GRIZZLY BEAR
POPULATION INVENTORY & MONITORING STRATEGY
FOR BRITISH COLUMBIA

Version 1.2

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SUMMARY

1. BACKGROUND

1.1 Introduction

The grizzly bear (*Ursus arctos*) is an iconic species of high public profile, and grizzly bear management garners attention from local to international levels. As with other species, effective conservation of grizzly bears requires understanding of population abundance, distribution and connectivity and the factors that influence associated trends through space and time. This is particularly relevant to grizzly bears given their demonstrated sensitivity to anthropogenic impacts and the need to ensure sustainability of any population harvest or other human-caused mortality.

Starting in the mid-1990s, there have been significant advancements in our ability to gain knowledge about grizzly bear populations at scales most relevant to proactive-conservation, mitigation, harvest management, and population recovery. Many of the new tools and techniques relate to remote and systematic hair-snag sampling and subsequent DNA analyses to confirm species, identify individuals, and characterize relatedness. Numerous sampling efforts have now been applied independently around British Columbia and elsewhere using techniques pioneered in the province. Presently, we are at a stage where grizzly bear conservation will be best served by a provincial strategy to direct and prioritize future goal-specific hair-snag/DNA sampling efforts and the allocation of limited funding resources. Moreover, as individual (and usually independent) sampling efforts continue across the province, consistency and coordination in design, field and analytical methods may allow us to address research and monitoring objectives not otherwise possible.

1.2 Inventory & Monitoring Objectives

In British Columbia, the goals of grizzly bear population inventory and monitoring pertain to (1) regulation of any legal harvest, as well as minimizing (2) bear-human conflict and resulting human-caused mortality, (3) broad-scale fragmentation of habitat and populations leading to decreased population resilience and range contraction, and (4) the degradation of quality habitat and its effectiveness in supporting a healthy and productive local population. For the present "snapshot" in time, primary questions that can be addressed relate to population size and demography, as well as spatial distribution, connectivity (demographic and genetic), and associated landscape factors. Over time, relevant questions relate to spatial or temporal changes in these attributes and the natural and human factors that explain apparent trends. Specifically, objectives for population inventory and monitoring are: (1) estimating absolute population size, (2) understanding population trend and demography, (3) predicting and understanding spatial distribution and influential factors, and (4) characterizing and understanding population connectivity and fragmentation. Knowledge of population distribution and connectivity can in turn inform revised delineation of grizzly bear population units (GBPUs), and subunits within, for which consistent management goals and planning are appropriate.

2. APPROACHES, METHODS & DESIGN CONSIDERATIONS

2.1 Introduction

Methods for remote hair-snag/DNA sampling in wildlife research were rapidly developed after important advancements in the extraction, amplification, and analysis of trace amounts of DNA from minute tissue samples, such as hair follicles. For carnivores, the main advantage of DNA sampling over other detection methods has been the ability to identify individual animals, facilitating the application of capture-recapture methods to estimate population size and monitor trends. The approach has been successfully applied in population estimation, spatial modeling of population density and distribution, and in characterizing population connectivity. It has become the primary tool for grizzly bear population inventory and holds considerable potential for monitoring long-term trends through time and space.

2.2 Analytical Approaches

Population Estimation & Monitoring – Depending on the objective, there are specific analytical approaches that are employed, and these in turn influence sampling design and methods. Population estimation involves capture-recapture analyses with at least two capture "sessions". The number of "uncaptured" (un-detected) bears is estimated by the proportion of individuals that are "recaptured" (re-detected) between or among sessions. The ratio of total individuals captured to those recaptured among sessions is termed capture (detection) probability. Ideally, capture probability is constant among animals. However it can and commonly does vary for several reasons. Selection of the most appropriate population estimation model depends on how capture probability varies. "Closed" models assume that the population is geographically and demographically isolated during the sampling period. But a capture-recapture design can also be employed to estimate population trend using an "open" model that does not assume population closure and estimates animals being added or removed from the population among sampling sessions over periods that can be many years. An open design produces results that are generally less precise but can be appropriate for tracking relative population change over time.

Population Distribution – The probable distribution of a population can be inferred from detection data by characterizing relationships between some surrogate to density, such as detection frequency, and environmental factors that directly or indirectly influence the productivity and persistence of grizzly bear populations. This approach is most relevant when sampling has been conducted at scales of regional population distribution, typically thousands of km^2. At such broad, regional scales, predictions are far more reliable than can be achieved by extrapolating models based on habitat selection by individuals within home ranges. That is, representative sampling can be readily achieved, and relationships that influence habitat selection at the individual level can differ markedly from those that influence population distribution.

Population Connectivity – Similarly, the objective of population connectivity is best addressed through sampling across broad, regional landscapes. However, the resolution at which sampling is systematic will influence the resolution at which patterns of genetic and demographic connectivity can be inferred and explained. Analyses require that individual genotypes be expanded well beyond that required for individual identity. For genetic connectivity, analytical methods involve model-based cluster analysis and population assignment techniques. For demographic connectivity, sex-specific movements among individuals can be plotted, and both male and female natal dispersal can be evaluated by considering distances between detections of parent-offspring pairs.

2.3 Sampling Protocol & Design Considerations

Field Protocol – For field sampling, the bait/scent station and barbed-wire enclosure is the primary technique for bear hair-snag sampling and has proven reliable and efficient. Current standard for the non-reward scent-lure is a combination of rotted cow blood and liquefied rotted fish. After establishment, sites are re-visited at the end of each sampling session. Samples are collected and sites are moved and/or re-lured or removed as required. Samples are labeled and grouped with reference to site, session, and barb-position relative to other samples. A database is built and maintained with respect to station locations, session dates, and samples collected.

Safety – In site establishment, options to promote safety include set-backs from human-use features, spot closures, careful use of signage, public information bulletins, communication with user-groups and personnel of any active industry, and attentive removal of stations. Several safety considerations should also be noted and practiced by field crews where appropriate.

Spatial Considerations – Typically, sampling distribution is controlled by grid cells. Sites are selected within each cell to maximize grizzly bear detection given local conditions. Cells dominated by inherently unsuitable conditions are typically left unsampled. Sites should be selected by experienced biologists and with consideration for study-design requirements, bear ecology, and consistency across the sampling area. Maps and remotely sensed imagery can assist. Site access, associated costs and the potential for bias relative to landscape conditions should be carefully considered.

Appropriate cell size and both location and configuration of the grid depends on sampling objectives, expected habitat distribution, and available budget. For capture-recapture analyses, sampling intensity, largely a function of cell size, should allow all bears some chance of detection. Moving stations within a cell among sessions can improve detection rates, particularly with increasing cell sizes, but this can increase cost considerably. Considerations for location of the sampling area include representation of the area to which inferences are intended, particularly with regard to ecosystem, habitat, human use, and resource/population management. For population estimation, geographic closure should be maximized to the degree possible, such that the sampling area corresponds to significant breaks in the distribution of home ranges. The sampling area should also be relatively compact and encompass a minimum expected population size. Violations to population closure can be accommodated, though with implications to confidence in estimates depending on severity relative to population size. In contrast, objectives of population distribution and connectivity are often best addressed through sampling that straddles potential population breaks, but differing requirements among objectives can be accommodated through appropriate study/sampling design.

Temporal Considerations – Spring to early summer is generally the most appropriate season for hair-snag sampling for bears using scent-stations. The appropriate start date may depend on phenology in a given year and snow should not unduly influence station distribution. Sampling should be completed before any significant shift in foraging strategy is expected, often the case as of late summer. Sessions should be long enough to assume that a bear can move and be detected among stations between sessions such that subsequent detections at the same station can be assumed to be independent. Sessions of 10-14 days are generally adequate and at least four sessions of this length can typically be accommodated in a year. Statistical power for capture-recapture modeling increases with the number of sessions. For trend monitoring, session length should remain the same among years though number of sessions can vary. Detection/field methods should also be consistent among years to avoid potential bias in estimates. Power analyses can inform decisions regarding annual sampling frequency and sessions for trend detection.

Genotyping – Once samples are collected, grizzly are differentiated from black bears through visual inspection and a single-locus species test. A minimum number of genetic markers (microsatellite loci) are then used to unequivocally differentiate individuals, which depends on genetic variability in the population. From the 6-7 typically used for individual identity, genotypes are expanded to at least 15 markers to address questions of relatedness and population connectivity.

Explanatory Covariates – Fundamental to population inventory and monitoring is the relationship of bear detections, demographic trends, or allele distribution with biological and environmental covariates that are explanatory and predictive. Derived models can be useful in projecting population abundance, stability and trend spatially and temporally. Across the greater focal area, key habitat and human-use variables potentially relevant at the population-level should be assembled and monitored/updated periodically. Particularly relevant to population monitoring are factors related to grizzly bear demography (including known mortality, reproduction, translocations) which can increase the power to detect trends and inform management. Also, other factors should be tracked that potentially influence spatial and temporal variability in detection rates.

2.4 Population Estimation & Monitoring – Alternate Approaches & Specific Considerations

Alternate Approaches – Other than hair-snag/DNA sampling, there are other approaches to population estimation that involve methods for sighting bears, several of which employ capture-resight methods. Direct-sighting methods are of limited utility in BC where forest cover is extensive. Most also require that an animal sample be initially captured and "marked" (typically collared). The use of radio/GPS collars can, however, be a viable alternative or compliment to hair-snag/DNA-based monitoring. That is, population rate of change (λ) can be estimated directly from population vital rates as sampled over the course of study. Such approaches likely have the most utility in very small populations, given their higher cost per bear.

Radiotelemetry vs. DNA for Trend Monitoring – There are limitations to population monitoring associated with both telemetry and DNA-based sampling. Hair-snag/DNA sampling can provide an initial population estimate, while a telemetry-based program cannot. An appropriate hair-snag/DNA sampling design can provide a "true" estimate of λ that accounts for births, deaths, immigration and emigration. However, only *apparent survival* and *rate of additions* can be estimated. Unknown is the role of mortality versus emigration under apparent survival, as is the role of births versus immigration under rate of additions.   In contrast, long-term telemetry monitoring of collared bears can directly estimate reproduction and mortality but typically cannot estimate immigration and emigration. Resulting estimates of λ will thus be biased depending on if and how the monitoring area is functioning as a net population source or sink in the context of adjacent areas. Also, λ estimated from short-term (e.g., ≤ 5 yrs) telemetry studies can be misleading with little management relevance, and temporal variation in vital rates are typically not considered. Ultimately, telemetry studies can provide better insight into causal mechanisms behind apparent population trends but are not often practical over the long term. The appropriate approach for monitoring depends on several factors and a combined approach may be useful in some situations.

Tracking Influential Factors – The concurrent tracking of influential factors, directly or indirectly, is perhaps the most important element in a monitoring design. These include environmental variation, habitat conditions including key food resources and major disturbances, trophic-level diet, potential human influences with reference to activity types and level, land-use changes, public education, and bear management. In addition, known bear mortalities, translocations, and anecdotal observations of females with cubs can be useful in explaining apparent survival and rates of addition. Where a radiocollaring program is ongoing, survival, recruitment and mortality causes should of course be documented.

The Best Monitoring Approach? – Decisions about if, where and how to monitor grizzly bear populations are complex. Multiple factors for consideration have been discussed and debated among biologists and analysts with some conclusions. Effective monitoring is expensive. In small populations, where fundamental requirements for recovery are clear, most resources should be allocated to management with some research investment. Rigorous population surveys should, however, be initially conducted perhaps with follow-up in 5-10 year increments. Larger, less threatened populations are more appropriate for monitoring. Hair-snag/DNA sampling approaches are generally most appropriate and cost-effective although data sampled concurrently from some collared bears can improve understanding and confidence.

2.5 Planning for Meta-Analyses

There is potential value in comparing ecosystems and relevant environmental variation at a provincial scale to better explore the underlying factors and mechanisms that control and limit grizzly bear populations. Such meta-analyses can be facilitated to the degree that sampling methods and designs are standardized. The specifics of required standardization depend on analysis objectives. However, representation of habitat and human conditions within and among ecosystems/GBPUs is an important consideration and would ideally involve "benchmark" sampling areas. Comparisons among ecosystems will be possible among sampling areas that are of appropriate design, scale and representation.

3. REVIEW OF GRIZZLY BEAR POPULATION INVENTORY & MONITORING TO DATE

3.1 Introduction

To date, there have been numerous grizzly bear hair-snag/DNA sampling efforts across British Columbia, with considerable variation in scale of projects and ability to make population inferences. With some exceptions, the primary objective of most surveys has been the estimation of population abundance or density. In several instances, objectives pertaining to distribution and connectivity have been addressed secondarily, sometimes in later years.

3.2 Project Review

To date, most grizzly bear population study or survey in British Columbia has occurred in the southeast, primarily within the Kootenay Wildlife Management Region. Here, there have been ≥12 hair-snag/DNA sampling projects (depending on grouping of multiple sampling grids from the same area) and a few telemetry-based population studies. There have been four hair-snag/DNA projects in East-Central BC in the vicinity of Prince George, one project in the northeast, and two in the northwest. On the central coast, there have been three hair-snag/DNA projects and one monitoring program based on aircraft-sighting. In southwest BC, there have been three projects in the southern Coast Ranges, one of which was an extensive program that addressed five distinct sampling areas over four years. And one project was completed in the southwest Interior. Three papers have pooled data among specific studies, though for different objectives.

At a provincial scale, there are presently two approaches for inferring grizzly bear population abundance and status for GBPUs for which adequately reliable and representative inventories or research-based density estimates are not available. Where empirical inferences are not possible or appropriate, population size and carrying capacity has been estimated through qualitative evaluation of broad-scale habitat potential in the context of assumptions regarding historic human impacts, and augmented with relevant anecdotal information. More recently, an alternate and more objective approach to inferring population density has been adopted for GBPUs within some areas of BC.

Predictions are based on regression modeling of empirically-determined density estimates from across western North America against broad-scale explanatory factors including climate and human use.

4. DETERMINING GEOGRAPHIC PRIORITIES FOR POPULATION INVENTORY & MONITORING

4.1 Definitions & Objectives

The two focal areas of this report are population "inventory" and "monitoring". Each is characterized by the following objectives. Inventory objectives: (1) absolute abundance, (2) population distribution and connectivity, (3) baseline for trend monitoring. Monitoring objectives: (1) trend in relevant parameters and indices over time, (2) spatial variation in the above. Grizzly bear population units (GBPUs) are the spatial management units defined and adopted by the Ministry of Environment to reflect our best present understanding of relatively cohesive and manageable populations of consistent ecotype.

4.2 Approach

In the process of determining population inventory and monitoring priorities across the province, I applied a structured rating system such that relative rankings among GBPUs are derived from objective and transparent logic. For each of the 57 provincial GBPUs, my intent was to derive a score reflecting the relative need for population inventory specific to estimating (1) abundance, (2) distribution and connectivity, and for (3) population monitoring. GBPU scores for each objective were derived on the basis of a common set of criteria:

1. Confidence in knowledge of population & status
2. Confidence in knowledge of distribution & connectivity
3. Current assumed status and need for recovery
4. Potential for recovery
5. Anticipated short- and long-term threats
6. Current-level and anticipated trend in bear mortality from harvest
7. Current-level and anticipated trend in bear mortality from conflict with people
8. Ecotype representation
9. Conservation significance to adjacent populations
10. Importance to existing/ongoing program.

For each inventory objective, the above criteria were weighted in a workshop[1] to reflect importance relative to each other. For each GBPU, each criterion was then scored on a 5-point scale according to the strength of agreement or degree to which it is expected to apply. Ten southern GBPUs were scored on the basis of discussion and consensus in the workshop. Remaining GBPUs

[1] October 2009. Attended by 14 – see Acknowledgements.

were scored primarily on the basis of opinions solicited among biologists with relevant knowledge and experience from across the province[2]. For each criterion, I based final scores on collective opinion among respondents, but I applied specific scoring rules to some criteria based on available "objective" information (e.g., currently provincial assumptions of population relative to carrying capacity). For each GBPU, I calculated a combined score for each objective (abundance, distribution/connectivity, or monitoring) based on a weighted average among criteria scores that is specific to each objective.

4.3 GBPU Scores & Rankings

Results can be used to rank GBPUs for each inventory objective, providing direction to project proponents and assistance to those involved in funding decisions. However, in addition to geographic priorities, there are additional criteria that should be considered in the preparation and evaluation of proposals. Again, the objective of this work was to provide a provincially consistent ranking method such that future efforts are directed to areas where we know the least about grizzly bear abundance, trend and distribution relative to apparent management need.

4.4 Conclusions & Recommendations

The future utility of this decision-support tool requires that it be periodically updated, refined, and perhaps include a greater level of input. In the least, scores will change as new information comes available to address existing information gaps and opinions are revised regarding other criteria. In the present version, scores presented should be considered in light of certain limitations and caveats. Units that were scored outside of a workshop setting did not benefit from discussion and debate regarding rationale, particularly relative to other units. Moreover, different individuals provided scores for different units and there were few opinions (often only one) to draw on for a particular unit. I provide some recommendations for the use of pre-existing assumptions and quantifiable information in the scoring of GBPUs on several criteria. I also suggest that all future opinion-based scores be derived in a workshop setting.

[2] 18 responded directly or indirectly – see Acknowledgements.

1.
BACKGROUND

1.1 INTRODUCTION

The grizzly bear (*Ursus arctos*) is an iconic species of high public profile. As a species of special concern in Canada (Ross 2002), grizzly bear management garners attention at local, national and international levels. British Columbia's commitment to grizzly bear conservation is reflected in the provincial Grizzly Bear Conservation Strategy (MELP 1995) which seeks to maintain in perpetuity the diversity and abundance of grizzly bears and the ecosystems on which they depend.

Fundamental to the conservation of any species is the ability to estimate the abundance, distribution and connectivity of populations, and to understand the factors that influence associated spatial and temporal variation and trend. Such knowledge is especially important for grizzly bears given their low ecological resilience (Weaver et al. 1996) and vulnerability to population decline and range contraction due to anthropogenic impacts (Mattson and Merrill 2000). Threats are both direct and indirect and relate to unsustainable human-caused mortality, degradation of habitat quality and effectiveness, and especially cumulative effects where such threats stem from multiple sources. These issues are particularly acute near southern range extents (McLellan 1998), but informed management of other populations is also essential, especially where sustained hunter-harvest is a management objective.

