Mapping ecological data and status of grizzly bears (*Ursus arctos*) in Canada

Final Report

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ABOUT THIS REPORT

This report summarizes and critically reviews the best available information at the time of writing on the means and methods by which grizzly bear distribution, abundance, trend, and status are determined and mapped by jurisdictions across the species' range in Canada. Funding for this report was supported by the "Open Data" Contribution Agreement 2020–2021 between Environment and Climate Change Canada (ECCC) and NatureServe Canada. The information contained herein is expected to be shared with NatureServe Canada (NSC) and its member Conservation Data Centres (CDC) where it can be made available to the public (according to NSC and CDC data-security policies and procedures where applicable). The conclusions contained in this report reflect the professional opinions of the listed authors without any editing or censuring by industry, government, or any other concerned parties including funders listed above.

PDM and GBS

May 1, 2021

1.0 EXECUTIVE SUMMARY

The mapping of habitat, abundance, trend, and projected trend or status of grizzly bears in Canada varies widely among jurisdictions in terms of approaches used, but also the scales at which maps have been produced. In this review, further to detailing the past and present approaches used by jurisdictions to map grizzly bears, we have come to the following conclusions with implications to how we might map the species in the future.

First, there appears to be a legacy effect of the grain (smallest unit) at which population parameters of grizzly bears are mapped that relates directly to the degree to which the species is or was harvested or managed, which continues to dictate resolutions and variations in resolution used to map grizzly bears. In particular, the shape and sizes of wildlife management or bear management units that may or may not be of biological relevance to bears. Second, departure from the latter is notable where the mandate of a jurisdiction has transitioned from planning for maintaining a population of bears to allow for sustainable harvesting, to one of planning for population recovery (e.g., revising bear management areas in Alberta to reflect core and recovery zones). Third, where grizzly bears are widespread or occur at high density (BC, Yukon), there is increased need and use of methods to indirectly project population parameters via a bottom-up, habitat-based approach. This method typically relies on predictive regression modelling, i.e., estimating population densities based on a suite of biophysical factors truthed where possible from demographic data, and adjusted by expert-opinion. One disadvantage of the latter is that population parameters and trend are not easily attributed confidence intervals, and hence changes in population size over time may not be discernable if biophysical attributes of habitat remain static, or effect sizes of changes in variables used in the regression are not well known. Elsewhere, it may be feasible (in terms of resources and personnel) to directly estimate grizzly bear trends and occurrence throughout a jurisdiction using iterations of spatially explicit capture-recapture (SECR) models, as is done in Alberta. SECR-based modelling is perhaps the “gold standard” by which sub-jurisdictional units of grizzly bears may be best mapped and monitored. However, increasingly sophisticated models of multi-scale occupancy and spatial ecology related to persistence, e.g., source-sink dynamics based on both animal behaviour (resource selection, movements including dispersal) and demographics, have also recently been made available. These tools show promise for the future mapping of grizzly bears at both large and small cartographic scales, including the process of habitat recolonization and long-term persistence in sink habitats.

There is now a critical mass of data throughout North America to apply models to evaluate spatial trends in abundance and map status beyond the grain of management units or provincial/territorial boundaries in place today. To this end, it is important to recognize the value of long-term data sets referenced in this review for the purpose of monitoring, understanding, and documenting any changes in the distribution, abundance and trend of grizzly bear populations in Canada. A number of jurisdictions have benefited greatly from having these long-term data sets that now enable them to better map and manage this species at a variety of scales. New and advancing technologies will allow future monitoring and mapping efforts to be undertaken more efficiently (e.g., using machine learning) over the vast areas where Canadian grizzly bear populations still reside, and on regular intervals, to ensure the long-term conservation of the species.

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2.0 INTRODUCTION

2.1 Background on Distribution and Occupancy

The distribution of the brown bear, *Ursus arctos*, is holarctic (Fig. 1.1). The species is extant in at least 42 countries of Eurasia in addition to the United States (US) and Canada (McLellan et al. 2017). In North America (Fig. 2.1), where the interior phenotype of the brown bear is known as the grizzly bear, distribution is comprised of fragmented populations in Montana, Wyoming, Idaho, and the North Cascade mountains of Washington and British Columbia (BC); and a largely continuous population arcing from transboundary populations in southwestern Alberta and southeast BC to the Pacific coast and north to Yukon and Alaska, and east to include much of mainland Northwest Territories (NWT) and Nunavut. Grizzly bears also occur on the tundra of northeast Manitoba (Rockwell 2008; Clark et al. 2019), while the species is expanding its distribution north to include southern islands of the Canadian Arctic Archipelago (Doupé et al. 2007; SARC 2017). Anecdotal reports of grizzly bears occurring on the Saskatchewan side of the NWT border suggest the species may also be present in the province, at least on occasion (M. Tokaruk, Saskatchewan Ministry of Environment, *pers. comm.*). Historically, the species (now extirpated) was found throughout the Great Plains and surrounding forest-transition zones, and non-desert regions of the western US and northern Mexico (Figs. 1.1 and 1.2). Evidence suggests a recently extinct subpopulation existed in northern Québec, the Ungava grizzly bear (COSEWIC 2012).

Within their contemporary North American range, grizzly bears occur across a range of habitats from low-elevation foothills and eastern slopes of the Rocky Mountains through the interior and coastal mountain ranges of British Columbia and Alaska, mountains and taiga of the Yukon and

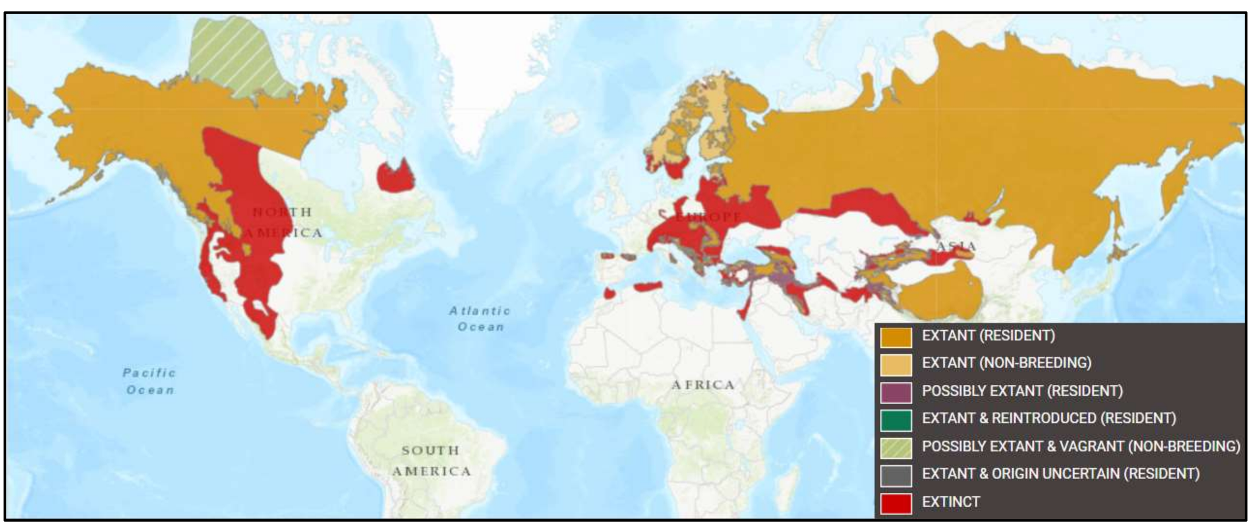


Figure 1.1. Worldwide distribution of *Ursus arctos*. Reprinted from McLellan et al. (2017).

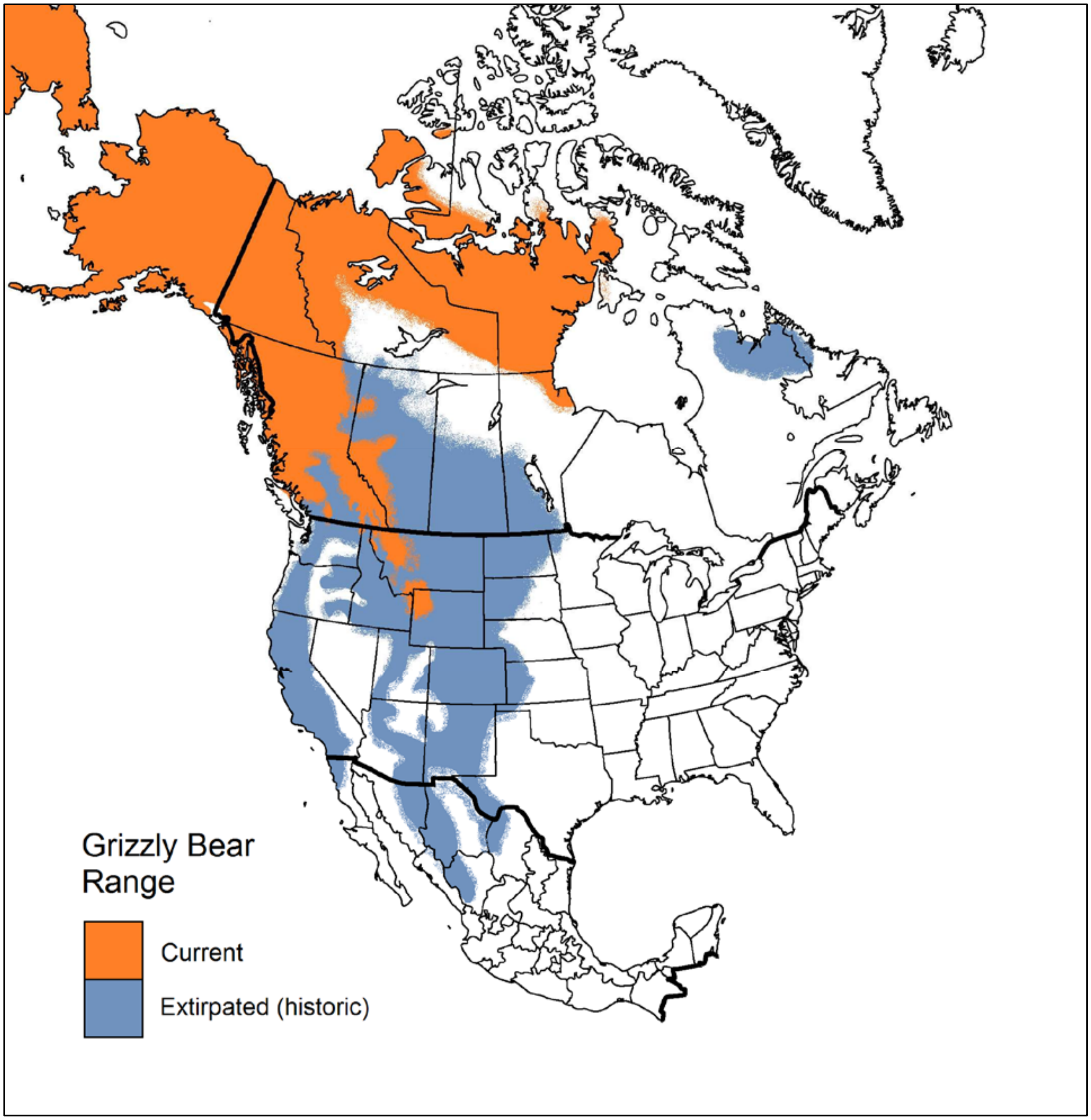


Figure 1.2. Approximate boundaries of the current and historic (i.e., 19th century) distribution of the grizzly bear, *Ursus arctos*, in North America (map produced by P.D. McLoughlin from numerous sources, data to March 2021).

NWT, and the barrens along the coast of the Arctic Ocean north of treeline. Habitat associations for grizzly bears are strongly seasonal and typically reflect local vegetation phenology, and, in mountainous regions, elevation (Schwartz et al. 2003). The wide distributional range of the species reflects the grizzly bear's generalist approach to both habitat selection and diet (Munro et al. 2006; Coogan et al. 2018) which can range from >85% herbivory to hyper-carnivory (McLellan and Hovey 1995; McLellan 2011; Edwards et al. 2011). However, throughout their continental range prior to dormancy (denning) grizzly bears are obligate consumers of carbohydrate-rich fruit, especially berries (Hertel et al. 2018). The latter can strongly influence survival (e.g., McLellan 2015) and habitat selection including encounters with humans, dictating local persistence probability (Lamb et al. 2018, 2020).

2.2 Grizzly Bears as an Ecological Integrator

Because they are large, long-lived, and wide-ranging omnivores grizzly bears are an excellent example of a mammalian “integrator” species. Its presence in an area conveys a level of ecosystem integrity and serves as a proxy for information on a suite of biophysical factors regarding habitat but also human density, and even relative density of competing black bears, *U. americanus* (Mowat et al. 2013). Grizzly bears are widely considered to be an umbrella species whose conservation may result in other species being conserved at the landscape level (Noss et al. 1996; Roberge and Angelstam 2004). There is thus strong interest in mapping biological data on grizzly bears from governments, organizations, communities, and researchers. However, the issues and approaches used to mapping aspects of the ecology of grizzly bears is complicated by not only the integrative and plastic nature of the species’ biology, but also because we have collated an immense amount of georeferenced data on the species—perhaps more than any other mammal outside our own species. What to map and why are as important questions to ask as is how.

Maps on grizzly bears have been published regarding historic observations of extirpated populations (Environment Canada 2009, COSEWIC 2012); evolutionary phylogeography (Waits et al. 1998) and genetic structure of contemporary populations (Kendall et al. 2008; Mikle et al. 2016); strategies of life history and predictors thereof (Ferguson and McLoughlin 2000; McLoughlin et al. 2000); distribution in relation to human influences like infrastructure and agriculture (Lamb et al. 2018, 2020; Proctor et al. 2019); conflicts with humans including bear attacks (Bombieri et al. 2019); Indigenous knowledge and traditional use (SARC 2017); regulation of harvesting based on expected sustainable mortality rates (Government of Yukon 2019); locations of known or suspected mortalities (e.g., Awan et al. 2019); independent auditing of sampling effort by governments charged with grizzly bear conservation (Auditor General of British Columbia 2017); and direct or integrative measures of local density or population growth, e.g., using spatially explicit capture-recapture models (Yukon Fish and Wildlife Branch Report 2017; Boulanger et al. 2018) and regressions from biophysical predictors (Mowat et al. 2013). Emergent properties of bear populations like equilibrium density (functional carrying capacity) and projected population trend are then used by governments, agencies, or committees to spatially assign legal or conservation status (e.g., COSEWIC 2012; McLellan et al. 2017; NatureServe EXPLORER maps [https://explorer.natureserve.org]). Maps are often the primary product of research and for knowledge dissemination on grizzly bears.

2.3 Report Objectives

Here we aim to present and review the means and methods used to map components of grizzly bear ecology with particular reference to jurisdictional approaches in Canada regarding distribution, abundance, and trend with implications to the scales at which status might be assigned to the species. Our objectives are to: 1) critically evaluate how and why maps on grizzly bears have been produced, including inherent constraints and value; 2) provide a review of the current efforts of jurisdictions in Canada to map grizzly bear biology and status; and 3) conclude with a discussion of how best emergent properties of grizzly bear biology, especially population trend and status, might be mapped at different scales for conservation purposes using the information available. The latter has relevance to standardizing methods on spatially assigning status of grizzly bears across their geographic range, e.g., as advocated by NatureServe and other conservation organizations. This information may be of value for the public and future researchers charged with producing meaningful maps of grizzly bear occupancy, potential occupancy, trend, and status for the species across Canada.

3.0 SPATIAL ECOLOGY AND MAPPING DATA ON GRIZZLY BEARS

3.1 A Problem of Pattern and Scale

Maps on grizzly bears vary widely in terms of resolution (grain of extent) and cartographic or ecological scale. Prior to engaging the topic on mapping, therefore, it may be useful to comment briefly the problem of pattern and scale in ecology (Levin 1992; Estes et al. 2018). Georeferencing the biology and ecology of a species can be confusing, and at times, use contradictory terminology. For example, ecological scale, which refers to the size or extent of a landscape under consideration, is the opposite of cartographic-map scale with respect to what is considered "large" and "small". This is because ecological scale is referenced from the point of view of an organism or species and its interaction with the environment, but cartographic scale is referenced to our point of view (e.g., on a 1:10000 scale map, 1 cm = 100 m on the ground; on a 1:100000 scale map, 1 cm = 1 km on the ground). Further, ecological scale is not to be confused with the level of ecological organization (individual-population-community-ecosystem) nor map resolution (grain). The latter refers to the spatial domain or unit of study, from the finest (e.g., point or pixel in space) to the coarsest (e.g., bounds of a population unit, ecoregion). Minimum grain size dictates extent, and mapping grain and extent are normally inversely correlated in information content (e.g., variation in species diversity; Sreekar et al. 2018).

Understanding the importance of scale and differences between extent and grain is critical for mapping the biology of a large, wide-ranging species like a bear. For example, Peek et al. (2003) notes that as a habitat map becomes finer in grain, small patches of very good and very poor grizzly bear habitat become more visible, so the range of animal densities increases. Whereas (for bears) a three-level ranking of habitat capability—high, moderate, and low—might be discernible on a very coarse-grained map, greater habitat resolution on a finer map scale might enable rankings above and below these. Often, the finer the grain of a map the greater the number of measured variables (layers) associated with a unit or measurement.

The mapping of biological data, which implicitly reflects ecological scaling on a cartographic scale, can be surprisingly integrative. For example, the smallest cartographic-scaled maps of grizzly bear abundance, e.g., at the continental scale in North America (Fig. 1.2), represent patterns of the biology of the species occurring at the largest ecological and hence longest temporal scales: occupancy of habitat post-glaciation and in response to colonization. Within a section of this range (Fig. 3.1), current distribution has been established based on constraints related to the above, but also more recent conservation measures and their influence on bear movements, reproduction, and survival. The home range of an individual bear is determined over its lifetime, constrained within its population range, and is reflective of selected habitat and resources or their modifiers (e.g., vegetation associations, distances to features like roads).

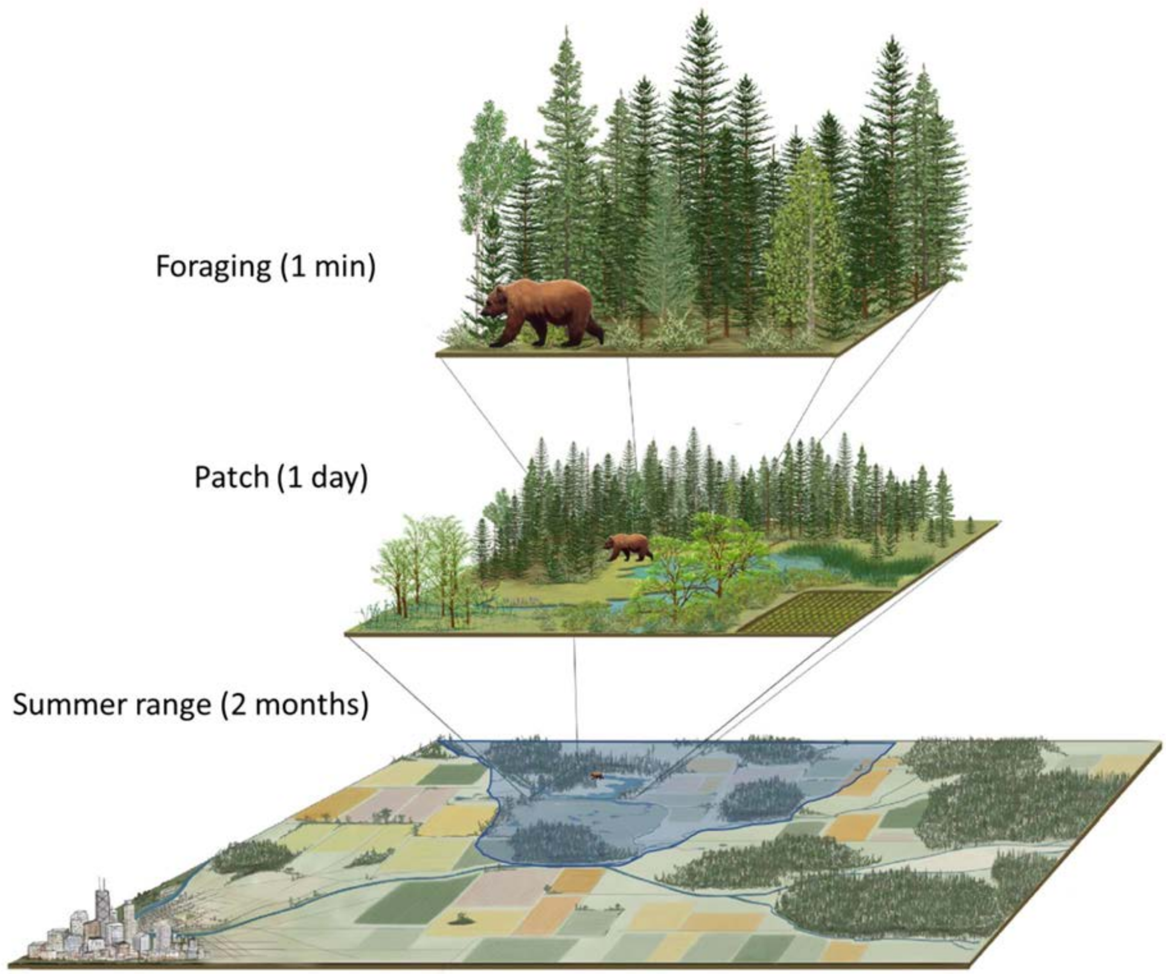


Figure 3.1. Hierarchical habitat selection in space and time (see text). Figure compiled by P.D. McLoughlin (art from Encyclopedia Britannica, Inc.).

