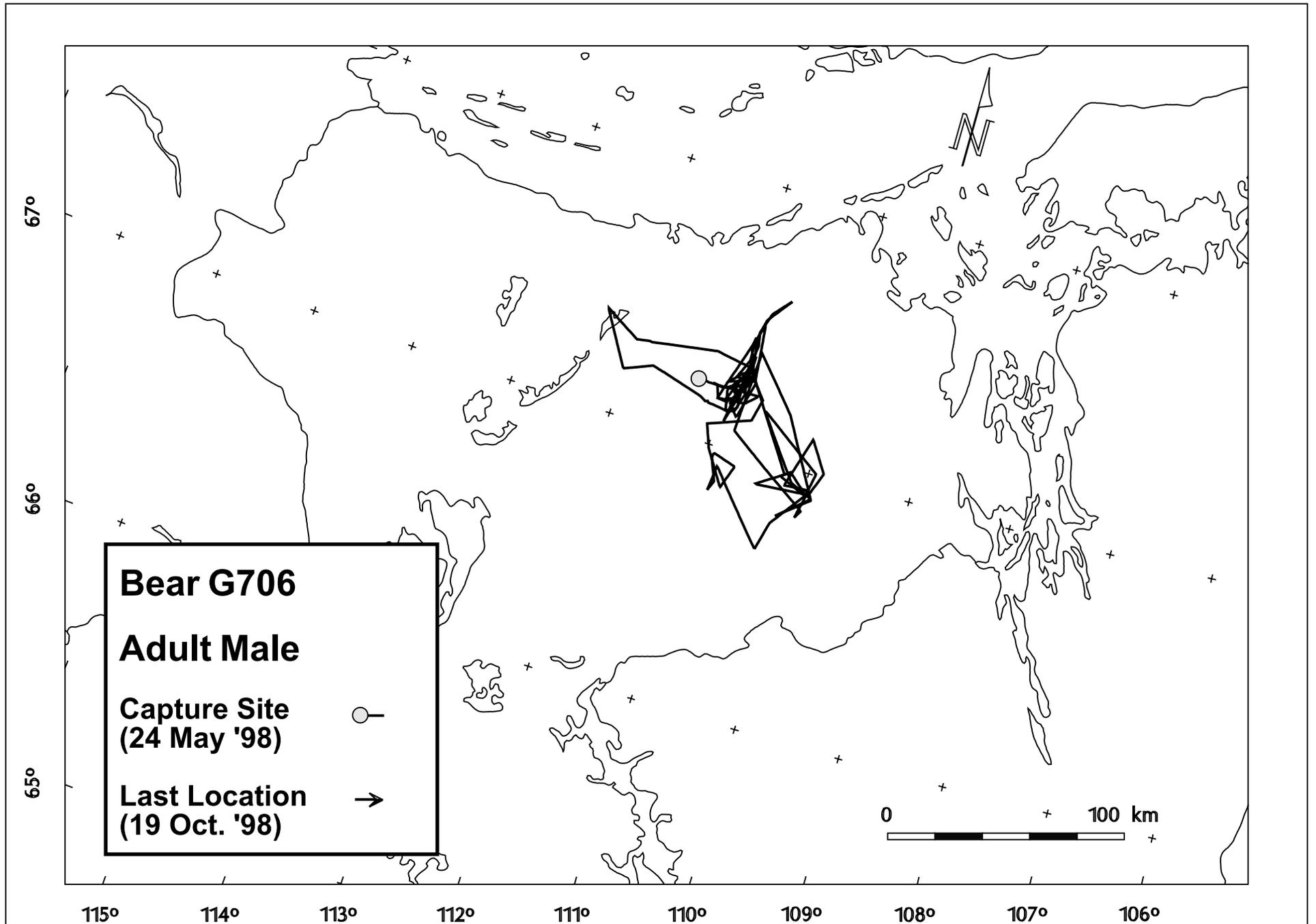


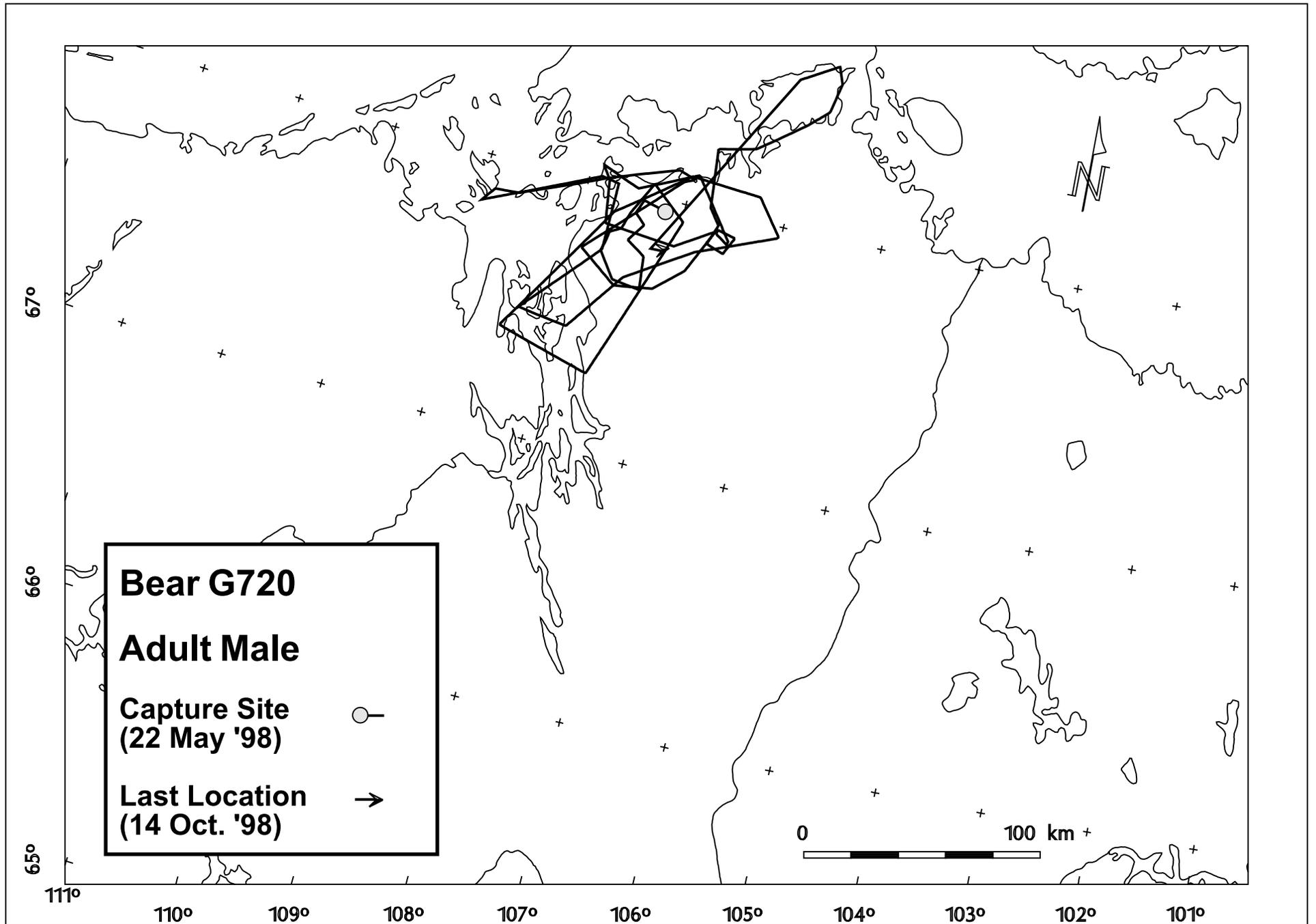


