Scientific Review of Grizzly Bear Harvest Management System in British Columbia

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Executive Summary

The objectives of this report are to review the background information on grizzly bear (*Ursus arctos*) management and conservation in British Columbia, to review the key controversies associated with grizzly bear harvest management, and to conduct a technical review of relevant documents applicable to grizzly bear harvest management. This report is intended to evaluate the sustainability of the grizzly bear hunt in BC, to assess the level of conservation risk associated with implementation of both the current and revised provincial grizzly bear harvest management procedures, and to provide recommendations for improving the Province's grizzly bear harvest management procedure.

Assessing the sustainability of wildlife harvesting is challenging — particularly so for a species such as the grizzly bear, with a low rate of potential population growth, low density, and high costs for monitoring. Moreover, the range of grizzly bears in BC is vast, and accessibility is often difficult. Despite these constraints, we conclude that the BC grizzly bear harvest management procedures have attained a high level of rigor with a solid scientific underpinning modified, as necessary, by professional judgment. We believe that adequate safeguards have been established to ensure, with a high degree of confidence, the sustainability of this harvest. Nonetheless, we identified some specific changes that could improve harvest management and the long-term conservation of BC's grizzly bears. The future of grizzly bears in the coming decades will be challenged as the human population in the Province increases. Rigorous planning, habitat monitoring, conservative harvest levels, and a predictable level of research, monitoring, and data assessment is essential for the continued conservation of this species.

Key recommendations:

1) Develop a transparent and repeatable process for calculating the allowable harvest in each GBPU, and make this information publicly available. Specifically, provide rationale and documentation for each population estimate (especially when expert opinion is used) and for step-downs.

2) Investigate the possibility of relating the rate of allowable human-caused mortality to current habitat conditions within management units.

3) For each harvest allocation period, employ updated geographic information system layers to redo and improve the modelling used to derive population estimates. The current approach to estimating population size for each GBPU could be improved by developing resource selection models for those areas with adequate data. Further, changing ecological conditions throughout the Province indicate that improved assessment of ecological parameters (e.g., key foods) are required to inform any observed changes in grizzly bear populations or to anticipate such changes.

4) Establish population trend monitoring procedures in areas where long-term population declines, or significant fluctuations (e.g., due to changing food availability), are suspected, or where non-harvest human-caused mortality is high. Additionally, use age-at-harvest data to assess population trends over larger regions. We recommend that application of Statistical Population Reconstruction (SPR), using recently developed

methods to investigate trends in grizzly bears across multiple Wildlife Management Units with data that are already available, should become a part of the normal monitoring system.

5) Increase opportunities for public consultation on grizzly bear harvest management in advance of recommendations pertaining to openings/closing of harvest and changing harvest levels.

6) Establish objectives for accommodating both hunting and viewing of grizzly bears, and investigate whether conflicts exist.

7) Habitat loss and degradations remain a significant challenge to grizzly bear conservation. Improved habitat monitoring is required to adjust harvest levels if ecosystem carrying capacity for grizzly bears declines.

8) Develop specific guidelines for access management as it pertains to grizzly bear habitat and harvest pressure.

9) Specific changes to the Grizzly Bear Harvest Management Procedures would improve the rigor and repeatability of the application of these procedures, and help ensure the sustainability of the harvest (e.g., mandatory harvest reporting procedures, developing GBPU-specific goals and objectives).

10) Increased cooperation and collaboration with adjacent jurisdictions (including Parks Canada, railways, Alberta, Montana, Yukon) would improve population management and monitoring.

11) Resources dedicated to grizzly bear harvest management are inadequate. Additional funding to improve population inventory, monitoring, data handling, and analysis is needed. Resources should be provided in a predictable manner to facilitate management needs and research requirements.