Seasonal ranges may be based on seasonal requirements of habitat, and on a given day within a season a bear may use a patch for foraging according to its caloric needs at the time (Fig. 3.1). Choice of foods to eat within a patch will be constrained by larger-scale behaviours; as will components of a food item from which to eat (part of a plant, roe of a salmon). At the finest levels of behaviour, decisions are made on a minute-by-minute or second-by-second basis, often following rules of optimality. At all levels, the reasons for observed patterns are expected to emerge from fitness-habitat relationships, with matching between proxies of fitness (energetic gain → body condition and growth → survival and reproduction → lifetime reproductive success and genetic fitness) scaling accordingly (Gaillard et al. 2010). Exceptions to this rule, mis-match between fitness and habitat selection as might be observed from attractive sinks or ecological traps (Delibes et al. 2001) are also likely to emerge from mis-match between our measures of fitness-performance relationships at different scales.

Nielsen (2011) provided commentary on this phenomena for grizzly bears, noting that an important challenge to including carnivores within ecoregional planning is the need for maps representing the habitat requirements but also vulnerabilities of the species. He noted that:

> "..this [is] particularly important for grizzly bears since selection of habitats by grizzlies in some populations may be maladaptive, whereby animals use habitats that appear suitable or perhaps benefit growth and reproduction but survival is low leading to population declines (Nielsen et al. 2006, 2008). Considering that the slow life-history traits of grizzly bears result in high elasticity to survival (especially adult females), habitat conditions that identify source-sink conditions or mortality risk are crucial for representing the vulnerabilities of the species and the sites best suited for further conservation actions (p. 137)."

A unit of conservation, if serving as an unrecognized drain on otherwise healthy adjacent units, may be a greater risk to an overall population's persistence probability than losing the sink unit from a plan. Sink areas and their importance must be therefore be recognized, which means that mapping habitat suitability for grizzly bears cannot be divorced from the demography of the species. As mortality risk to occupying habitat increases, sink habitats should no longer be considered suitable habitat, regardless of the occurrence of the species. However, the scale at which to map suitability must also therefore correspond to the spatial and temporal domains in which a source vs. sink habitat component might be differentiated. Ecology and evolutionary ecology are hierarchical, which means that conservation biology needs to be as well.

When it comes to creating informative maps for a species, then, choice of scale must therefore take into account not only our intended use of the map but also the spatio-temporal processes giving rise to the patterns presented. For example, it is now widely considered that patterns emerging at larger ecological scales are constrained by and reflect the increasing importance of limiting factors to population growth of a species (Rettie and Messier 2000). The southeast distribution of boreal caribou in North America may be determined by the presence of meningeal (brain) worm (Anderson 1972); but occupancy of habitat within its current geographic range by predation from wolves (McLoughlin et al. 2005). The continental distribution of white spruce is strongly linked to seed dispersal and heat supply in the context of competition with deciduous species (Egorov and Afonin 2018); while stand resilience within the range is dictated by fire history and local biophysical conditions (Johnstone et al. 2010). The presence or absence of grizzly bears in North America is undoubtedly constrained by human density, but within the species' extant range other factors may be more important than anthropogenic disturbance (Mowat et al. 2013). Understanding this, perhaps more than anything, is critical for developing our smallest-scale cartographic and largest-scale ecological maps for species like bears which are distributed across non-coastal regions of North America at relatively low densities (e.g., 23.0 ± 15.1 bears/1000 km^2 [$\bar{x}$ ± SD, n = 76 studies]; Mowat et al. 2013). Indeed, planning for recovery and habitat conservation and monitoring must occur at small cartographic scales but integrating the most meaningful data—not just all data—available at large cartographic scales remains the principle challenge of mapping grizzly bear biology (see, e.g., Mowat et al. 2013; Boulanger et al. 2018; Bischof et al. 2020; Fig. 3.2). It is also important to recognize the need to integrate changing landscape conditions that may impact these ecologically meaningful data, while very few researchers are able to map or model the latter over time time implicitly. This is likely because 2D models (abundance × space) are easier to convey and populate with data than a 3D approach (abundance × space × time; G. Mowat, Wildlife and Habitat Branch, BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, *pers. comm.*)

Further, if our goal is to map an emergent process related to fitness—e.g., equilibrium density (functional carrying capacity) or population trend and hence conservation status—we would be wise to understand why movements, births, and deaths of individuals scale the way they do. While scaling of ecological patterns in space is widely appreciated, the temporal scales of ecology and observation needed to determine the former are perhaps less well understood. Estes et al. (2018) noted that beyond resolution and extent the temporal domains of interval and duration must also be considered, if emergent spatial patterns are to be trusted. We intuitively know this to be true, e.g., population trend based on density estimates for two successive years is not easily extrapolated to the time frames in which status is generally assessed (often over three generations for a species like the grizzly bear; COSEWIC 2012). Expanding on ideas of Estes et al. (2018), it thus makes sense that the larger the grain at which trend is to be mapped the longer the duration of assessment should be expected, and, depending on status rank—which can be correlated with unit size due to small-size population biology (Caughley and Gunn 1996)—the more frequent reassessment may be needed.

3.2 Current Issues

Unlike many species-at-risk, the history of the grizzly bear and our approaches to documenting its occurrence and biology in space has been informed by a mix of curiosity in their presence (or absence), the pursuit of science, and societal values surrounding the place of the grizzly bear in nature. However, maps, as is well known, can play roles that are more important than documenting spatial facts. This has also been the case for mapping metrics of grizzly bear biology and conservation status. Indeed, our approaches to mapping the species have varied considerably depending on political borders and, in particular, whether the species has been managed for increasing abundance and range maintenance or expansion for recovery and restoration of ecosystem functioning; or for maintaining abundance and protecting harvesting opportunities for people. Mapping approaches and needs may also be influenced by other land use activities occurring or planned within identified grizzly bear range. These different objectives require much different resolutions and types of data, and hence allocation of resources, which directly translates into the geographic expression of these data. The legacy of these distinctions can remain with us in our approaches to mapping bears today—even where bears are no longer hunted—with the consequence that almost every jurisdiction charged with managing bears and their habitat has adopted different approaches, layers to atlas, and resolutions at which to map. Context-specific discussion of how and why grizzly bears are mapped by provincial and territorial authorities is presented in Chapters 4.0–9.0, with implications to higher-order mapping efforts for status assessment (federal, international) discussed in Chapter 10.0.

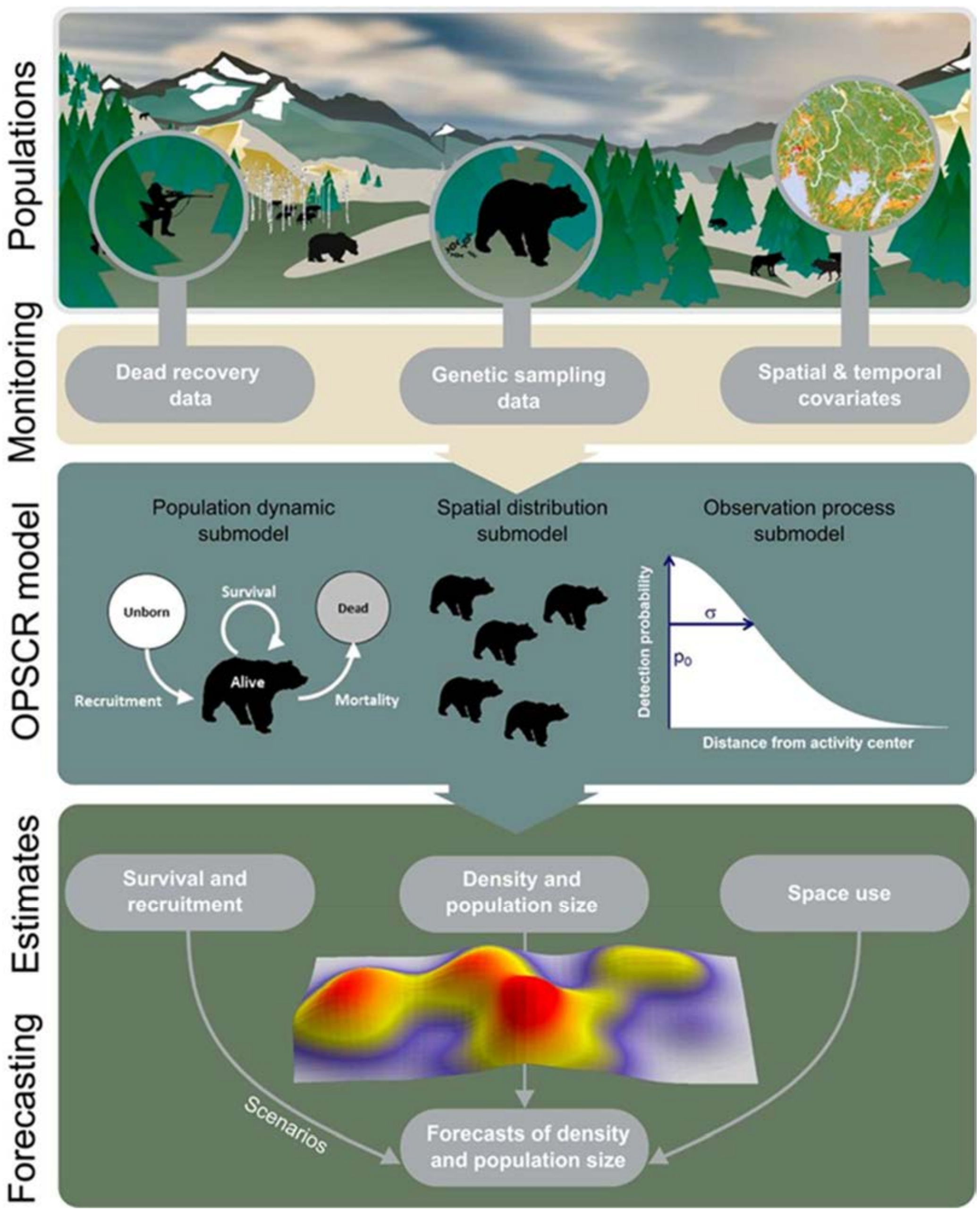


Figure 3.2. The process of turning long-term monitoring data, such as non-invasive genetic samples and dead recoveries, into population density maps and vital rate estimates, e.g., following an open-population spatially explicit capture-mark-recapture program (example and figure from Bischof et al. 2020).

4.0 MAPPING GRIZZLY BEARS IN BRITISH COLUMBIA

4.1 Background

British Columbia (BC) supports approximately 15,000 grizzly bears (Mowat et al. 2020), roughly 25% of the North American population (McLellan et al. 2017). Mapping of grizzly bear biology in BC has been an increasingly important mandate of the BC Government (Ministry of Forests, Lands, Natural Resource Operations and Rural Development). Historically, the provincial grizzly bear population was managed for sustainable harvesting (Fuhr and Demarchi 1990; Peek et al. 2003; Boyce et al. 2016), and mapping of grizzly bear densities to estimate sustainable harvest rates was conducted using a variety of means including expert-based methods. In the late 1970s, the distribution and relative abundance of bears in BC was mapped at a relatively small scale (1:2,000,000 and 1:5,300,000) using information provided by regional wildlife biologists (e.g., BC Fish and Wildlife Branch 1977, 1978). Initially, abundance categories were more qualitative than quantitative (e.g., moderate to plentiful, few to very few, and nil; although these levels were tied to estimated bears/km^2) and based on the available literature (Fuhr and Demarchi 1990). By the late 1980s, there was a clear need to map the ecology of grizzly bears, principally in relation to abundance, to manage for a sustainable harvest.

BC was one of the first jurisdictions—with Fuhr and Demarchi (1990) and subsequent works—to adopt a bottom-up approach to estimating bear densities and from there sustainable harvest levels (~6%; Harris 1986; Miller 1990). The latter was based not on direct population data, but rather knowledge of the species inside and outside the province and assessment of available habitat (capability) to estimate carrying capacity (75, 50, 25, 5, and 1 bears/1000 km^2; Fig. 4.1), with reductions from carrying capacity allowed for a variety of (step-down) reasons, especially increasing human impacts on the landscape and history of human-caused mortality (review in Hamilton and Austin 2001; Peek et al. 2003). Data were applied to Grizzly Bear Population Units (GBPUs), boundaries for which are rooted in the amalgamation of provincial Wildlife Management Units (WMUs; Fig. 4.2). However, in the south GBPUs now appear coincident with natural (large river, e.g. Fraser, Columbia) and anthropogenic fragmentation of bear habitat (Mowat et al. 2020). At the time, the Fuhr-Demarchi approach was truly born out of necessity: research projects of capture-recapture or radio-tracking while being able to provide some local estimates of population size were rare and not extrapolative to the entire province.

Fuhr and Demarchi (1990) recognized the importance to map scale as it might relate to stratifying population estimates based on habitat to scales of 1:50,000, while the process was performed largely using small-scale maps (e.g., 1:500,000 and 1:250,000). Other issues related to the method, including the use of relatively few benchmarks to gauge habitat suitability, or potential mis-match between a benchmark and independent estimates of that mark's population size (Peek et al. 2003), led to the Fuhr-Demarchi method to be replaced by newer techniques to estimate population size in the 2000s (Mowat et al. 2004; Hamilton et al. 2004; Mowat et al. 2013).

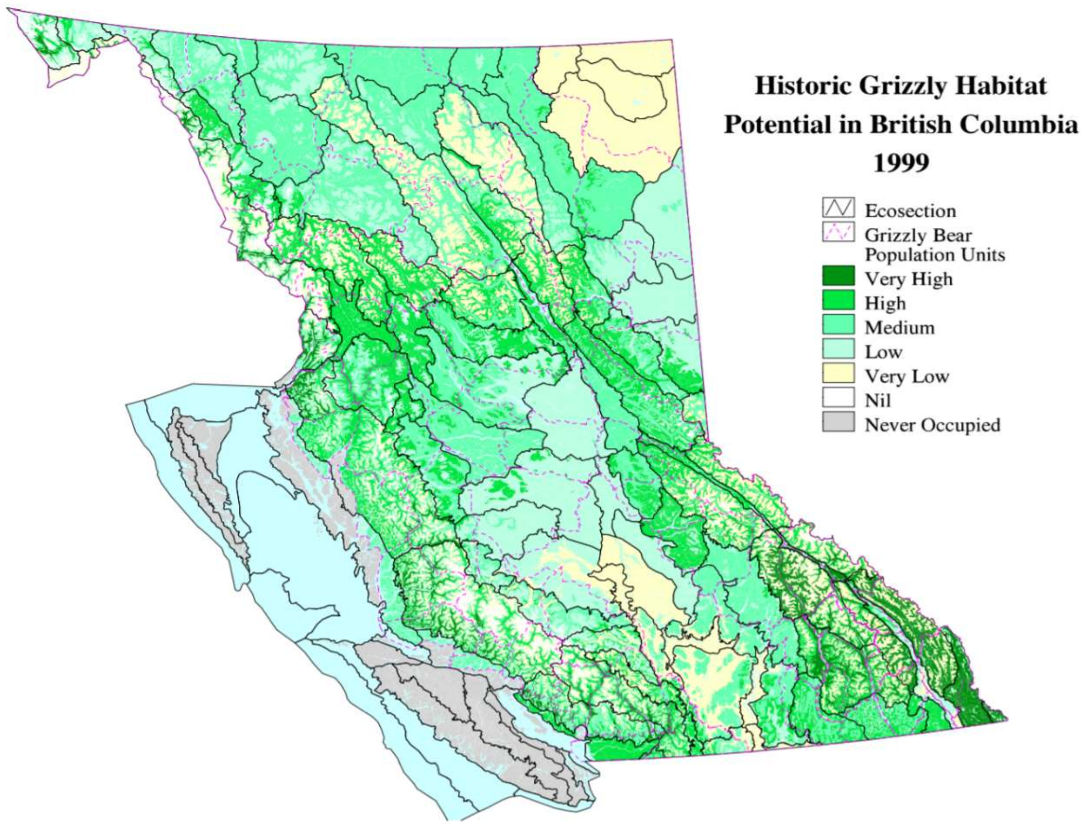


Figure 4.1. Mapping of grizzly bear habitat potential (green), overlaid on grizzly bear population units. Following the Fuhr-Demarchi method each GBPU would be assessed for carrying capacity and population size for estimating sustainable harvest deduced from data and expert opinion. Map from Hamilton and Austin (2001).

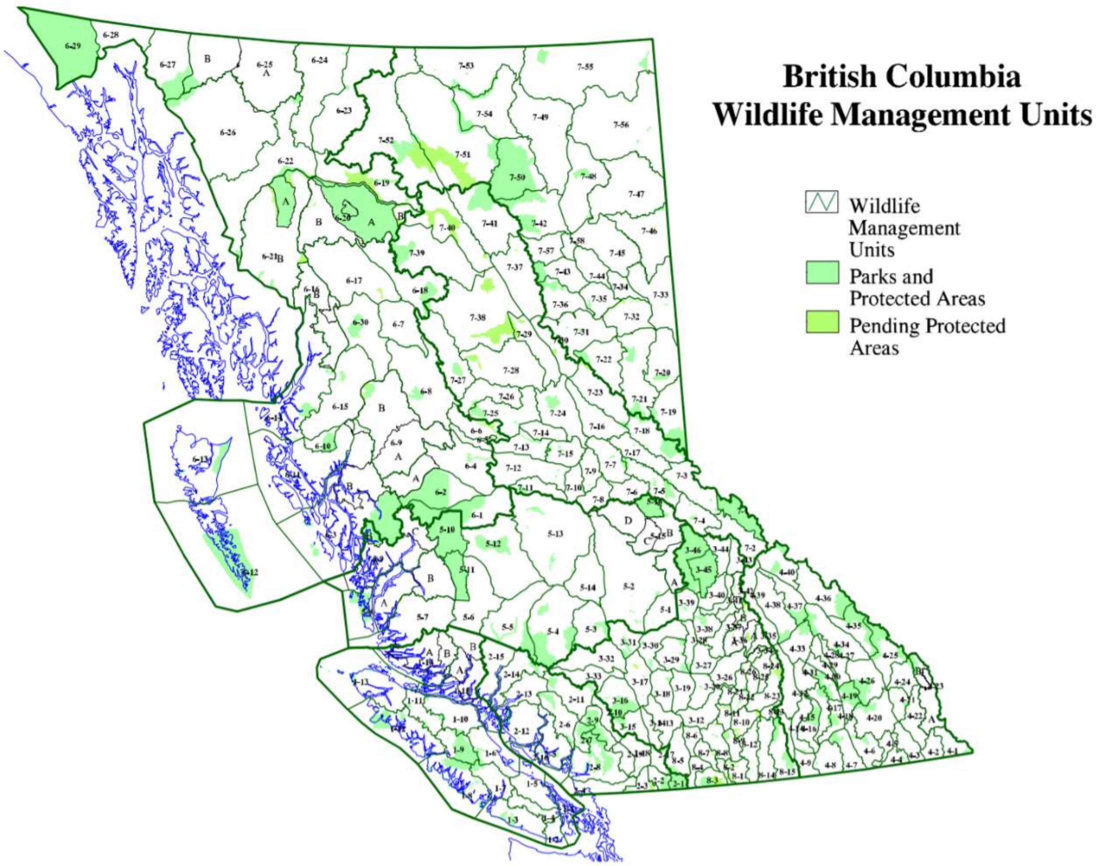


Figure 4.2. Grizzly bear population units (GBPUs) are comprised of one or more Wildlife Management Units (WMUs) in BC (boundaries as at 2000). The latter are used for management of multiple wildlife species in BC. Map from Hamilton et al. (2001).

4.2 Current Approach

The province of BC currently uses a regression approach to estimate grizzly bear abundance through most of the GBPUs in the province (Fig. 4.3). The current model, detailed in Mowat et al. (2013) and applied in Mowat et al. (2020), uses 89 estimates of grizzly bear density from study areas across the interior of western North America, and predicts density using variables such as precipitation, vegetation type, and human and livestock density. Biophysical data are associated with continued efforts to update grizzly bear habitat capability in the province (Fig. 4.4), e.g., using methods of Hamilton et al. (2018). A separate regression model is used to predict bear density for coastal areas (where salmon is a large part of the diet but not a major food source in the interior populations used to build the model).

Whereas previous abundance estimates were constructed at the grain of the GBPU in BC, current models have been applied at the finer scale of Wildlife Management Units (WMUs) to better reflect density differences within GBPUs (most GBPUs incorporate several WMUs; Compare

Fig. 4.2 with 4.3). These data are then used to compile an estimate for a GBPU. Also, all estimates are evaluated and in some cases modified based on expert opinion of ministry regional biologists. For example, in Mowat et al. (2020), for 17 of 184 WMUs, the opinion of experts differed from model estimates (e.g., six WMUs predicted no bears, but because bears were known to exist in these areas, the model estimate was changed, or modified where it was apparent that available of salmon was not accurately translating into bear abundance).