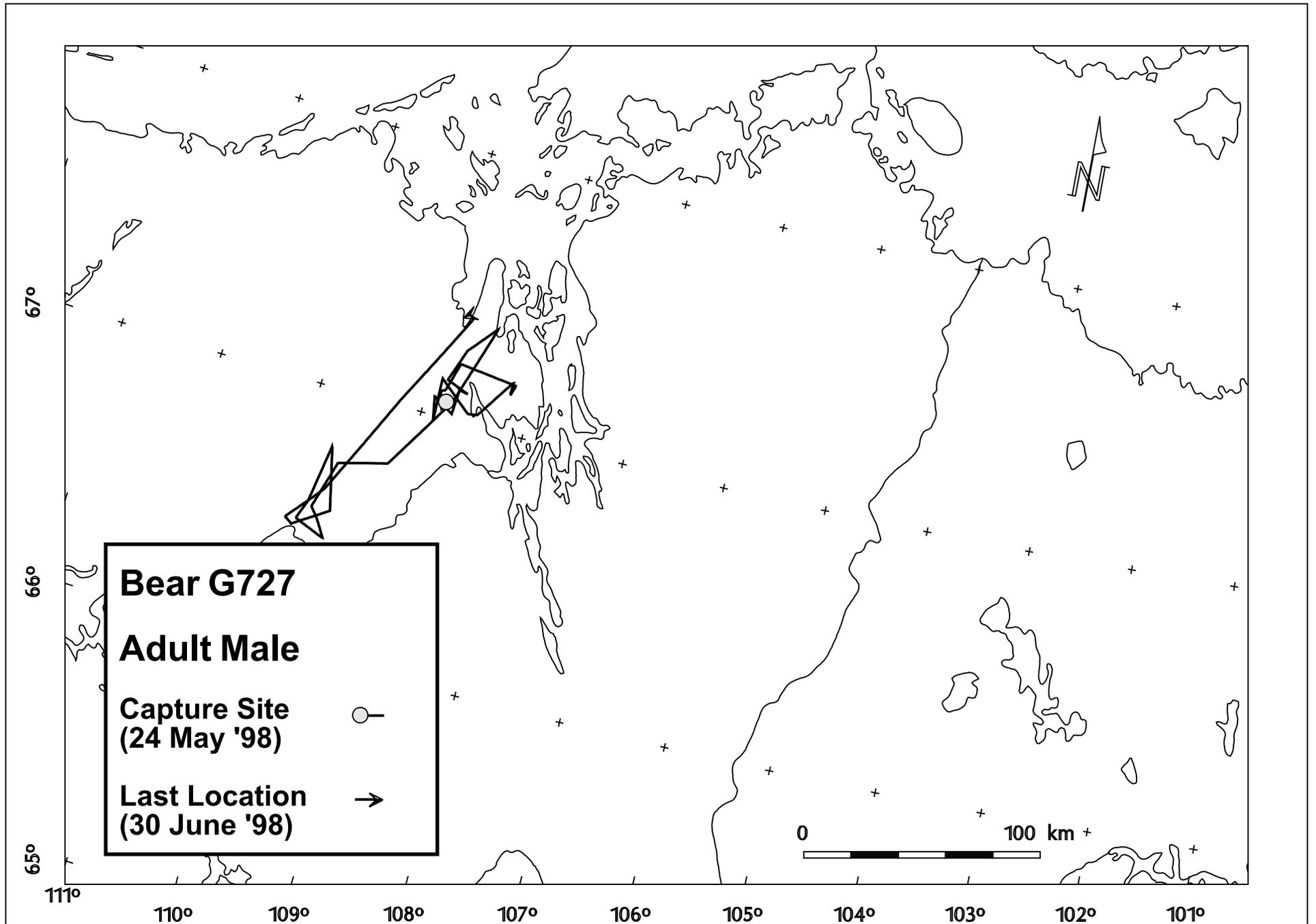


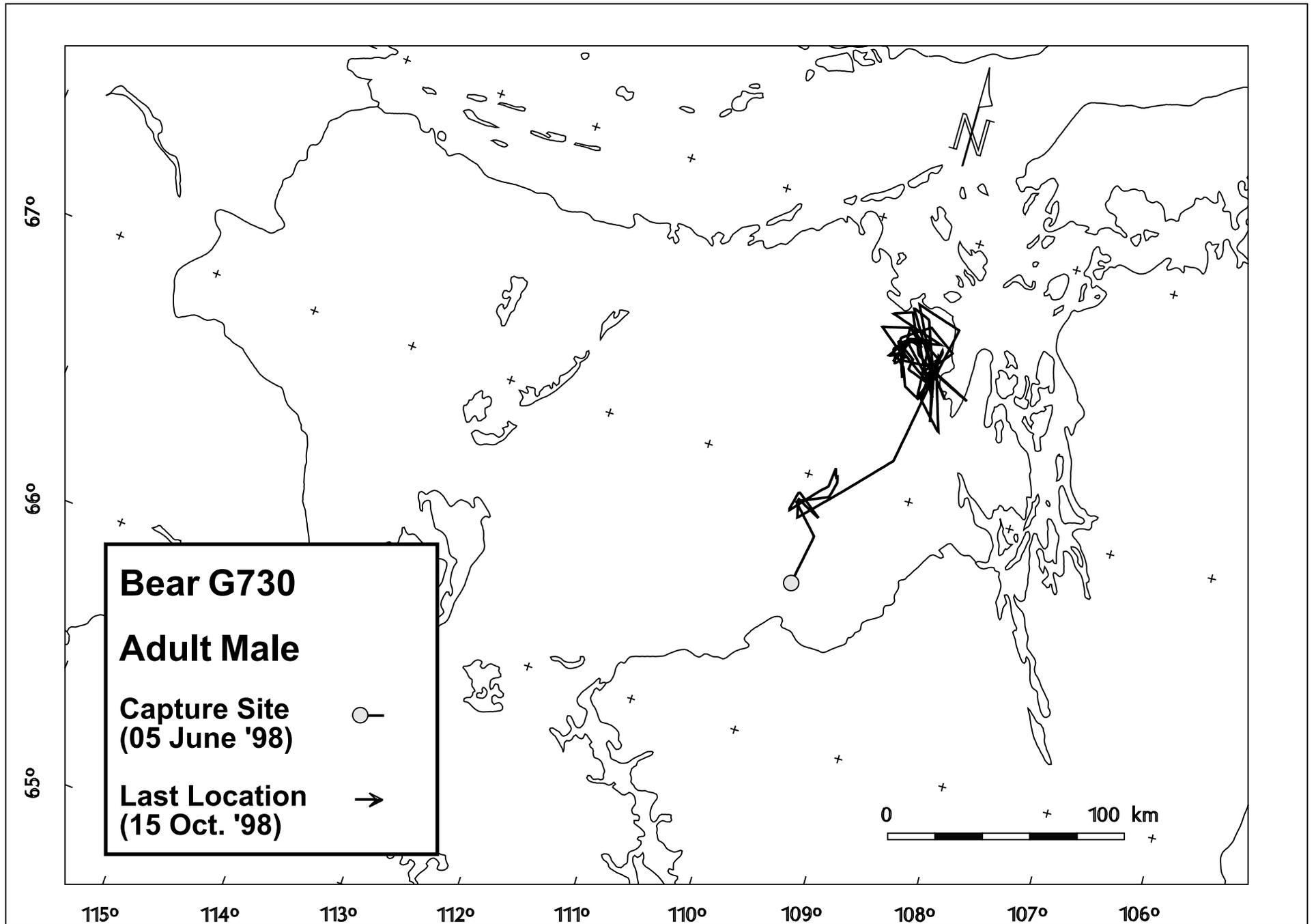