As of the mid-1990s, the techniques available for survey and monitoring of bear populations were fraught with limitations and potential bias (RIC 1998). Since then, however, there have been significant advancements in our ability to gain reliable knowledge about grizzly bear populations at scales most relevant to proactive-conservation, mitigation, harvest management, and population recovery. Many of the new tools and techniques relate to remote and systematic hair-snag sampling and subsequent DNA analyses to confirm species, identify individuals, and characterize relatedness. Associated research and inventory approaches were developed primarily in British Columbia, and numerous sampling efforts have now been applied independently around the province. These projects all contributed to the development and refinement of methods to address questions relevant to population monitoring and conservation.

We are now at a stage where grizzly bear conservation will be best served by a provincial strategy to direct and prioritize future goal-specific hair-snag/DNA sampling efforts and the allocation of limited funding resources. Moreover, as individual (and usually independent) sampling efforts continue across the province, consistency and coordination in design, field, and analytical methods may allow us to address research and monitoring objectives not otherwise possible. This includes comparisons among ecological regions and across gradations of natural and human influence at a provincial-scale (including changes in climate, ecosystems, and disturbance), as well as long term trends.

This report is intended to provide general direction and strategy for planning and funding future programs of grizzly bear population inventory and monitoring across British Columbia. It is organized into four partitions. Initially, I clarify relevant goals for inventory and monitoring. I then review approaches to achieving these goals, describing methods and design considerations with special focus on hair-snag/DNA sampling. Next, I review population sampling efforts, studies, and monitoring programs across the province to date. Finally, I describe a decision process for establishing geographic priorities for grizzly bear population inventory and monitoring based on objective and transparent criteria.

1.2 INVENTORY & MONITORING OBJECTIVES

In British Columbia, the underlying need for grizzly bear population inventory and monitoring relates to the following conservation issues: (1) regulation of any legal population harvest, (2) bear-human conflict and resulting human-caused mortality, (3) broad-scale fragmentation of habitat and populations leading to decreased population resilience and range contraction, and (4) the degradation of quality habitat and its effectiveness in supporting a healthy and productive local population. For the present "snapshot" in time, primary questions that can be addressed pertain to population size and demography, as well as spatial distribution, connectivity (demographic and genetic), and associated landscape factors. Over time, relevant questions relate to spatial or temporal changes in these attributes and the natural and human factors that explain apparent trends. Inventory and monitoring goals are discussed below.

1.2.1 Absolute Population Size

A discrete estimate of population size is an important objective of an inventory program, and is relevant to the evaluation of population status, viability and the sustainability of any current or planned harvest. Sampling designs that employ hair-snag/DNA methods have potential to provide relatively precise population estimates. Precision is, however, a direct function of (1) sample size and proportion of the population detected, (2) the degree to which the sampled population is geographically and demographically “closed”, and (3) the assumption that all bears have an equal chance of being sampled (termed capture heterogeneity). Although methods have been developed to best address these issues (Boulanger and McLellan 2001, Boulanger et al. 2002), the minimum sampling requirements for temporally-discrete population estimation can be costly to achieve. That is, sampling areas must be large enough to minimize violation of population closure and to achieve a minimum sample size. Sampling intensity must also be high enough to detect a sufficient proportion of the population while characterizing and accounting for inherent capture heterogeneity (Boulanger et al. 2004b). Such "snapshot" estimates of course do not allow for inference of population trend, which may be more relevant to many management issues.

1.2.2 Understanding Population Trend and Demography

The principal objective of long-term population monitoring is to estimate trend in abundance and the factors that are influencing underlying demographic changes. Any change to the population may be due to changes in rates of (1) immigration and emigration, (2) reproduction, or (3) survival. Trend monitoring may or may not involve an initial inventory and estimate of absolute population size. The statistical power to detect change over time, a function of sample size and variance, depends on factors that include (1) the detection technique employed and the associated probability of detecting animals that are resident within the landscape, (2) the intensity of sampling relative to the actual range of population densities being sampled, (3) the minimum rate of population change (often denoted as λ) that must be detectable, and (4) the time period over which it is necessary to detect such a change. With increases in both animal detection probability and sampling intensity, the probability of actually detecting a given change in the population will increase. This probability is equal to $1-\beta$ where β is the likelihood of not detecting a decline that has in fact occurred (termed a Type 2 error). This contrasts with the Type 1 error rate (α), or the probability of rejecting the null hypothesis (no population change) when it is true, which is usually fixed between 0.05 and 0.3.

Fundamental in population trend monitoring is the time-scale over which a given degree of change should be apparent. Given the time intervals of COSEWIC[3] in reviewing species status and considering changes, it has been suggested that a given trend should be detectible over a period of three grizzly bear generations (e.g., ≤ 20 years) at most and should be specific to a geographical region that would include a potential population of at least 100 bears (Apps et al. 2005). Estimates of population trend may well be feasible in shorter (e.g., 5 year) time intervals. However, grizzly bear populations may display periodic or random fluctuations around a stable λ value, and short-term estimates of λ (obtained via radio telemetry or DNA sampling) may not reflect long term trend and the conservation issues of most relevance.

The value of population monitoring to bear management and conservation depends entirely on the understanding of demographic mechanisms involved and the ecological and human factors controlling them. That is, it is the *explanation* of trend (λ and/or demographic estimates) that is most relevant. A population monitoring program should be able to explore links between spatial and temporal variation in grizzly bear demography with a suite of *a-priori* variables that directly or indirectly account for potential causes related to habitat/food resources, known or potential mortality, and management practices. Moreover, the evaluation of trend is in fact statistically more powerful when explanatory covariates are considered.

[3] Committee on the Status of Endangered Species in Canada

1.2.3 Occurrence and Distribution Relative to Influential Factors

In addition to absolute abundance for a given area or management unit, an understanding of the spatial distribution of that population and related landscape factors is highly relevant to grizzly bear conservation, particularly in supporting population recovery. Given design requirements (addressed in Section 2), a sampling program may not directly correspond to the management unit(s) for which estimates are required. Extrapolation is therefore inevitable but will preferably be based on robust ecological rationale. Moreover, the spatial distribution of mortality risk and population refugia is an important consideration in harvest management (*sensu* McCullough 1996). For wide-ranging species, the broad scale that is relevant often covers extensive, multi-jurisdictional regions of various land-uses and factors influencing bear mortality risk. However, in addition to assessing population status and managing harvest, spatial modeling of landscape potential and population distribution is also pertinent to land-use planning, assessment of cumulative impacts, directing finer-scale ecological research, and designs for effective population monitoring (Gibbs 2000). Relevant to all applications, population distribution can be translated to zones useful for planning and assessment and that follow from basic tenets of conservation biology (see Noss and Cooperrider 1994, Noss et al. 1996): (1) *productive population cores* – areas that support multiple overlapping reproductive females; (2) *peripheral areas* – surround and connect core areas and into which grizzly bears (especially males and transient subadults) often range; (3) *linkage zones* – landscapes that are likely to allow at least ephemeral residence and movement; (4) *fracture zones* – landscapes that lack options for bears to move and/or persist; and (5) *perpetually unoccupied areas* – broad areas that extend beyond landscapes where grizzly bears are expected to reside and move regardless of recovery efforts.

1.2.4 Population Connectivity and Fragmentation

Landscape factors can not only influence the distribution and size of localized grizzly bear populations, but also the connectivity among them. The continual or periodic population augmentation that connectivity facilitates can support peripheral populations that may not otherwise persist, and can result in a stable and resilient metapopulation anchored by secure and productive habitat cores (Brown and Kodric-Brown 1977, Fahrig and Merriam 1994). Maintaining genetic flow among historically connected populations also contributes to localized adaptability in addition to the purging of deleterious alleles that can manifest in the reduction of individual fitness and ultimately population productivity and resilience (Schonewald-Cox et al. 1983, Frankham et al. 2002). From both perspectives (demographic and genetic), population connectivity can facilitate ecological and geographic shifts in response to a changing environment such as due to climate change (Root et al. 2003, Parmesan 2006).

The history of connectivity within and among populations is reflected in the distribution of alleles (paired DNA sequences at specified genetic locations) among individuals across the larger region (Holderegger et al. 2009). This pattern can provide insight into current and historic population fracture, isolation, and contributing natural and human factors. An examination of the spatial distribution of individuals relative to ancestral landscapes, and the hybridization among ancestral groups can also suggest whether spatial expansion and/or reconnection since isolation has occurred and the process of this expansion (Apps et al. 2009). In some cases, landscape features likely to have fractured populations are obvious, such as major transportation and development corridors, in which case specific hypotheses and associated implications can be directly evaluated using assignment tests (Proctor et al. 2005).

1.2.5 Defining Populations for Management Goals

For a given snapshot in time, the above objectives of population size, distribution and connectivity can inform the most appropriate delineation of populations for management, conservation and recovery. The Ministry of Environment uses the best available information and assumptions to identify cohesive and manageable populations of consistent behavioural ecotype as the spatial units for management. However, the boundaries of these grizzly bear population units (GBPUs) can and should be changed as better information comes available. In most cases, population interchange among adjacent units can be expected. Where genetic and demographic discontinuity becomes obvious through inventory work, units should be adjusted to reflect this knowledge. This may result in some relatively small GBPUs, particularly in southern regions. But distinct conservation planning (including enhancement of population linkages) for these fringe populations is justifiable to promote recovery and to prevent inadvertent localized extirpation and/or range contraction due to differing conservation needs and issues among bears within a defined GBPU. As populations recover and/or expand, small units may be amalgamated. GBPU boundaries should also expand if and where resident and reproductive females are detected in previously unoccupied landscapes as supported by indisputable sighting, genetic, and/or movement information. In northern regions, discrete populations may not be obvious, and unit boundaries should secondarily correspond to the expectation of ecotypic differences in foraging and habitat use patterns (e.g., by ecoprovince), natural and human features that are likely to influence movement, and existing wildlife management units. Across the province, where mortality and/or cumulative impacts are of concern, subpopulation units defined by landscapes within GBPUs can be helpful in assessment, mitigation-planning and management.

2.
APPROACHES, METHODS & DESIGN CONSIDERATIONS RELEVANT TO DNA-BASED POPULATION INVENTORY & MONITORING

2.1 INTRODUCTION

Methods for remote hair-snag/DNA sampling in wildlife research were rapidly developed after important advancements in the extraction, amplification, and analysis of trace amounts of mitochondrial and nuclear DNA from minute tissue samples, such as hair follicles (Foran et al. 1997, Waits 2004, Waits and Paetkau 2005). For carnivores, the main advantage of DNA sampling over other detection methods (e.g., Zielinski and Kucera 1995) has been the ability to identify individual animals, facilitating the application of capture-recapture methods to estimate population size and monitor trends. The approach is being applied to a growing number of species (Kendall and McKelvey 2008). But it has proven particularly effective for grizzly bears (Woods et al. 1999), and has been successfully applied in population estimation (e.g., Mowat and Strobeck 2000, Boulanger et al. 2002), in spatial modeling of population density and distribution (e.g., Apps et al. 2004), and in characterizing population connectivity (e.g., Proctor et al. 2005, Apps et al. 2009). Thus, hair-snag/DNA sampling is becoming the primary tool for grizzly bear population inventory as well as monitoring long-term trends through time and space, especially where limitations to sightability preclude the application of traditional capture-mark-resight methods (see 2.4.1).

In this section, I review the technology, methods, utility and issues associated with hair-snag/DNA sampling for population inventory and monitoring, building on Apps et al. (2005). I begin with an overview of analytical approaches specific to the objectives presented in Section 1. Within this context, I then review specifics of sampling methods, design considerations and associated issues. Where applicable, my review summarizes and compares alternative and/or complimentary techniques that could also be applied within largely-forested landscapes typical of British Columbia, with particular emphasis on the use of radiotelemetry.

2.2 ANALYTICAL APPROACH

2.2.1 Capture-Recapture Population Estimation

Deriving estimates of abundance and density for relevant management/population units is usually a key objective for grizzly bear population inventory projects. Field sampling is typically designed to optimally address this in addition to other objectives within a realistic budget. Typically, a

K-samples capture-recapture design is employed (Williams et al. 2002). Traditionally, wildlife census and population estimation employed mark-resight methods based on observations (e.g., Miller et al. 1997). However, such an approach is generally problematic for grizzly bears in British Columbia given extensive forest cover and limited sightability from aircraft that is typical of most regions. In general, individuals can only be detected and identified through remote and systematic sampling. Remote cameras are generally ineffective for individual identification at a large-scale. But genetic profiling from snagged hair is ideal, and allows capture-recapture estimation that is far more reliable than any other census or minimum-count methods possible.

Capture-recapture analysis requires a minimum of two capture "sessions", and the number of uncaptured individuals is estimated by the proportion of recaptures in the second session. The ratio of total individuals captured to the number recaptured between or among sessions is termed capture (or detection) probability, and it is applied to estimate the population as follows:

$$\widehat{N} = {}^{M}/_{\hat{P}}$$

where M is the number of animals detected over sampling sessions, $\hat{P}$ is the proportion of those animals initially captured that were then recaptured (i.e., estimate of capture probability), and $\widehat{N}$ is the estimate of population size. In traditional census $\hat{P}$ = 1, assuming that all animals have been caught/observed. This is not typically the case in capture-recapture sampling, and the estimation model and corresponding formula most appropriate depends on assumption of how $\hat{P}$ varies. In particular, unequal capture probabilities among animals (termed capture heterogeneity) are common (Boulanger et al. 2002) due to (1) *inherent heterogeneity* such as the possibility of lower detection rate of females, (2) *behavioural response* such as waning interest in sampling sites after initial visitation, and (3) *time,* as factors such as weather may influence detection rates among sampling sessions. Estimators have been developed that are robust to heterogeneity variation (Otis et al. 1978). These are "closed" models that assume the sampled population is demographically and geographically isolated during the sampling period. A more detailed review of theory and specific estimators is provided by others (Krebs 1989, Lancia et al. 1996, McCallum 2000). Although this report is focused primarily on applications of hair-snag/DNA sampling, see 2.4.1 for a brief summary of alternate approaches and their utility for estimating abundance and trend in British Columbia.

2.2.2 Trend Monitoring

In addition to absolute abundance, capture-recapture designs can also be employed to estimate population trend using "open" models[4]. Rather than assuming demographic and geographic closure, these models estimate animals being added or removed from the population. There have been considerable advancements in the application of open capture-recapture models to estimate

[4] The primary contributor to the topic of bear population abundance and trend estimation in British Columbia using capture-recapture designs has been John Boulanger (Integrated Ecological Research, Nelson, BC).

population trend, accounting for ecologically relevant covariates using an information-theoretic framework for model selection (Burnham and Anderson 2002). Most notably, the Pradel model (Pradel 1996), available in program MARK (White and Burnham 1999) was developed specifically for trend estimation. This model estimates apparent survival, recapture rate, rate of additions, and population rate of change (λ). *Apparent survival* reflects population losses due to emigration and/or death, while *rate of additions* is the proportion of births and immigrants at time j+1 per individual at time j. *Population rate of change* (trend; λ) is the sum of apparent survival and rate of addition, and equates to population size at time j+1 divided by that at time j. Population trend will either be stable (λ=1), increasing (λ>1), or decreasing (λ<1).

Causal influences of λ can be explored through modeling. Controlling for different parameters can assess the role of apparent survival versus rate of addition in determining λ (Schwarz 2001, Franklin 2001). Environmental covariates that vary spatially or temporally, and that may or may not be unique to individual animals, can also be used to better estimate and explain parameters of the Pradel model (e.g., Boulanger et al. 2004a). The Pradel model is apparently robust to capture heterogeneity, and moderately resilient to behavioural response (i.e., decreasing detection success after initial session) (Hines and Nichols 2002).

Aside from hair-snag/DNA sampling designs, radiotelemetry methods can be applied to address population monitoring objectives. However, given costs and long-term commitments associated with either approach, careful decisions must be made about if, where, and how to effectively monitor populations. See 2.4.2 for a review of associated considerations.

2.2.3 Occurrence, Distribution & Associated Factors

Understanding patterns of grizzly bear population distribution, identifying factors that may influence these patterns, and predicting changes through time is essential for effective conservation. The probable distribution of a population can be inferred from detection data sampled using hair-snag/DNA techniques. This involves characterizing of predictive relationships between some surrogate to density, such as detection frequency, and environmental factors that directly or indirectly influence the productivity and persistence of grizzly bear populations. Such an approach to evaluating influential landscape factors and predicting grizzly bear population density and distribution over extensive areas was initially described by Apps et al. (2004) and has been applied in several instances (e.g., Apps et al. 2009). The approach evaluates landscape composition relative to data of grizzly bear detection frequency sampled at the scale of regional population distribution, typically over thousands of km^2. Such models that predict broad-scale population distribution and associated landscape potential can be of considerable value in regional conservation planning that considers current, potential, historic, and futures scenarios.

Factors and relationships that control population persistence and distribution can differ (in some cases markedly) from those that influence habitat selection by individuals within occupied landscapes.

Hence, models derived from ecologically representative population-level sampling should provide more robust predictions at the regional level than can be achieved by extrapolating habitat selection models. Moreover, where such spatial prediction is the primary objective, genetic detection techniques such as hair-snagging may be more efficient, cost-effective, and ethical than telemetry-based methods (Apps et al. 2004). As noted elsewhere, the consistency and repeatability of hair-snag methods can facilitate long-term monitoring at the population level, but certain short-term monitoring or research objectives are still best addressed by tracking the movements and life histories of individual animals that is only possible with telemetry-based sampling (including use of GPS collars).

The family of analytical techniques typically applied in evaluating and predicting species population distribution is sometimes referred to as "resource selection function" models (RSF; Manly et al. 2002). Essentially, grizzly bear occurrence data sampled using hair-snag/DNA techniques are evaluated and described as a function of landscape variables of habitat and human influence derived from digitally-available spatial information that may include remotely-sensed indices. Specific methods and design issues related to species distribution modeling are addressed by others (see Corsi et al. 2000, McGarigal et al. 2000, Boyce et al. 2002, Burnham and Anderson 2002, de Leeuw et al. 2002, Manly et al. 2002, Scott et al. 2002).

Interspecific competition can also influence population density or persistence, but is rarely considered explicitly in the evaluation or prediction of species distribution. Competition between grizzly and black (*U. americanus*) bears is expected where they are sympatric, given their similar body forms, diets, and their relatively recent (in evolutionary terms) range convergence. Using hair-snag/DNA methods, sampling for the relative-abundance and distribution of black bears is incidental to grizzly bear sampling. Landscape partitioning and associated hypotheses of competition between the species can be addressed using RSF methods (Apps et al. 2006), the results of which may represent an important covariate in explaining the spatio-temporal population trends of grizzly bears.