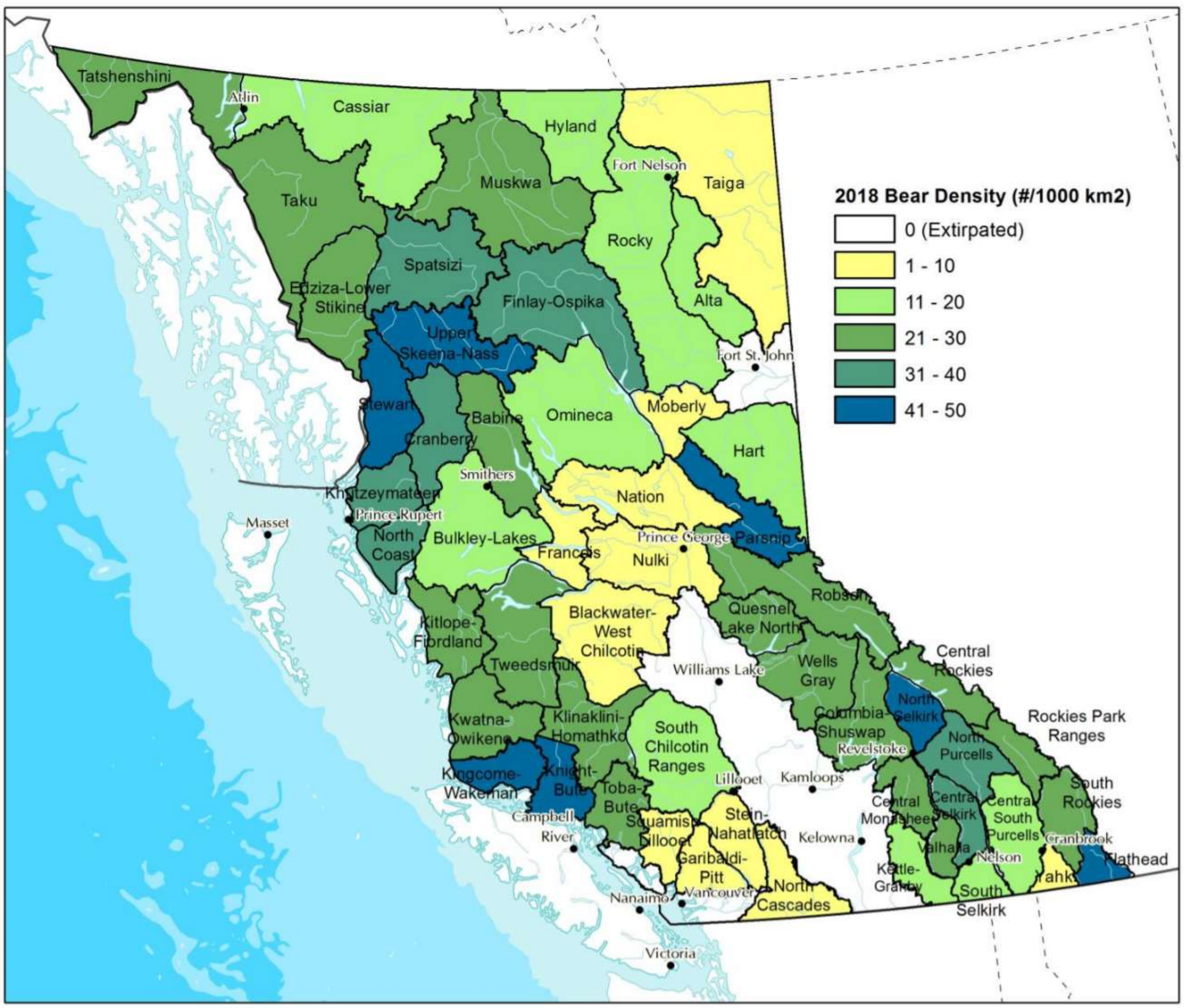


Figure 4.3. Mapping of grizzly bear relative densities for each of 55 grizzly bear population units (GBPUs) in British Columbia. Map and data in Mowat et al. (2020).

Mapping Grizzly Bears in Canada

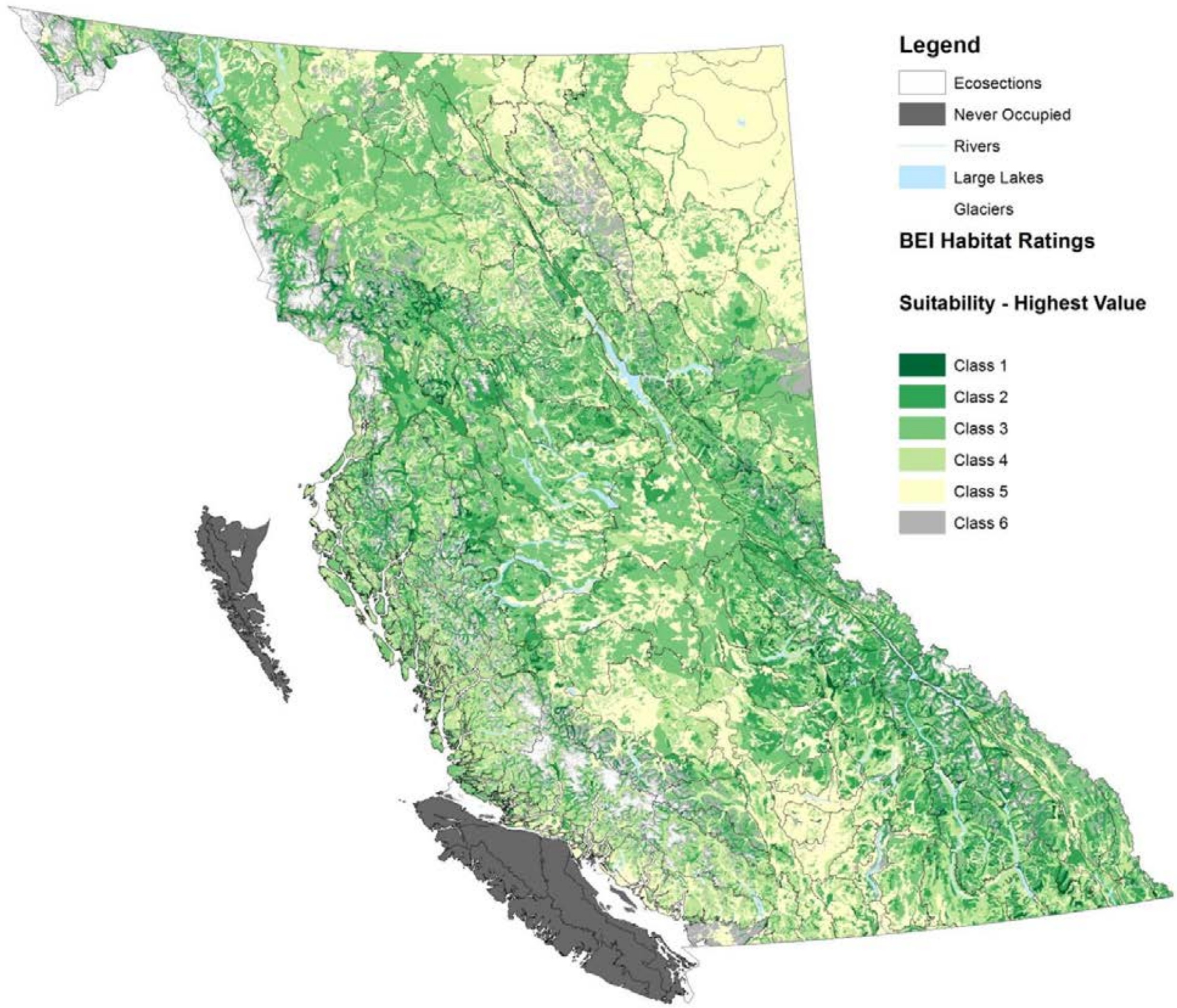


Figure 4.4. Grizzly bear current habitat suitability ratings from ecosections, biogeoclimatic ecosystem classification, and broad ecosystem inventory. Reprinted from Hamilton et al. (2018).

The current estimate of 14,925 (15,000) grizzly bears for BC cannot be qualified with confidence intervals: the method relies to some extent on expert-based opinion (Mowat et al. 2020). Estimates for GBPUs using the current method are also not directly comparable with previous estimates, like the Fuhr-Demarchi. Hence, population trend information on a province-wide basis is not directly available. One criticism of this approach, too, is that trend information will not be able to be assessed based on directly-measured demographics of most GBPUs at a consistent interval. Over a long temporal duration, due to the costs involved, a comparable change in density may only projected with a change in underlying biophysical predictors.

Mapping Grizzly Bears in Canada

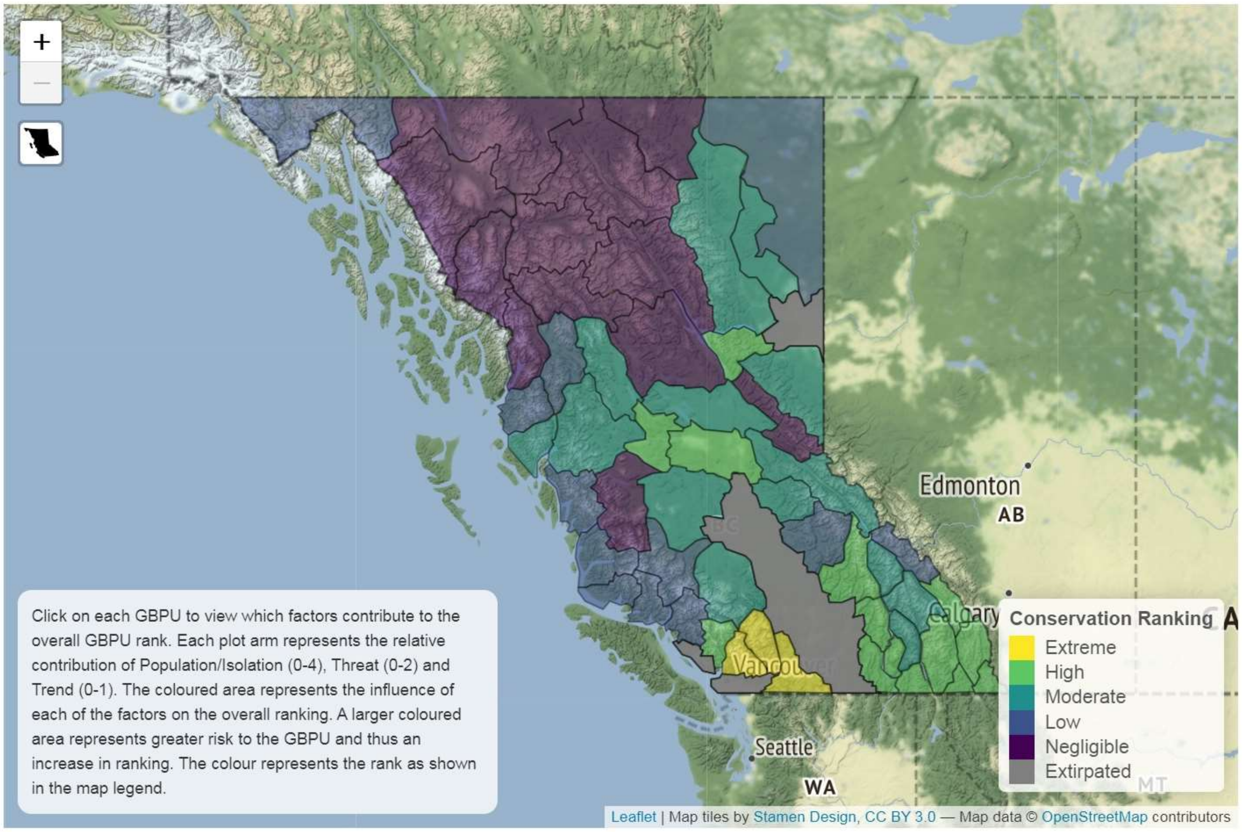


Figure 4.5. Conservation rankings currently applied to grizzly bear management units (GBPUs) in BC. Data accessed on March 27, 2021 at http://www.env.gov.bc.ca/soe/indicators/plants-and-animals/grizzly-bears.html).

While trend information is not available for most of the 55 GBPUs, each is mapped and ranked on a scale of low to extreme conservation ranking (Figs. 4.6 and 4.7). Rankings are determined using internationally recognized methods developed by NatureServe and the IUCN and based on: 1) population size (Mowat et al. 2020) and isolation (degree of connectivity with other GBPUs); 2) population trend (where known); and 3) level of threat assessment to demographics or bear habitat based on metrics assigned to a GBPU related to human activity. Human activity is thought to be a primary determinant of grizzly bear occupancy at both small and large cartographic scales (Fig. 4.7; Apps et al. 2004; Mowat et al. 2013; Boulanger and Stenhouse 2014; Lamb et al. 2018, 2020). While not every GBPU can be assessed for trend quantitatively, given the means of estimating density, above, some units have independent assessments of demographic data including DNA capture-recapture data and long-term monitoring to allow for local trend assessment (e.g., McLellan 2015; Mowat and Lamb 2016; McLellan 2018). Threat ranks are applied based on expert-opinion, and conservation rank is derived from the combination of trend, population size and degree of isolation, and level of threats facing the GBPU (Figs. 4.5 and 4.6). Maps are readily available to the public and presented using a web-based interactive map (Figs. 4.5 and 4.6 are derived from this site, available at http://www.env.gov.bc.ca/soe/indicators/plants-and-animals/grizzly-bears.html).

Mapping Grizzly Bears in Canada

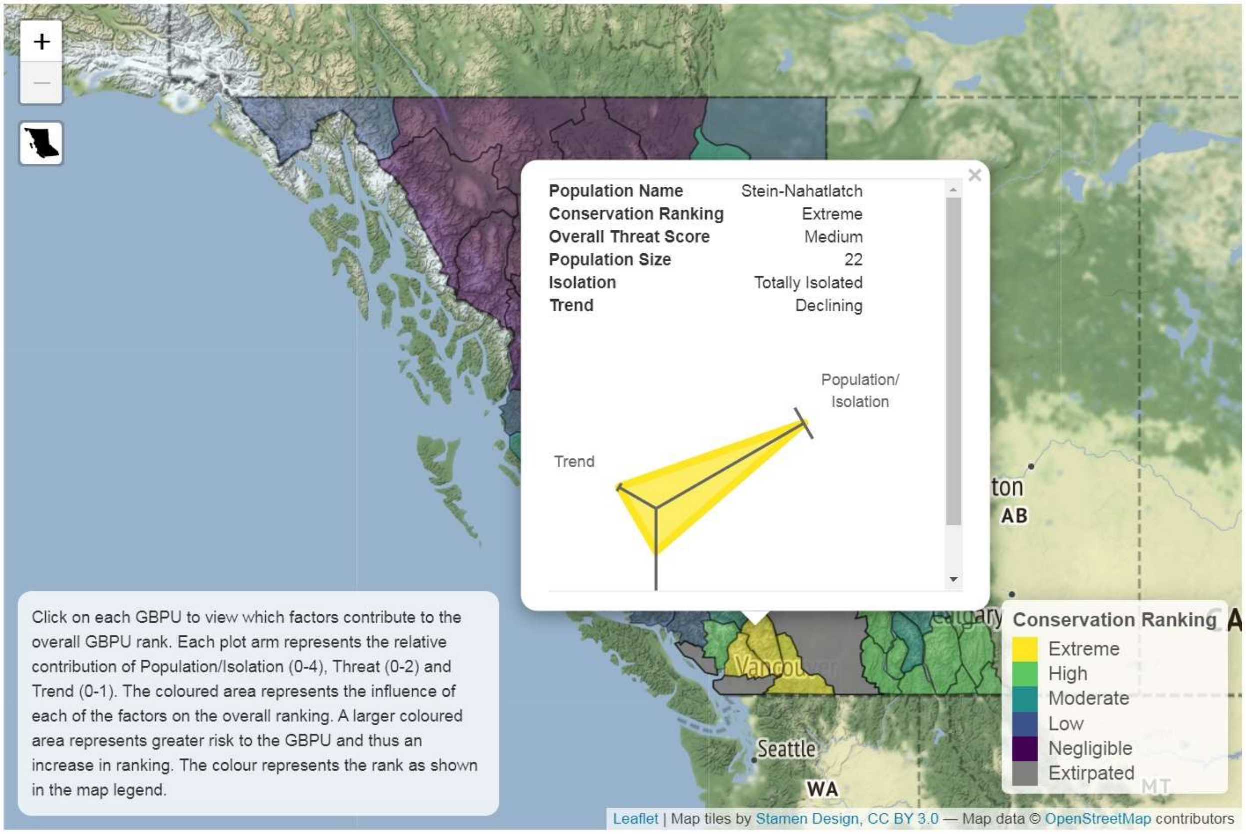


Figure 4.6. Example data as applied to a conservation ranking for a grizzly bear population unit (GBPU) in BC (Stein-Nahatlatch). Data accessed on March 27, 2021 at http://www.env.gov.bc.ca/soe/indicators/plants-and-animals/grizzly-bears.html).

Mapping Grizzly Bears in Canada

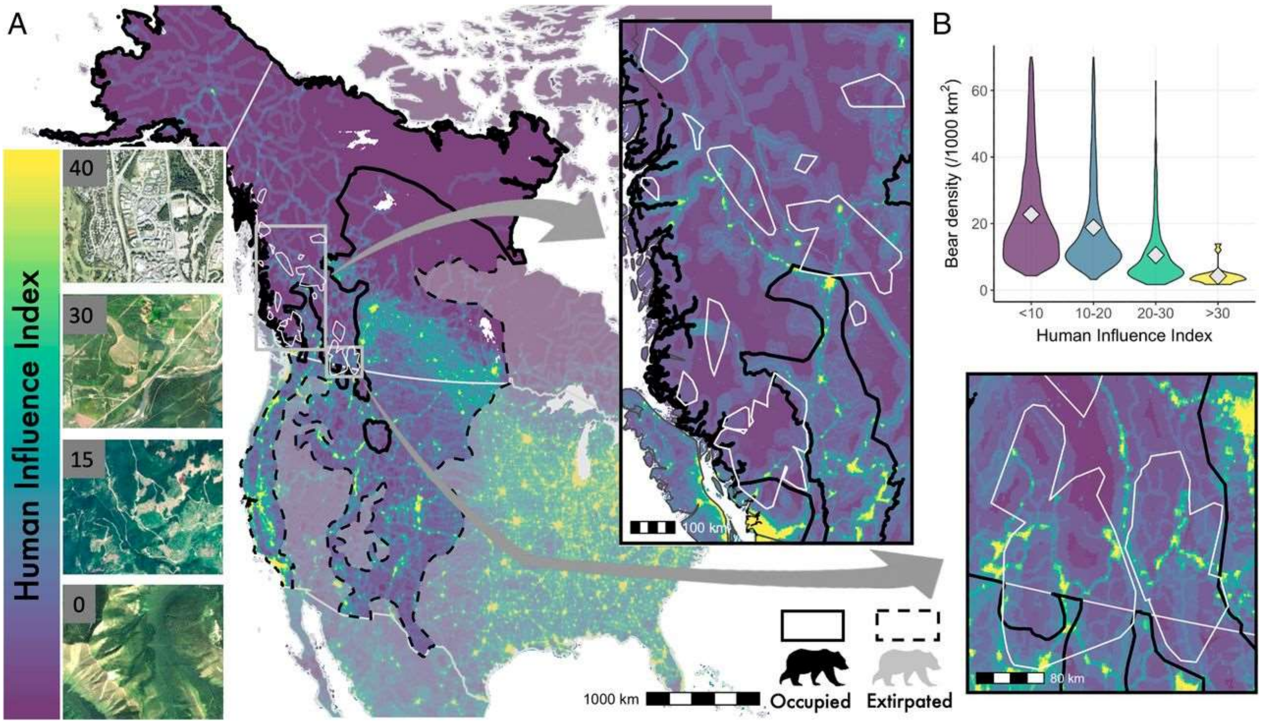


Fig. 4.7. Lamb et al. (2020) presented (A) Study extents (white polygons) for each of 12 telemetry and 29 genetic tagging studies on grizzly bears in North America. They constructed a Human Influence Index (HII) depicted with satellite images from across the species' range (left). HII was a composite index derived by combining human population density, human land use and infrastructure (built-up areas, nighttime lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers). The index ranged from 0 (lowest human impact) to 64 (the most human-dominated category). The authors considered the range from 0 to 40 as grizzly bears generally don't use—or survive in—habitats exceeding HII of 40. National borders in grey. Inset maps show the variation in human influence within and among studies. (B) Relationship between brown bear population density and HII within the study extents. Figure from Lamb et al. (2020).

4.3 Discussion and Management Implications

British Columbia is responsible for the conservation and management of more grizzly bears than any other province or territory in Canada. Similar to Alaska and Yukon, grizzly bears can be found over large areas of the province but densities are not homogeneous. Further, grizzly bears occur in BC in varied habitats, from the Pacific coast where densities are highly influenced by salmon to the interior taiga and southern continental divide, where the climate is much different and salmon may not occur. In terms of relative equilibrium density, grizzly bear densities can vary by two orders of magnitude across these habitats (<1–856 bears/1000 km^2; Mowat et al. 2013) with coastal bears presenting markedly different life histories than interior populations (Ferguson and McLoughlin 2000). No other jurisdiction in Canada faces such varied ecological conditions in which to model and map grizzly bear occurrence and demography.