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List of Acronyms

AAH – Annual Allowable Harvest
AAM – Annual Allowable Mortality
COSEWIC – Committee on the Status of Endangered Wildlife in Canada
CPUE – Catch Per Unit Effort
F-D – Fuhr-Demarchi method
FWB – Fish and Wildlife Branch of the MFLNRO
GBHM – Grizzly Bear Harvest Management
GBHMPM – Grizzly Bear Harvest Management Procedure Manual
GBPU – Grizzly Bear Population Unit
GOABC – Guide Outfitter Association of British Columbia
HCTF – Habitat Conservation Trust Foundation
MFLNRO – Ministry of Forests, Lands and Natural Resource Operations
MSE – Management Strategy Evaluation
MSY– Maximum Sustainable Yield
MU – Management Unit
PVA – Population Viability Analysis
RSF – Resource Selection Functions
SECR – Spatially Explicit Capture Recapture
SPR – Statistical Population Reconstruction

1. Introduction

The management of wildlife deals with the practical aspects associated with the day-to-day procedures to avert species extinctions at one end of the spectrum, and more broadly to determine treatments for small or declining populations, acceptable levels of harvest for a sustainable yield, or to reduce a population that is too dense or negatively affecting other resources (Caughley 1977; Caughley & Gunn 1996). Management of grizzly bears (*Ursus arctos*) has a long and varied history in North America with range contraction, attempts at eradication, and subsequent efforts to restore and conserve remnant populations (Servheen, Herrero & Peyton 1999; Miller, McLellan & Derocher 2013). The species as a whole occupies about 60% of its former range in Canada, close to all of its historic range in Alaska, and about 2% in the US south of Canada; it is extirpated from Mexico (Servheen, Herrero & Peyton 1999; Miller, McLellan & Derocher 2013). In British Columbia (BC), grizzly bears occupy about 90% of their historic range (estimate provide by MFLNRO[1]).

Grizzly bears were assigned as a species of *Special Concern* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2012; www.cosewic.gc.ca). In BC, grizzly bears are listed as S3 (Vulnerable) by the Conservation Data Centre (www.env.gov.bc.ca/cdc). Human-caused mortality for grizzly bears include legal hunting, defence of life and property, poaching, and vehicle and train collisions (COSEWIC 2012). COSEWIC reported that in Canada as a whole, there was no evidence of an overall population decline over the past 20 years but concerns were raised about populations in Alberta, southern BC, and parts of the Yukon where recent mortality trends indicate possible declines. Further, concerns were raised about genetic fragmentation in the southern parts of its range where some populations are increasingly isolated and subject to demographic stochasticity. The report noted concerns about naturally low reproductive rates, increasing pressures of resource extraction, and cumulative impacts affecting the longer-term status of the species without adequate attention to conservation concerns. It was noted that, at high densities, in addition to food, grizzly bear populations might be limited by intraspecific predation or conflict. Legal hunting was identified as a threat by COSEWIC (COSEWIC 2012: pg. ix) although the basis for this assessment is unclear.

Hunting of grizzly bears has been particularly controversial in BC, both in terms of ethics and beliefs, and long-term sustainability. Apparently viewing this hunt as unsustainable, in 2002 the European Union banned the import of grizzly bear trophies from BC to EU member countries. A panel of outside experts was convened in 2001 to evaluate the question of whether the harvest management procedures were conservative enough to reasonably ensure long-term population stability or growth. That panel (Peek et al. 2003: 67) concluded, "the harvest of grizzly bears in BC *can* [our emphasis] be managed on a sustainable basis, with minimal risk of population declines." The panel also identified a number of safeguards to alleviate risk that were in place within the management system at that time, but also posed a number of improvements to further reduce risk of population declines. The following excerpt (p. 68) summarizes the tenor of that panel's report:

[1] Occupied area was determined by totaling the area for viable and threatened GBPUs and dividing it by the total of viable, threatened, and extirpated GBPUs. Areas of BC grizzly bears are classified as "threatened" are considered to be occupied.

> "Overall, the Panel concludes that current protective measures, combined with some additional measures listed in the recommendations section of this report offer a robust conservation strategy for grizzly bears. Our confidence in this conservation strategy is enhanced by the recognition that the B.C. government has access to a group of engaged and qualified professionals that are committed to the long-term conservation of grizzly bears. Accordingly, we do not see any justification for imposition of a ban on imports of bears (e.g., by the European Union) that are legally harvested in B.C."