Again, I highlight that the approach described here is relevant only to the broad scales at which grizzly bear populations are typically distributed and at which planning for their conservation is most appropriate. However, it is important to note that spatial predictions at finer-scales derived from research employing radio-telemetry and/or GPS collars (or expert-opinion) at the finer "within home range" level can be of great value in the management of habitats, human disturbance, and sources of grizzly bear mortality. Predictions of population distribution can serve to focus these finer-scale efforts, and outputs at the different scales are complimentary in conservation planning.

Finally, while the *potential* for occupancy can be inferred through modeling, actual landscape occupancy can be demonstrated directly from the distribution of indisputable detections, particularly of reproductive females. GBPU boundaries can be adjusted in light of both modeling and detections, ideally with reference to movements and/or genetic relatedness. In many instances, extra-territorial sightings are due to periodic forays by males or otherwise transient bears. However, where female occupancy is suspected but uncertain, opportunistic hair-snag/DNA sampling focused on the basis of habitat and recent sighting information can be helpful.

2.2.4 Population Connectivity

Relevant questions of grizzly bear population connectivity and fracture can be addressed without concern for sampling design issues that pertain to estimation of abundance and trend. Aside from *a-priori* testing for the influence of a specific feature (e.g., a highway), population connectivity may be best characterized through an inductive approach with spatially extensive sampling conducted across broad, regional landscapes. At the same time, the resolution with which potential fragmentation can be inferred and causal factors explored depends on spatial intensity of sampling.

In general, questions related to genetic connectivity across regional populations are addressed through a suite of individual-based genetic analysis techniques (Paetkau et al 1995; Waser and Strobeck 1998; Pritchard et al. 2000; Pearse and Crandell 2004; Manel et al. 2005, Falush et al. 2007). These analyses require that genetic profiling be expanded to at least 15 microsatellite loci from the 6 or 7 typically required for individual identity.

Analytical methods involve model-based cluster analysis and population assignment techniques. Model-based clustering (Pritchard et al. 2000, Falush et al. 2007) groups individuals based on their genetic similarity with no *a-priori* assumptions of group membership. The algorithm iteratively assigns individuals to groups based on similar allele frequencies. The geographic origin of each ancestral group can then be inferred, and secondary regression analyses can evaluate the role of natural and human factors in fracture or discontinuity of populations (Proctor et al. 2004, Apps et al. 2009). Population assignment methods (Paetkau et al. 1995, 2004; Pritchard et al. 2000) can then be used to explore sex-specific movement rates across apparent fracture lines.

In addition to genetic connectivity across regional landscapes, demographic connectivity can be inferred in two ways. First, sex-specific movements among individuals detected can be plotted directly. Secondly, 15-locus genotypes can be used to define parent-offspring pairs, and both male and female natal dispersal can be evaluated (e.g., Proctor et al. 2004).

2.3 SAMPLING PROTOCOL & DESIGN CONSIDERATIONS

2.3.1 Field Methods & Protocol

<u>Site Setup</u> – For bears, hair-snag sampling methods include scent stations encompassed by barbed-wire corrals (Woods et al 1999), scented rub pads (McDaniel et al. 2000, Weaver et al. 2003), enhanced natural rub trees (Kendall et al. 2009), and passive snagging on existing trails and/or movement pinch-points (Kendall and McKelvey 2008). Rub-pad sampling is primarily used for felid species, although bears are often incidentally detected (Apps et al. 2007). In contrast to barbed-wire

corrals, the scent-lure applied to rub pads does not provide long-distance attraction (it is meant to illicit a rubbing response), and rub-pad stations cannot provide sufficient opportunity to detect multiple bears; therefore they are not suited for a population inventory or monitoring. Enhancing the ability of natural rub trees to snag hair by adding barbed wire strips has proven effective in detecting bears but detection rates are markedly skewed to males (Kendall et al. 2009). Other passive methods can be helpful in some monitoring designs but generally are of limited value in addressing typical population inventory objectives.

Currently, the Woods et al. (1999) bait-station and barbed-wire corral is the primary technique for bear hair-snag sampling and has been proven reliable and efficient for representative population-level sampling over extensive areas and with relatively high detection rate. Each sampling station consists of a small corral-like enclosure of four-pronged, double-strand barbed-wire nailed around several (3 to 6) trees at about 0.5 m from the ground. Within each enclosure, a brush pile is built and baited with a non-reward liquid lure to entice bears to enter and leave hair on the wire (Figure 1). Simple tools are required and precut lengths (30m) of wire can be prepared for field use. Field crews are easily trained and consistency in methods can be readily achieved across field workers and through time. Only a single strand of barbed-wire is commonly used at present. A second lower strand may increase the detectability of cubs, though this can increase sampling cost significantly and one test did not find a notable benefit (Boulanger et al. 2006).

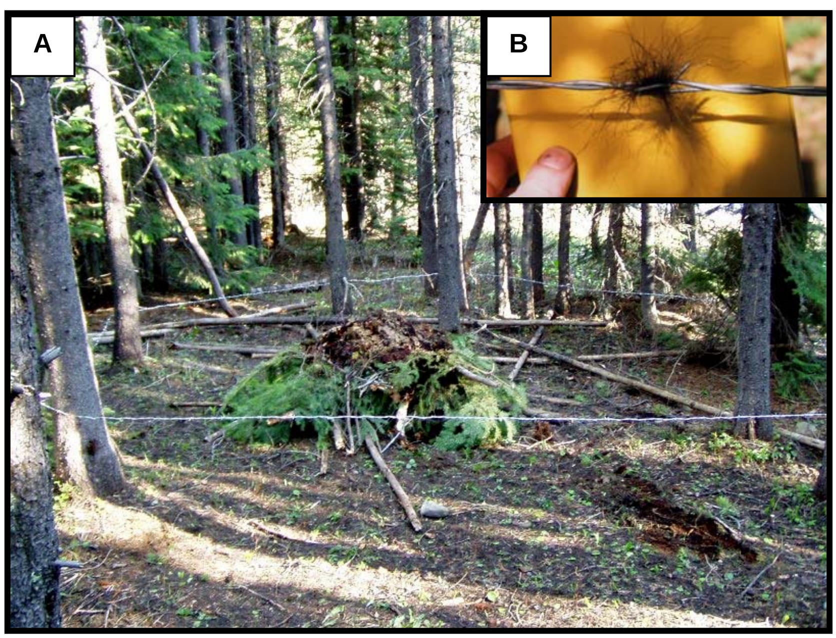


Figure 1. Scent-station setup for hair-snag/DNA detection of bears. Each station consists of a barbed-wire enclosure and brush pile over which scent-lure is poured (A). Hair is typically snagged (B) from bears entering the site.

Use of non-reward scent lure for attracting bears to sampling stations has evolved over the past decade, and the current standard is a combination of liquid rotting cow blood (3.8 l) and liquefied rotten fish and its oil (1.9 l). The use of liquids allows consistency of dose, efficient handling of bait by field crews, and effectiveness in attracting from long-distances. Both the blood and fish are rotted for several months prior to application. It is important to use some predetermined minimum rotting time to ensure that the attractiveness of the lure is effective and consistent across sampling years. Generally, lure is prepared 8-12 months prior to use. Site application of lure should be kept consistent among stations and through the years of sampling. Current methods involve building a brush pile (up to 1 metre high) within the barbed wire enclosure, topped with material to hold the scent (e.g., moss or duff) over which the lure is poured. This setup allows for wind-dispersed scent, safety (no tree climbing required), and bears are consistently attracted to sites but are provided with no caloric reward as is important for any capture-recapture project.

During site setup, GPS positional coordinates are recorded with reference to grid-cell number and/or other coding. Notes on site access and/or helicopter landing should be recorded.

<u>Session Visits & Sample Collection</u> – At the end of a sampling session, sites are re-visited and hair samples are collected. Each sample held on an individual barb is removed and placed in an individual coin envelope and labeled. A single entry or exit of an individual bear can result in multiple hair-snags on adjacent barbs. Labeling samples with reference to their adjacency to others allows for efficient subsampling to minimize the cost of laboratory analyses of samples that are most likely to be from the same bear. Each set of adjacent samples is assigned a letter (A, B, C…) and each sample is assigned a subscript (1, 2, 3…) according to its position within the set. For example, three contiguous samples would be labeled A_1, A_2, A_3, while the next two samples that are not contiguous to others would be labeled B_1 and C_1. All samples from the site and session are then placed within a larger envelope and labeled as to site/cell number, session, and date. After samples are collected, barbs should be sterilized using a small torch. Some designs may call for sites to be disassembled and re-established elsewhere among sessions. If not, the brush pile is rebuilt if needed, and the site is re-lured if a new session is to follow. Samples are stored in a secure and dry indoor location. If wet when collected, samples should be dried on a table in a secure location while remaining in their envelopes.

Upon completion of sampling, stations should be disassembled and wire removed. One database is typically created with a summary record for each station/session combination. A second database provides a unique record for each sample collected with reference to site, session and location/identifier code. Each site/session is assigned a unique identifying code, and each sample's identifier in the database corresponds to this code appended with the sample letter/subscript within that site/session.

2.3.2 Safety Considerations

Hair-snag DNA sampling for grizzly bears has been conducted extensively in northwestern North America since 1995. Across >30 projects, I am aware of no bear-related injuries to people associated with sampling sites. Nonetheless, as with any field work, there is potential for injury. The following recommendations can serve to minimize risk to the public and researchers.

Public Safety – The objective of using bait stations for DNA hair-snagging is to attract bears to sampling sites but not to hold them there for any length of time or to facilitate habitual visitation. It is for this reason that only liquid scent-lure that does not provide a caloric reward is used. Anecdotal evidence from remote cameras suggests that visits are less than 10 minutes, and it is reasonable to expect that bears will exhibit defensive behaviour during this time. Therefore, the following precautions should be applied for public safety:

- Standard set-back rules of ≥ 200 m from any road or human-use trail and ≥ 500 m from any trailhead, campground, or otherwise human-occupied site should be applied.
- Localized spot closures should be considered in unique circumstances.
- Laminated signs providing both warning and explanation should be placed at the start of obvious human ground-routes leading to a given site and at sites with reasonable potential to be found by people. If possible, warning signs should not be directly visible from roads or trails normally traveled by people to avoid unduly attracting people to sites. The following text is recommended: "Warning. Bear research sampling station ahead. Please stay away. Your presence may interfere with this study. Thank you." Contact information for researchers and responsible agencies should follow.
- If it is expected that the public or local license/ tenure holders may still come into contact with sampling stations, then a public information bulletin could be posted via local media and at trailheads. However, the actual density of stations, set-back precautions, and low risk to the public should be highlighted to alleviate concerns.
- The locations of sampling sites (including coordinates) should be provided to groups that may be using sampling areas for employment (timber crews, tree planters, trail maintenance crews, guide-outfitters, etc).
- Although the effectiveness of the liquid lure apparently dissipates in a matter of days, lye or bleach could be spread for added precaution after removal of bait stations and warning signs.
- All wire and staples should be removed from the site upon completion of sampling.

Researcher Safety – Safety risk to field personnel can be minimized as follows:

- Field workers should be required to view the International Bear Association safety video "Working in Bear Country", and field work should only be conducted by personnel who demonstrate understanding of and willingness to apply the precautions described within.

- Bear spray should be carried and quickly accessible at all times, especially when a helicopter is not being used to access baited stations.
- If baited stations are not being accessed by helicopter, or if the helicopter cannot land directly near a site, a "bear-scare" device should be carried and used prior to approaching baited sites on foot or wherever else appropriate.
- Gloves should be used when handling lure, and hands should be washed between handling lure and eating.
- Pilots normally communicate helicopter safety to field workers or any other passengers. Precautions to which field workers will adhere include: never walking towards the rear of the machine, keeping your head low when leaving or approaching the machine, moving slow around the machine, never walking upslope from the machine or downslope to the machine, and ensuring that external cargo baskets are closed and secure after access.
- Field workers should carry and be proficient in the use of either satellite phones or radios with local forestry and/or warden channels for emergency contact if necessary.
- Field workers should be proficient in operating 4-wheel drive vehicles on backcountry and industrial forestry roads.
- For any sites accessed via the ground, field workers should use a "check-in" system, leaving a daily field plan, access routes and expected return or check-in time with at least one responsible individual, ensuring that a search can be promptly initiated if necessary. The use of SPOT satellite GPS messenger technology is also recommended.
- Field workers should have first-aid training, and a wilderness first-aid kit and overnight survival kit should be carried for all field work.
- All provincial laws should be adhered to when operating motor vehicles and a helmet should be worn while operating all-terrain vehicles.

2.3.3 Spatial Sampling Considerations

Site Selection & Access – Site selection is likely the most important consideration in setting out sampling stations. Typically, the population is randomly sampled using grid cells to control distribution. To maximize sampling effectiveness, sites are selected within each cell to maximize the potential for grizzly bear detection given variation in landscape and habitat conditions in the context of season. Thus, sampling is random only at the scale of the grid-cell and broader. Where distribution and abundance is to be related to landscape conditions, some attention should be given to placing stations in sites that are generally representative of the habitat and human conditions in the larger cell. The grid cells will themselves determine sampling representation at broader scales. Grid cells dominated by inherently unsuitable habitat (e.g., rock, ice, water) are typically left unsampled. Site selection should be conducted by experienced biologists familiar with study-design requirements and bear ecology. To achieve consistency in the quality of sampling sites (and for efficiency in the field), candidate sites or areas should be selected prior to field set-up using terrain maps, satellite images, air photos, and personal knowledge of the study area. Consideration should be given to expectations of seasonal foods, foraging strategies, and habitat selection patterns.

Access to sampling sites is an important consideration in the design of effective and representative sampling, and in project budgeting. Ideally, access issues will not influence general site selection within a given sampling cell. In general, helicopter access can best achieve site selection that is unbiased with respect to conditions within the cell and expected bear detectability. Although helicopters are also constrained by landing sites, this is generally not related to broad landscape factors that influence bear distribution (including road access). If site selection is constrained, such as by road access or along rivers, this must be accounted for in design of subsequent analyses. That is, assumptions should consider the population/cohort being sampled, landscape conditions represented, and associated biases (which can often be quantified).

Grid-Cell Size – The appropriate cell size for a sampling grid depend on underlying sampling objectives, expected bear habitat distribution in the local area, and available budget. For capture-recapture modeling, an important assumption is that any bear within a sampling area must have a >0 probability of capture (detection). Thus, the cell size of the sampling grid must be small enough to ensure that each bear is likely to encounter a sampling station (i.e., move within the attraction radius) during the sampling period, regardless of the number of sessions. That is, cell size should not be larger than the smallest home range expected during the sampling period. Results from previous DNA studies allow an approximation of detection probabilities, and hence power analyses, with different sampling intensities (Boulanger et al. 2002), although detection probabilities have increased in more recent years perhaps reflecting improvements in lure preparation and site placement. However, bear movements (rates and constraints) is a function of their local ecology and pattern of habitat distribution, and so appropriate cell size will vary among study areas. Larger cells are best accommodated if stations are moved among sampling sessions (J. Boulanger, *pers. comm.*), but this adds considerable time and cost to the sampling effort (station rotation is addressed in more detail further below). Sampling efforts to date across British Columbia have employed grids with cells ranging from 5x5 to 16x16 km. Larger cells facilitate more extensive and geographically representative sampling (given funding limitations) resulting in a greater area of inference. Thus, cell size should be maximized if requirements of statistical power/precision can also be satisfied. Large cells (spatially less intensive sampling) may be particularly appropriate in surveys near range peripheries where landscape occupancy is uncertain.

Sampling Area Location, Size and Configuration – For spatial modeling of population density and distribution, the primary consideration in the location of sampling areas is the representation of environmental conditions (ecosystem, habitat, current and future human use) and management jurisdictions within the greater focal region to which model extrapolation is intended. If digital inventories of habitat and human conditions are available and can be assembled, then it is possible to apply spatial modeling to identify the most optimal sampling area within a defined extrapolation area. Although modeling can assist with grid location, other important criteria must also be considered.

To the degree possible, sampling areas should be defined such that geographic closure is maximized in the population sampled. That is, boundaries should correspond to significant breaks in home range distribution among animals, translating to demographic discontinuity. With this in mind, the sampling area should also be maximally compact (minimal edge). The greater the area relative to perimeter, the greater the potential detection rates among individual bears and thus statistical power for estimating abundance and trend. The size of the sampling area is relevant in that closure violation becomes less relevant as more bears are entirely contained within the grid. The population model/estimator that is most appropriate will depend on the degree to which the assumption of geographic or demographic closure holds true. Adjustments to naïve estimates must then be applied to arrive at a superpopulation estimate that accounts for the number of bears likely to have ranged beyond the grid and their amount of time spent out of the sampling area. Assumptions in this regard can be informed by movement data from collared bears where available. Spatial modeling of landscape quality has also been used to predict the distribution of bears that may range beyond a grid (Apps et al. 2009). Although it is rare that complete geographic closure can be assumed for the sampled population (Boulanger and McLellan 2001), decreasing the proportional adjustment to estimate population density reduces additional uncertainty inherent in the adjusted superpopulation estimate. If there is an intention to monitor long-term population trend, then the area should encompass an expected population of at least 25 individuals (J. Boulanger, *pers. comm.*).

In a monitoring design employing the Pradel model, considerations for spatial sampling distribution can be more relaxed. In particular, population closure is not relevant. To increase cost-effectiveness for detecting temporal trend, sampling intensity can in fact be stratified on the basis of predicted population distribution (Boulanger and Apps 2002). In this case, less effort would be allocated to landscapes with lower detection probability.

In complete contrast to considerations of population closure, objectives related to population connectivity and influential factors, as measured by allele distribution and assignment, are best served by sampling areas that straddle potential population breaks and associated features. To satisfy the conflicting requirements of different study objectives, one may consider independent but adjacent areas that must each be sampled in a given year but can collectively be sampled over multiple years (e.g., Proctor et al. 2005, Apps et al. 2009).

In summary, factors to consider in the delineation of sampling grids are: (1) representation of ecological and human (including management) conditions, (2) geographic closure of the sampled population, (3) compactness, (4) expected size of the sampled population, and (5) potential to evaluate relevant questions of local population connectivity and associated landscape factors.