The logistics of mapping grizzly bear abundance and trend is likely the principle issue facing managers charged with monitoring the species in BC. The need to accurately identify grizzly bear numbers at the level of the GBPU was, for most of the 2000s, very high because of prior mandates to ensure bear harvests were sustainable (Peek et al. 2003; Boyce et al. 2016). The current approach taken for mapping grizzly bear densities based on predictive regression models from biophysical features was born out of this necessity. While managing bears for sustainable harvesting is not part of the current mandate of the BC government, the species still must be monitored closely as the province supports some of the most imperilled and isolated units of grizzly bears in Canada (Fig. 4.5; Garibaldi-Pitt-Stein-Nahatlatch-North Cascades units; Southern Selkirks and Yahk). These southern units are of international significance as natural sources or rescue populations to those in the US.

The methods used to map abundance and trend, threat levels, and degree of isolation and ultimately status can be confirmed by direct empirical evidence for some units in BC, but this is not possible to do on a province-wide basis due to the size of the provincial grizzly bear range. Reliance on predictive regression modelling, i.e., estimating population densities based on a suite of biophysical factors truthed where possible from demographic data, and adjusted by expert-opinion, holds some disadvantages in this regard. In particular, population parameters and trend are not easily attributed confidence intervals (Mowat et al. 2020), and hence changes in population size over time may not be discernable if biophysical attributes of habitat remain static (not updated), or effect sizes of changes in variables used in the regression are not well known. In addition the biophysical attribute approach will not detect high levels of unreported human caused mortality which can result in population declines. The latter is very hard to monitor and map.

Revising models as new data become available will be key to the process adopted in BC to map grizzly bears going forward. Issues regarding the modelling of density from habitat variables for coastal vs. interior bears are known (Mowat et al. 2013), the former being highly influenced by salmon and the successful runs of salmon, some of which are at-risk of failure in recent years (e.g., sockeye salmon, COSEWIC 2017). Biophysical predictors may not capture the annual effects of salmon failures; hence, bottom-up, habitat-based approaches to estimating bear densities and trends may lead to mis-match in the spatio-temporal scales operating on bears in a changing environment. Predicting grizzly bear abundance from habitat features inherently takes advantage of long-term habitat associations occurring at large ecological scales (e.g., densities and life history traits of coastal bears, feeding on salmon, have evolved differently from bears of the interior; Ferguson and McLoughlin 2000). Acute changes in drivers of the evolutionary ecology allowing for a habitat-density association may be difficult to capture when mapping at the fine grain of the GBMU.

The short-comings of predictive modelling, however, can be overcome with more data, and our datasets on grizzly bears are increasing rapidly. These types of models will only be as good as the training sets made available to them, and in the absence of current data on key drivers of bear biology (e.g., importance of salmon in the diet or not for a coast bear unit) expert-opinion is still required fit models to reality (Mowat et al. 2020). However, there are approaches that may be adopted to improve predictive capacity beyond human intervention, including the application of machine-learning techniques (see Ch. 10).

5.0 MAPPING GRIZZLY BEARS IN ALBERTA

5.1 Background

Grizzly bears were once found throughout much of Alberta (review in ASDRACA 2010). However, by the late 1800s, grizzly bear range in the province was increasingly restricted to the west. The modern range of the species in Alberta has not changed since the early 1900s, and today covers approximately one third of the province.

The first provincial grizzly bear management plan was prepared by Nagy and Gunson (1990) with input from staff of the provincial government (now Alberta Environment and Parks, Fish and Wildlife). Throughout the 1980s there was an ongoing, regulated spring grizzly bear hunt for which regional staff delineated a series of bear management areas (BMAs) to assist in the distribution and evaluation of managed grizzly bear harvesting. The boundaries of these BMAs were delineated from expert opinion and local knowledge of the staff involved in the preparation of the management plan (Fig. 5.1). This map represented the first formal delineation of grizzly bear distribution in Alberta; however, limited data on the abundance and distribution of the species was available at this time. Little understanding outside of local contexts was known for several BMAs.

The BMA boundaries delineated by Nagy and Gunson (1990) remained in place until the advent of genetic-based approaches to document grizzly bear occupancy (e.g., Proctor and Paetkau 2004). Proctor and Paetkau (2004) used biological samples containing DNA from grizzly bears across their identified range in Alberta and adjacent areas in BC to delineate previously unrecognized sub-populations. This spatial-genetic analysis allowed the definition of new management unit boundaries based on genetically distinct groupings (Fig. 5.2). While the mapping methods of Proctor and Paetkau (2004) presented a great refinement to earlier methods, throughout the 2000s concurrent advances in methods of DNA-based capture-recapture, habitat mapping, and resource selection modelling led to the evolution of the province’s current approach to mapping distribution and abundance of bears in Alberta. This approach builds on all the above to inform both small- and large-scale grizzly bear occupancy models for the province.

5.2 Current Approach

Herrero (2005) spear-headed Alberta’s first efforts at mapping potential habitat for grizzly bears as part of the Eastern Slopes Grizzly Bear Project (1999–2004). The project largely focused on grizzly bear land-cover classes for Banff National Park and Kananaskis Provincial Park, and used remote sensing greenness mapping approaches to identify habitat values for resident grizzly bear populations. These mapping products were initially not linked to provincial BMAs, however. Extension of approaches developed by Herrero (2004) were expanded to the BMA-level as part of the long-term fRI Grizzly Bear Program (GBP), 1999–2021.

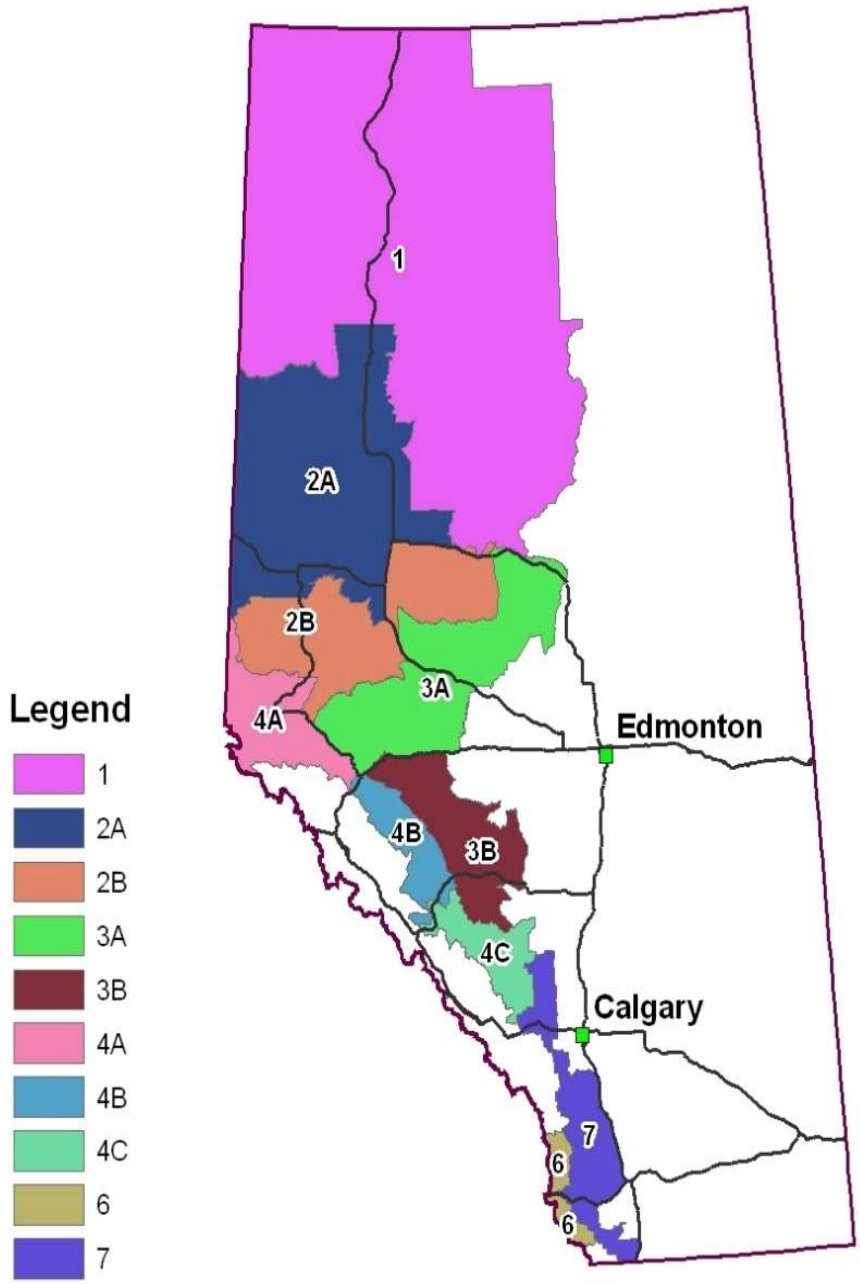


Figure 5.1. Provincial Bear Management Areas (BMAs) circa 1990 (adapted from Nagy and Gunson 1990).

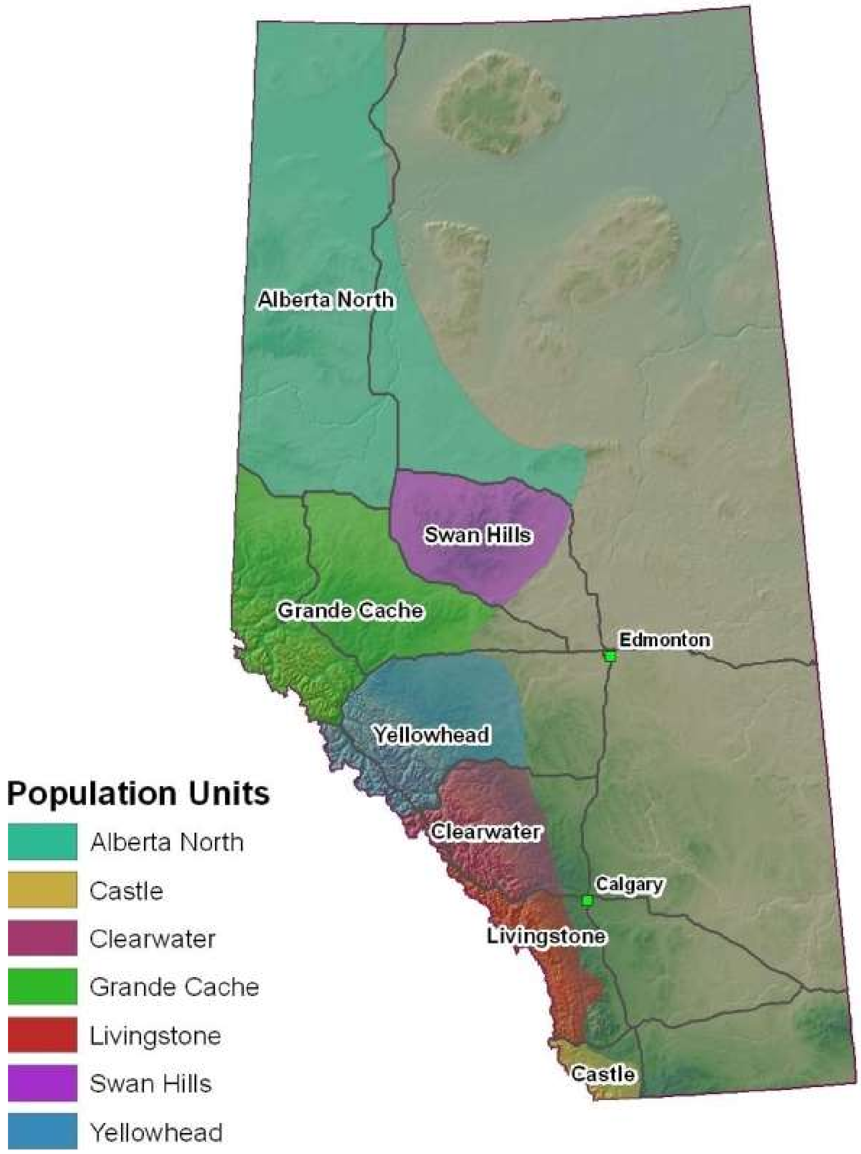


Figure 5.2. Alberta Grizzly Bear Management Areas (BMAs) based on genetic analysis, revising Fig. 5.1 to account for current known sites of occupancy (Proctor and Paetkau 2004).

Habitat-mapping work by the fRI GBP began in 2000, initially in what is now BMA 3 or the Yellowhead BMA of Proctor and Paetkau (2004; Figs. 5.2, 5.3, and 5.4). This mapping effort had a goal of providing comprehensive coverage of grizzly bear habitat for the entire BMA, including Jasper National Park. Remote sensing approaches (using Landsat 7.0 Thematic Mapper products were selected to provide a 10-class landcover classification map with a 30-m pixel resolution. These landcover maps (Franklin et al. 2001, 2002) comprised a first step to documenting current landscape conditions for BMA 3. They formed the basis to determine whether the approach would provide the needed data for grizzly bear management, and more broadly, land management decisions in provincial grizzly bear range (Fig. 5.3).

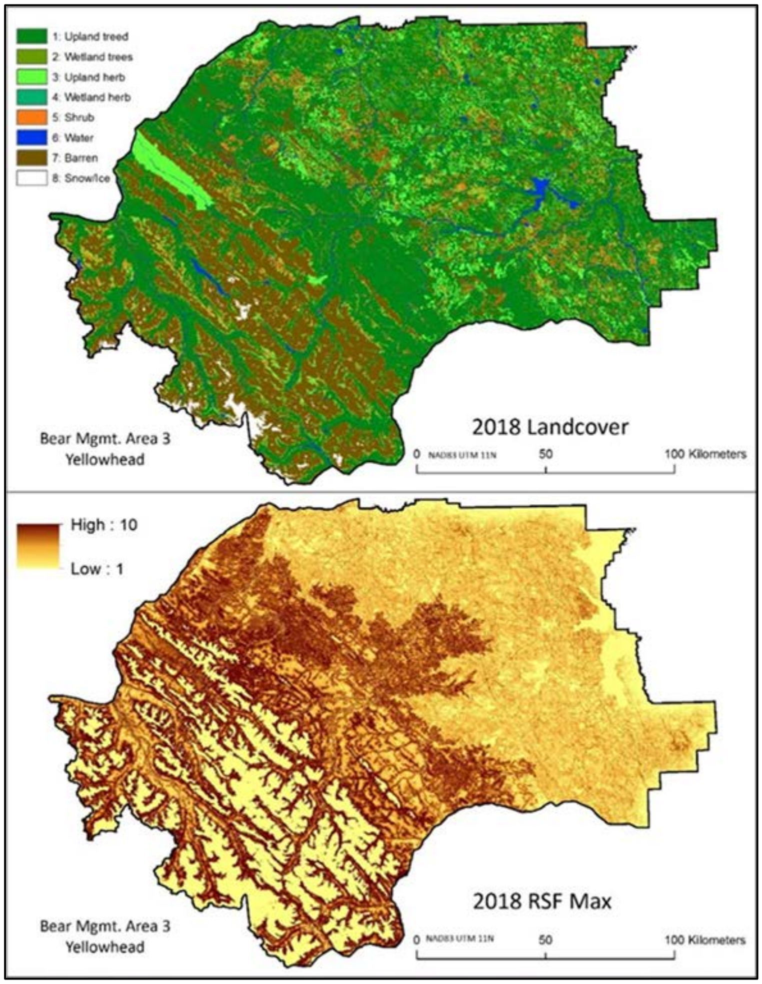


Figure 5.3. Landcover and Resource Selection Function (RSF) habitat maps for BMA 3 (Alberta) updated to 2018 conditions.

These first landcover map products for grizzly bears were evaluated against other spatial data (roads, rivers/streams, human features) and Global Positioning System (GPS) data from radio-tracked grizzly bears (Fig. 5.4) to produce resource selection function (RSF) map layers (Nielsen 2005). RSF-map layers were used as a surrogate of habitat quality for grizzly bears. The latter was an assumption, since an RSF-surface only indicates the proportional probability animal occurrence on a landscape (Boyce and MacDonald 1999). However, these RSF surfaces were used to help plan (in 2004) the first DNA-based grizzly bear population inventory of BMA 3 (Boulanger et al. 2005). It was this early application of DNA-mark-recapture analysis, combined with the work of Proctor and Paetkau (2004), and the comparison of these methods with GPS-based RSF-modelling, that proved illuminating to the Alberta-approach to understanding the distribution and abundance of grizzly bears in BMA 3.

Mapping Grizzly Bears in Canada

The results of Boulanger et al.'s (2005) DNA-based inventory work showed that the RSF surfaces of Nielsen (2005) were strongly correlated with both the distribution and abundance of grizzly bears in BMA 3, providing support for their management importance to understanding grizzly bear habitat. This linkage between the RSF surfaces, which were based on the landcover mapping products, suggested that both products were useful for BMA-specific grizzly bear inventory work with practical application to estimating both distribution and spatial heterogeneity in abundance (density). The result is now known as a spatially explicit capture recapture (SECR) approach, which has now evolved to include estimating not only distribution and abundance but grizzly bear habitat and mortality risk to test local density associations using density surface modelling (e.g., Boulanger et al. 2018).

In 2004, DNA-based population inventory was soon expanded in Alberta to include the Livingstone (BMA 5, Fig. 5.2) unit (Boulanger et al 2005a, 2005b). Importantly, results from both the 2004 and 2005 projects for BMA 3 and 5 provided evidence that there were fewer bears than were previously thought inhabiting in the management units. These findings resulted in the suspension of grizzly bear hunting in Alberta in 2006, and work commenced to prepare a provincial recovery plan. During the preparation of this recovery plan it was recognized that a more detailed understanding of provincial grizzly bear habitat was required.

Following initial work on combining GPS-telemetry data with remote-sensing and DNA mark-recapture analysis that proved so useful for BMA 3 and 5, a five-step process was established by the province to determine distribution and abundance of grizzly bears in Alberta. These steps included:

Step 1: Preparation of a landcover base map of a BMA using remote-sensing techniques and including GIS layers related to roads, streams, and anthropogenic features;

Step 2: Gather GPS-location data from radio-collared bears residing in the BMA over at least a two-year period to determine habitat use;

Step 3: Prepare RSF-map products for the BMA by combining GPS data with landcover maps;

Step 4: Using the RSF maps prepare a sampling design to undertake a spatially explicit DNA based mark-recapture population inventory (SECR); and

Step 5: Conduct a SECR-population inventory of the BMA to determine abundance and distribution of grizzly bears.

Mapping Grizzly Bears in Canada

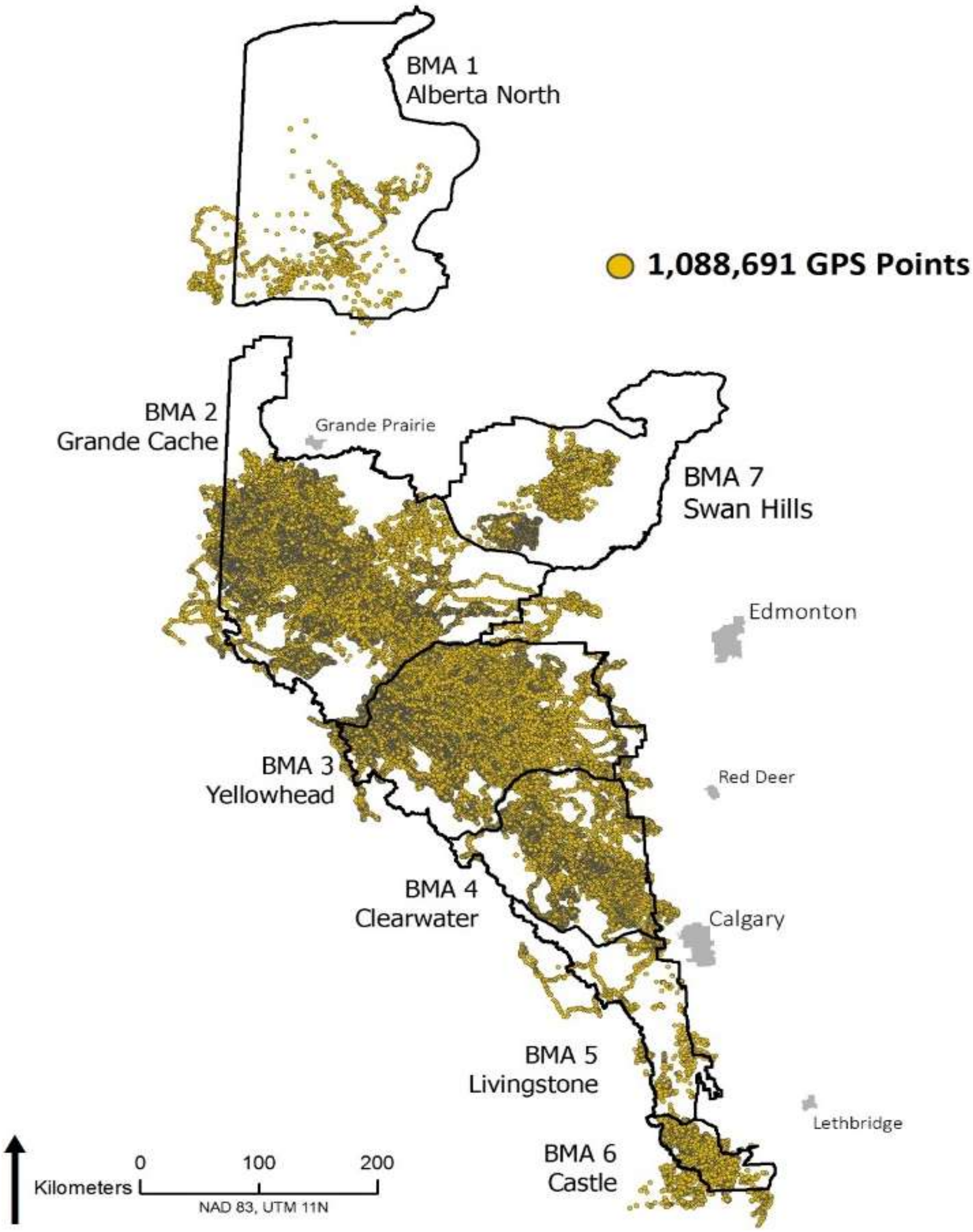


Figure 5.4. GPS data from radio collared grizzly bears in Alberta (1999-2021).