Some of the recommendations of that panel were followed, and some not, partly because some aspects of the management system, specifically the way in which grizzly bear abundance was estimated, was changed, so that panel's evaluation of the older system was no longer germane. Criticisms of the revised system, though, both in the scientific literature (e.g., Artelle et al. 2013, 2014) and popular press (e.g., http://www.vancouverobserver.com/special-reports/trophy-hunt), heightened concerns, especially in the general public, that BC grizzly bears remain at risk from over-hunting. This motivated the BC government (MFLNRO) to conduct another outside evaluation of the management system, which is the basis of this report.

An estimated 15,000 grizzly bears exist in BC and they are managed in 56 Grizzly Bear Population Units (GBPU) (Figure 1).[2] Of these, 9 GBPU are listed as threatened; additionally, the bears were extirpated from areas of the SW coast, lower mainland, central interior, and NE BC around the Peace River area near Fort St. John. The remaining 47 GBPUs are considered viable and the stated objectives include maintaining current population abundance and distribution, and providing sustainable harvest and viewing opportunities where appropriate.[3]

Grizzly bears are susceptible to local extinctions due to their low density and slow life history (Purvis *et al.* 2000). This has been borne out by the disappearance of these bears from large parts of their range south of Canada; but notably, they remain widespread across BC, occupying the majority of their historic range. Being omnivores, grizzly bears feed on a wide diversity of species and this flexibility is important because it provides a cushion should shortage of a particular food should happen. Thus their foraging behaviour likely reduces extinction risk rather than inflating it. While advances in research methods can improve grizzly bear management, uncertainty is an ongoing concern in any management program (Artelle *et al.* 2013; Artelle *et al.* 2014; Legge 2015).

The intent of this report is not to address the benefits or ethics of grizzly bear harvest but rather to review and reassess the management procedures used in BC in terms of whether it adequately safeguards the species. Within this context, the authors note that the International Union for the Conservation of Nature (IUCN) states that hunting plays a positive role in conservation because "the social and economic benefits derived from such use provide incentives for people to conserve them." The 2003 panel (Peek *et al.* 2003) made a similar observation: "An ironic benefit

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[2] BC Ministry of Forests, Lands, and Natural Resource Operations. 2012. 2012 Grizzly bear population estimate for British Columbia.

[3] Stephen MacIver, A/Manager, Wildlife Management Section, Fish & Wildlife Branch, Ministry of Forests, Lands, and Natural Resource Operations, BC Ministry of Forest, Lands, and Natural Resource Operations

of harvesting is that it prompts agencies to conduct research and monitoring that they otherwise might not do; some non-harvested bear populations may be in jeopardy from human-imposed alterations to their habitat but monitoring of these populations is often inadequate."

Figure 1. Grizzly bear population unit (GBPU) map for British Columbia. From BC Ministry of Forests, Lands, and Natural Resource Operations. 2012. 2012 Grizzly bear population estimate for British Columbia.

Hunting of grizzly bears for sport remains a controversial issue in BC (e.g., Artelle *et al.* 2013; Artelle *et al.* 2014; Gallus 2014); concurrently, an increasing interest in non-consumptive use in the form of bear-viewing has spurred a growing industry (e.g., Nevin & Gilbert 2005; Rode *et al.* 2007; Nevin, Swain & Convery 2014). Concerns have been raised over presumed conflicts between consumptive and non-consumptive use of grizzly bears. However, little research has been conducted on the effects of hunting on grizzly bear viewing. Studies of human observers (tourists) in an experimental situation found that such activities had little effect on the bears (Rode *et al.* 2007). This study noted, though, that bear viewing altered the spatiotemporal resource use and urged managers to consider procedures to reduce nutritional impacts (e.g., predictability of bear-viewing). The authors commented that in areas where hunting occurs, it is likely that bears may view humans with a stronger anti-predator (avoidance) response (*sensu* Frid & Dill 2002).

2. Objectives

The objectives of this report are to review the background information on grizzly bear management and conservation in BC, to review the key controversies associated with grizzly bear harvest management, and conduct a technical review of relevant documents provided by the Ministry of Forests, Lands and Natural Resource Operations applicable to grizzly bear harvest management. The review was to undertake scientific analyses of grizzly bear harvest management if required. Further, the report is intended to evaluate the sustainability of the grizzly bear hunt in BC, to assess the level of conservation risk associated with implementation of both the current and revised provincial grizzly bear harvest management procedures, and to provide recommendations for improving the Province's grizzly bear harvest management procedure.