Station Rotation – Rotating sampling stations within cells among sessions or (for monitoring) among years has potential benefits and implications. Particularly at larger cell sizes, site rotation can result in a greater and more even probability of detection among individual bears, particularly females (Boulanger et al. 2006). For spatial modeling, it also increases the degree to which sampled landscape conditions are likely to represent variation within the study area. Finally, rotation may alleviate habituation and (given that the stations are assumed to provide no caloric reward) the possibility of reduced detection probability across sessions for a given individual. However, for population monitoring, station rotation could violate the assumption that the same population of bears is being sampled among sessions. This in turn introduces uncertainty around the degree to which an apparent trend is due to bear population demography or simply differences in detection probability due to variation in sampling sites. Moreover, selecting new sites and moving stations among sessions will increase costs substantially, and some have found it unnecessary (Mowat and Strobeck 2000, Boersen et al. 2003). For monitoring, it may be acceptable to establishment of permanent sampling locations with only minor location shifts (i.e., < 500 m) if deemed necessary to counter site-habituation. Alternatively, one may establish two sites per cell and alternate their employment between sessions in years when only two sessions are required (Apps et al. 2005).

2.3.4 Temporal Sampling Considerations

Timing of Sampling – Spring to early summer is generally the most appropriate season for hair-snag sampling for bears using scent-stations. Bears are likely to be most attracted to stations in the spring after they have emerged from their dens. For population monitoring, spring habitat is more consistent among years, therefore minimizing annual variation in perceived grizzly bear abundance and distribution that can be related to the ephemeral nature of certain foods (e.g., berry production or salmon escapement). Within a given year, detection probability should remain relatively constant across sampling sessions without influence from major shifts in foraging strategy by bears. Thus, sampling should ideally occur within two months from May through July[5]. The specific start date may depend on phenology in a given year and area, and a phenological trigger could also be used for the start date where sampling is repeated among years. Ideally, timing should ensure that snow does not greatly influence the distribution of stations across elevation, especially if they are not being moved among sessions; stations set where there is significant snow cover likely are less effective.

Session Duration – Among the various grizzly bear hair-snag DNA studies, the length of sampling sessions has varied from 7 to >20 days. At a minimum, session duration should be long enough to assume that, on average, the detection of an individual at the same site in subsequent sessions represents independent visits (i.e., long enough for a bear to have moved to other parts of its home range). Because stations are not expected to "hold" bears for multi-day periods, the session length should be long enough to allow a bear to move beyond the attraction radius and sampling cell,

[5] Hairs with follicles may also be more readily obtained during this period when bears shed their winter coat.

which may require >1 week. Session length must also allow sufficient time for bears to encounter a site while accommodating a number of sessions within the specified sampling period and season. A session-length of 10-12 days may be appropriate if four sessions are being conducted within a year. Sampling effort is not a direct function of session duration given that the attractiveness of bait-stations will decay through time at some unknown but negative exponential rate, and it is thus difficult to account for changes in effort due to changes in session length. For trend monitoring, session length should remain consistent among years, with changes in effort reflected in the number of sessions conducted.

Number of Sessions – The greater the number of sampling sessions, the greater the statistical power for capture-recapture modeling. Multiple sessions also increase the size of the independent-detection sample for spatial modeling of distribution and underlying landscape factors. Given sampling timing and duration, above, up to five sessions could reasonably be conducted depending on budget, but four sessions are commonly employed. For trend monitoring, multiple sessions should be conducted during the initial sampling year at least, to maximize the initial capture sample. It is possible to vary the number of sampling sessions each year without biasing estimates of trend and demography as long as the same sites are sampled among sessions. Biased estimates will result if sampling areas, bait station configuration, or season of sampling is changed. That is, different populations of bears would be sampled and therefore demographic estimates would be influenced by sampling rather than the actual demography of the populations (Franklin 2001).

Changes in Effort Among Years – For monitoring, sampling effort can change among years if it can be quantified. However, changes in sessions or effort should be made with caution if data are collected from multiple DNA sources (i.e. scat, rub tree, hair snag) that may be associated with skewed detection rates among sex and age cohorts. Within a year, changes in effort that is not consistent among sources of DNA samples could produce an apparent demographic change that is an artifact of the change in relative contribution among detection methods.

Annual Sampling Frequency – For monitoring, the question of sampling frequency among years can be explored through simulation analyses (J. Boulanger, *pers. comm*.). In one example, the statistical power attained from sampling on an annual basis was not substantially greater than designs that sample bi-annually after an initial 3 - 4 years of annual sampling (Apps et al. 2005). Power analyses can be conducted during the initial project design. However, given considerable uncertainty, refined power analyses should be conducted after 3 - 4 years of data are collected.

2.3.5 Genotyping

Prior to detailed genetic analysis, hair-snag samples from black bears are differentiated from grizzly bears using both visual inspection (for obvious black bears) and a single-locus species test (D. Paetkau, *pers. comm.*). For those grizzly bear samples containing adequate genetic material individual genotypes can then be resolved at two levels; the first to establish individual identity and the second to characterized relatedness among individuals. At present, age cannot be determined from DNA[6].

Initially, genotypes must be resolved to unequivocally differentiate individual grizzly bears from all others, including close relatives. Typically, many hundreds and samples are analyzed, many of which are from the same individual. Thus, a minimum number of genetic markers (loci) are used for efficiency, with the number needed depending on the genetic diversity (i.e., heterozygosity) of the population sampled (less diversity requires more markers) (Paetkau 2003). That is, the number of and specific marker used should be sufficient to ensure that the number of individuals that match at all but one allele is close to zero. Samples that mismatch at one (and occasionally two) alleles can then be re-analyzed to ensure that the mismatch is not due to genotyping error. Generally, markers are initially selected from a nearby study or a pilot capture effort to maximize variability and hence power to discriminate individuals and to estimate error probabilities. Ideally, the expected number of mismatches at single marker should be zero, making samples with likely genotyping errors (single mismatch) obvious (Paetkau 2003). In low diversity populations, single mismatches may in fact be two individuals. Although very rare, two individuals can also have an identical genotype at the loci considered, but the probability of this can be calculated as the P_{SIB} statistic (Woods et al. 1999). In general, 6-7 microsatellite loci are sufficient for individual identity and 15 loci for addressing population-level questions pertaining to relatedness (D. Paetkau, *pers. comm.*).

2.3.6 Explantory Covariates

Measurement & Tracking of Biological and Environmental Covariates – Fundamental to understanding and prediction for both population inventory and monitoring is the relationship between bear detections, demographic trends, or allele distribution and relevant covariates, both biological and environmental. Derived models can be useful in projecting population abundance, stability and trend spatially and temporally. Across the greater focal area, key habitat and human-use variables should be assembled and monitored/updated periodically.

Particularly relevant to population monitoring, explanatory covariates related to grizzly bear demography can increase the power to detect trends and can be critical in focusing management actions (e.g., mortality, habitat, specific foods). Important variables to track include known grizzly bear mortalities, translocations into or out of the study area, observations of females with cubs, unbiased estimates of survival, recruitment and mortality causes from concurrent telemetry-based research (if available), and output from predictive modeling for population distribution and landscape quality.

Detection Probability and Landscape Occupation – For trend monitoring, the potential effect of spatial and temporal variability in rates of detection should be considered. For example, the rate of

[6] There have been developments in estimating the age of individuals in some species from reductions in the ends of chromosomes (telomeres), which are known to shorten as an individual ages (Nakagawa et al. 2004). At present, this technique is not available for application to wildlife.

detection at a given bait station is influenced by weather events. In this case, the probability of detection within a given sampling session will be a function of both weather and the probability of grizzly bear landscape occupancy during that season. To avoid erroneous conclusions regarding temporal changes in demographics and occupied landscapes, (1) a record of daily weather conditions during the sampling period should be maintained, and (2), sampling season should be consistent among years and sessions, to the degree possible. Variation in detection probabilities among sessions (from the Pradel model) due to weather can then considered as a covariate or a weighting term in spatial analyses.

2.4 POPULATION ESTIMATION & MONITORING – ALTERNATE APPROACHES & SPECIFIC CONSIDERATIONS

2.4.1 Alternate Approaches

It is worth noting the various alternate approaches that have been applied in estimating grizzly bear population abundance and trend. In Alaska, Miller et al. (1997) counted marked (collared) bears from aircraft using a capture and "recapture" (sighting) approach. This method is, however, problematic across most ecosystems in BC due to forest cover and limited bear sightability, and even in more open ecosystems of northern British Columbia that have considerable high-shrub cover. In Yellowstone National Park (another largely open ecosystem), counts of unduplicated females with cubs has been used to approximate trend (Schwartz et al. 2005). This requires at least moderate sightability and consistent effort among years. Along some salmon rivers of coastal BC, bears can be consistently sighted from aircraft. However bear presence (and sightability) is confounded by salmon escapement which varies among years (Boulanger et al. 2004a). Finally, prior to development of hair-snag/DNA sampling methods, remote cameras were used in one forested ecosystem for capture-mark-resight population estimation where a sample of bears was collared (Mace et al. 1994).

Radiotelemetry – Radiotelemetry, including the use of GPS collars, is a tremendously helpful tool in the study of grizzly bear ecology, including probable requirements and limiting factors. Applications specific to the research and monitoring of behavioural responses by individual bears to conditions of habitat and human influence are outside the scope of this report. However, field methods that involve the use of VHS or GPS collars placed on individual animals are also relevant to the inventory and monitoring of populations. For estimating population abundance, the application of radio-telemetry is reviewed elsewhere (White and Shenk 2001). For grizzly bear population inventory, there is general consensus that hair-snag/DNA sampling approaches can be more reliable, cost-effective and ethical than radiocollaring. For population trend monitoring, however, the multi-year data from individual bears that presently can only be obtained from collars represents an alternative or compliment to hair-snag/DNA methods, particularly in smaller populations. The specific roles of DNA versus radiotelemetry approaches for grizzly bear population monitoring have been discussed and debated among researchers (Proctor et al. 2007a).

Traditionally, estimates of grizzly bear population trend have relied on demographic projection using vital rates obtained from radiotelemetry study (Eberhardt et al. 1994, Hovey and McLellan 1996). Specifically, reproduction and survival among age classes are estimated from the radiocollared sample. These estimates are then applied in a matrix model to estimate population rate of change (λ) and associated sensitivity to variation in demographic parameters. In this case, λ and associated vital rates are assumed to remain constant over time, with reproduction offsetting mortality in proportion to λ. Where estimated over short time frames, λ may be irrelevant and possibly misleading to decisions regarding appropriate management. Ideally, long-term studies should account for temporal variation in vital rates, accepting reduced precision of λ (Boyce et al. 2001).

2.4.2 Radiotelemetry vs DNA for Trend Monitoring

Comparison of Radiotelemetry vs DNA for Trend Monitoring – There are substantial differences in the type of information about population trend that can be obtained through monitoring programs that employ radio/GPS collars versus hair-snag/DNA sampling. A hair-snag/DNA monitoring program can provide an initial population estimate, while a telemetry-based program cannot. For a given monitoring area, hair-snag/DNA sampling (with an appropriate design) can provide a "true" estimate of λ that accounts for births, deaths, immigration and emigration. However, this estimate can only be broken down in terms of *apparent survival* and *rate of additions* (Pradel 1996, Franklin 2001). Unknown is the role of mortality versus emigration under apparent survival, as is the role of births versus immigration in determining rate of additions. In contrast, long-term telemetry monitoring of collared bears can directly estimate reproduction and mortality but generally cannot estimate immigration and emigration. Resulting estimates of λ will thus be biased depending on if and how the monitoring area is functioning as a net population source or sink in the context of adjacent subpopulations.

In both hair-snag/DNA sampling and radiocollaring studies, the ability to make reliable inferences about the population depends on issues of design, methods, sample size, and representation across a defined population/monitoring area. Telemetry studies can, however, provide insight into the causal factors and mechanisms influencing reproduction and survival (including unreported mortality; McLellan et al. 1999) and recommend specific management actions where appropriate. However, it is costly to collar and maintain an appropriately large sample of bears representative of the population and age/sex classes. Ultimately, the ability of a collaring program to address spatial variation in mortality and reproductive success, and associated management issues, is a direct function of the geographic extent and intensity at which bears are collared and monitored. In contrast, monitoring on the basis of hair-snag sampling can easily achieve representation of the population, and both spatial and temporal variation can be related to environmental covariates. However, ultimate causal factors may remain unclear.

In light of the above, the understanding derived from a hair-snag/DNA-based population monitoring program can be enhanced through incorporation of external data. Specifically, estimates of survival can be enhanced using hair-snag detection data (live-encounters) combined with data of known (reported) mortalities. The result is an estimate of both survival and the reporting rate of actual bear mortalities (Barker 2001). Also, data from radiocollaring and hair-snag/DNA sampling can be combined in a single model to obtain joint, potentially less biased estimates of survival and movements into and out of the population than possible using either technique alone (*sensu* Powell et al. 2000).

It is important to remember that the above comparison of the use of radio/GPS collars versus hair-snag/DNA sampling is specific to *population* monitoring only. This does not pertain to monitoring in terms of bears movements and habitat use through space and time. Such behavioural responses may be equally pertinent in monitoring and mitigating short-term individual or cumulative impacts to habitat effectiveness and connectivity at local and landscape levels. In these situations, the use of GPS collars is more appropriate. However, due to technological limitations, there is presently a substantial tradeoff between the spatial/temporal resolution of GPS movement data and the utility of each collared bear for long-term population monitoring discussed above. Under typical duty-cycles (e.g., 1-hr fix rates), GPS collars generally function for only 1 – 3 years and it is thus more difficult, requiring greater investment and risk to individual animals, to keep a representative sample collared over the long-term. This is in comparison to traditional VHF collars that may easily function for 5 years but yield data that is of comparatively poor spatial/temporal resolution. Therefore, the need to monitor behavioural responses does not make the choice of collaring and telemetry for long-term population monitoring necessarily more appropriate.

2.4.3 Tracking Influential Factors

Regardless of approach, it is imperative that a monitoring program be designed to evaluate the plausible hypotheses regarding factors controlling population productivity and persistence, and to highlight appropriate management responses given current understanding. In this sense, a monitoring program should be designed to track (and ideally project) spatial and temporal variation in underlying habitat and human influences, including types, levels, and patterns of human use across the landscape, and key food resources. Some relevant information that can be easily tracked includes bear mortalities and bear-human conflicts reported to conservation officers, roads and access management, formal land-uses and changes, and major habitat change (e.g., wildfire, logging).

There are several types of static and dynamic environmental factors relevant to population monitoring. Macro-climate and physiography can be modeled using existing spatial data. Vegetation and land-cover as tracked with existing inventory updates as well as remote-sensing (e.g., Landsat

TM). Bear foods can be directly or indirectly monitored, some of which may be available through existing programs. This may include, for example, indices of berry productivity, salmon escapement, ungulate densities and calving areas. Spatial and temporal shifts in tropic-level diet can be evaluated through elemental-isotope analyses of the hair-shafts from samples (Hobson et al. 2000, Mowat and Heard 2006). Variation in plant phenology, as reflected in the timing and progression of snow-melt, may be a relevant consideration. Weather can also influence bear movement and foraging patterns as well as hair-snag detection rates.

A human-use inventory should be developed and maintained with reference to annual changes. Points, networks, and areas that differentiate activity types, levels, and management should be incorporated, and human use sampling may be considered (e.g., Gregoire and Buhyoff 1999). Some relevant variables may be tracked through ongoing ecosystem monitoring. Otherwise there should be close coordination among resource agencies, industry groups, and researchers to avoid duplicating effort. Hunter days should be tracked by management unit and include legal harvest of both bears and ungulates (the latter being a risk factor for bears). Bear-awareness activities should be at least qualitatively tracked. Changes in the number and pattern of human residence should be tracked (and projected to future). Other variables include spatial and temporal patterns and intensity of motorized recreation, forest access roads and associated traffic volume, trail use, helicopter-assisted recreation, back-country use, highway traffic volume, and habitat mitigations (including highway mitigation).

Several bear population variables can be tracked to help understand and explain (1) changes in bear detection rates, and (2) local demography of the monitored population. A comprehensive database of known bear mortalities is essential and relevant to explaining apparent survival where DNA-based monitoring is employed. This should include date, location, age, sex, DNA identifier, and cause. Such detail should also be tracked for bear translocations into or out of the monitoring area. A database with anecdotal observations of females with cubs can be useful in describing temporal variation in rates of addition. Where a radiocollaring program is ongoing, survival, recruitment and mortality causes should of course be documented.

2.4.4 The Best Monitoring Approach?

Decisions about if, where and how to effectively monitor grizzly bear populations are complex. The approaches outlined above are expensive and require long-term commitment of financial and human resources. Not all populations can be monitored, and priorities must be established depending on management goals and objectives. Monitoring may be more important where conservation concerns are acute and there are options for active management of underlying human factors. The known conservation issues themselves may guide the specific monitoring objectives and approach. Is a decline suspected but with unknown cause? Or, is a key management issue obvious with unknown implications to the population? Several conclusions on population monitoring approach can be drawn from a workshop among several bear biologists and associated analysts (Proctor et al. 2007) summarized below.

Population monitoring is expensive. Even for a small population of ~50 animals, a λ estimate within 15 years will cost ~$50,000 - $80,000 per year, and this can increase substantially (up to $240,000 per year) for a large ecosystem depending on design and statistical power (Apps et al. 2005). Telemetry-based monitoring for a larger ecosystem (>300 animals) that may derive λ in 5 – 7 years costs ~$400,000 per year (Mace 2005). The consensus among workshop participants was that such allocation to λ is not the best use of limited resources that may be available for small populations, especially where fundamental requirements for recovery are clear. Resources should be directed to management and to learn about local ecology including cause-specific mortality, habitat-use and movement patterns. However, initial population surveys should be conducted with enough rigor to reliably estimate current abundance, distribution and connectivity, and these may be followed up with additional surveys (in 5-10 yr increments) to track status and associated spatial/temporal change.

The less threatened a population is, the more appropriate is the allocation of resources to monitoring versus direct management. However, telemetry-based monitoring that is appropriately intensive and representative over large regional ecosystems is still unlikely to be feasible for most populations over the long-term. A hair-snag/DNA sampling approach that requires fewer resources and consistent commitment may be sufficient to track trend and infer cause in order to assess long-term management and/or mitigation strategies. Models of predicted population distribution can be used to stratify sampling effort to most cost-efficiently detect temporal trend (Boulanger and Apps 2002). As previously noted however (2.4.2), data sampled concurrently from collared bears can improve understanding and confidence around λ as estimated from hair-snag/DNA sampling.