In preparation for large-scale implementation of a SECR-approach to mapping grizzly bears in Alberta, a major program of remote sensing work was conducted in the 2000s to complete the assembly of a single, landcover map layer that would allow the quantification and analysis of the spatial distribution and configuration of grizzly bear habitat within all 228,000 km^2 of provincial grizzly bear range. Accomplishing this task took approximately ten years, with annual field campaigns by teams of field staff to ground-truth remote sensing products. The work was headed by Dr. Steven Franklin and Dr. Greg McDermid, supported by their many students, at the University of Calgary (e.g., McDermid et al. 2005a, 2005b and 2009).

Mapping Grizzly Bears in Canada

During the preparation of this small-scale, high resolution seamless landcover mapping product, the fRI GBP, using these base map layers and GPS radio-tracking data from collared bears within each BMA, developed regionally specific, 10-class RSF maps (habitat and mortality risk) for each of the seven provincial BMA's (Figure 5.5 and 5.6). These RSF maps showed seasonal habitat use as well as an annual RSF values at a 30-m pixel resolution, within each BMA based on current landscape conditions.

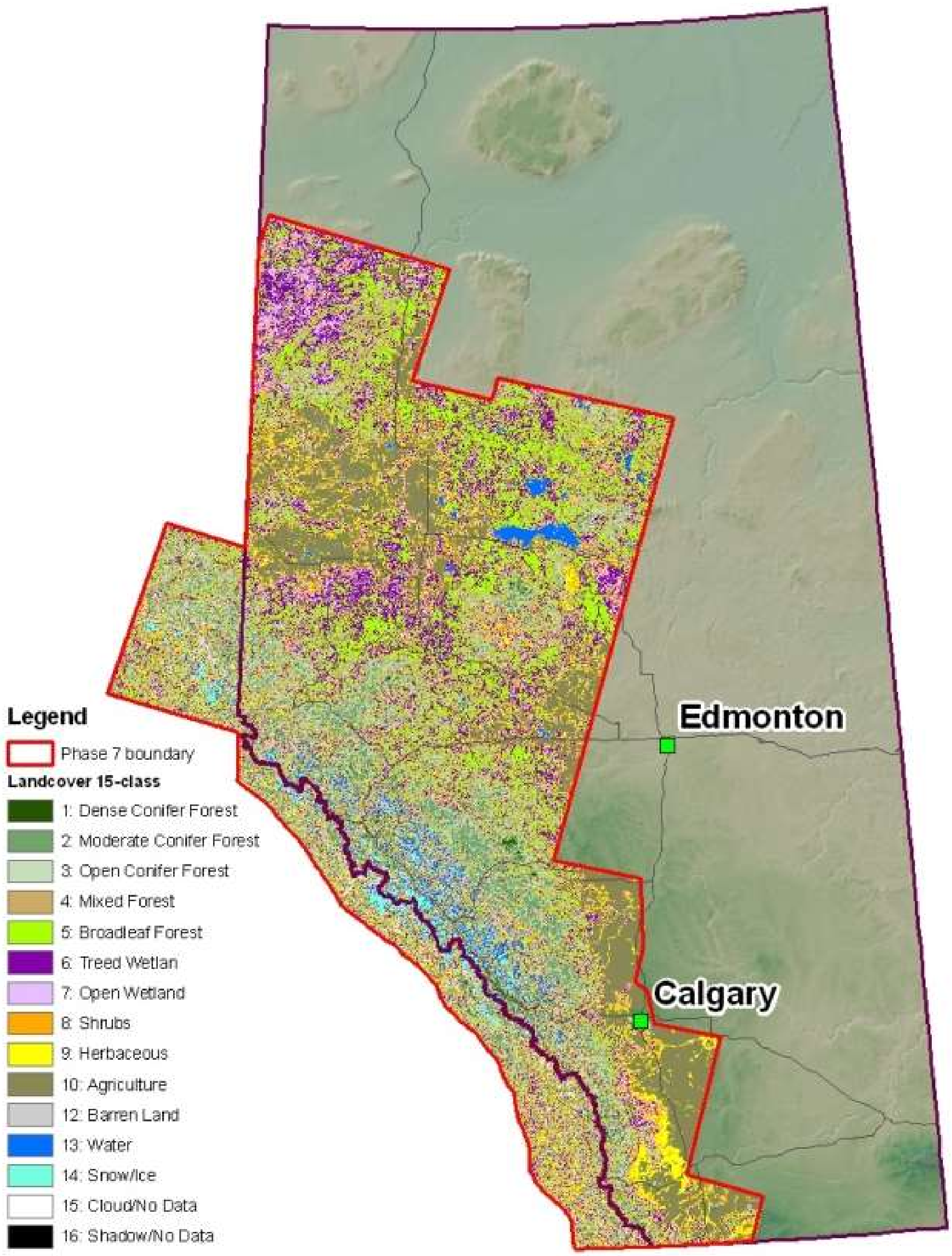


Figure 5.5. Landcover base map of grizzly bear range in Alberta (fRI GBP, unpublished data).

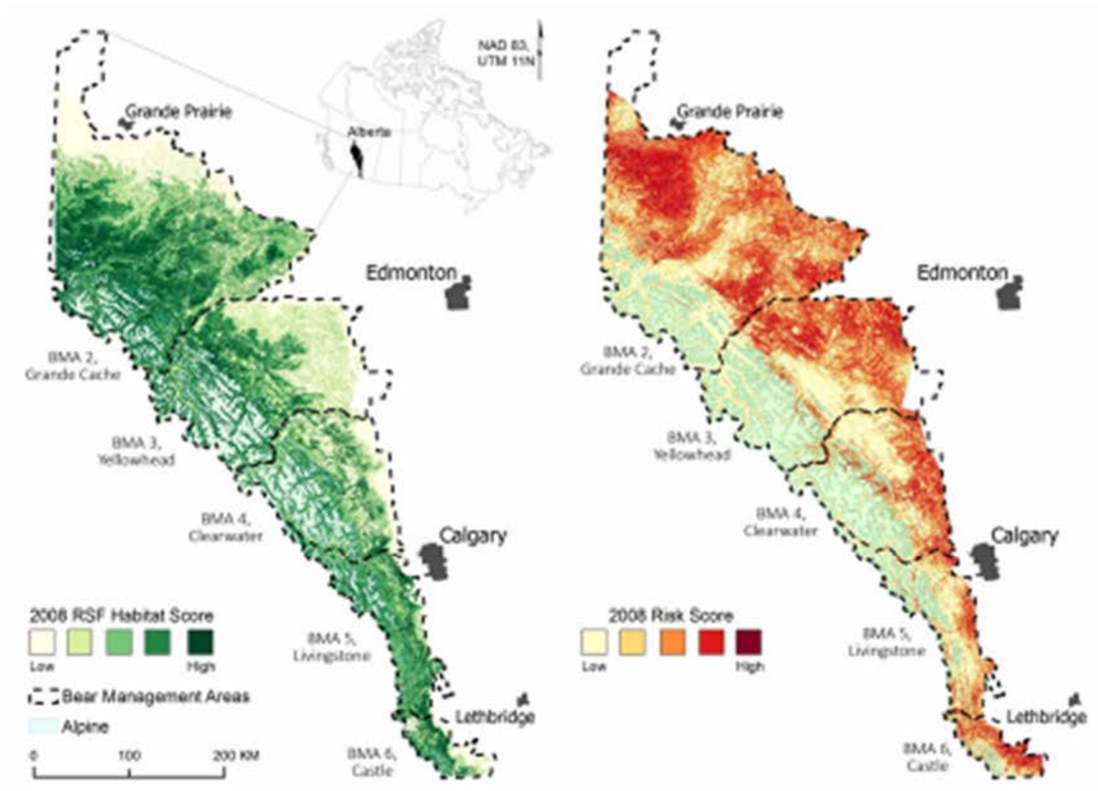


Figure 5.6. Grizzly bear RSF habitat and mortality-risk scores for BMAs in Alberta (fRI GBP, unpublished data).

Following the completion of these mapping and modeling products there was recognition that land-use practices within grizzly bear range in Alberta were resulting in ongoing landscape change and modification, primarily related to natural-resource extraction. Hence, the base landcover maps could not be treated as a “static map product” but needed to be regularly updated to better reflect changing conditions.

The remote-sensing group within the fRI GBP then began to investigate how the landcover base map products could be updated to better coincide with current landscape conditions that grizzly bears were experiencing (Pape and Franklin 2008; Linke et al. 2013, 2014; White et al. 2011; White et al. 2014). This research provided new tools and approaches to produce both annual as well as 16-day (Hilker et al. 2011) landcover layers which were used to regenerate RSF-model outputs for “current” conditions (Fig. 5.7).

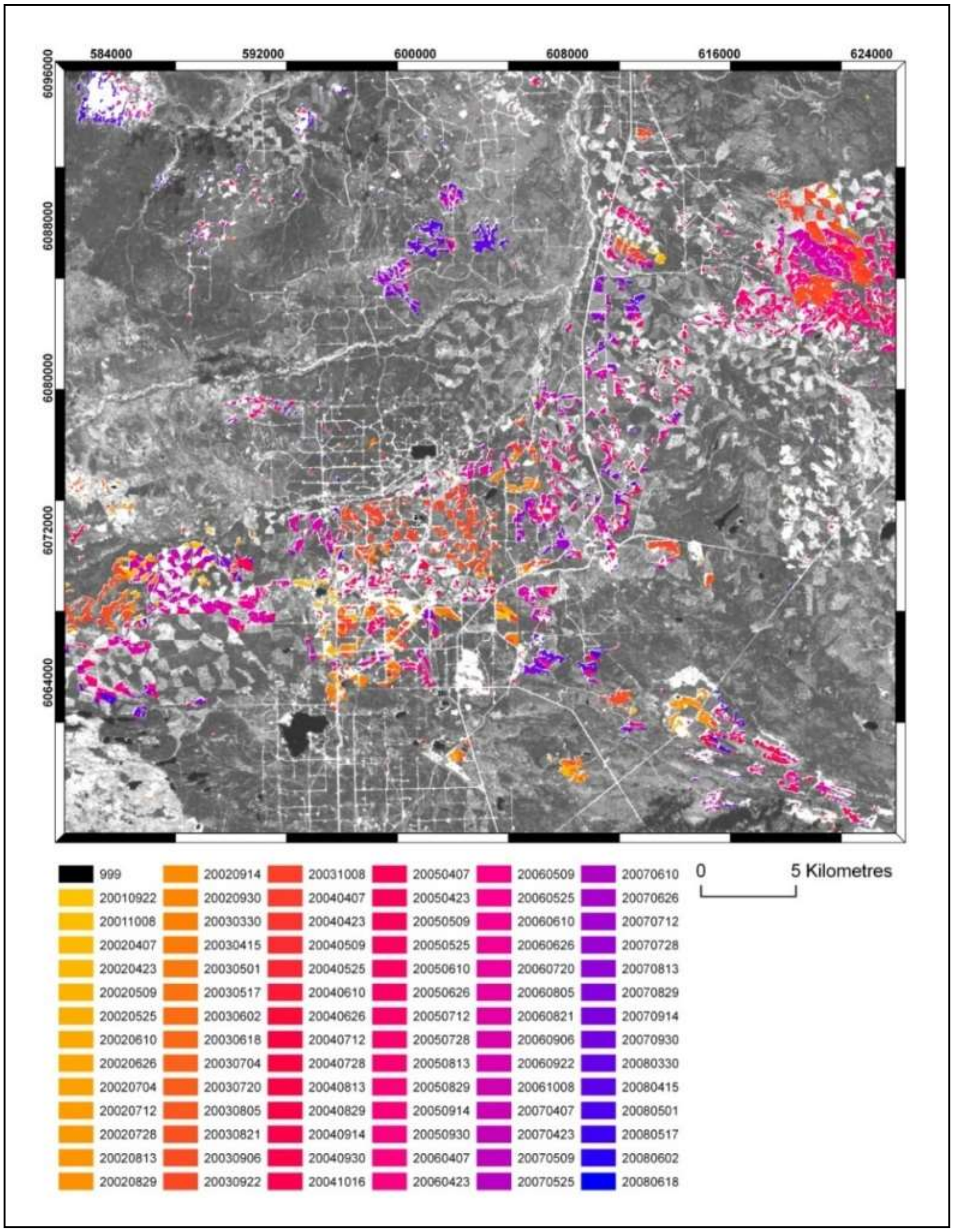


Figure 5.7. Example of 16-day landscape change determination for updating grizzly bear landcover types in Alberta based on satellite imagery (fRI GBP, unpublished data).

In addition, the fRI remote-sensing team investigated and developed a series of new approaches to improve and enhance data on ground-cover vegetation with relevance to grizzly bears (Franklin et al. 2002b, Gaulton et al. 2011, McClelland et al. 2020, Nijland et al. 2013, 2014, 2015, 2016), which were then integrated with the broad landcover classes to further enhance and improve the RSF models that had been used to identify grizzly bear habitat values in Alberta.

Mapping Grizzly Bears in Canada

By the early 2010s, while fRI's work on habitat mapping work was underway, new research by Boulanger and Stenhouse (2014) showed clear relationships between open-road densities and grizzly bear survival. These results were subsequently integrated into grizzly bear habitat mapping efforts to include road features into mapping products and thus allow for evaluation of road density conditions within watershed units inside each BMA for management attention (Fig. 5.8).

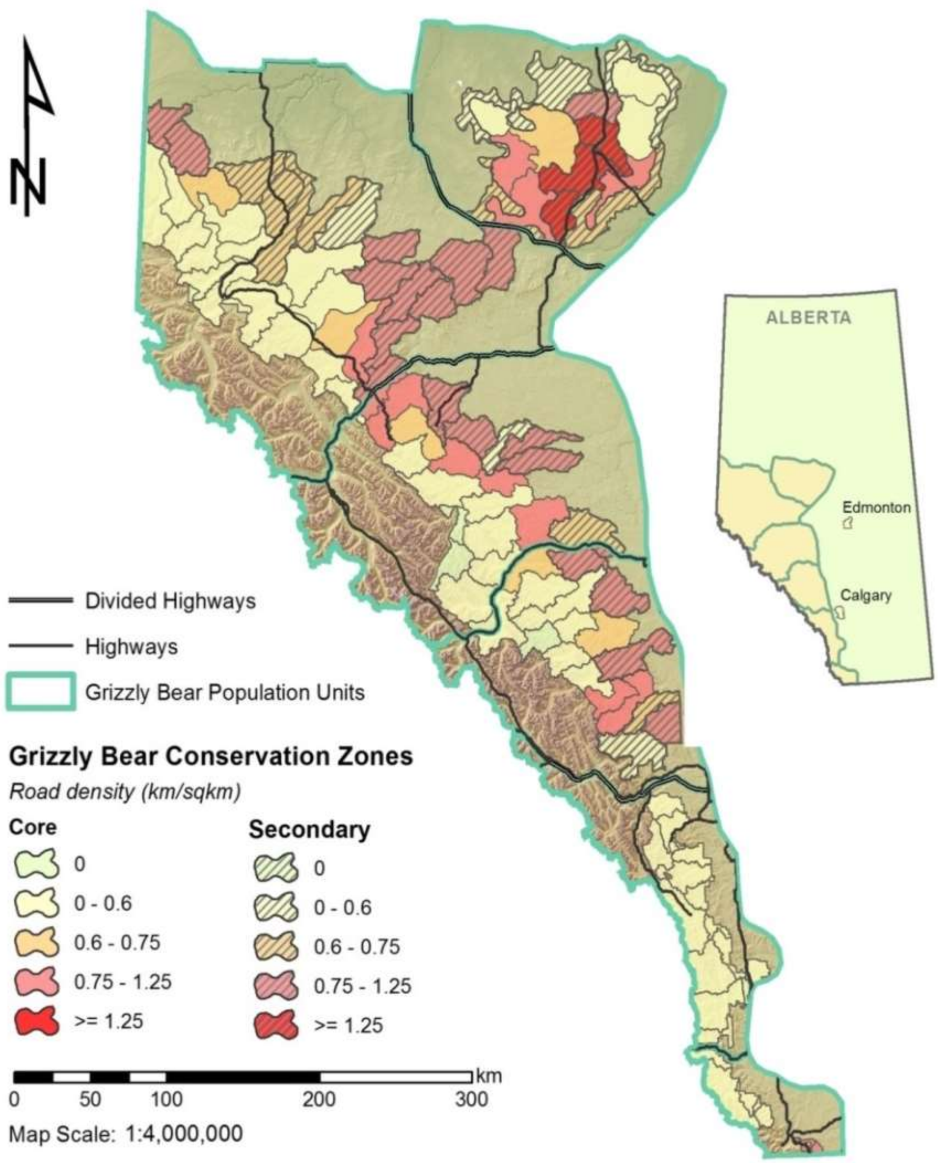


Figure 5.8. Open road densities within Alberta BMA's showing core and secondary conservation areas for grizzly bears (Boulanger and Stenhouse 2014).

Mapping Grizzly Bears in Canada

More recently, grizzly bear habitat mapping efforts have expanded and become more focused on modelling and mapping grizzly bear foods and their nutritional value within provincial BMAs (Nielsen et al. 2010, 2017, Coogan et al. 2012, 2014). This effort requires an understanding of grizzly bear feeding ecology and plant phenology to produce nutritional-landscape models which represents a more detailed habitat mapping product for land use planning and to allow the forecasting of future habitat supply for grizzly bears. This new “food model” work has provided finer-scale detail to the understanding of grizzly bear habitat beyond broad land cover mapping.

While the preparation of the first Alberta Grizzly Bear Management Plan was underway (2004–2006), population inventory work began which followed the completion of the remote sensing landcover mapping and the RSF surfaces for each BMA, and the five step-approach described in *Section 5.2.3*. During a 5 year period from 2004–2008 the fRI GBP conducted grizzly bear population inventory projects in five provincial BMAs (BMA 3, 4, 5, 6 and 2, respectively; Fig. 5.9). These DNA based inventories (e.g., Boulanger et al. 2018) provided population and density estimates for each BMA along with the spatial distribution of bears within the sampling grids (Fig. 5.10).

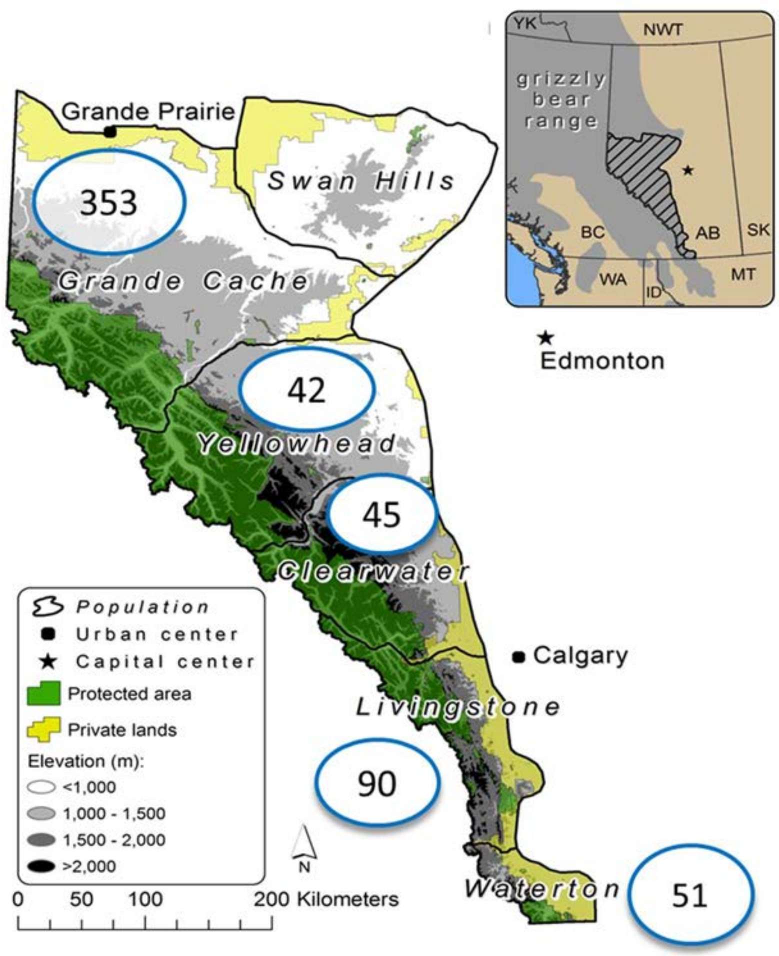


Figure 5.9. DNA based population point estimates for Alberta BMA’s (2004-2008). fRI GPB, unpublished data.