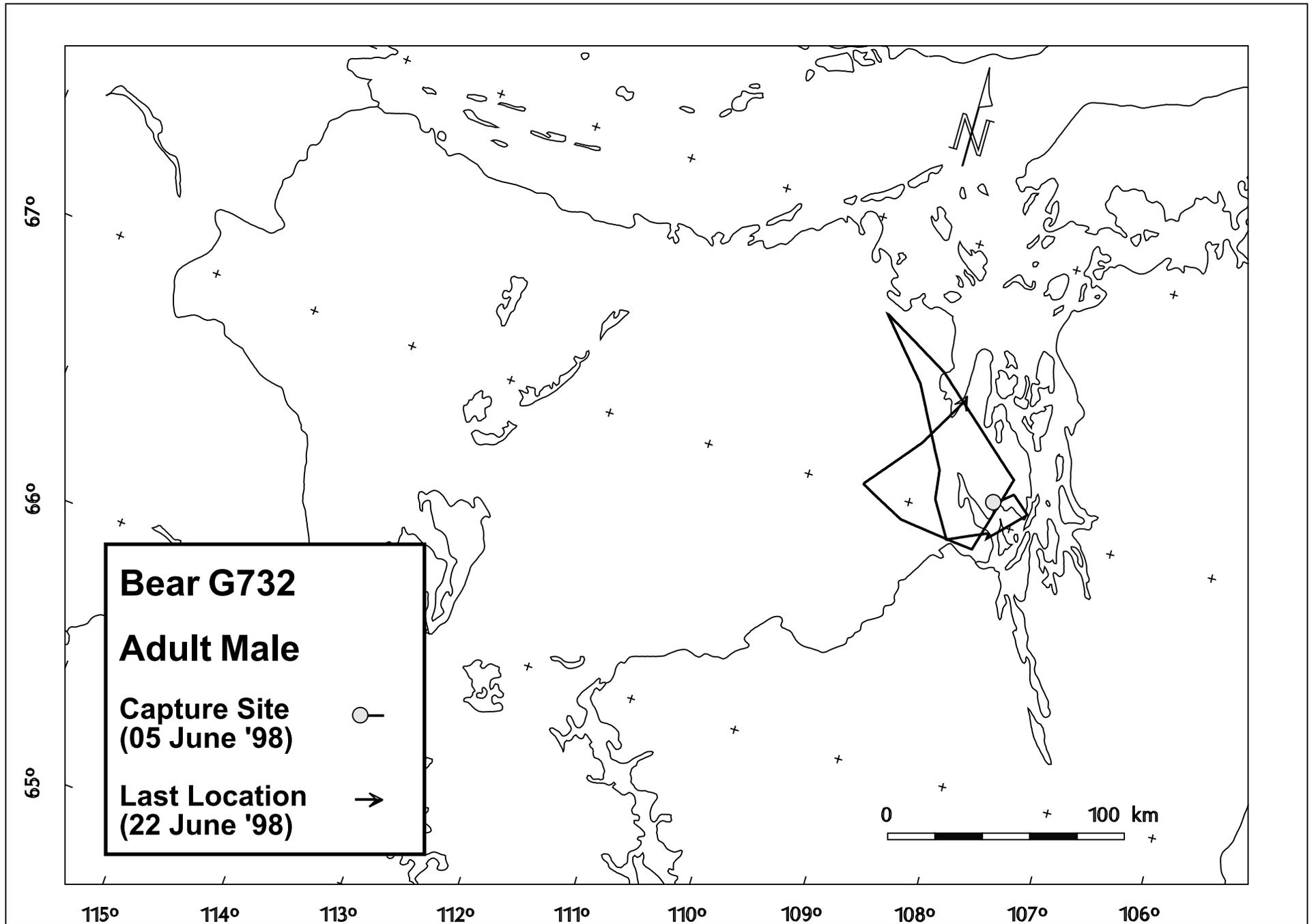






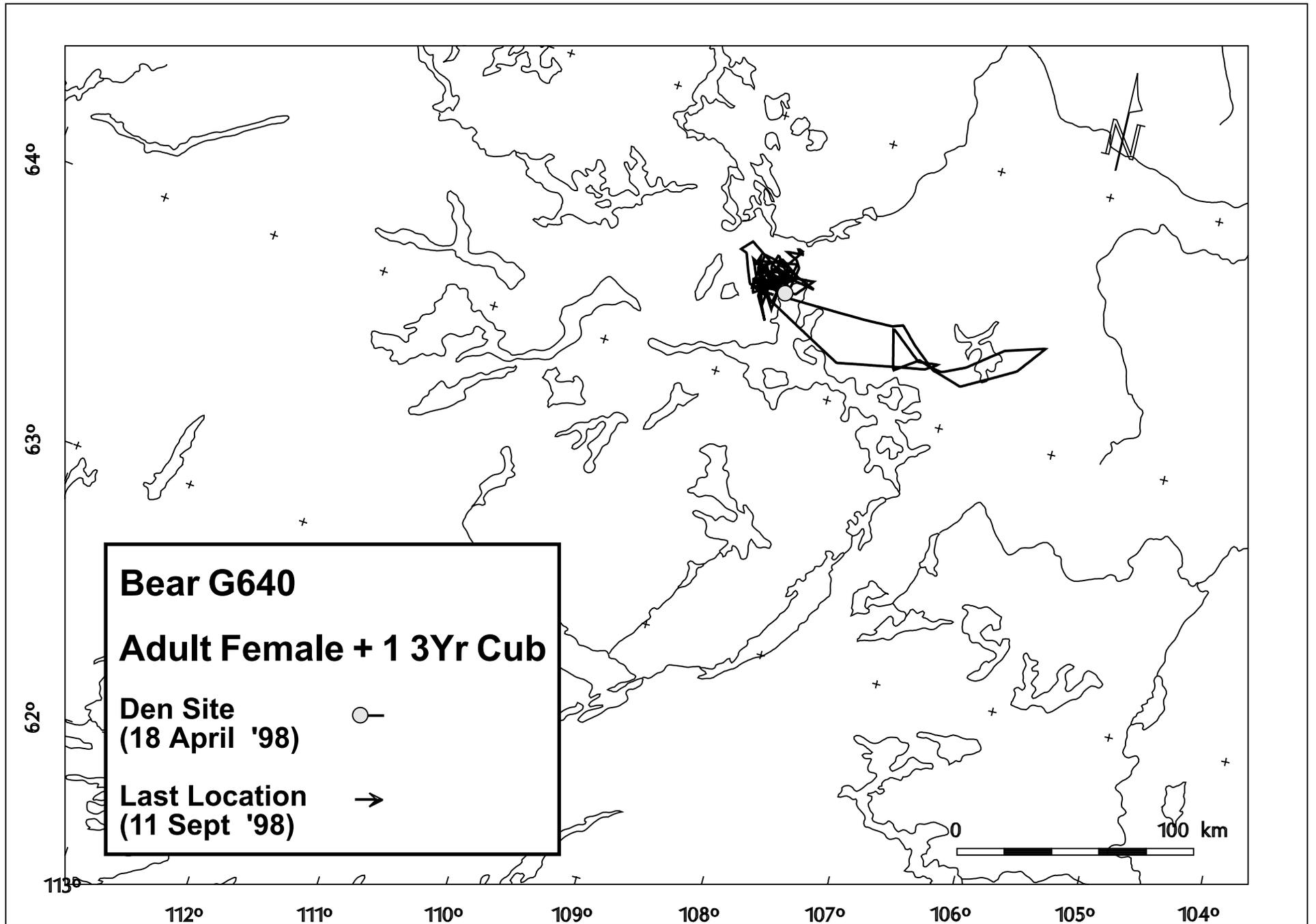