2.5 PLANNING FOR PROVINCIAL-SCALE META-ANALYSES

One of the motives behind this report is the potential value in comparing ecosystems and relevant environmental variation at a provincial scale to better explore the underlying factors and mechanisms that control and limit grizzly bear populations. Such meta-analyses can be facilitated to the degree that sampling methods and designs are standardized. For density estimation, this includes aspects pertinent to assumptions of capture-recapture modeling and the precision and bias of estimates (Boulanger et al. 2002). For scale-dependent analyses of landscape factors influencing abundance and distribution, differences in sampling design can generally be accommodated. But representation of habitat and human conditions within and among ecosystems/GBPUs is an important consideration and would ideally involve "benchmark" sampling areas across the province (Apps et al. 2004). For pooled analyses of population fragmentation and connectivity (e.g., Proctor et al. 2005, 2009), field sampling is not as much an issue as consistency in genotyping. However, hair samples can usually be re-analyzed as long as they are stored properly and securely and can be accessed. Comparisons among ecosystems (e.g., Mowat et al. 2005) will be possible among sampling areas that are of appropriate design, scale and representation. For population monitoring, considerable coordination and standardization among efforts will be required to benefit from comparative analyses. But such comparisons may illuminate causal factors of demographic trends that may differ among local areas. For example, under a consistent design, it is possible to group individual areas into sub-groups in program MARK (White and Burnham 1999) to test logical hypotheses concerning trends in demography (J. Boulanger, *pers. comm.*). Such coordination at the provincial level is particularly relevant to testing hypotheses and understanding implications of large-scale environmental change such as global warming and pine beetle infestation and control. Specific recommendations for coordinated grizzly bear population monitoring at a provincial-scale is beyond the scope of this report and are best derived through collaboration among several individuals. Relevant issues pertain to monitoring approach, monitoring areas and the type of variation (ecological and/or human) they should represent, as well as specific field methods, sampling intervals, and options for long-term funding and responsibility.

3.

REVIEW OF GRIZZLY BEAR POPULATION INVENTORY & MONITORING TO DATE ACROSS BRITISH COLUMBIA

3.1 INTRODUCTION

Since the utility of hair-snag/DNA sampling for the survey of grizzly bear populations was first demonstrated, there have been many applications and some adaptations of the techniques in and outside of British Columbia. Among projects, the scale of sampling has varied considerably as have the sampling objectives. With some exceptions, the primary objective of most surveys has been the estimation of population abundance or density. In several instances, objectives pertaining to distribution and connectivity have been addressed secondarily, sometimes in later years.

Below, I summarize efforts to date in terms of objectives, scale, outputs, basic design parameters, and grizzly bear population unit (GBPU) of relevance. I note here that several of the grizzly bear hair-snag/DNA projects undertaken across the province cannot be used to derive reliable results with respect to abundance and distribution due to the small scale and/or inadequate sampling design. In addition to surveys based on hair-snag/DNA sampling, I make reference to the few other studies (primarily radiotelemetry) from which population demographics have been inferred. My geographic referencing of these studies is specific to defined sampling or study areas (Figure 2, Table 1), regardless of any inferences or models that may have been extrapolated beyond these bounds. Readers should refer to the studies themselves for details of results, inferences, associated confidence, and design issues influencing precision and bias (also see Boulanger et al. 2002) as well as the ecological conditions to which the sampling area may be considered representative. However, in general, grizzly bear detection rates and precision of estimates have increased considerably in more recent years as compared to earlier surveys that date back to 1996, notwithstanding variation in sampling design among studies. Likely, this is a direct result of improvements and standardization of scent-baits and their application, and a greater level of experience and communication among researchers.

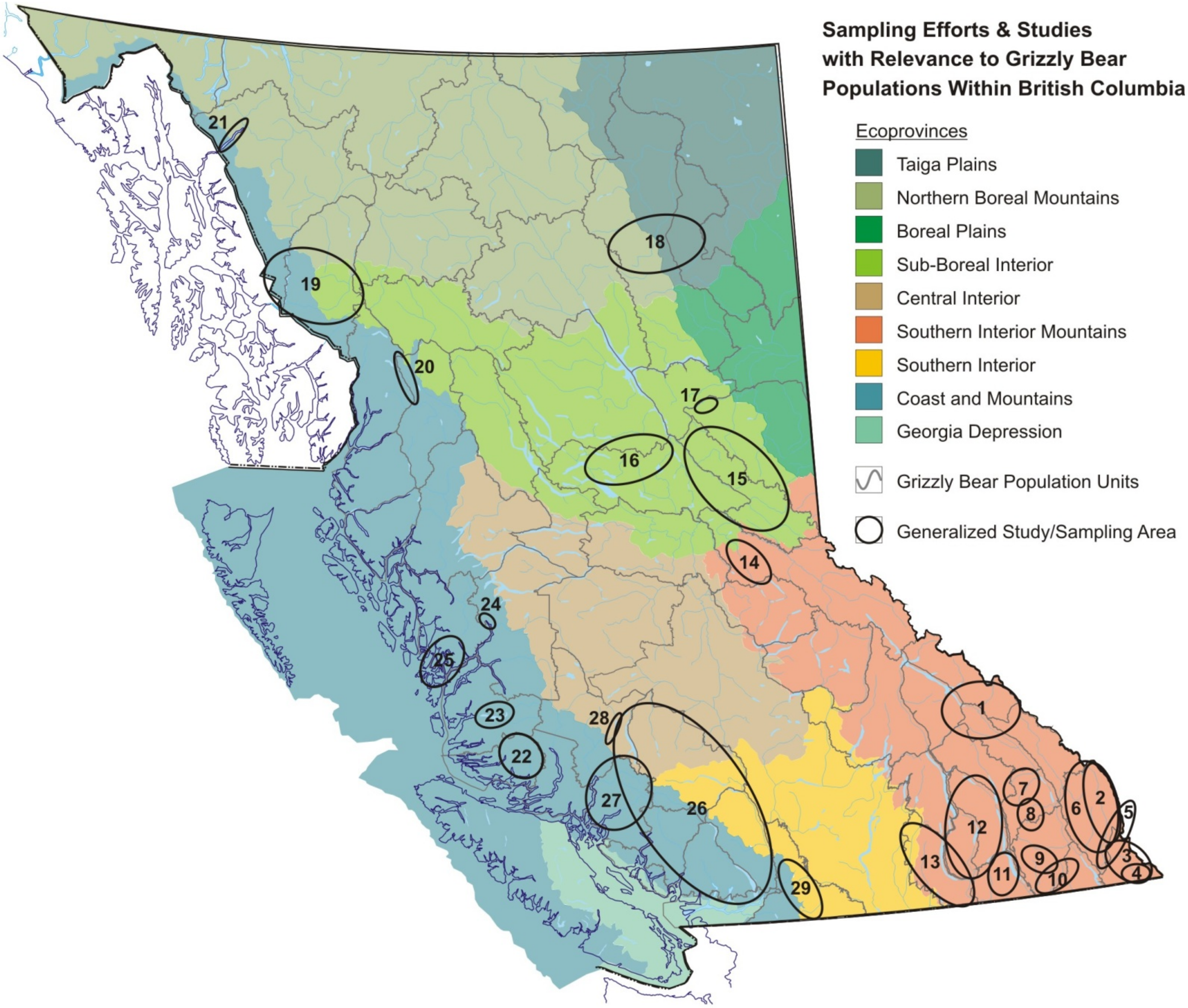


Figure 2. Areas addressed (to 2009) by studies or surveys in British Columbia to estimate grizzly bear abundance, demographics, distribution/connectivity and/or spatial and temporal variation or trend. Included are projects based on both hair-snag/DNA sampling, radiotelemetry, and areal survey. Area numbers are indexed to Table 1.

Table 1. Studies or surveys in British Columbia (indexed to Figure 2) to estimate grizzly bear abundance, demographics, distribution/connectivity and/or spatial and temporal variation or trend.

Index #	Project/Area	Objectives[a]	Method	Year(s)	References
1	Upper-Columbia	A	DNA	1996-98	Boulanger 2001a
1	Upper-Columbia	D	DNA	1996-98	Apps et al. 2004, 2006
2, 3	Elk-Valley/Flathead	A	DNA	1996-97	Boulanger 2001b
3	Flathead	A	DNA	2007	HacHutchon et al. 2008
4	Flathead	T	Telemetry	1978 -	McLellan pers. comm. Hovey & McLellan 1996
5	Crowsnest Hwy	D, C	DNA	2002-03	Apps et al. 2007
6, 3	South Rockies, Flathead	T	DNA	2006-08	Mowat et al. 2009
7	Jumbo	A	DNA	1998	Strom et al. 1999
7	Jumbo	D	DNA	1998	Boulanger & Apps 2002
8	Purcell Conservancy	A, D	DNA	2002	Proctor et al. 2007b
9	South Purcells	A, D	DNA	2001	Proctor et al. 2007b
10	Hwy-3 - Purcell-Yahk	A, D	DNA	2004-05	Proctor et al. 2007b
11	South Selkirks	A, D	DNA	2005	Proctor et al. 2007b
12	Central Selkirks	A	DNA	1996	Mowat & Strobeck 2000
	Southern Kootenays	C	DNA		Proctor et al. 2005
13	Granby-Kettle	A	DNA	1997	Boulanger 2000
14	Bowron	A	DNA	2001	Mowat et al. 2002a
15	Parsnip/Herrick	A	DNA	2000	Mowat et al. 2002b
16	Nation	A	DNA	2003	Mowat & Fear 2004
17	Burnt River	A	DNA	1997	Wentworth Assoc 1998
18	Prophet	A	DNA	1999	Poole et al. 2001
19	Galore/Stikene	A, T	DNA	2004-05	Rescan 2008
20	Nass	?	DNA	2002	Demarchi 2002
21	Taku	A	DNA	2001-03	Heinemeyer & Griffin 2006
22	Kingcome	A	DNA	1997	Boulanger & Himmer 2001
23	Owikeno	T	DNA	1998-02	Himmer & Boulanger 2003 Boulanger et al. 2004a
24	Kimsquit	T	Heli	1998 -	Dielman 2010
25	Bella Bella	A	DNA	2009	C. Darimont, pers. comm.
26	Southern Coast Ranges	A, D, C	DNA	2004-07	Apps et al. 2009
27	Toba/Bute	A, D, C	DNA	2008-10	Apps 2010, Apps 2011
28	Tatlayoko	A	DNA	2006-07	Mueller 2008
29	North Cascades	A	DNA	1998	Mowat & Davis 1998 Romain-Bondi et al. 2004

[a] A = abundance/density; D = distribution/occurence; T = Trend/Demographics; C = connectivity/fragmentation

3.2 PROJECT REVIEW

3.2.1 Southeast BC

To date, most grizzly bear population study or survey in British Columbia has occurred in the southeast, primarily within the Kootenay Wildlife Management Region (Region 4). The Upper Columbia study (a.k.a., West Slopes) surveyed 5,496 km^2 over three years and was the first to demonstrate the utility of hair-snag/DNA sampling in the survey of grizzly bear populations (Woods et al. 1999). The 1996 grid was of 64 8x8 km cells, while 1997 and 1998 grids were of respectively 76 and 94 5x5 km cells, each of which partially overlapped the 1996 grid. This sampling area was not central to any GBPU but straddled boundaries among the Central Rockies, Rockies Park Ranges, Spillamacheen, and North Selkirk units. Population abundance was estimated independently for each grid (Boulanger 2001a, Boulanger et al. 2004b). Sampling represented a range of habitat and human conditions in the local region. Population distribution given landscape factors was modeled spatially and extrapolated beyond the combined sampling area (Apps et al. 2004), and landscape partitioning between grizzly and black bears was also explored (Apps et al. 2006).

Also in 1996 and 1997, surveys were conducted in the Elk Valley (2,688 km^2) and Flathead (3,264 km^2) drainages using 8x8 km grid and four sessions (Boulanger 1997, Interior Reforestation 1997, Halko 1998, Boulanger 2001b). The Flathead GBPU was well covered in this effort but only the eastern (Elk Valley) portion of the South Rockies GBPU was sampled. Within the Elk Valley, this sampling effort exhibited severe closure violation due primarily to the long, narrow shape of the sampling area (Boulanger and Hamilton 2001). The Flathead drainage was again surveyed in 2007 (5x5, 4 sessions) resulting in a population estimate that was virtually identical to the initial survey (MacHutchon et al. 2008). In 2002 and 2003, a 1,900 km^2 area was sampled across and around the Crowsnest Highway (Hwy 3) transportation and development corridor (Apps et al. 2007). Objectives pertained to distribution and movements, and geographic closure was not a consideration in the design. These data were combined with the 1996/1997 Elk Valley/Flathead surveys to model regional population distribution in the southern Rockies (ibid.).

Within the Flathead drainage, grizzly bear population demographics have been monitored using radio-telemetry study since the late 1970s. Several aspects of grizzly bear ecology have been addressed through this study, but demographic parameters have been monitored (*sensu*, McLellan 1989a,b,c, Hovey and McLellan 1996) to present and can be related to some potential factors of influence (B. McLellan, pers. comm.). Also, an effort was recently initiated to employ hair-snag/DNA sampling to monitor population trend in the Flathead and South Rockies GBPUs (Mowat et al. 2009).

South of the Flathead GBPU, an extensive hair-snag/DNA sampling program was carried out across the 31,410 km^2 Northern Continental Divide Ecosystem of Montana (Kendall et al. 2009). This effort employed scent-stations (7x7, 4 sessions) and also made use of established rub trees to estimate abundance, demography and genetic structure.

West of the Rockies, there have been two sampling efforts in the Purcell Mountains. The "Jumbo" survey area covered 1,650 km^2 in the middle of the central Purcell GBPU, and was sampled in 1998 (5x5, 4 sessions) to derive a population estimate (Strom et al. 1999). From these data, population distribution across the unit was subsequently modeled (Boulanger and Apps 2002). Several sampling efforts and outputs are described by Proctor et al. (2007b) for the Central Purcell, South Purcell, South Selkirk, and Yahk GBPUs. The additional sampling across the Central Purcells (Purcell Wilderness Conservancy) in 2002 covered 1,300 km^2 (7x7, 4 sessions). In the southern Purcells, 1,500 km^2 were sampled in 2001 (8x8, 4 sessions). Straddling Highway 3 between the South Purcell and Yahk units, 2,500 km^2 were sampled in 2004-05 (5x5, 4 sessions). And 1,950 km^2 of the South Selkirk GBPU was covered in 2005 (5x5, 4 sessions). From these data, population estimates were derived for each unit and distribution was modeled. Using data from the aforementioned Selkirk, southern Purcell and southern Rocky Mountain sampling efforts, Proctor et al. (2005) addressed questions of population fragmentation.

East of the Purcells and north of the south Selkirks, one of the early sampling efforts in the province was across the Central Selkirk and Valhalla GBPUs in 1996, with the objective of estimating abundance (Mowat and Strobeck 2000). Here, 9,856 km^2 were covered (8x8, 5 sessions) with every second cell going unsampled in a checkerboard fashion. Abutting to the southwest of the central Selkirks area, a 4,480 km^2 area covering the Granby-Kettle GBPU was sampled for abundance in 1997 (8x8, 5 sessions). Although this population is undoubtedly small, issues of sampling design and/or methods precluded a precise population estimate (Boulanger 2000).

3.2.2 East-Central BC

There have been several grizzly bear surveys to date in the vicinity of Prince George. A 2,494 km^2 area of the Bowron drainage, ~90 km southeast of Prince George, was sampled in 2001 (8x8, 3 sessions) to estimate abundance and document fall movements (Mowat et al. 2002a). This area was set largely within the Quesnel Lake North GBPU, but forest landscapes were almost entirely of early succession due to extensive logging in recent decades. North of this and 110 km northeast of Prince George, the Parsnip/Herrick sampling area covered 9,452 km^2 of both mountainous and interior-plateau topography (Mowat et al. 2002b). This area fell largely within the Parsnip GBPU but also extended into the eastern portion of the Nation unit. Population abundance was addressed, and the notable difference in densities between mountain and plateau landscapes was documented. A short distance to the west, ~100 km northwest of Prince George, a 7,031 area of the Nation River drainage was sampled (8x8, 4 sessions) in 2003 (Mowat and Fear 2004). This area was and more centrally located within the Nation GBPU, and the sampling objective was abundance estimation. The low population density found is expected to have been influenced by the history of human-caused bear mortality in the area. North of the Parsnip, a limited sampling effort was conducted in the Burnt River area during 1997 (Wentworth Associates 1998).

3.2.3 Northeast BC

North of Fort St. John in northeast BC, one grizzly bear survey has been conducted to date. In 1999, an 8,527 km^2 area largely within the Prophet River drainage was sampled (9x9, 5 sessions; Poole et al. 2001). This area included portions of both the Rocky and Alta GBPUs. Within the sampling area, population density was estimated separately for the Northern Boreal Mountains and Taiga Plains ecoprovinces.

3.2.4 Northwest BC

Grizzly bear population surveys have also been limited to date in the northwest quadrant of the province. The Galore Creek study area, encompassing drainages of the upper Stikine River, was initially sampled in 2004-05. Across 10,240 km^2 (16x16), population density was estimated for both interior and coastal sections of the sampling area (Rescan 2008). After this, additional hair-snag/DNA sampling was conducted in 2006 and 2007 with the objective of monitoring population trend and bear movements. Further north, hair-snag/DNA sampling was carried out from 2001 to 2003 along 110 km of the Taku River with the objective of estimating bear density along the river during salmon spawning (Heinemeyer and Griffin 2006). Another river sampling effort was conducted in 2002 along the lower Nass River between communities of Greenville and Mill Bay, east of Kincolith (Demarchi 2002). This effort was referred to as a monitoring program, and a minimum count and location of bears detected was reported among 34 stations along ~40 km of river but a population estimate is not possible.

3.2.5 Central Coast

Within ecosystems of the BC central coast, there have been two grizzly bear population inventory projects (one very recent) and two population monitoring programs. In 1997, a population inventory was completed for a 2,450 km^2 sampling area (7x7, 5 sessions) within the Kingcome and Wakeman watersheds, ~100 km northeast of Port Hardy (Boulanger and Himmer 2001). Another inventory was recently initiated (2009) in the south of the Kitilope-Fiordland GBPU (C. Darimont, pers. comm.). Along six salmon streams in the Owikeno Lake drainage, hair-snag/DNA surveys were conducted between 1998 and 2002, with objectives of deriving independent estimates of population trend and demographics (Himmer and Boulanger 2003, Boulanger et al. 2004a). During this period, helicopter surveys for grizzly bear sightability were also conducted along these rivers as well as the Kimsquit and Dean Rivers further north (Himmer and Boulanger 2003). The Kimsquit helicopter surveys have continued annually through to present (A. Hamilton, pers. comm.).