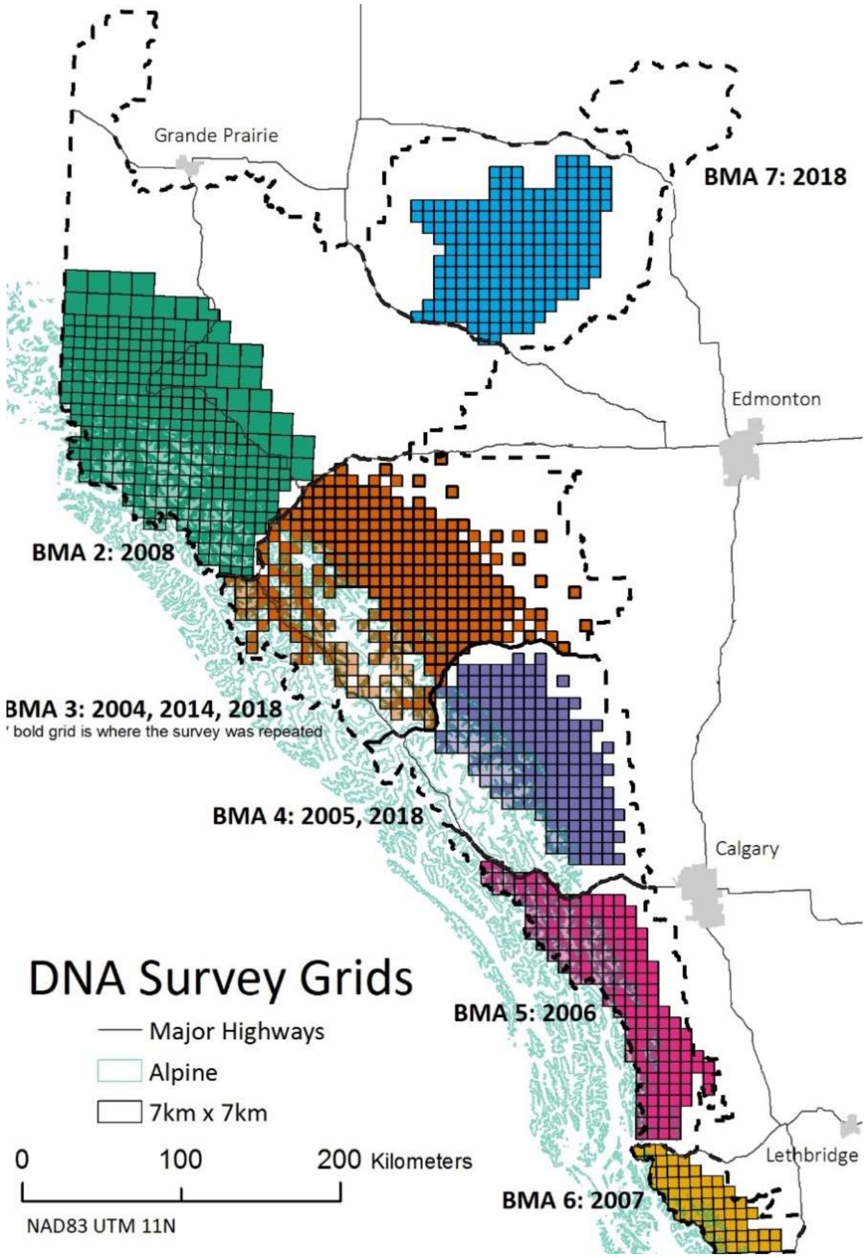


Figure 5.10. DNA survey grids used for Alberta provincial population inventories of grizzly bears (Boulanger et al. 2018).

Using the SECR-approach and common techniques, Alberta has now undertaken a comprehensive inventory of grizzly bear distribution and abundance in all BMAs in the province. In addition, there has now been repeat inventories undertaken in two BMAs (BMA 3 and BMA 4) using the same study design. The ability to repeat a SECR approach in these units indicated that the grizzly bears of the BMAs were increasing in population size, in fact doubling in a 10 and 13 year-time period, respectively (Stenhouse et al. 2015, 2020).

Alberta's modern use of the SECR method of determining the abundance and distribution of grizzly bears is now commonly seen as the "gold standard" for determining grizzly bear numbers over large areas (Boulanger et al. 2018). These data sets form the basis for the province's current understanding of the abundance and distribution of grizzly bears and their habitats in Alberta.

5.3 Discussion and Management Implications

The approach developed over more than two decades in Alberta to document and understand the abundance and distribution of grizzly bears and their habitat has led to a number of important management actions related to land management in provincial grizzly bear range. The data from RSF mapping, DNA-population inventory results, and research findings on mortality risk related to open roads were combined to identify core and secondary conservation areas in each of the provincial BMAs (Fig. 5.11; Nielsen et al. 2009). With the identification of core habitats (areas with high RSF scores, higher number of bears, and lower morality risk associated with low road densities) land management efforts focused on ensuring the maintenance of high RSF scores over time and established open road density thresholds (0.6 km/km^2) within these areas. In secondary conservation areas open road density thresholds were established at 0.75 km/km^2 (Fig 5.11).

The fRI GBP also developed a suite of GIS applications (GB Tools) that are provided to government and industry partners. These tools can be used to evaluate and assess changing landscapes associated with land use activities within provincial grizzly bear habitat. This assessment can determine level of change to both RSF habitat scores along with assessments of human caused mortality risk. In this manner, when combined with regularly updated landscape data (or planned change) land and resource managers can understand how grizzly bear habitat supply will be affected. Current BMA and Recovery Zones for BMAs in Alberta in use in 2021 have been largely established as a result of these mapping and modelling efforts (Fig. 5.12).

The approach presented here has evolved primarily within the course of a long-term research program in Alberta. The achievements, which are arguably among the best available for mapping distribution and abundance of grizzly bears in Canada, were the result of almost 25-years of work by an integrated team of scientists working towards a common goal of grizzly bear conservation as part of the fRI GBP. The work undertaken in Alberta has provided important remote-sensing based grizzly bear habitat map products, allowed the development of models to identify important grizzly bear habitat, provided science-based data on the distribution and abundance of grizzly bears, and allowed managers to understand how landscape change will impact grizzly bear supply over time.

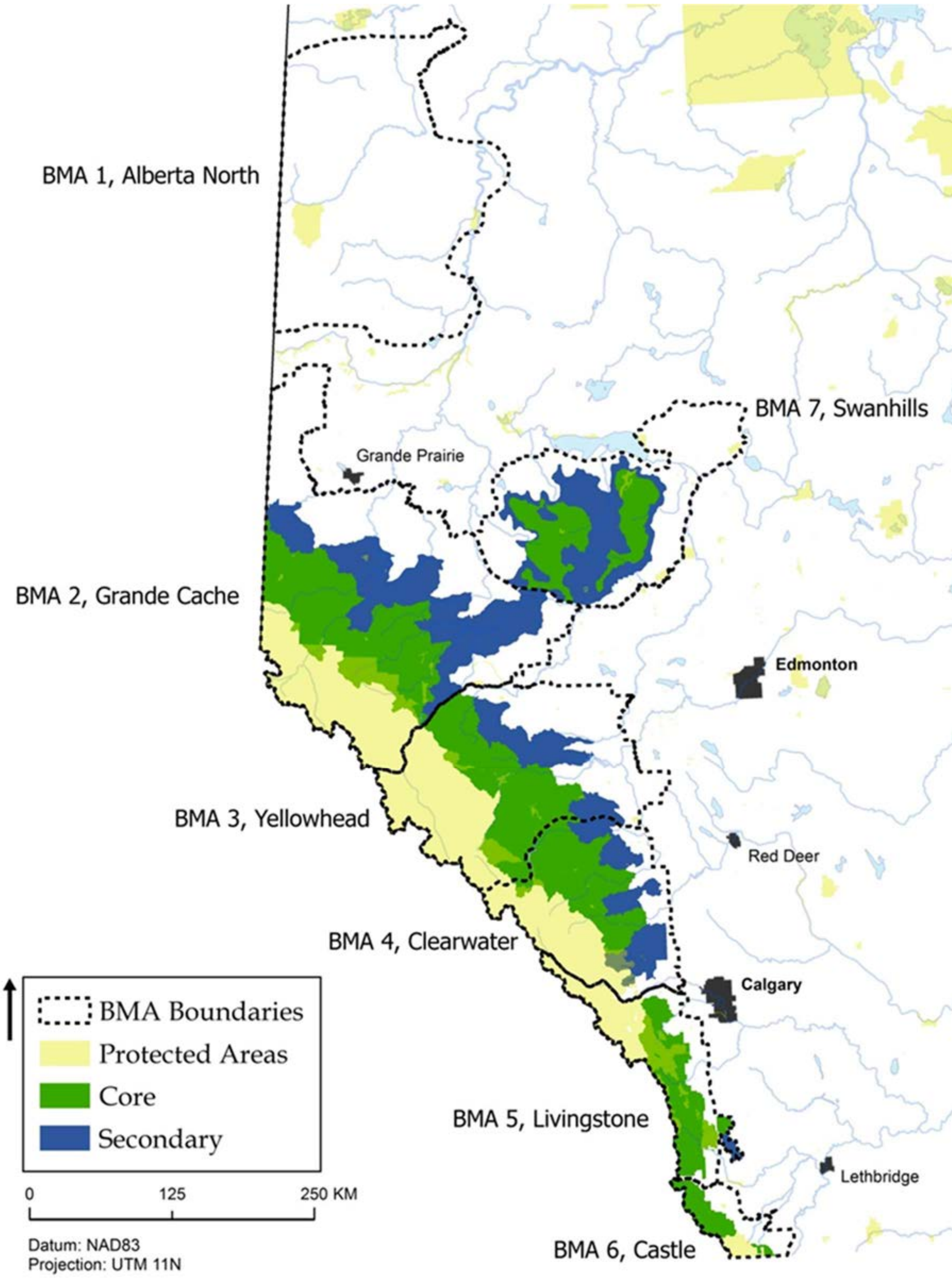


Figure 5.11. Core and secondary conservation areas within Alberta BMA's.

Figure 5.12. Grizzly Bear Management Areas (BMAs) and management zones. Protected areas include both federal National Parks and provincial protected areas (from 2020 Alberta Grizzly Bear Recovery Plan draft).

Mapping Grizzly Bears in Canada

Overall, the mapping of grizzly bears and their habitats in Alberta have been driven by the need to gain a better understanding of the needs of provincial grizzly bear populations in a landscape dominated by human use and anthropogenic landscape change. This work also gained momentum as the provincial status designation for the species was changed to "Threatened" in 2010 and recovery efforts proceeded. These science-based population estimates have shown their importance in understanding grizzly bear population trends over time and have been tested over periods of longer time periods (10–13 years) in two BMAs. And, having established relationships between bio-physical land characteristics and population distribution and abundance allows for population forecasting over time with changing landscape conditions. However, the Alberta approach has required large capital investment and an experienced technical team to gather the needed, and validated, data sets for the development of the maps and models used to understand grizzly bear habitats in Alberta. But, now that these products have been established, and ecological relationships between habitats and populations established, it is becoming easier to provide the public and managers with regular updates to guide management and land use planning within the framework of a provincial grizzly bear monitoring program.

6.0 MAPPING GRIZZLY BEARS IN THE YUKON

6.1 Background

Grizzly bears continue to be found throughout their historic range in the Yukon, which includes all ecoregions (O'Donoghue and Staniforth 2004). The species occurs in a diversity of habitats, from the Pacific Maritime ecozone near Mount Logan through the Boreal and Taiga Cordillera and Taiga Plains, and north to the Yukon Coastal Plain of the Southern Arctic Ecozone. Grizzly bears are classified as a big game species under the Yukon *Wildlife Act*, and managed accordingly with respect to legal and regulatory requirements for big game species in the territory (Yukon Government 2019).

Reported estimated total population size for the species has varied for the territory, ranging from 5,700 bears (Lortie 1978) to 14,000 animals (Pearson 1977). Estimating and mapping the abundance of grizzly bears in the Yukon has been a challenge because of: 1) the relatively few studies of the species in the region; and 2) the diversity of ecoregions within the territory, many of which are unique to the Yukon and incomparable with other jurisdictions where grizzly bears have been studied. Hence, extrapolations of local grizzly bear densities to the extent of the territory have relied on limited datasets and largely expert opinion.

While the current mandate for grizzly bear management in the Yukon is wide in scope (Yukon Government 2019), management and mapping for the species was initially driven by the need for successful and sustainable harvesting. Indeed, the earliest mapping efforts surrounding grizzly bears were focused on identifying population densities from which hunting quotas could be allocated (reviews in Pearson 1975, 1977; Sidorowicz and Gilbert 1981; Smith and Osmond-Jones 1990). Today's current abundance range estimates are (6,000–7,000 bears; Yukon Government 2019) which is derived from, and remains largely unchanged from, the findings of Smith and Osmond-Jones (1990), whom estimated an abundance of 6,600 bears.

6.2 Current Approach

Smith and Osmond-Jones's (1990) expert-based population estimation approach involved a conceptual ranking by experienced biologists of the availability of habitat components thought to influence bear density, compared with some independent estimates of abundance, combined across ecoregion boundaries (Fig. 6.1). Current BMUs largely follow outfitter concessions, and population densities for bear are calculated by a Geographical Information System (GIS)-based overlay extraction process directly converting from ecoregion density estimates (Figs. 6.2a,b; J. Pongracz, Government of Yukon, *pers. comm.*).

Many groups including the Yukon government recognize the uncertainty surrounding the current estimate of 6,000–7,000 grizzly bears for the territory. DNA-based or spatially explicit capture-recapture (SECR) approaches of population inventories have been implemented in a few areas

Mapping Grizzly Bears in Canada

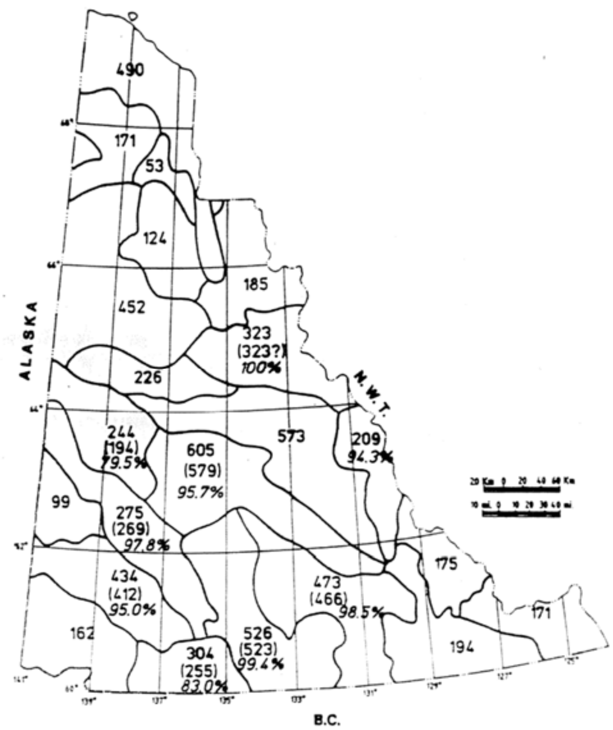


Figure 6.1. Territory-wide abundance estimates for grizzly bears in the Yukon presented in Smith and Osmond-Jones (1990). Estimates were used as a basis for establishing quotas for each area (numbers in brackets are estimates reduced because of past mortality). The expert-based approach to estimating numbers of grizzly bears in space is adapted for current use (Figs. 6.2a,b).

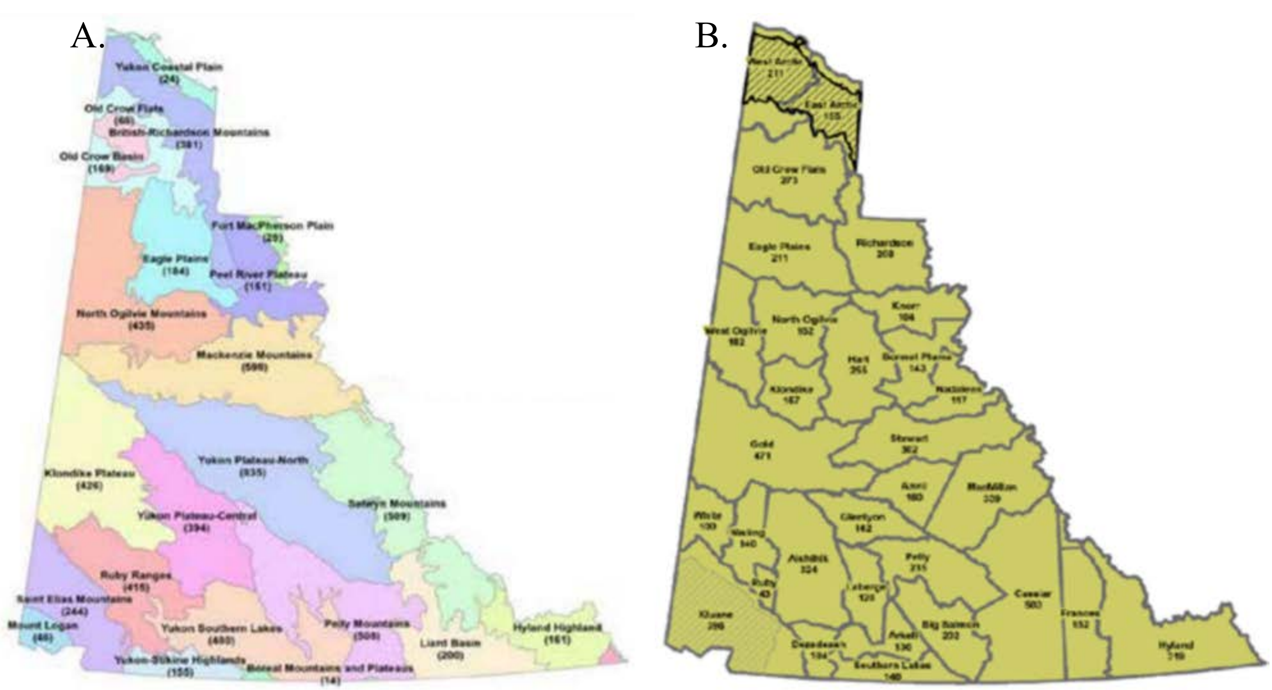


Figure 6.2. (A.) Population size estimates for grizzly bears are currently identified for each of the coloured ecoregions of the Yukon based on expert opinion and following methods of Smith and Osmond-Jones (1990). (B.) Population estimates for management purposes are “clipped” from ecoregion estimates to roughly follow outfitter concession boundaries. Maps reproduced from YGBWG (2019).

(e.g., in the Yukon's North Slope, 2006–2007 [YGBWG 2019]; and Southern Lakes Region, [Yukon Fish and Wildlife Branch 2017]). Traditional ecological knowledge research is also being used to help assess grizzly bear population trend data (e.g., for the Inuvialuit Settlement Region, GRRB [2002]/Gwich'in Social and Culture Institute Study [2014]; summaries in YGBWG 2019). Maps of grizzly bear densities and trends at the extent of the territory, further to what might be deduced from Figs. 6.2a,b and densities of reported mortalities, are not available.

6.3 Discussion and Management Implications

The Yukon Government (2019) has embraced a mandate to adopt an adaptive management plan for grizzly bears in the territory, respective of co-management agreements and following precautionary principles. At this time, and with available data, there is no wide-spread evidence that the estimators used to set harvest rates (and map grizzly bear densities) are leading to population decline in the Yukon (e.g., public surveys in Jung et al. 2018; data in YGBWG 2019). Along the Yukon North Slope, empirical and qualitative estimates of grizzly bear population sizes and trend from the 1970s through to 2007 have indicated consistency in the number of bears occupying the coast and the Inuvialuit Settlement Region (data from DNA capture-recapture; telemetry; and traditional knowledge [YGBWG 2019]). Although the GRRB/Gwich'in Social and Culture Institute Study (2014) noted fewer bears in their region since the 1940s through early 2000s, community members indicate population stability or increase as at 2012 (YGBWG 2019). However, using a SECR approach, Yukon Fish and Wildlife Branch (2017) produced estimates (various models) of density for the Southern Lakes study area at around 10 bears/1000 km^2, compared to earlier density estimates applicable to the area which ranged from 15.4–22.2 bears/1000 km^2 for the two ecoregions spanning the Southern Lakes study area (Smith and Osmond-Jones 1990: 11–15). Population decline may be likely for areas with increasing human density like the Southern Lakes region, but at this time the determination and mapping of population trend is not possible as current and past methods are not directly comparable.

The Yukon Government (2019) states in its conservation plan for grizzly bears a commitment to updating grizzly bear population status information at management unit levels; re-evaluating the appropriate scale of management units; and developing and implementing a monitoring plan for grizzly bears using innovation and traditional knowledge for the purpose. Meeting these goals is expected to lead to the production of updated maps of grizzly bear abundance and trend in the future (Table 6.1).