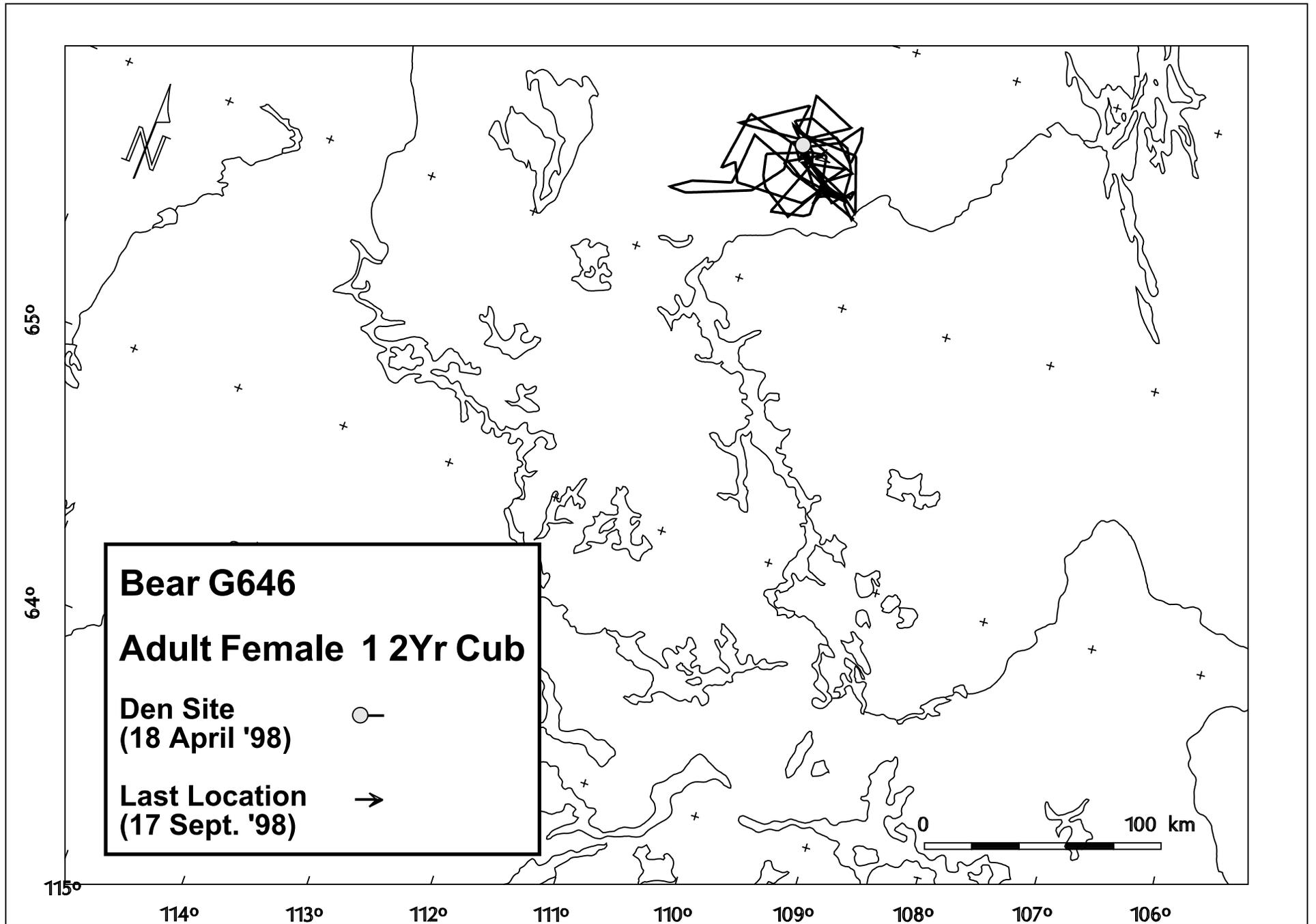


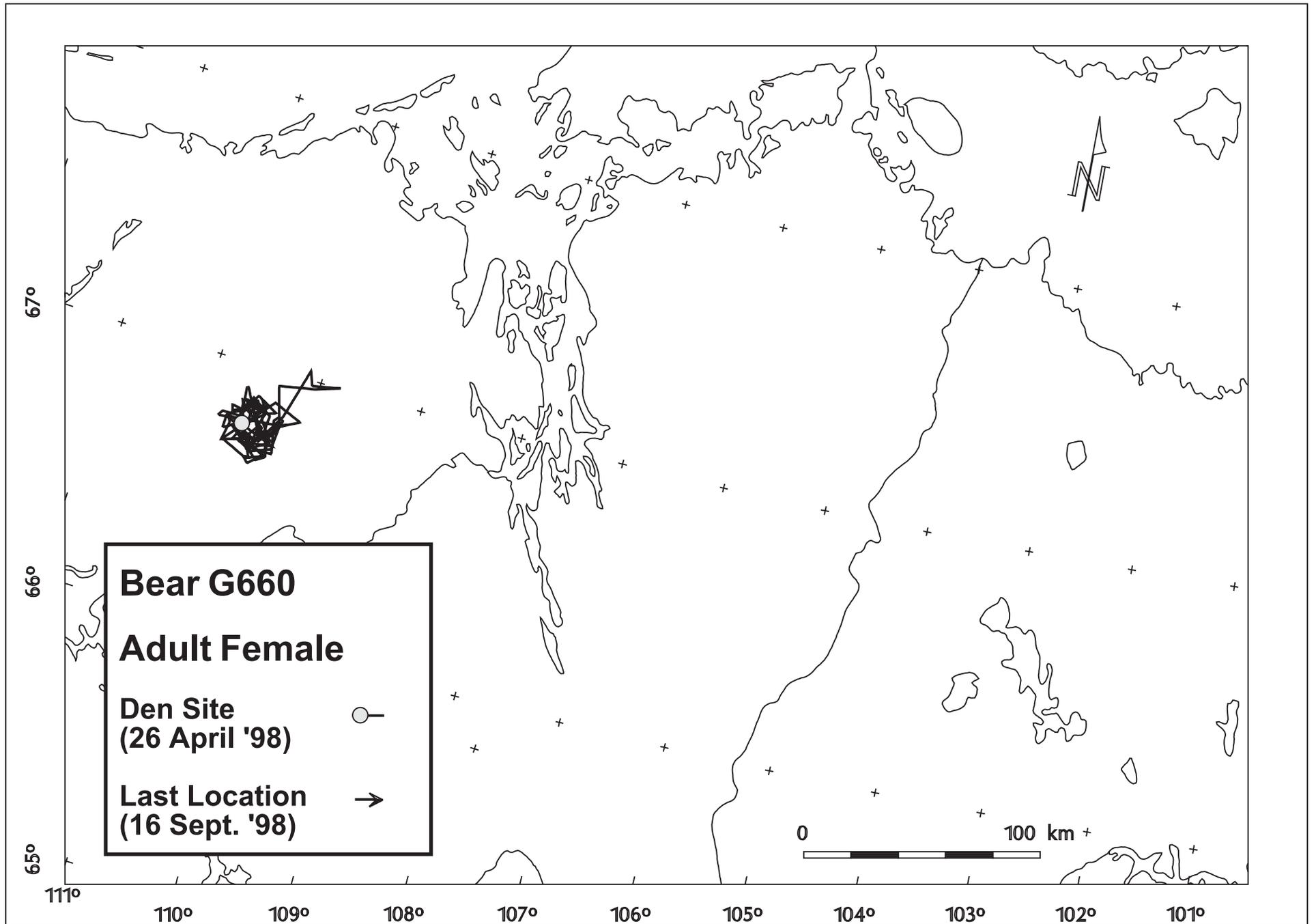