3.2.6 Southern Coast & Interior

The southwest quadrant of British Columbia, including the southern Coast Ranges, received little focus for grizzly bear population survey until more recent years. In 2004, a multi-year effort was initiated to survey ~50,000 km^2 of the southern Coast Ranges to address the primary objective of population distribution and connectivity, and the secondary objective of abundance (Apps et al. 2009). Annual sampling was conducted over the next four years (10x10, 4-5 sessions), across five GBPUs, four of which are considered Threatened. The Squamish-Lillooet and southern portion of the Toba-Bute units were sampled in 2004, the Stein-Nahatlatch in 2005, the Garibaldi-Pitt and southern portion of the South Chilcotin Ranges in 2006, and the central to northern portion of this latter unit in 2007. Estimates of abundance were derived, and population distribution and connectivity were modeled while exploring the influence of landscape factors. These analyses also made use of data derived through more localized, finer-scale sampling (5x5, 2-4 sessions) within the Squamish Forest District (Apps et al. 2009). Within the larger southern Coast Ranges regional study area, finer-scale sampling was carried out across the occupied portion of the Toba-Bute GBPU (5x5, 4 sessions). The first phase of this effort covered 3,675 km^2 encompassing the Toba and Orford drainages for which population abundance/density was derived and distribution modeled (Apps 2010). The second phase covered 2,450 km^2 encompassing the Southgate drainage (Apps 2011).

Within the North Cascades GBPU, grizzly bear hair-snag/DNA sampling was conducted during 1998 (5x5, 2 sessions, methods issues noted) across a disjunct area of ~2,400 km^2 total (Mowat and Davis 1998). An additional 1,250 km^2 was sampled during 1999 and 2000 (5x5, 2-4 sessions) in the US portion of the North Cascades ecosystem (Romain-Bondi et al. 2004). Geographic closure was not a consideration in either sampling effort, and the underlying objective appears to have been simply detection of resident bears. This was objective was appropriate given that residency of any population within the North Cascades was uncertain. Only a single male grizzly bear was detected in the British Columbia effort (ibid, D. Paetkau, pers. comm.). The very low apparent population density for the larger North Cascades ecosystem was inferred by Romain-Bondi et al. (2004) given the modeled relationship between catch per unit effort and density estimates for several other populations.

3.2.7 Meta-Analyses

There have been three papers that have pooled data among sampling areas, though for different objectives. The Central Selkirks, Bowron, Parsnip and Prophet and one Alberta sampling area (Yellowhead) were pooled for analysis by Mowat et al. (2005) for broader-scale population inference. The authors considered differences in population density among associated ecosystems and made inferences about underlying factors of influence. A pooled evaluation was also completed by Boulanger et al. (2002) for the Upper-Columbia (West Slopes), Jumbo, Kingcome, Granby-Kettle and Prophet sampling areas. They evaluated how well these studies were able to estimate population size in terms of precision, bias, and meeting mark-recapture assumptions. To address questions of population connectivity, Proctor et al. (2005) pooled data sampled from the South Rockies, Flathead, South Purcell, Yahk, Central Selkirk and South Selkirk GBPUs, and Proctor et al. (2009) expanded this analysis by pooled these populations and others from northern BC, Alberta and the northern USA.

3.2.8 Provincial-Scale Inferences

At a provincial scale, there are presently two approaches for inferring grizzly bear population abundance and status for GBPUs for which adequately reliable and representative inventories or research-based density estimates are not available. Where empirical inferences are not possible or appropriate, population size and carrying capacity has been estimated through qualitative evaluation of broad-scale habitat potential in the context of assumptions regarding historic human impacts, and augmented with sightings records where available (Hamilton and Austin 2004). The approach is a refinement of that presented by Fuhr and Demarchi (1990), where density classes are assigned to combinations of biogeoclimatic subzone/variant and ecosection as best approximated given current knowledge, including the proportion of salmon or meat in the diet. These densities are then "stepped down" by wildlife management unit to account for habitat loss, alienation, fragmentation, and mortality history. This approach has been repeatedly criticized because of its subjectivity; both the initial ratings and the subsequent step-downs are opinion based.

More recently, an alternate and more objective approach to inferring population density has been adopted for GBPUs within some areas of the province (Mowat et al. 2004). Predictions are based on regression modeling of empirically-determined density estimates from across western North America against broad landscape factors related to habitat productivity, human activity (influencing habitat effectiveness and/or unreported mortality risk), as well as known mortality (past 10 years). The authors did not trust predictions for coastal ecosystems due in part to an inadequate sample, and predictions for some interior GBPUs were considered unrealistic. However, the model will be improved, particularly as additional inventories are completed (see Section 4 for priority assessment) or otherwise reliable density estimates can be incorporated (G. Mowat, pers. comm.). Separate coastal and interior models may also be derived.

4.

DETERMINING GEOGRAPHIC PRIORITIES FOR GRIZZLY BEAR POPULATION INVENTORY & MONITORING

4.1 DEFINITIONS & OBJECTIVES

The two focal areas of this report are population "inventory" and "monitoring" and are briefly defined as follows:

Inventory – outputs pertaining to the present state of a grizzly bear population that are specific to a defined geographic unit. In British Columbia, such products can usually only be derived through hair-snag/DNA sampling at the population level.

Monitoring – activities that pertain to the tracking of long-term population trend, ideally with understanding of the biological mechanisms and underlying causal factors. Behavioural responses of individual bears are excluded from consideration here (e.g., changes in movements and/or habitat selection patterns), regardless of assumptions about how such responses manifest at the population level.

Each focal area is further characterized by the following objectives:

4.1.1 Inventory Objectives

1. *Absolute abundanc*e – present population estimates with defined confidence.
2. *Population distribution and connectivity* – understanding and associated prediction pertaining to bear population distribution and connectivity (genetic and demographic) relative to, and as influenced by, landscape-level environmental factors. This objective includes information pertaining to landscape occupancy.
3. *Baseline for trend monitoring* – establishing a baseline for subsequent long-term sampling to monitor trend in abundance, distribution, connectivity and individual or cumulative causal factors. The inclusion of this objective acknowledges the fact that an "inventory" project can provide a foundation for long-term monitoring, depending on the monitoring approach.

4.1.2 Monitoring Objectives

1. *Trend in relevant parameters and indices over time* – parameters may include measures of bear abundance (relative or absolute), population vital rates and demographics (reproduction, survival, immigration, emigration), and environmental (habitat and human) factors of potential influence at the population or subpopulation level. This objective is specific to a defined geographic unit or group of bears.

2. *Spatial variation in the above* – This objective accounts for the importance of understanding spatial patterns in bear-population trend and associated factors, within and among defined populations.

4.1.3 Grizzly Bear Population Units

Grizzly bear population units (GBPUs) are the spatial management units defined and adopted by the Ministry of Environment (MOE) to reflect our best present understanding of relatively cohesive and manageable populations of consistent behavioural ecotype (Figure 3). GBPU lines correspond to geographic breaks or restrictions in population connectivity where known, although significant population boundaries may not exist between many adjacent units, particularly in the north. I use GBPU as the spatial unit of comparison in evaluating geographic priorities for inventory and monitoring across British Columbia.

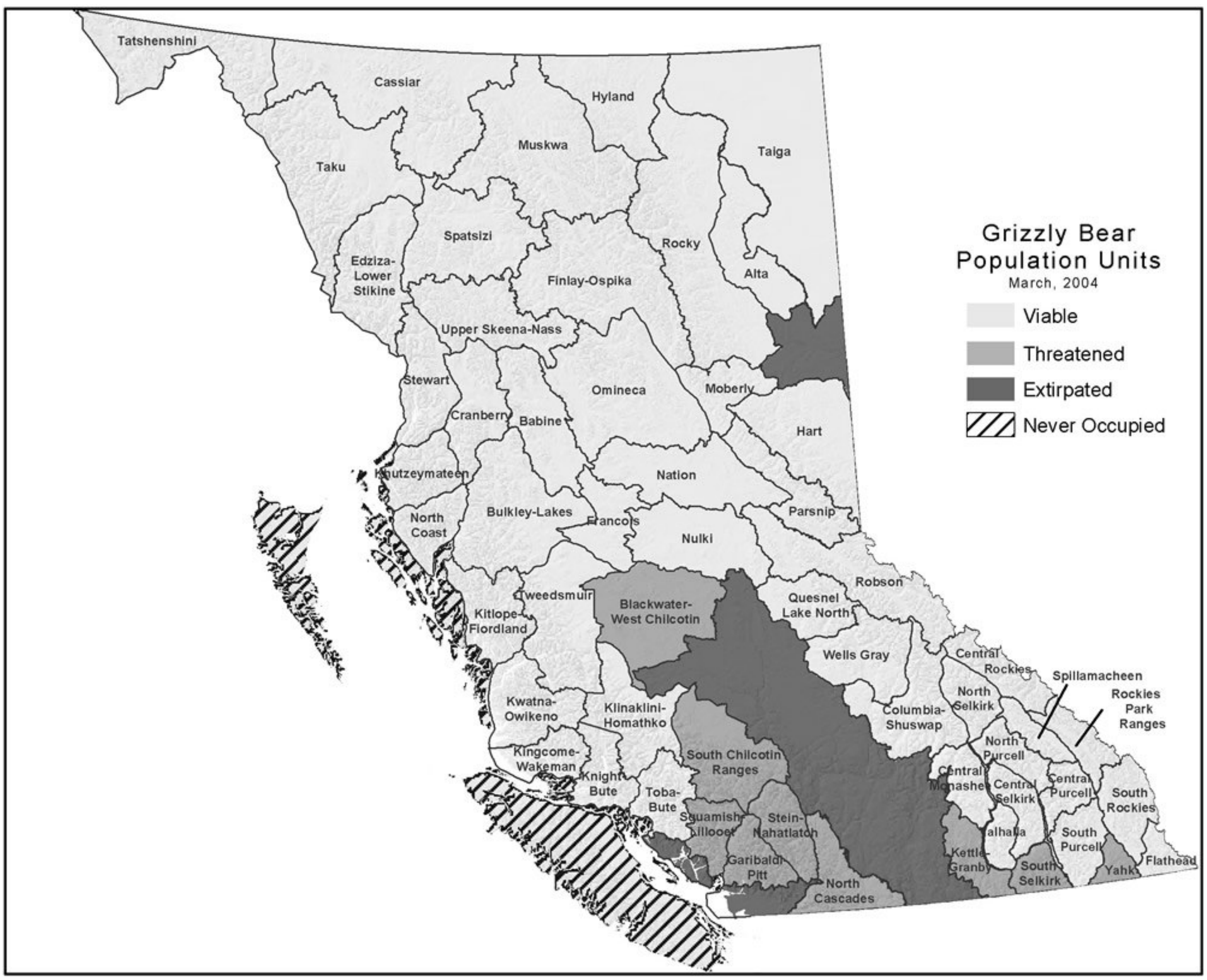


Figure 3. Defined grizzly bear population units (GBPUs), and associated status, across British Columbia (from Hamilton and Austin 2005).

4.2 APPROACH

In the process of determining population inventory and monitoring priorities across the province, I applied a structured rating system such that relative rankings among GBPUs are derived from objective and transparent logic. For each of the 57 GBPUs across the province, my intent was to derive a score reflecting the relative need for population inventory specific to (1) abundance, (2) distribution and connectivity, and for (3) population monitoring. GBPU scores for each objective were derived on the basis of a common set of criteria.

4.2.1 Criteria

The following criteria were selected and vetted, with minor refinement, among several bear research and management biologists in a recent workshop (Compass 2009).

11. *Confidence in knowledge of population & status*
    - Gap in our knowledge of present population, taking into consideration predictors (models and/or existing quantitative estimates) relative to existing representation of broad ecological/human conditions and expected ecotypic variation.
12. *Confidence in knowledge of distribution & connectivity*
    - Gap in our knowledge of spatial pattern of abundance (including landscape occupancy), population connectivity, and associated landscape factors.
13. *Current assumed status and need for recovery*
    - Current assumed status directly reflects expected population relative to maximum potential population given inherent habitat potential. Considered in this criterion are expectations of population distribution and degree of or potential for isolation.
14. *Potential for recovery*
    - Potential for management actions to affect habitat suitability, effectiveness, and mortality risk to allow recovery (regardless of population status and *need* for recovery).
15. *Anticipated short- and long-term threats*
    - Susceptibility to threats that pertain to habitat and human influence, local or broad (e.g., climate change). Threats are expected to decrease supply of suitable and effective habitat and/or reduce population connectivity with the potential for fracture.
16. *Current-level and anticipated trend in bear mortality from harvest*
    - Considers not only present hunter harvest but potential harvest demand.
17. *Current-level and anticipated trend in bear mortality from conflict with people*
    - Consider existing mortality classed defense of life and property as well as the potential for future bear-human interactions resulting in bear mortality.

18. *Ecotype representation*
    - Accounts for the potential of the unit to represent the ecotype to which the population is expected to belong, as delineated by ecoprovince.
19. *Conservation significance to adjacent populations*
    - Accounts for the potential importance of a population to the connectivity and viability of one or more adjacent or nearby populations.
20. *Importance to existing/ongoing program*
    - acknowledges the importance of the unit to a recognized program of research, inventory, or monitoring, and the value-added from such prior investment.

4.2.2 Criterion Weights (by Objective) & Scores (by GBPU)

For each of the aforementioned objectives (abundance, distribution/connectivity, trend monitoring), the above criteria were weighted to reflect importance relative to each other (Figure 4). Weightings were discussed and finalized at the October workshop (Compass 2009)[7].

For each GBPU, each criterion was then scored on a 5-point scale according to the strength of agreement or degree to which it is expected to apply. In the case of the "knowledge gap" criteria (first two above), "lower" confidence corresponded to a higher score. This process required some iterative refinement and discussion to ensure that weightings and scores reflected the collective "intuition" among biologists. At the October workshop, scores were finalized for 10 southern GBPUs (8 Threatened, 2 Viable) for which participants had sufficient collective knowledge. From biologists across the province, I then solicited opinions among criteria and suggested scores for remaining GBPUs[8]. For each criterion, I based final scores on collective opinion among respondents, but I applied certain logical scoring rules to some criteria as follows:

- *Confidence in knowledge of population & status* – scores reflect existing empirical knowledge from recent inventories or population research, associated confidence, and GBPU representation (as reviewed in Section 3 of this report). This criterion was weighted most heavily among participants at the October workshop. However, its actual weighting had to be increased further to ensure that GBPUs for which thorough and representative inventories have been recently completed could not be ranked high on the basis of combined score.
- *Confidence in knowledge of distribution & connectivity* – since anecdotal knowledge and sightings can be relatively reliable for this criterion, scores reflected collected opinion, with adjustments only to maximize consistency. As with the previous criterion, weighting had to be increased considerably to ensure that GBPUs for which distribution and connectivity has recently been well-addressed could not be ranked high on the basis of combined score.

[7] October 2009. Attended by 14 – see Acknowledgements.
[8] 18 responded directly or indirectly – see Acknowledgements.

- *Current assumed status and need for recovery* – For this criterion, I relied on current provincial assumptions of actual population relative to carrying capacity and assigned scores as follows: <40% = 1, 40-60% = 2, 60-70% = 3, 70-80% = 4, 80-100% = 5.
- *Potential for recovery* – This criterion is considered independent of any assumed need for recovery. It reflects a manager's control over factors influencing bear demographics, including habitat and mortality. Because legal harvest can be directly controlled, I assigned a score of 5 to all GBPUs for which hunting is open across 90% of the unit. I assigned 4 to those with hunting across 50-90%, and 3 to where hunting occurs across 25-50%. Beyond this, I deferred to the collective opinion of contributors and workshop participants.
- *Anticipated short- and long-term threats* – I deferred to the collective opinion among contributors for this iteration. However, I recommend using the proportion by which assumed carrying capacity is "stepped-down" to reflect human impacts by wildlife management unit.
- *Current-level and anticipated trend in bear mortality from harvest* – I deferred to the collective opinion among contributors for this iteration.
- *Current-level and anticipated trend in bear mortality from conflict with people* – I deferred to the collective opinion among contributors for this iteration. However, average annual reports of bear-human conflicts relative to GBPU size could be used to index the score for this criterion.
- *Ecotype representation* – I deferred to the collective opinion among contributors for this iteration. However, I recommend that units be scored according to (1) the degree to which they are encompassed within a single ecoprovince, and (2) the degree to which they are expected to contain naturally functioning ecosystems perhaps as inferred from provincial road densities.
- *Conservation significance to adjacent populations* – I deferred to the collective opinion among contributors for this iteration.
- *Importance to existing/ongoing program* – I deferred to the collective opinion among contributors for this iteration. However, scores higher than 1 should be justified by the existence of some existing or ongoing monitoring and/or research program.

For each GBPU, I calculated a raw combined-score for each objective (abundance, distribution/connectivity, or monitoring). That is, I multiplied the criterion score by the criterion weight for the given objective, summed the products among criteria, and divided by the maximum possible raw-score. I then scaled raw GBPU scores for comparison among GBPUs for each objective. That is, I subtracted from the raw score the minimum raw-score among GBPUs, and divided this by the range of raw-scores among GBPUs. For each objective, scaled GBPU scores thus ranged between a pegged minimum of 0 and maximum of 1. Scores were translated to a 5-point scale for map display.