3. Response to Previous Recommendations for Grizzly Bear Management

The previous panel (Peek *et al.* 2003) made a series of recommendations. We reviewed which of these was followed and which were not (those not followed, but still relevant, are **bolded**).

A. Estimation of grizzly bear numbers

1. The Panel recommends that the MWLAP recalibrate the scale of densities associated with the various habitat categories (i.e., habitat capability rating) by using additional benchmark density estimates, especially for habitat categories three to five. Benchmark density estimates must be based on rigorous sampling designs such as mark-recapture models for open populations. An effort should be made to secure "replicates" for each of the habitat categories, resulting in a single reference density per habitat category. Further, the calibration should be based on the (point) estimate of density, not the estimate minus 1 SE.

The Fuhr-Demarchi (F-D) method of estimating grizzly bear numbers is no longer used. The Fish and Wildlife Branch (FWB) of the Ministry of Forests, Lands and Natural Resource Operation now bases population estimates on DNA-hair snaring inventories or regression modelling based on DNA inventories (Mowat, Heard & Schwarz 2013). In some cases, and especially along the coast where modelling was deemed less reliable (smaller samples and fewer variables), estimates were over-ridden by "expert opinion" of wildlife managers. In 17 of 184 Management Units (MUs), expert opinion differed greatly from model estimates (Ministry of Forests Lands and Natural Resource Operations 2012).

2. The Panel recommends that the MWLAP explore the possibility of using resource selection functions (RSF) to assess bear density by MUs based on habitat attributes and other disturbance factors. It would be advisable to develop RSFs through studies in areas with a range of average habitat capabilities.

As per above, a different modelling approach is now used to estimate grizzly bear densities. The current approach to estimating population size for each GBPU could be improved by developing resource selection models for those areas with adequate data. Such an approach may increase the objectivity of assessing the density of grizzly bears in a GBPU. We

recommend development of transparent and repeatable step-downs for determining the annual allowable harvest. The information used to determine the harvest should be made available for each GBPU.

3. The Panel recommends fully documenting and standardizing the basis for the rating of the final step-down in the F-D process, concerning "human-caused mortality." Ideally, the rating should be based on a demographic model to assess the effect of past harvests and the sex/age ratio of such harvests

F-D is no longer being used for estimating grizzly bear numbers.

4. The Panel recommends that the MWLAP take steps to ensure consistencies in the application of the F-D step-down process relative to habitat changes. The goal should be to develop standardized, well-documented protocols that will be applied in a systematic way for all MUs. Considering this, protocols should be applied province-wide, and the central office should play a pivotal role in coordinating and assuring continuity and consistency in implementing policies.

F-D is no longer being used for estimating grizzly bear numbers.

B. Risk management in grizzly bear harvests

1. The Panel recommends that the MWLAP assign higher priority to securing precise population size estimates, than to securing precise vital rate estimates. Sampling error in population estimates are particularly important in terms of risks of population decline due to over-harvest, especially under a LEH system.

This recommendation has been followed. Since 1996, a large number of DNA mark-recapture inventories have been conducted across the province, concentrating especially in the more southerly areas where grizzly bears are most vulnerable (Apps 2010). Both field and analytical methods for producing these estimates have continually improved (e.g., Efford, Borchers & Mowat 2013; Mowat, Heard & Schwarz 2013; Apps et al. 2016).

2. The Panel recommends that the MWLAP acknowledge the effect of sampling error on estimates of population size and vital rates when establishing maximum allowable human-caused mortality rates. Instead of attempting to incorporate uncertainty into population estimates (e.g., by reducing estimates by the equivalent of 1 SE), we recommend including effects of this uncertainty in the scale of maximum allowable human-caused mortality. Until better information becomes available, we recommend that the upper end of the current scale be reduced by 1% (i.e., from 6% to 5%) to ensure that it captures the full extent of uncertainty.