Table 6.1. Prioritized timelines (orange, ranked 1-3) for acquiring better knowledge about grizzly bears in the Yukon following the Government of Yukon's (2019) conservation plan for the species. All sub-goals are likely to result in revisions to current maps used to illustrated grizzly bear abundance, trend, and status information in the territory.

Goal 3: Improve future decision-making by acquiring better knowledge about grizzly bears			
3.1	Improve use of traditional knowledge and local knowledge when making conservation decisions related to grizzly bears	1	• Increased availability of traditional and local knowledge for future management discussions • Use and interpretation of traditional knowledge is done in respectful and appropriate manner
3.2	Update grizzly bear population status information at management unit levels	1	• Population status information for grizzly bears updated and improved
3.3	Evaluate the appropriate scale of management units for grizzly bears	1	• Yukon grizzly bear management units reviewed and updated, as appropriate
3.4	Develop and implement a monitoring plan for grizzly bears	2	• Yukon grizzly bear monitoring plan established, including considerations of methods and priorities • Biological sample collection from hunted or killed grizzly bears expanded
3.5	Innovate and look for new ways to monitor grizzly bears	3	• New and innovative ways of monitoring grizzly bears explored, developed, and evaluated

7.0 MAPPING GRIZZLY BEARS IN THE NWT

7.1 Background

Grizzly bear range in the Northwest Territories (NWT) includes most of the mainland except the Taiga Plains south of Great Bear lake and east of the Mackenzie Mountains, and excluding the Taiga Shield to the southeast of Great Slave Lake. The grizzly bear occupies almost all its historic range and is expanding its distribution into the southern islands of the Canadian Arctic Archipelago (Fig. 7.1; review of traditional and scientific knowledge in SARC 2017). The best available information suggests that there is no evidence of decline and the population is at the very least stable, with local population increases likely occurring in the Mackenzie Mountains, parts of the mainland Inuvialuit Settlement Region, and most certainly in the Arctic Archipelago (although densities remain very low). The one exception of local extirpation for the territory appears to come from areas of the southern Dehcho, immediately north of the Alberta border. For example, traditional knowledge held grizzly bears in the Cameron Hills region to as recently as the 1990s (SARC 2017).

Using study-specific density estimates and assigning them more broadly at the ecoregion level provides an estimated population of between 4,000–5,000 grizzly bears in the NWT (SARC 2017). The species was assessed as Special Concern by the NWT Species at Risk Committee in 2017. Following consideration of this assessment, the NWT Conference of Management In 2018 authorities arrived at consensus not to add the species to the NWT List of Species at Risk. (NWT Conference of Management Authorities 2018).

7.2 Current Approach

The presence and of grizzly bears and relative densities at localities are well documented throughout the NWT from traditional knowledge studies, some of which overlap with Yukon (e.g., GRRB 2002; RWED 2003; ICC et al. 2006; Gwich'in Social and Culture Institute Study 2014), and several scientific research projects (>10) conducted from the 1970s through to the present. Methods of the latter have ranged from telemetry-based estimates prior to the 2000s, after which DNA non-systematic, mark-recapture, and spatially explicit capture-recapture methods have been used (review in SARC 2017); however, no-density stratified maps have been created specific to the NWT.

7.3 Discussion and Management Implications

Accurately mapping the distribution and abundance of grizzly bears in the NWT is an important priority for the Government of the NWT and communities of the region. The mapping of grizzly bears is also of wider significance, however, because of the clear expansion of range for the

Figure 7.1. Grizzly bear distribution as mapped across the NWT. Hatched lines represent areas of increased presence. Map by B. Fournier, Government of the NWT, as published in SARC (2017).

species in the NWT and what this may mean for the continental population, including status assessments. The reasons for the population expansion are believed to be linked to climate change, for which a generalist species like the grizzly bear is likely benefiting (SARC 2017). The combination of traditional ecological knowledge and increasing use of genetic sampling and the application of SECR methods to estimate occupancy or density and trend by communities and the NWT government will prove useful for understanding the process of range expansion under climate change in the subarctic. As results of these studies accumulate, decreasing grain size will be afforded to map grizzly bear densities at resolutions below that of the area of occupancy for historic and expansion ranges (Fig. 7.1). Sufficient data to construct such a map is likely already available, at least to stratify densities for the grizzly bears according to ecoregion and/or map grizzly bear habitat suitability across the territory.

8.0 MAPPING GRIZZLY BEARS IN NUNAVUT

8.1 Background

The contemporary occupancy of grizzly bears though mainland Nunavut (Fig. 7.1, previous page) is known from traditional ecological knowledge and from observations of western science and harvest records (McLoughlin 2001; McLoughlin et al. 2003a,b; Clark 2007; Doupé et al. 2007; Nirlungayuk 2011; Dumond et al. 2015, SARC 2017; Awan et al. 2019; Awan 2021). The current abundance and distribution of grizzly bears has certainly increased from historic levels. Awan (2021) points out that for many years hunters of the Kitikmeot (western mainland Nunavut) had been reporting an increase in bear sightings and occurrences of bears in places they had not been seen before, or very rarely (e.g., on Victoria Island); while similar observations were noted from the Kivalliq region (eastern mainland Nunavut) from community members of Arviat, Baker Lake, and Rankin Inlet.

Currently, Inuit are able to harvest grizzly bears for subsistence and in defense of life and property with no restrictions (Awan 2021). Community organizations for both the Kitikmeot and Kivalliq have also received support from the Nunavut Wildlife Management Board (NWMB) for quotas to allow for non-resident sport hunting (15 and 10 tags for the Kitikmeot and Kivalliq, respectively). While the Kitikmeot has a long history of sustainable sport harvesting and is known for having a comparably high density of grizzly bears that can support current levels of total human-caused mortality (Dumond et al. 2015), it is important to note that the killing of bears in eastern Nunavut is not necessarily directed at sustainable harvesting. Today, the increased presence of bears was and is an issue of safety concern for most communities of mainland Nunavut (Dumond et al. 2015; Awan et al. 2019; Awan 2021).

The increased number of grizzly bears observed in northeast Manitoba near Hudson Bay (Clark et al. 2019) is also indicative of recent eastward expansion of the species in the subarctic, despite increasing harvest pressure. While long-term (2005–2019) reported harvest trends in the Kitikmeot has averaged around 13 bears/year, in the Kivalliq, 20 bears have been killed annually from 2010–2019, up from only 6 bears/year from 2000–2008 (Awan 2021). Current distribution of kill (from all sources) is linked to proximity to communities (Fig. 8.1), is male-biased (more so in the Kitikmeot, where it is 89% male vs. 82% in the Kivalliq), and reflects an older population in the Kitikmeot vs. Kivalliq (Awan 2021). The age-sex structure of mortalities in Kivalliq is consistent with what might be expected of a population experiencing immigration, dispersal and/or population growth (66% of the kill is aged 0–5 years). Barren-ground grizzly bears in the central Canadian Arctic have later ages of maturation than elsewhere, occur at very low density, and thus have relatively low population growth (McLoughlin et al. 2003a). Lifespan, which is reflective of the trade-off between growth, reproduction and survival, can be very long in the area with age at first reproduction averaging >8 years (Ferguson and McLoughlin 2000; McLoughlin et al. 2003a). It is notable that a 32-year-old female was recently

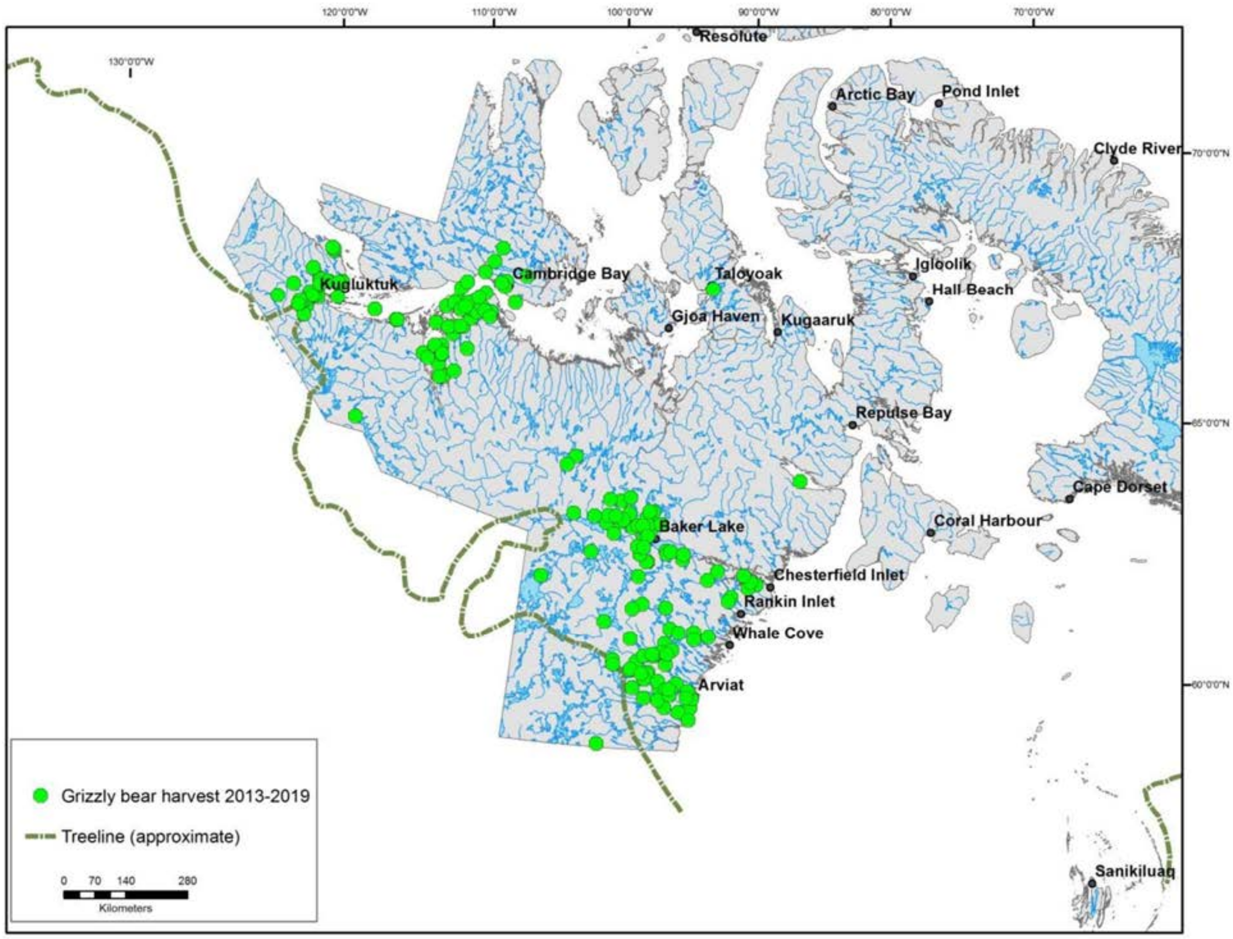


Figure 8.1. Distribution of reported grizzly bear harvest locations in Nunavut from 2013–2019 (from Awan 2021).

harvested in the area of Arviat (in 2013). The relatively low density of barren-ground grizzly bears, late age at first reproduction, and slow intrinsic rates of population growth suggest the population is not likely to support high subsistence and sport hunting at the same time (Awan 2021).

8.2 Current Approach

Although territory-wide surveys have not been conducted to support mapping efforts, in 2008–2009 Dumond et al. (2015) estimated a consensus density of 5.0 bears/1,000 km^2 in the vicinity of Kugluktuk and the Bluenose East caribou herd calving grounds comparing both aspatial and SECR-based approaches from DNA-hair post sampling. In comparison, McLoughlin and Messier (2001) estimated a density of 3.5 bears/1,000 km^2 at the North Slave/Kitikmeot boundary. McLoughlin et al. (2003a) projected an increasing population in the area based on a demographic model of reproduction and survival ($\lambda = 1.033$), which would have yielded a roughly 5 bear/1000 km^2 density by the time of Dumond et al.'s (2015) study (as noted by these authors).

A very similar density to that of McLoughlin and Messier (2001) was estimated by Awan et al. (2019) using DNA-hair posts in 2016 and 2017 (four 60-km × 60-km grids for the Kivalliq (3.5 bears per 1000 km^2 (95% CI: 2.1–6.1 bears/1000 km^2), while locally some regions like the area around the Henik, Oftedal, and Roseblade Lakes were reported to be as high as 9.6 bears/1000 km^2 (95% CI: 4.4–20.9). However, as noted in Ch. 2 care must be taken with interpreting local study area densities and not extrapolating outside the grain of inference without supporting data (especially with few benchmark data).

8.3 Discussion and Management Implications

The current focus in Nunavut regarding grizzly bears is quite different from that of southern Canada, the latter being directed at curbing human-caused mortality, maintaining habitat supply over time, and planning for population increase or recovery (Ch. 4 and 5). Maps of bear mortalities in Nunavut are available (Fig. 8.1); however, population density maps are restricted to only areas of recent research on abundance. Maps depicting relative abundance have also been produced with community members; however, these maps are likely biased towards areas of experiences nearer communities and seasonal human use and thus not be representative at a regional level (A. Malik, *pers. comm.*). Excluding zones within 50 km of settlements, and adopting a density of 3.5 bears/1000 km^2, Awan et al. (2019) estimated for the 209,000 km^2 region a total population size of 662 bears was estimated for the Kivalliq, cautioning that this estimate is still an extrapolation from what cannot be construed as representative (regional) grizzly bear habitat. For places like Nunavut, where data are available on local densities but the region is large, and some GPS-based habitat selection data are available (e.g., McLoughlin et al. 2002), bottom-up mapping of grizzly bear habitat suitability might be the most cost-effective option for modelling expansion and of the population over time.

Whether the Kitikmeot and NWT are source populations to what might now be an active sink population in the Kivalliq is not known, but the latter is possible given the relatively heavy harvest in recent years in the Kivalliq. The direction of population growth in the Kivalliq (relative to the early 2000s) may no longer be positive, or at least self-sufficient without immigration. Modelling by McLoughlin et al. (2003b) suggests that for a population of barren-ground grizzly bears existing at 3.5 bears/1000 km^2, assuming an age-sex ratio as is found in the Kitikmeot, that a harvest rate of 20 bears/year for a ~200,000 km area would almost certainly decline over time.

The Kivalliq may thus present an opportunity to map not only the process of range expansion but also potential regional source-sink dynamics for grizzly bears. The prediction of Lamb et al. (2020) is that while human-dominated landscapes are highly lethal, especially to young bears, those that survive through early ages can learn to adapt to people as they mature. Lamb et al. (2020) presents a spatial model for which predictions can be examined using data from the Kivalliq (see Fig. 4.7); however, spatial data on where harvested animals have been born will be needed (i.e., direction of immigration and distinguishing between apparent and natural survival). Further, the extent to which directional climate change has been improving habitat for bears in Nunavut will need to be understood. This may be where focus for mapping the ecology of grizzly bears in Nunavut is now needed, e.g., to distinguish survival rates from apparent (immigration-boosted) survival rates and the extent to which breeding has been or is now localized in the Kivalliq potentiating self-sufficient population growth. Maps of genetic interchange—e.g., gene-flow and migrants per generation; genetic parentage assignments in conjunction with demographic simulations to infer the level of immigration into a putative sink population (e.g., Peery et al. 2008; Draheim et al. 2016)—may prove useful in the context of understanding both the process of dispersal, coexistence, and expansion of grizzly bear range.

The ecology of range expansion in the face of human-caused mortality is not well known for grizzly bears, for which the ecology of range retraction has far and wide been the paradigm (Lamb et al. 2020). But bears are plastic in behaviour, and times are changing for the grizzly bear in more than just the subarctic. The process playing out in the Kivalliq may be analogous to and informative for understanding and mapping similar processes now underway in the northwest conterminous US, where grizzly bears appear to be expanding in response to recovery efforts (Bjornlie et al. 2014; see Ch. 9.0).

9.0 MAPPING GRIZZLY BEARS IN MANITOBA AND SASKATCHEWAN

9.1 Review and Discussion

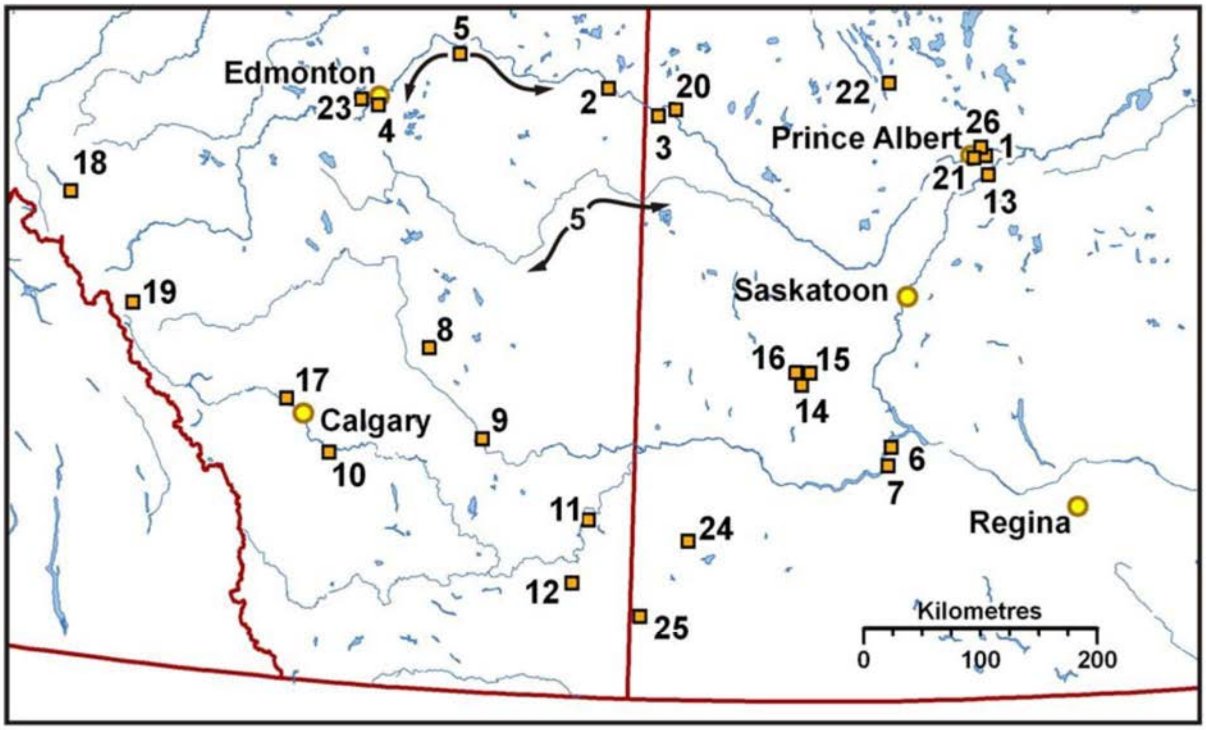
Both Manitoba and Saskatchewan supported historic populations of grizzly bears in the grassland, parkland, and boreal transition ecoregions of the provinces; with bears also known from parts of the boreal plains (Fig. 9.1; Nielsen 1975; Environment Canada 2009). The last of the species of the southern parts of these provinces, also known as the Plains grizzly bear, persisted until the mid-20th century in the Pasquia and Porcupine Hills of Saskatchewan and Duck Mountains of Manitoba (White 1965; Sutton 1967; Stonehouse 1967). Grizzly bears were largely extirpated by 1900, however.

Today, grizzly bears are currently observed in the far north, where they are rare. In Manitoba, barren-ground grizzly bears along the tundra near Hudson Bay are known from recent observations and photographs (e.g., Clark et al. 2019); while a male was recently released after capture (and equipped with a GPS collar) south of Churchill, in 2018 (V. Trim, Manitoba Sustainable Development, *pers. comm.*). Grizzly bear sightings have become more numerous in recent years in the area, likely in association with increasing abundance of bears in eastern Nunavut (Ch. 8). However, Manitoba continues to list the species as extirpated for status under the Manitoba *Endangered Species and Ecosystems Act* (no official rank), at least until a female with cubs is documented within the province, which to date has not been the case (V. Trim, *pers. comm*.). Due to limited number of sightings/occurrences in Manitoba and Saskatchewan no work has been undertaken to map grizzly bear habitats or distribution to date.

In Saskatchewan, plausible observations of grizzly bears or their sign are known from the far north (M. Tokaruk, Saskatchewan Ministry of Environment, pers. comm.), noting that DNA-hair snagged grizzly bear samples in Nunavut occur within 150 km of the provincial border (Awan et al. 2019). The species remains listed in the province's Wild Species at Risk Regulations under the Saskatchewan *Wildlife Act* as 'Extirpated'.