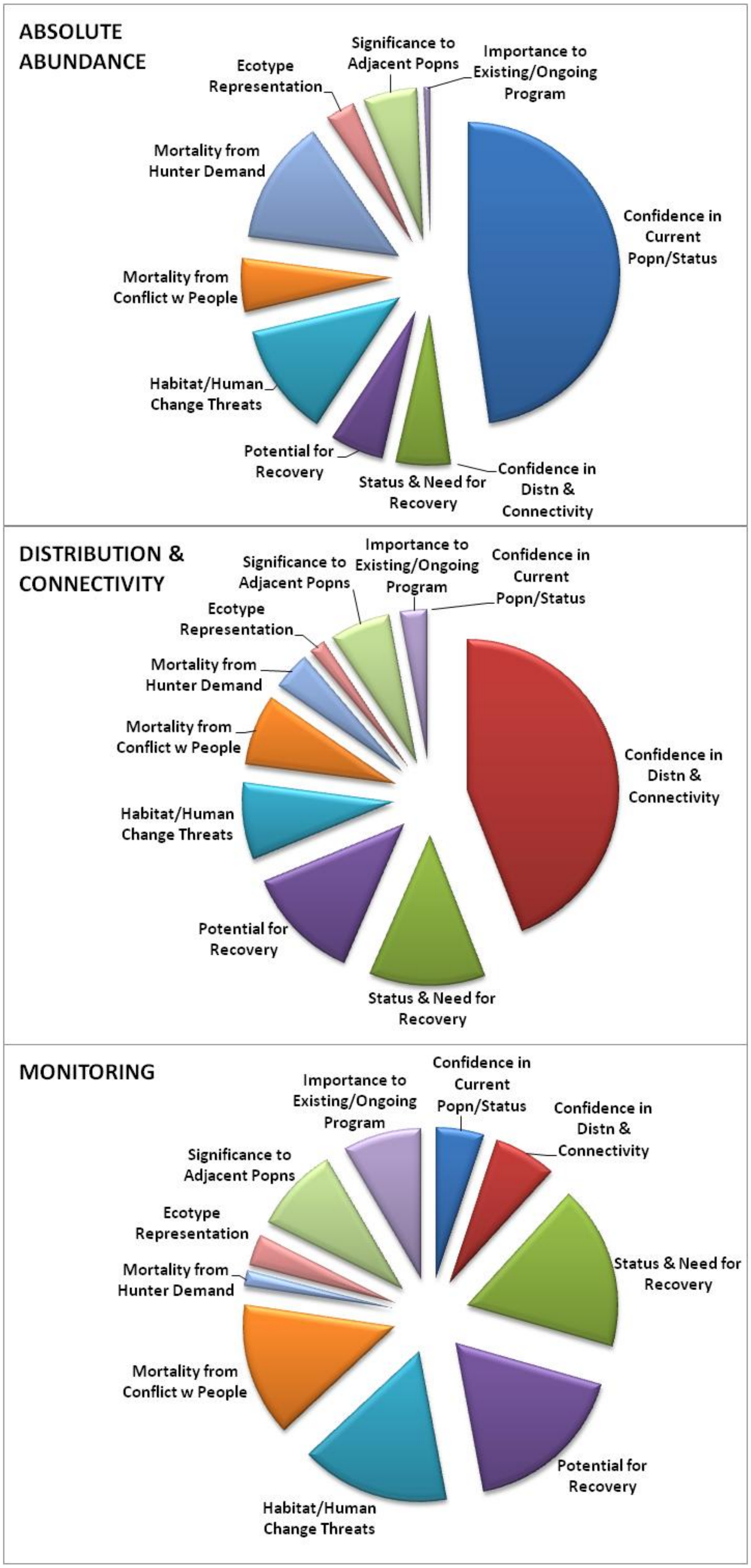


Figure 4. Relative weights among ranking criteria for each of three grizzly bear inventory objectives.

4.2.3 Interpretation & Application for Decision-Support

For each objective (abundance, distribution/connectivity, monitoring) rankings and associated scores derived as above can provide direction to project proponents and assist funding decisions. Specifically, grizzly bear population inventory and monitoring proposals can be compared and ranked based on geographic priorities. Because GBPUs are scored from 0 to 1 for each objective, their relative priority in comparison to each other can be gauged. Moreover, proposals can be compared on the basis of only specific criteria or combinations thereof. This may be helpful in applying the tool to proposals that address objectives other than population inventory or monitoring. Finally, specific GBPUs can be selectively included/excluded, for example, to compare only among units that are subject to population harvest or only among those considered Threatened.

It is essential to note that this decision-support tool will be of most help if updated on an annual basis given projects approved or completed, newly available information, and/or changing assumptions. In the least, scores per GBPU/Objective should be re-visited annually. The weightings among criteria could also be re-evaluated and periodically revised if needed.

4.2.4 Further Criteria and Direction for Proposal Evaluation

In addition to establishing geographic priorities for encouraging and evaluating proposals, there are additional criteria against which independent proposals should be evaluated. The following should be considered collectively in proposal evaluation: (1) objective-specific geographic (GBPU) priority, including the urgency of conservation action in Threatened units, (2) the likelihood of achieving objectives with adequate confidence, (3) cost-effectiveness including the potential for funding partnerships, and (4) alignment and consistency with any specific approach, design and protocol that has been promoted or encouraged for the province or given area (or ecoprovince). How a proponent may best satisfy this last criterion is somewhat debatable. It depends on other existing projects and the degree to which meta-analyses and/or comparisons among projects (both in terms of outputs and in pooling data) are desirable and possible. It is incumbent on the proponent to highlight issues of consistency, coordination, and the use of adopted standards, as well as if and how the work can contribute to addressing the broadest-scale questions pertaining to environmental (e.g., climate change) and/or mortality factors that could only be addressed at the provincial or eco-provincial scale.

Specific funding sources may have their own sense of provincial and geographic priorities. Proponents would do well to at least contemplate what those priorities might be, and balance funding requests among sources given the primary objectives and geographic area. For example, some sources may be more inclined to support projects within GBPUs where hunting is open; others may wish to support recovery in Threatened units only

4.3 GBPU SCORES & RANKINGS

The following maps and charts illustrate GBPU scores for each criterion and the combined score by inventory objective. Among GBPUs, the five-point scores applied for each of the 10 criteria are presented (Figure 5) along with the combined score (given weightings among criteria) derived for each inventory objective but generalized to a five-point scale (Figure 6). The specific (0→1) score calculated can be applied to rank GBPUs from high to low priority for each inventory objective. Current rankings are shown relative to all provincial GBPUs (Figures 7 - 9) and only GBPUs considered Threatened (Figure 10).

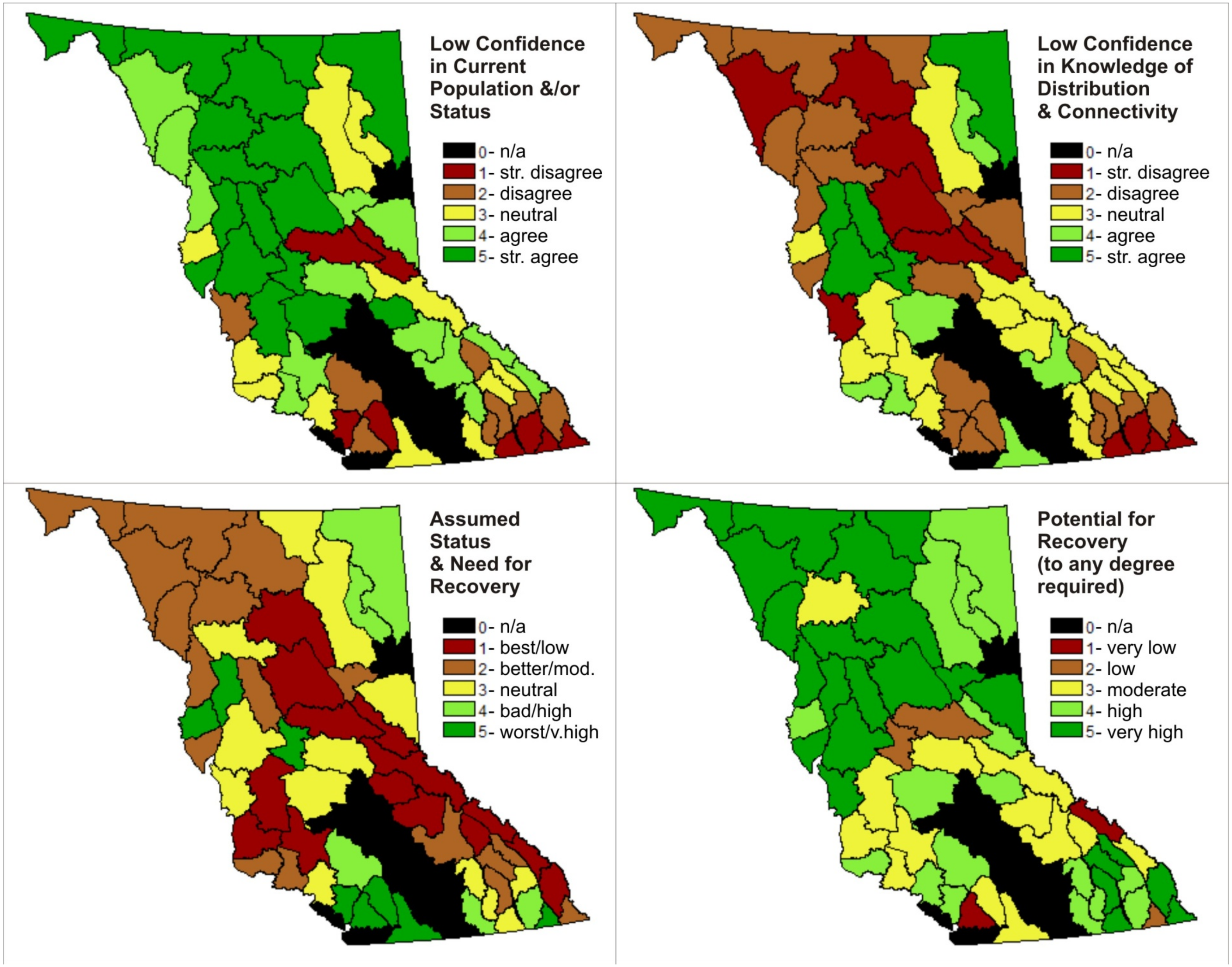
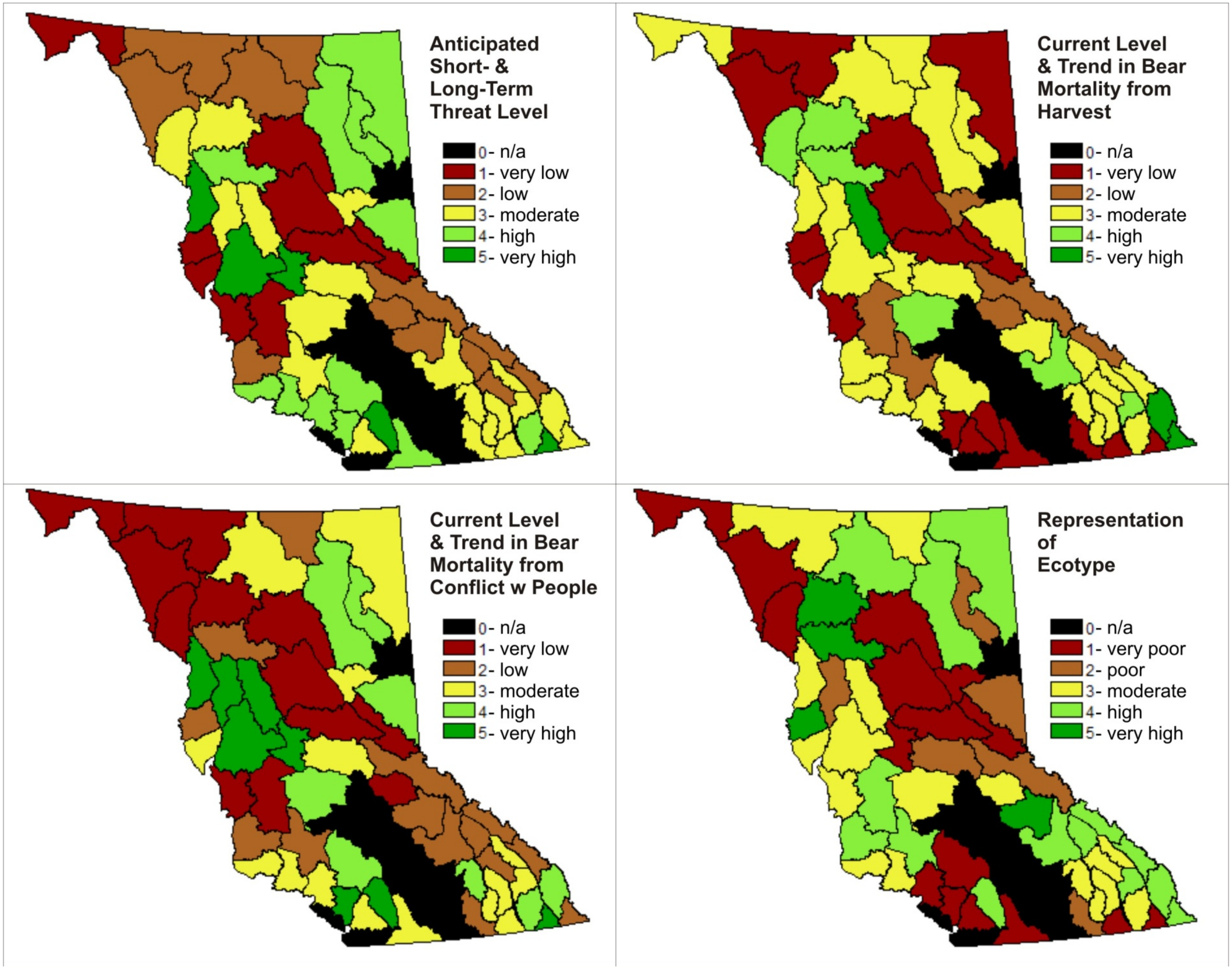


Figure 5. GBPU scores by each of 10 criteria used for determining geographic priorities for each of three inventory objectives. Continues on next pg.



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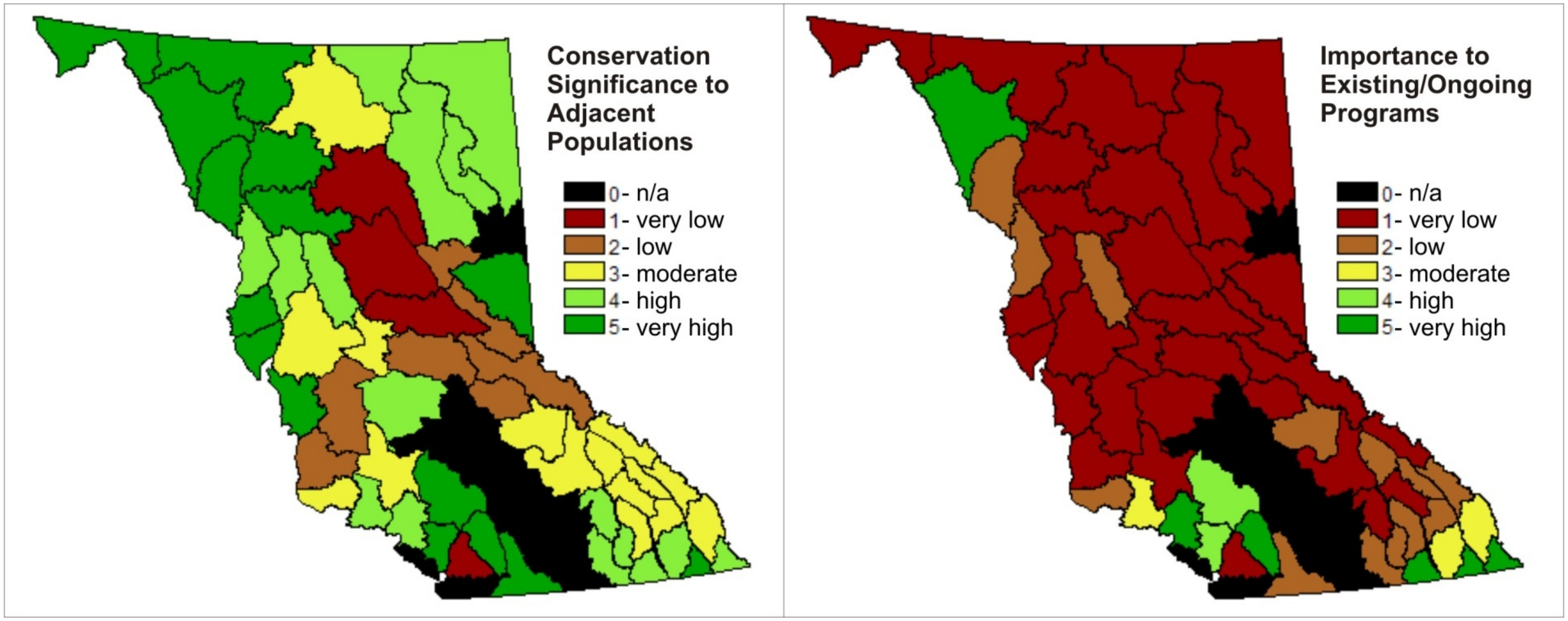

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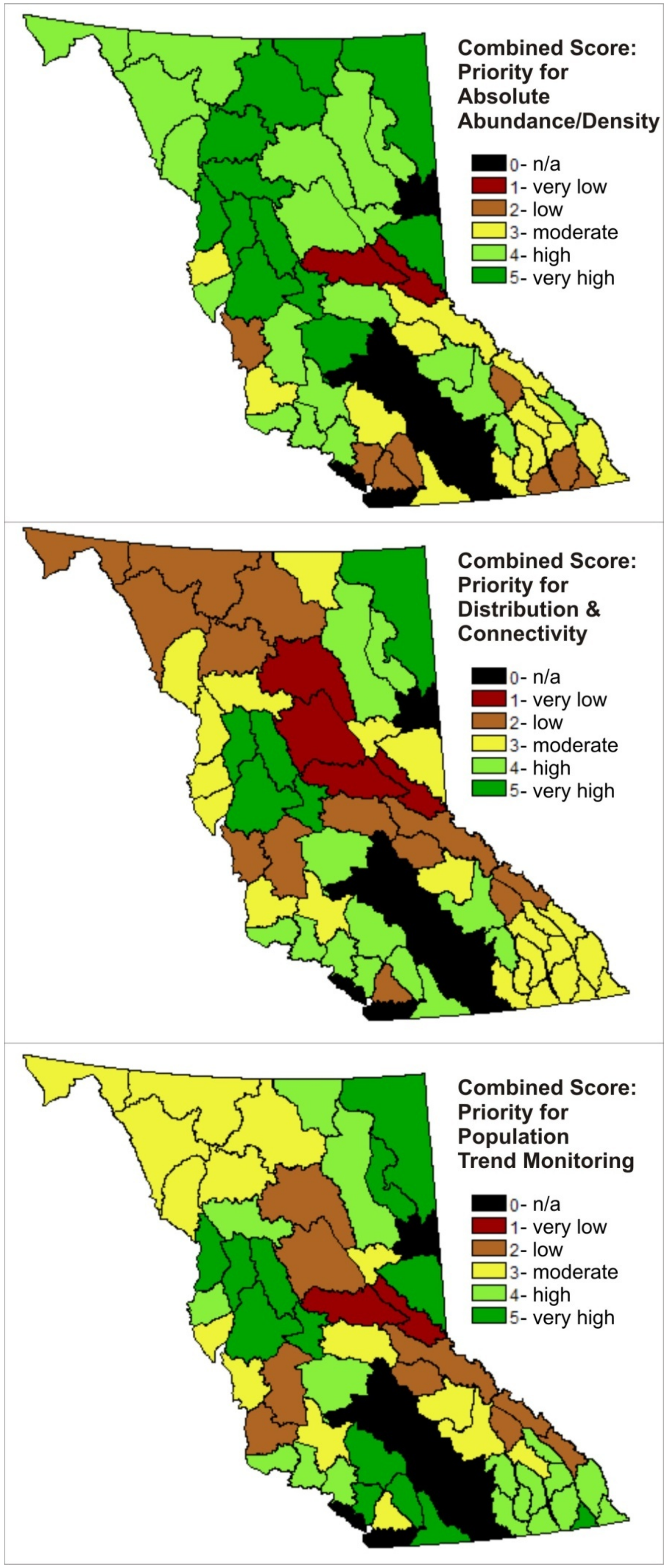

Figure 6. Combined and generalized (5 classes) GBPU scores among criteria for each inventory objective.