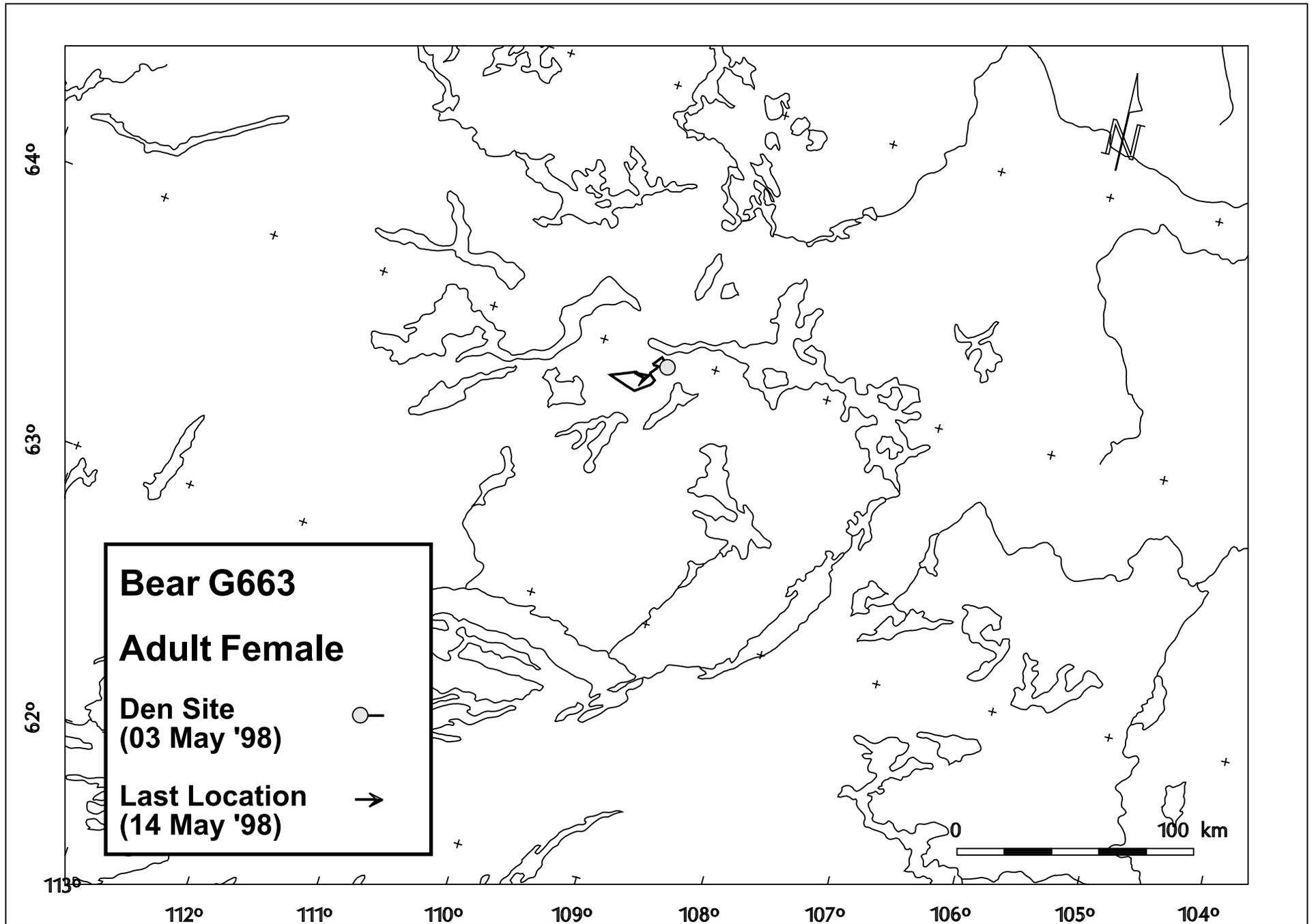
APPENDIX II

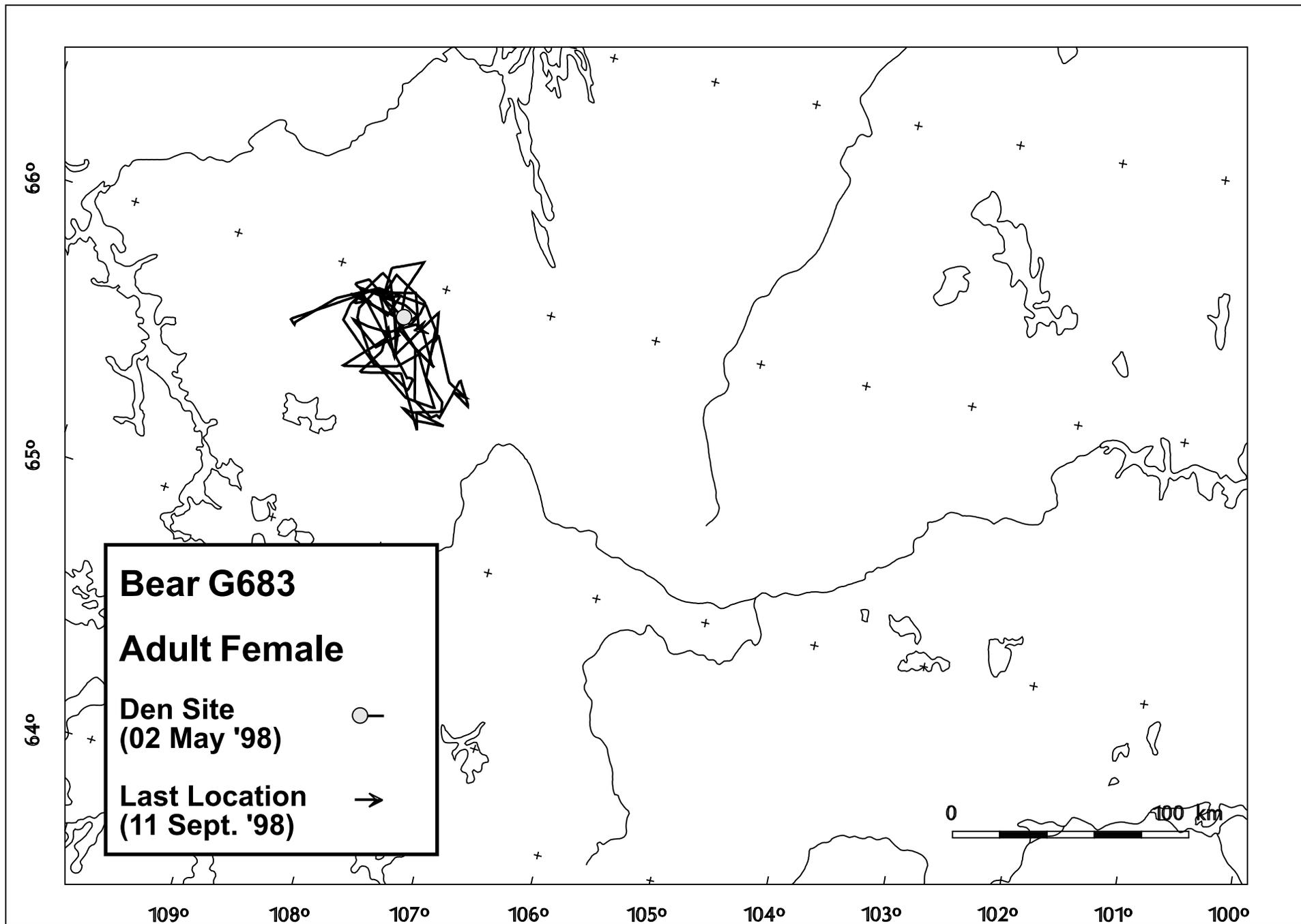
Movements of female barren-ground grizzly bears in the
Slave Geological Province, 1998.