Maps of the densities of grizzly bears for northern Manitoba are not available at this time, only noted occupancy (e.g., Fig. 1.2). However, grizzly bear habitat suitability maps have been developed for the Prairie Ecozone of the provinces of Alberta and Saskatchewan as part of Environment Canada's (2009) *Recovery Strategy for the Prairie Grizzly Bear in Canada* (Fig. 9.2). When the latter was published, it was concluded that: "Recovery of this species is considered not technically or biologically feasible at this time." At the time, Environment Canada (2009) noted some occurrences of grizzly bears occasionally venturing into the St. Mary's and Milk River drainages but these were not permanent movements (citing Morton and Lester 2004). Since then, however, increasing numbers of grizzly bears and eastward expansion of range in Montana, may, in due course, lead to increased occupancy of grizzly bears within

Mapping Grizzly Bears in Canada



Grizzly Bear Observations on the Western Prairies Recorded from 1820 to 1869

No.	Name	Date	Location	Details
1	John Richardson	May, 1826	Fort Carlton	Observed grizzly bear hunt
2	David Douglas	May, 1827	Fort Vermilion	Observed 1 grizzly bear
3	Paul Kane	Sep 24, 1846	Half way between Fort Edmonton and Fort Carlton	Shot a grizzly bear
4	Paul Kane	Dec, 1847	5 or 6 miles from Fort Edmonton	Observed 1 grizzly bear
5	Fredric Ulric Graham	Aug & Sep, 1847	Along the North Sask. and Battle Rivers	Made many observations of grizzlies
6	Palliser Expedition	Sep 26, 1857	South Sask. River	Observed a grizzly on the riverbank
7	Palliser Expedition	Sep 27, 1857	South Sask. River	Observed 2 grizzly bears and shot 1
8	Palliser Expedition	Jun, 1859	Sand Hills	Killed 3 grizzly bears
9	Palliser Expedition	Jul 17, 1859	Plains north of Red Deer River	Observed 5 grizzly bears
10	Palliser Expedition	Jul 21, 1859	Bow River near Drowning Ford	Observed 3 grizzly bears
11	Palliser Expedition	Jul 23, 1859	South Sask. River	Observed 7 grizzly bears in two days
12	Palliser Expedition	Jul 28, 1859	Little Plume Coulee	Observed 1 grizzly bear
13	Henry Youle Hind	Aug, 1858	Upper South Sask. River	Referred to presence of grizzly bears in area
14	Earl of Southesk	Jul, 1859	Bad Hill	Indian killed by grizzly bear
15	Earl of Southesk	Jul 20, 1859	Bad Hill	Observed sow and cub and shot boar
16	Earl of Southesk	Jul 21, 1859	Cherry Bush	Observed 1 grizzly bear
17	Earl of Southesk	Sep, 1859	Bow Fort	Observed 1 grizzly bear
18	Earl of Southesk	Sep 5, 1859	Medicine Tent River	Observed 2 grizzly bears and much sign
19	Earl of Southesk	Sep 17, 1859	Kootenay Plains	Observed much grizzly bear sign
20	Earl of Southesk	Nov 7, 1859	Vicinity of Fort Pitt	Grizzlies common in area
21	Milton and Cheadle	Sep, 1862	Vicinity of Fort Carlton	Observed 2 grizzly bears
22	Milton and Cheadle	Feb, 1863	La Belle Prairie	Indian killed by grizzly bear
23	Milton and Cheadle	May 14, 1863	Lac St. Albans	5 grizzlies attacked herd of horses
24	Issac Cowie	1868	Big Sandy Hills	Indians killed by grizzly bear
25	Issac Cowie	Winter, 1868	Cyprus Hills	Grizzlies abundant
26	Charles Messiter	1860s	Vicinity of Fort Carlton	Killed 2 grizzly bears on river bank

Figure 9.1. Recorded observations of grizzly bears in Alberta and Saskatchewan during 1820-1869 (data from Nielsen 1975; prepared and published by Environment Canada 2009).

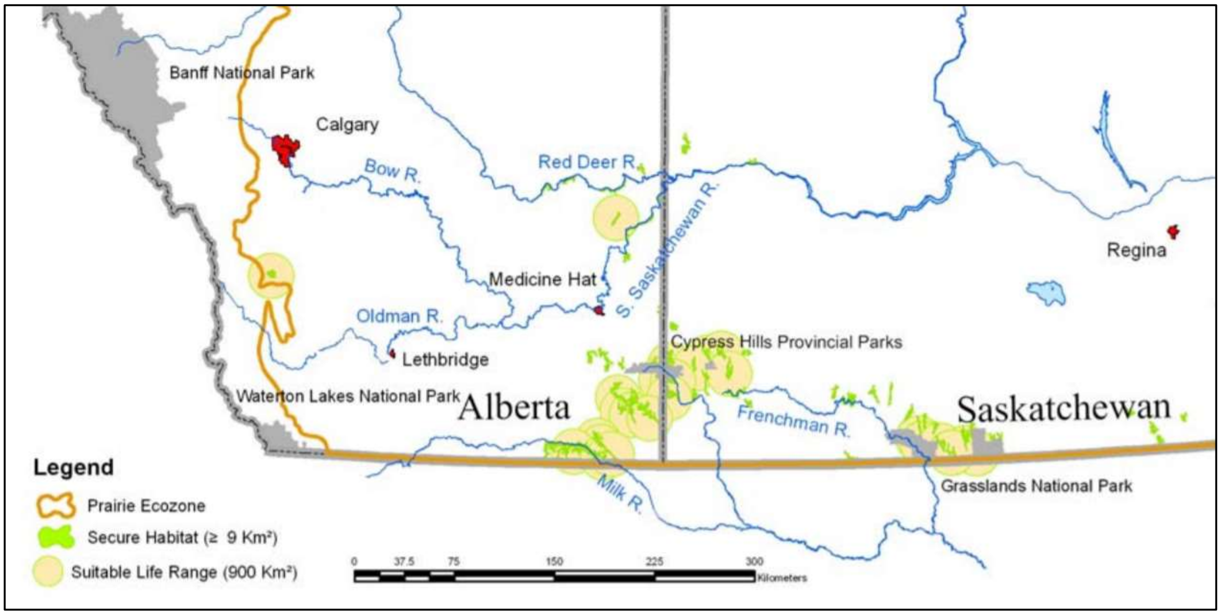


Fig. 9.2. Map of secure habitat and suitable life ranges in the Prairie Ecozone of Saskatchewan and Alberta, published by Environment Canada (2009). Twenty five overlapping life ranges were identified as potentially suitable habitat for adult female grizzly bears in the Prairie Ecozone. Suitability in the context of human-caused mortality, however, is not modelled (but see Fig. 4.7, Lamb et al. 2020).

parts of southeast Alberta and southwest Saskatchewan. Likely areas of occupancy would occur near the Milk River and the large tracts of native mixed grassland and mixed-wood and pine forests in and around the Cypress Upland ecoregion, which historically supported a high density of grizzly bears (Fig. 9.1; White 1965; Nielsen 1975; Environment Canada 2009). Appearances of male and female grizzly bears (with cubs) are increasing in prairie habitat connected to the above, e.g., in the Sweet Grass Hills of Montana and near the towns of Cutbank, Kevin, Shelby, and Sunburst. A public awareness campaign regarding the presence and eastward expansion of grizzly bears, including occurrences and conflicts with bears, is documented and discussed in the Montana Fish, Wildlife, and Parks (MFWP) "Prairie Bear Monitor" Facebook page (https://www.facebook.com/prairiegriz/).

Notably, several observations of grizzly bears from 2016 to 2020 have occurred within 20–80 km of the "suitable life range" polygons identified by Environment Canada (2009) as likely being able to support adult female grizzly bears (Fig. 9.2; modelling conducted as part of Environment Canada's *Recovery Strategy for the Grizzly Bear, Prairie Population, in Canada*). Life-range polygons were defined as ≥900 km^2 polygons with a road density ≤0.6 km/km^2, <0.5 humans/km^2, and <10% of the landmass being cultivated (for crops or hay). Further, to be suitable the polygons also were required to have components of secure habitat (Fig. 9.2; each component being ≥9 km^2 and >500 m from any road or railway, intersecting with a lake or watercourse and covered by natural prairie vegetation suitable for bears [e.g., including buffaloberry, *Shepherida* spp.; chokecherry, *Prunus virginiana*] inclusive of drainage landforms like coulees, canyons, and valleys). Based on their review and analysis, Environment Canada (2009) concluded that the collective Cypress Hills-Milk River Drainage polygon would be suitable to support 17 adult female grizzly bears on the Canadian side of the border. The next largest block of habitat would, however, be separated by long distances (e.g., Grasslands National Park).

Because of the plasticity of bears to learn to live in human-dominated landscapes, in combination with surplus recruits from the west presented by current protections afforded grizzly bears, over the long-term it is feasible and perhaps likely that grizzly bears will return to re-occupy parts of at least the southeast of Alberta and southwest of Saskatchewan. Indeed, modelling by Lamb et al. (2020) is illuminating in this context (see Figs. 4.7). The Human Influence Index (HII, https://doi.org/10.7927/H4BP00QC) critical to estimating persistence of grizzly bears with or without immigration (Lamb et al. 2020) within areas identified as suitable for the life ranges of female grizzly bears in Fig. 9.2 is, in fact, lower than areas of current areas of extant occupancy. Immigration required to maintain a grizzly bear population, if established within the suitable life range polygons of Fig. 9.2 may still be necessary but not necessarily high (e.g., Fig. 2 of Lamb et al. 2020).

Further monitoring and modelling of the potential for grizzly bear re-occupancy of areas presented in Fig. 9.2 is likely warranted to prepare the public and governments of Alberta and Saskatchewan for an increased presence of grizzly bears in the region.

10.0 DISCUSSION AND CONCLUSIONS

The mapping of habitat, abundance, trend, and projected trend and status of grizzly bears in North America and Canada has varied and continues to vary widely among jurisdictions. While differences can be attributed to several factors commonalities exist between jurisdictions for why bears are mapped the way they are. In our review, we have made the following observations.

First there is a legacy effect of the grain at which population parameters of grizzly bears are mapped that relates directly to the extent to which the species is or was harvested and managed in a jurisdiction, that continues to inform the resolution and variation in resolutions used to map grizzly bears. At the broadest scale, perhaps the greatest contrast in how we have historically mapped grizzly bears emerges at the southern border between Canada and the United States (US). In the lower 48 states, distribution and biological data for the species has almost exclusively been documented over the past 50 years for conservation and recovery. In 1975, under authority of the US *Endangered Species Act*, the US Fish & Wildlife Service listed disconnected populations of grizzly bears as "Threatened" in response to the species then occupying only about 2% of its former range (south of the Canadian border). Licensed hunting ceased for the species and almost all mapping efforts developed out of a mandate for recovery. This included efforts directed at surveillance and mapping activities of population occurrence but also genetics, identification of and mapping of potential habitat that, even if as yet unoccupied (e.g., Bitterroot Recovery Area; Boyce and Waller 2003), was believed to be consistent with the needs of grizzly bears and range expansion. Because of the high profile nature of the grizzly bear and the availability of resources to promote its recovery, its presence and absence has been noted at a fine grain.

In contrast to work conducted south of the 49th parallel, through much of Canada (with the exception of Alberta) and Alaska mapping of the distribution and abundance of grizzly bears has traditionally been carried out for the purpose of establishing hunting quotas and managing a sustainable harvest. Here, spatial units for estimating and tracking densities typically originate from boundaries of wildlife management units (WMUs) or, in some cases, outfitter concessions for hunting bears (e.g., Smith and Osmond-Jones 1990). However, as the hunting of grizzly bears (for sport) has diminished and appreciation for the role of the species as an apex omnivore in the socioecology of systems and for non-consumptive use (e.g., bear-viewing; Nevin et al. 2014) has increased, governments have turned to developing maps more for conservation and recovery. This transition can be perhaps be viewed as part of society's multi-decadal changing views on conservation (Mace 2014), which has moved away from protecting spaces and managing wildlife for recreation to that of managing regions for ecosystem functioning, environmental change, and strengthening people's relationship with nature. Changing rationales for management tied closely to the mapping of grizzly bear biology, which might seem relatively new on paper (e.g., in the case of BC and Alberta, where moratoria on hunting have been in place since 2017 and 2006, respectively), have in fact emerged over several decades and not without debate and an increasing call for quantitative- vs. qualitative-based management (e.g., Peek et al. 2003; Boyce et al. 2016; Auditor General of British Columbia 2017).

It is perhaps no coincidence, then, that our highest resolution data on the biology of grizzly bears in Canada is to be found along what may be perceived as the front of historic range retraction for the species, in southern BC (Chapter 4.0) and the east slopes of the Rocky Mountains in Alberta (Chapter 5.0). It is here that we see widespread use some of the most advanced methods in mapping grizzly bear distribution and abundance, including e.g., combinations of DNA capture-recapture and GPS telemetry-based resource selection modeling (spatially explicit capture-recapture) and high-resolution biophysical habitat mapping (e.g., Mowat et al. 2013; Nielsen et al. 2004; Lamb et al. 2018, 2020; Hamilton et al. 2018; Boulanger et al. 2018). These methods are also now being adopted in the territories for portions of grizzly bear range (e.g., Yukon Fish and Wildlife Branch 2017; SARC 2017; Awan et al. 2019). However, in most cases the adoption of new grains of analysis and approaches are no longer directly comparable to what was used in the past, meaning trend information for many grizzly bear units and jurisdictions in Canada is not estimable or comparable in a quantitative sense. This differs strongly from the early adoption of standardized, nation-wide approaches used to model trend in other widely distributed species like boreal caribou (Johnson et al. 2020).

The legacy of grizzly bear harvest management in Canada continues to inform mapping practices of both the current distribution and abundance of this species as it often delineates the grain at which properties of populations are defined and status assessed (e.g., wildlife management unit [WMU] or grizzly bear population units [GBPUs] in BC; bear management units [BMUs] in Yukon, and bear management areas [BMAs] in Alberta]). Units used today can convey discreteness, e.g., Alberta's BMUs are largely genetically distinct entities (Proctor et al. 2012); while southern GBPUs in BC follow natural and anthropogenic fractures in distribution (e.g. large rivers, settled valleys) that also reflect a degree of genetic isolation (Proctor et al. 2012). Elsewhere, study-area specific densities are mainly extrapolated to coarse-grained ecoregion boundaries to summarize density (e.g., NWT, SARC 2017) or densities remain averaged to the grain of political boundaries (e.g., in Nunavut [Awan et al. 2019]).

While the boundaries of some management units may no longer hold much meaning—e.g., those derived from outfitter concessions (Government of Yukon 2019)—they may nevertheless be expected to be retained due to tradition but also as a necessity for estimating trend and comparison with historical datasets previously recorded at the grain of the unit. Yet, bottom-up habitat approaches designed to define and rate habitat components for grizzly bears (e.g., Hamilton et al. 2018) may be mapped at multiple different scales compared to that of the management unit. Mis-match in the grain of analysis for mapping habitat and emergent properties of grizzly bear populations can present a challenge for understanding spatial heterogeneity in population parameters critical to conservation rankings (e.g., NatureServe and IUCN rankings) from population size and isolation, population trend, and level of threat to bears or bear habitat.

Mapping Grizzly Bears in Canada

Mis-match in grain of extent between what was historically acceptable for managing bears for maintaining (sustaining) abundance may mask risks and opportunities for increasing abundance or otherwise conserving the species. For example, the exceptionally large grain of resolution used to map the cross-border distribution of grizzly bears in the Chinchaga high country of northwest Alberta and northeast BC (Alberta BMA 1 [Fig 5.11] and BC GBPU "Taiga" [Fig. 4.3]), where the population is likely both small and isolated, hides possible fragmentation and isolation of grizzly bears. Currently, a NatureServe (IUCN) status rank of "Low" is applied to this population in BC, which is mapped as having a density (2 bears/1000 km^2) which is as low as the most imperilled units of the province. True status of this unit may be much higher than this. Newest data from DNA hair snagging work in 2018 in Alberta found a point estimate of 14 grizzly bears on the Alberta side of the Chinchaga range and sampling done on the adjacent BC side found no grizzly bears, while collectively 592 black bears were identified [FRIAA Report FFI-15-004) Indeed, it is not unlikely that the cross-border Chinchaga population now presents an isolated remnant at the eastern front of range retraction for the species. The region may not be suitable habitat for grizzly bears, or at least may no longer be given the amount of human-caused disturbance in the region (forest cut-lines, roads, and pipelines occurring at a density of 3.36 km lines/km^2 over an area of 17,100 km^2; Schneider et al. 2010).

Other examples of status-relevant discrepancies between grain of management unit status and population data were noted by Hamilton et al. (2018), e.g., the peculiarity that the extirpated area between Prince George and Quesnel which includes the GBPUs "Nulki" and "Francois", may be larger than previously thought; while the extreme northeast of the province of BC (where the Alberta, BC, and NWT borders connect) is currently mapped as showing occupancy despite lack of any recent data on grizzly bears present in the region.

While several jurisdictional management-unit boundaries may not be biologically based, it is true that re-evaluation of the appropriate scale of management units for grizzly bears has been an ongoing theme over the past two decades. Examples of adaptive management in this context includes the transition in Alberta from collecting and mapping data on grizzly bears and their habitat from simple BMA boundaries to modified BMAs with Recovery, Support, and Habitat Linkage Zones (Alberta Government 2020; Chapter 5.0). Recommended actions to re-evaluate the appropriate scale of management units for grizzly bears is ongoing in places like Yukon (Government of Yukon 2019), while in places like BC the resolution of the GBPU, which generally is thought to follow natural and human-caused fractures in grizzly bear movements (Mowat et al. 2020), may only need revising in certain circumstances. GBPUs are examined every 5–10 years.

It is clear, however, that where grizzly bears are widespread or occur at high density, there is increased need and use of means to project population parameters via a bottom-up, habitat-based approach that relies on predictive regression modelling (e.g., Mowat et al. 2013, Government of Yukon 2019). Elsewhere, it may be feasible (in terms of resources and personnel) to directly estimate grizzly bear trends and occurrence using iterations of spatially explicit capture-recapture

(SECR) models, as in Alberta. However, in all cases the use of newly available remote sensing technologies is needed to allow for the mapping of grizzly bear habitat over large areas. Combining remote sensing data with habitat use information from radio-collared bears and an understanding of key foods of regional bear populations and the demographics of animals in responses to human influences is important both in the context of regression-based analyses and spatially explicit resource selection modelling in combination with capture-recapture.

The approach afforded in Alberta has provided clear methods and approaches that can be applied to other grizzly bear habitats in Canada where the need for this level of detail and data exists. The SECR-based approach has now been adopted in many study areas in Canada; however, a successful implementation at the level of a jurisdiction will require a strong foundation and access to both quality datasets and skilled personnel.

Datasets from camera trapping are also becoming more common, presenting an opportunity to map occupancy or even relative abundance. Camera-trapping is integral to the mapping and understanding of distribution of grizzly bears in Manitoba (Clark et al. 2019), for example. Other platforms of sharing photographic evidence of grizzly bear occupancy including iNaturalist (https://www.inaturalist.org/) may be particularly informative for tracking range expansion. Datasets generated by cameras may be both large and informative, but beyond documenting occupancy as presence/absence, treatment of data to map relative abundance and detect trends over large areas (e.g., dynamic occupancy modelling) will require much effort not only in terms of assembling data but analyzing it. Methods do exist to apply camera-trap data to understand dynamic occupancy trends, however (e.g., following methods of Fisher et al. [2020]).

Increasingly sophisticated models of occupancy and the variables both bottom-up and top-down that can predict multi-scale occupancy and spatial ecology related to persistence, e.g., source-sink dynamics, have also recently been made available (e.g., Lamb et al. 2020). These tools show exceptional promise for the future mapping of grizzly bears at both large and small cartographic scales, including the process of habitat recolonization like in the Prairies and subarctic. However, methods like Lamb et al. (2020) will also require much data. That said, there is now a critical mass of data throughout North America to apply models like Lamb et al. (2020) to evaluate spatial trends in abundance, trend, and identify status beyond the grain of management units or provincial/territorial boundaries in place today. Increasing use of computer science to enable this, e.g., machine (deep) learning using neural networks may prove useful in this endeavour.

Increasingly, the handling of large datasets to understand and identify emergent patterns is benefitting from machine learning or artificial intelligence (AI), taking humans out of the equation to minimize the need for expert-adjustments or to identify patterns that are not obvious to the human eye (or brain). Using 'deep' convolutional neural networks, e.g., AI-methods allow us to learn a representation of the data without specifying parameters by hand (Kahn and Stavness 2019). This makes them potentially more robust to variations in data (e.g., salmon in the diet or not, even if living on the coast; the role of human or livestock density diminishes in effect size with latitude), as networks can adapt to such differences (LeCun et al. 2015)—

something that is critical to analyses of ecological data. For example, identifying habitat that interacts with human density to convey bear density, where in one habitat a unit change in human density might have great effect size or nil, because human density is not tied to livestock or roads or cities as in the subarctic. While deep networks have the representational capacity to learn complex models of object characteristics; the robustness of these representations relies on the quality and quantity of the initial training data used (LeCun et al. 2015). Hence, an important first step for adopting regression models to spatially predict grizzly bear occupancy and density will be to fully evaluate the suite of technical, and abiotic variables that will ultimately influence the performance of classification algorithms at different scales. Thankfully, the long-term data sets and works of the many authors cited in this review already have us far along this path.

Ultimately, joint efforts to map grizzly bear demographics, abundance, trend, projected trend, and status at multiple scales using common methodology across the Canadian range is possible with coordination among jurisdictions. Coordinated research in this fashion may be very informative to our understanding of persistence probability for grizzly bears at multiple scales, respectful of both the spatial and temporal scales at which emergent properties for populations arise. Results of such a program may further not only our understanding of small-scale ecology of grizzly bears but also larger questions of evolutionary ecology and conservation biology.

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