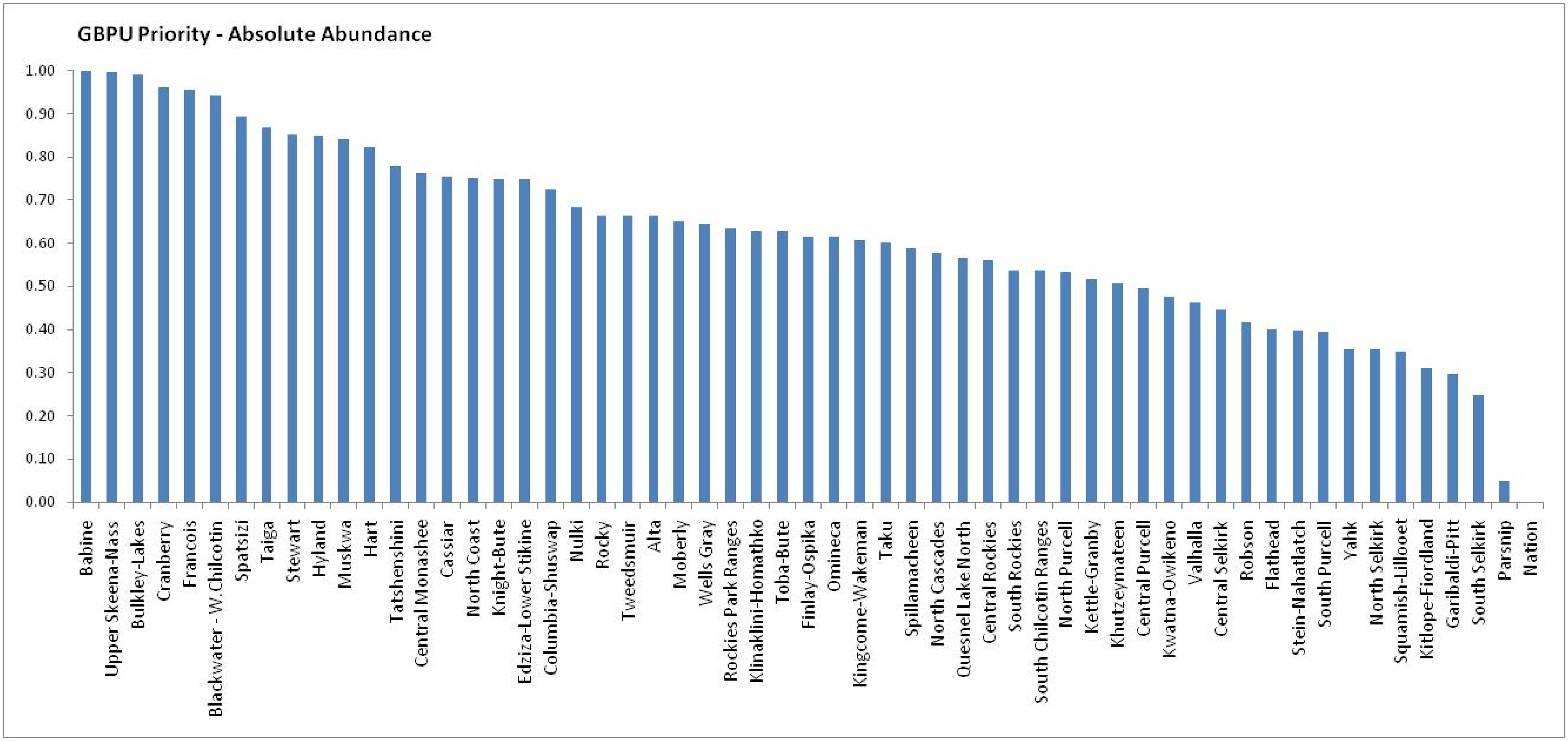

Figure 7. Comparison of combined scores among all provincial GBPUs for the inventory objective of estimating abundance.

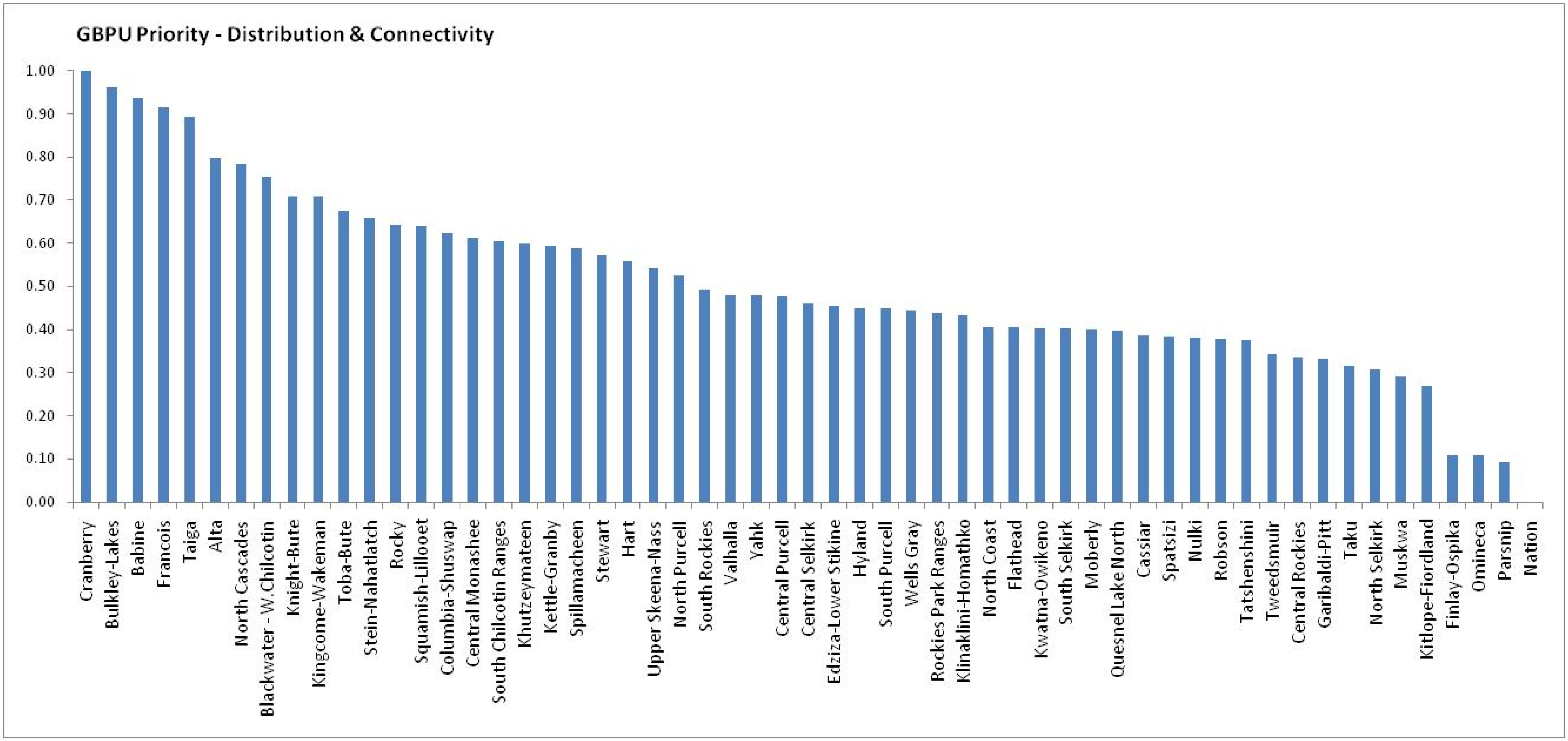

Figure 8. Comparison of combined scores among all provincial GBPUs for the inventory objective of estimating distribution and connectivity.

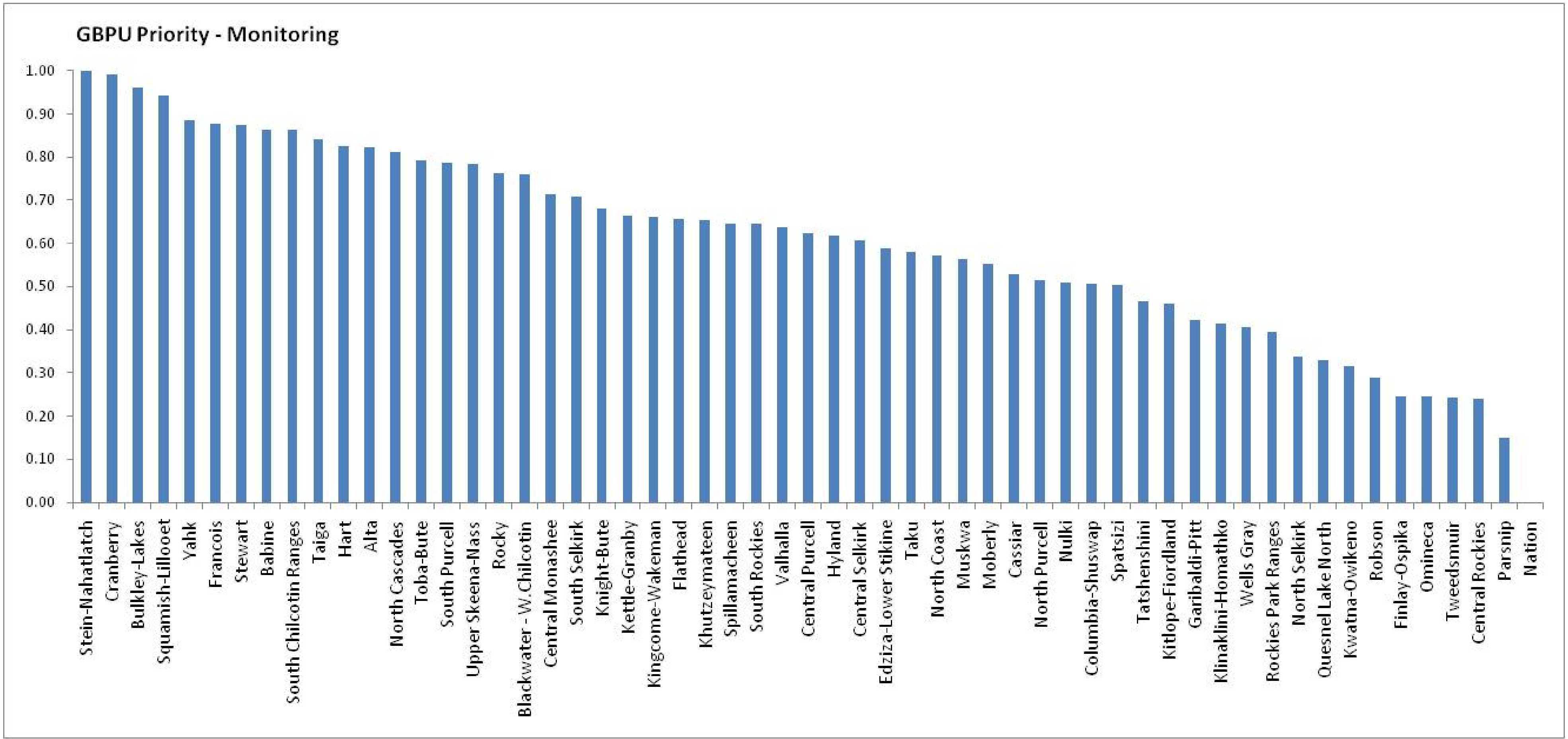

Figure 9. Comparison of combined scores among all provincial GBPUs for the inventory objective of population monitoring.

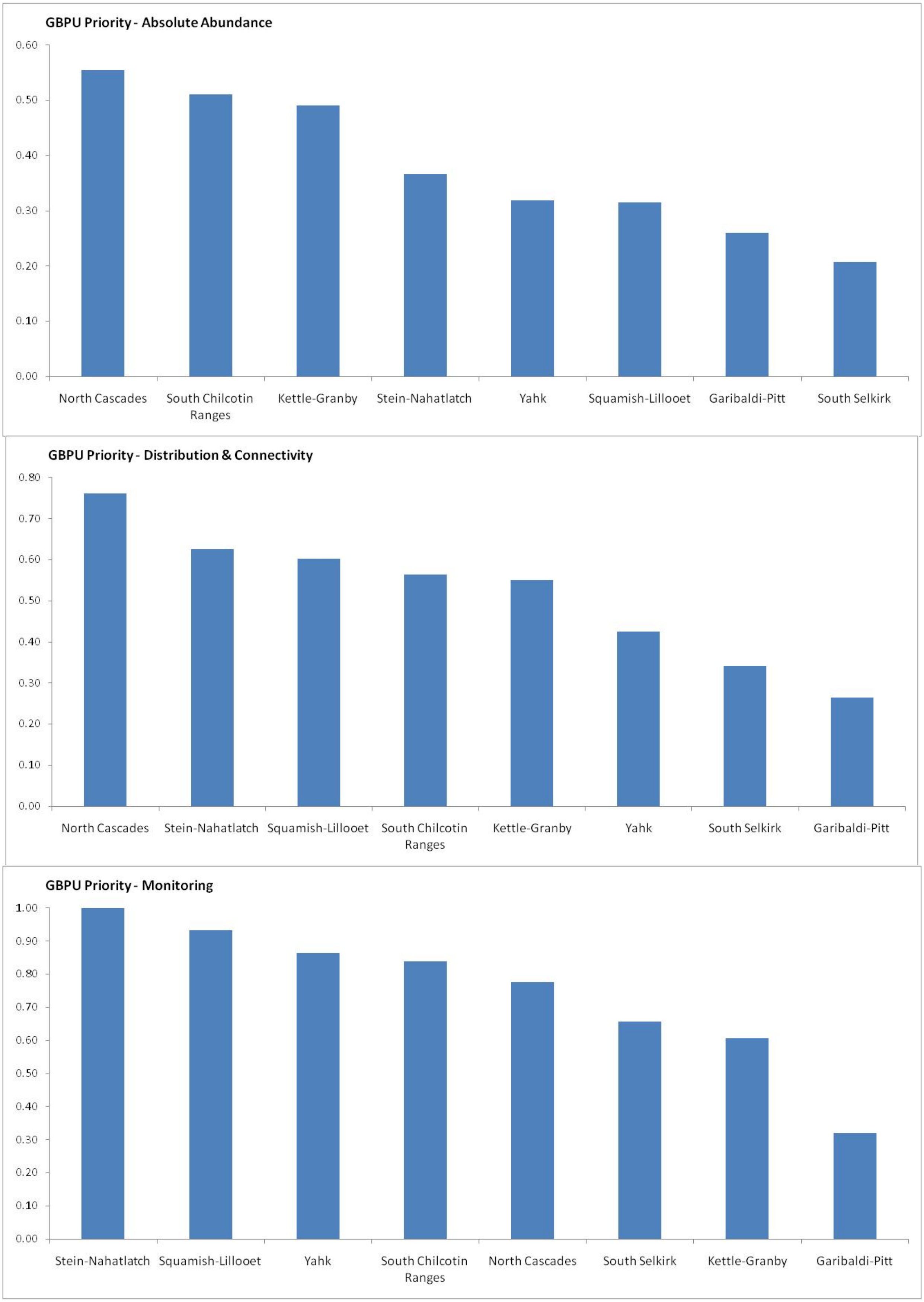

Figure 10. Comparison of combined scores among Threatened GBPUs for each inventory objective.

4.4 CONCLUSIONS & RECOMMENDATIONS

The scoring exercise described in this section clearly highlights certain GBPUs and/or regions that should be of relatively high priority for inventory specific to the objectives of abundance/density, distribution/connectivity, and baseline for trend monitoring. Rankings are largely determined by current information gaps, but other criteria serve to further differentiate and prioritize among those units for which there is presently little reliable knowledge. The final GBPU scores derived from the combination of weighted criteria are only for the purpose of comparison and ranking among units, and nothing further should be inferred from these scores. Outputs are intended only to support decisions in the allocation of limited funding and other resources for grizzly bear population inventory and monitoring.

Current outputs from this exercise are intended to provide direction for future grizzly bear population inventory in the immediate future, but the tool itself should be considered dynamic as it is updated and refined. In the least, scores will change as new information comes available to address existing information gaps and opinions are revised regarding other criteria. Hence, the tool should be redressed periodically (annual is ideal).

In this report version, it is important to stress that scores presented should be considered in light of certain limitations and caveats. Among southern units (including all Threatened units), scores were derived in a workshop setting on the basis of involved discussion, debate and consensus among biologists with relevant experience and knowledge of those units. However, the remaining majority of units across the province were scored on the basis of inputs from biologists that were provided on an individual basis. These scores did not benefit from discussion and debate regarding rationale, particularly relative to other units. This potential for discrepancy was exacerbated by the fact that different individuals provided scores for different units and there were few opinions (often only one) to draw on for a particular unit. As noted (Sec. 4.2.2), scores for some criteria can in fact be based on pre-existing assumptions and quantifiable information. Where scores must be based on opinion, I recommend that these be derived in a workshop setting that facilitates adequate discussion and ensures that differences in scores among units are justifiable. I suggest that these improvements be applied in the next iteration of GBPU scoring and ranking, and that this report be updated as appropriate. A future update to this report may also be appropriate to reflect any evolution in methods and design considerations (Section 2) and the summary and review of projects initiated and/or completed to date (Section 3).

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