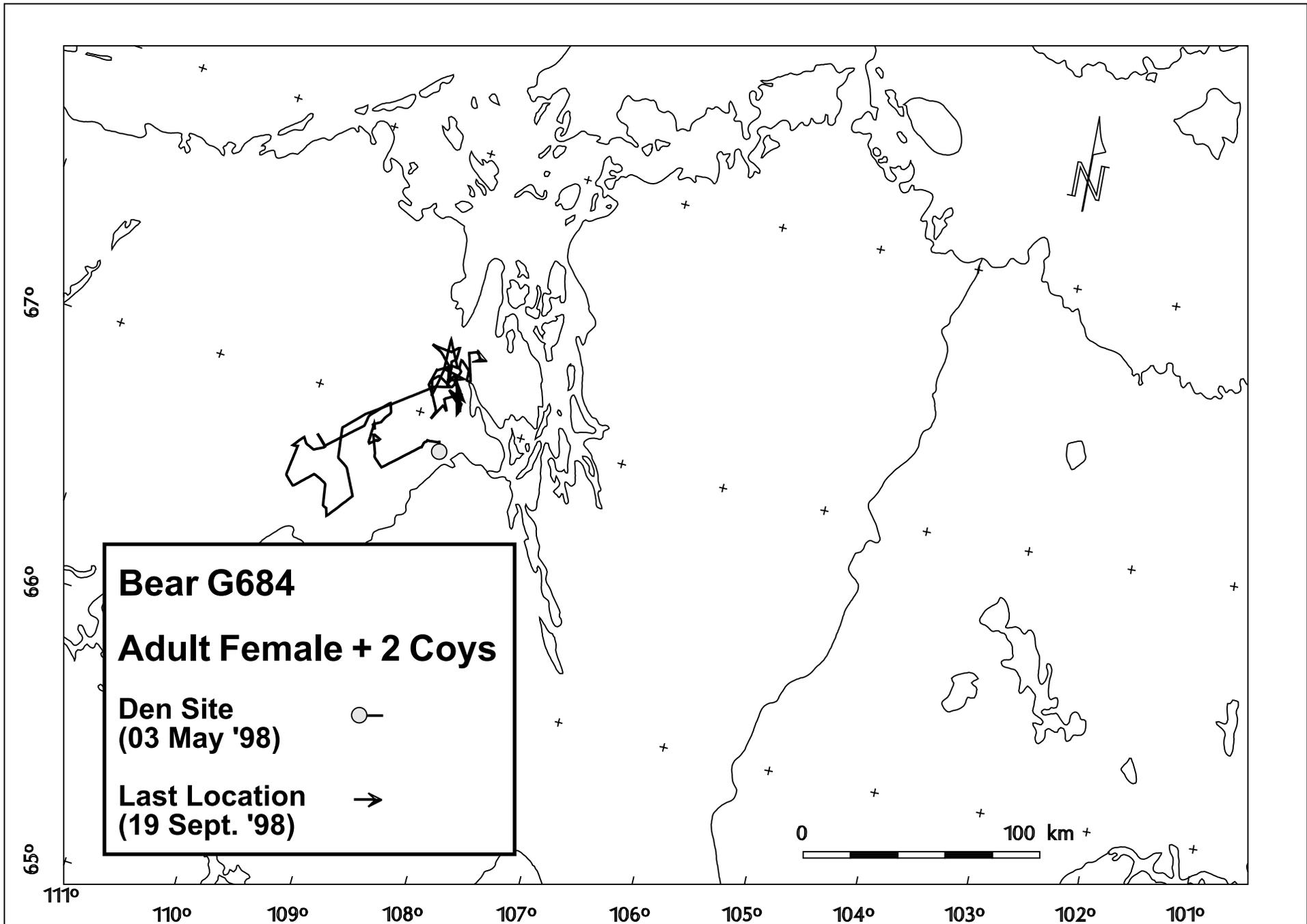


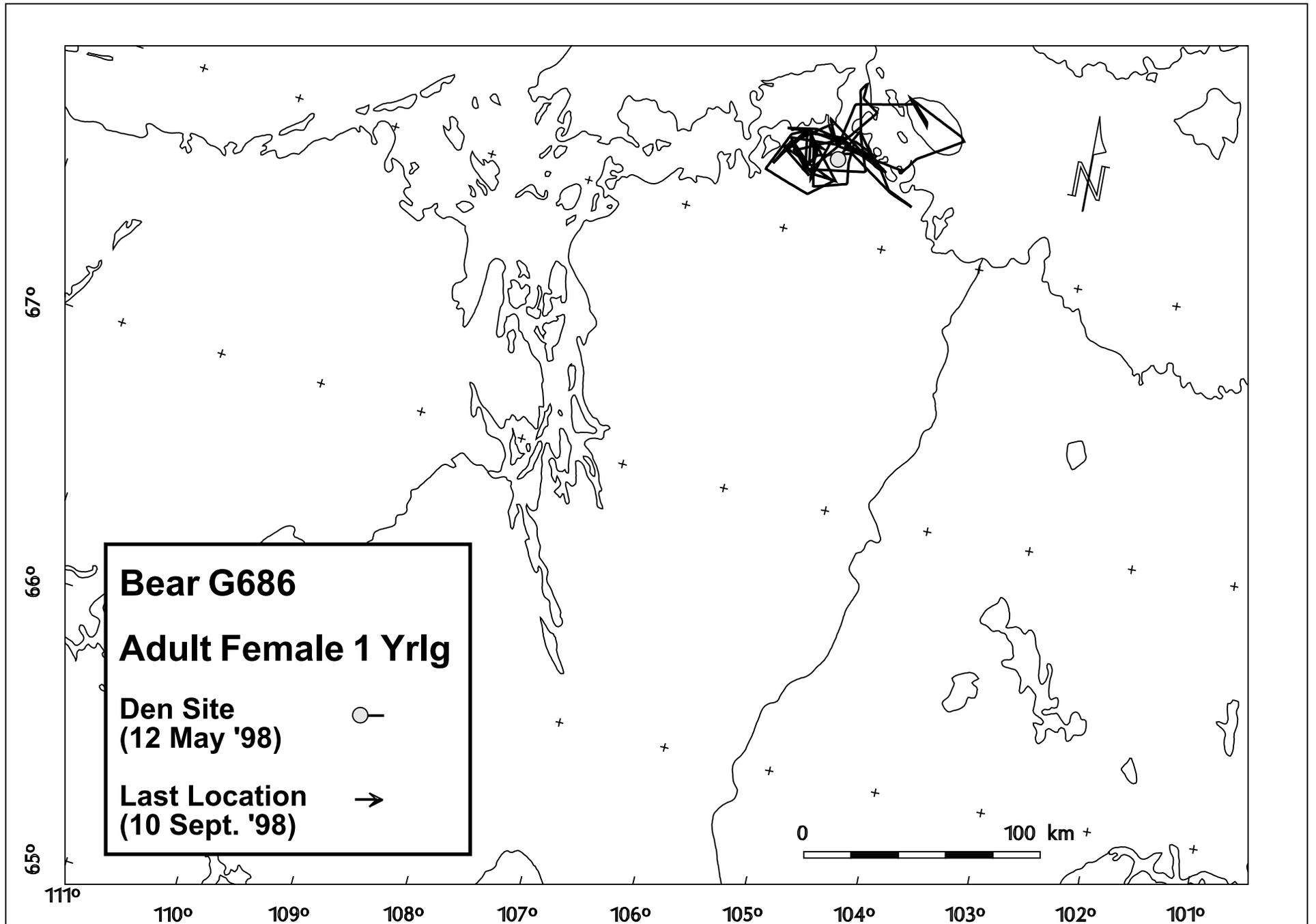


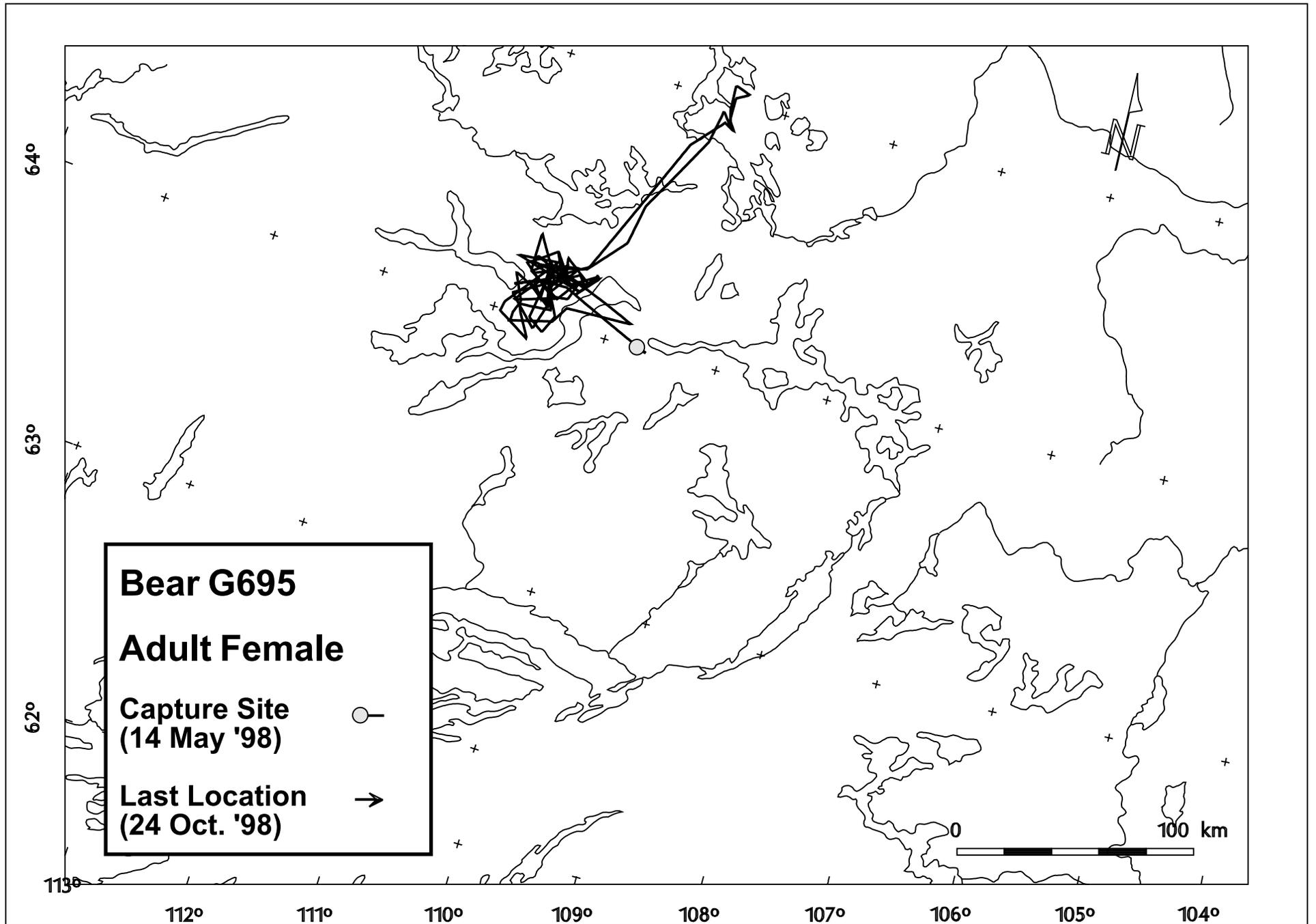


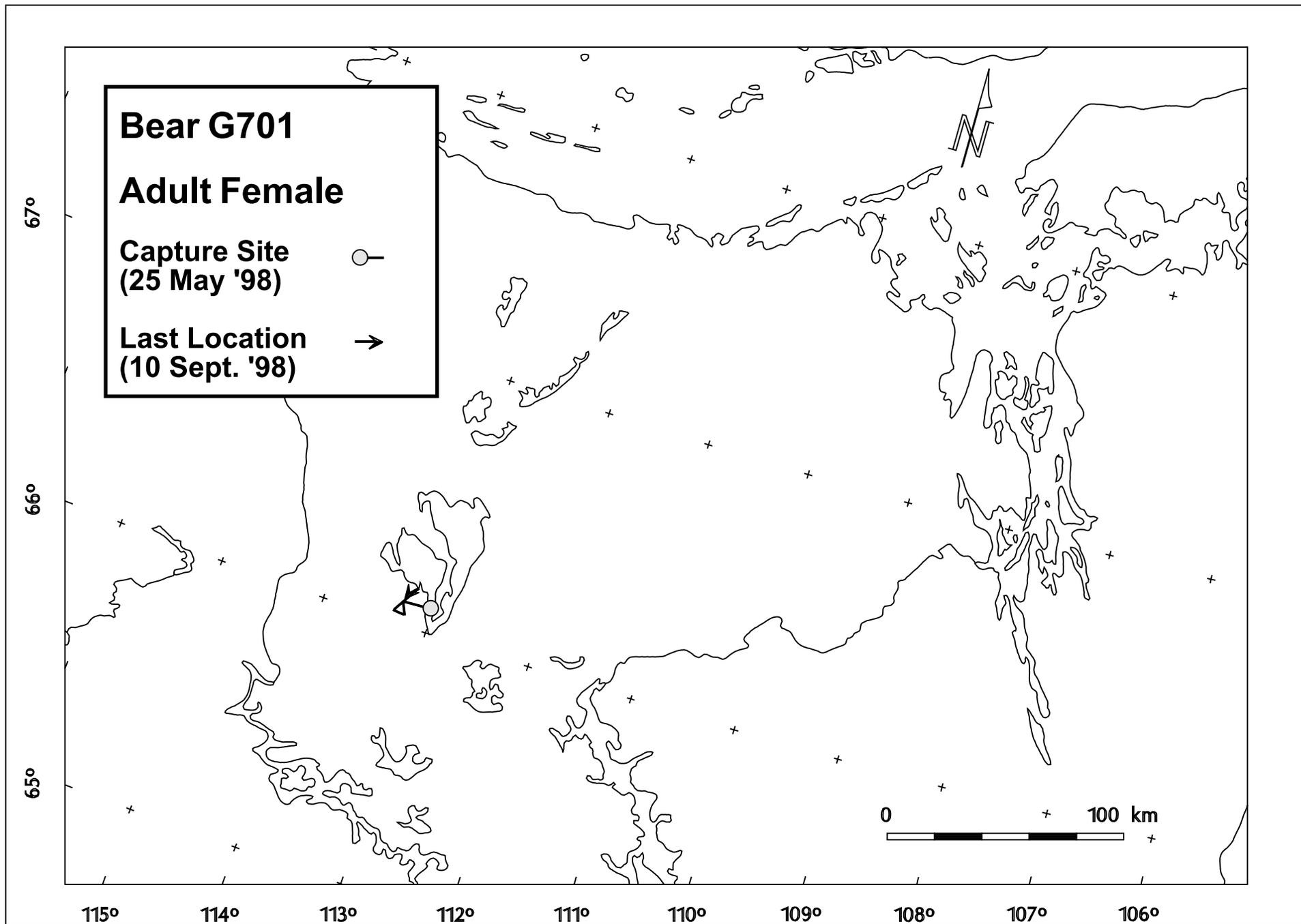












Bear G702

Adult Female + 2 Yrlds

Capture Site
(22 May '98)

Last Location
(27 Oct. '98)

67°

66°

65°

115°

114°

113°

112°

111°

110°

109°

108°

107°

106°

0 100 km