A maximum 6% human-caused mortality rate is still being applied in many GBPUs (rather than 5%). FWB reviewed more recent literature suggesting sustainable human-caused mortality rates can often exceed 6%, which means that 6% allows for some uncertainty.

3. The Panel recommends that the scale used to determine the level of allowable human-caused mortality be matched to the current habitat conditions of a MU (and hence the actual productivity of resident grizzly bears), not the potential habitat capability without human disturbances (as is currently the case).

This has not been done explicitly. Mowat, Heard & Schwarz (2013) incorporated a number of habitat-related variables to estimate grizzly bear densities (e.g., densities increase with levels of precipitation, certain vegetation types and ruggedness; but decline with human density and livestock density). However, current habitat conditions have not been taken into consideration when allocating allowable human-caused mortality, mainly because data relating specific habitat conditions to population growth rates are lacking. Nevertheless, it is now well known that changing food conditions can radically affect vital rates of grizzly bears, and hence population growth rates (Boulanger, Himmer & Swan 2004; McLellan 2015). This will remain a continuing research topic because obtaining adequate data on reproductive rates is so challenging.

C. Administrative process for managing grizzly bears

1. The Panel recommends that regional biologists prepare a report describing the procedure used for estimating population sizes and quota allocation in MUs for each allocation period, including justification of parameters (e.g., F-D step-down). The report should include all information used in estimating population sizes and harvest allocations, as well as documentation of model assumptions, model outputs, and other data that were considered (e.g., trend information, demographic data, etc.).

F-D method is no longer used. Nevertheless, it would still be useful to provide reports describing the procedure and justification for harvest setting, especially when expert opinion about bear density is employed. This would serve 2 purposes: (1) providing managers a means of looking back at what they did, enabling an adaptive management approach, and (2) dispelling the notion among the public that decisions are arbitrary, or worse, motivated by pressures from local guides and outfitters. The goal is to provide transparent disclosure on how population estimates and quota levels were obtained for each GBPU. This is especially important when expert opinion is applied.

2. The Panel recommends that management boundaries be revised as necessary so that each LEH zone is contained wholly within a MU and each MU contained wholly within a GBPU. There should be a direct correspondence between the unit base used for calculating an allowable quota and the area where the quota is used. Hunting statistics should be compiled at the LEH level, but they can be summarized at the GBPU level.

This has largely been done. There are still some MUs in Region 6 where MUs are split between adjacent GBPUs. In ~95% of the cases, the MU boundaries align with GBPU boundaries. GBPU boundaries are periodically reviewed.

3. The Panel recommends that GIS layers for land use and land condition attributes be updated prior to each allocation period to ensure that the latest habitat information is used in estimating populations and allowable harvest rates.

Land-use layers are not routinely updated; however, it turns out that they were updated before each of the previous three allocation periods. It would be useful to ensure that the information is updated and the model rerun before the next allocation period. Deteriorating habitat conditions are the biggest cause for grizzly bear population declines. Therefore, GIS analysis for land condition should be updated for the application of the Mowat, Heard & Schwarz (2013) model. Development and application of RSF models for those units where RSFs have been estimated would be an improvement over the current approach.

4. The Panel recommends better joint planning between the Ministry of Forests, Ministry of Sustainable Resource Management, and the MWLAP. For example, the MWLAP should ensure that land-use planning initiatives by the Ministry of Forests reflect the needs of wildlife in general, and the needs of grizzly bears in particular, within a context of ecosystem management.

There is no higher-level planning occurring in the Province. FWB indicates that they are reaching the limits of habitat protection for grizzly bears. Moreover, there are other species (e.g., caribou) with greater habitat and conservation needs than grizzly bears.

5. The Panel recommends the establishment of management objectives for bear populations (i.e., GBPUs) using a formalized planning process. Management objectives should recognize that both hunting and non-consumptive uses are acceptable. Province-wide guidelines should be developed to guide this planning process, especially with regard to the interaction between hunting and bear-viewing activities.

Objectives are established in the Grizzly Bear Harvest Management Procedure, but there is no formal planning process in place at the level of GBPUs. Guidelines for bear viewing have been established, but not specifically with regard to the interaction between viewing and hunting. However, conflicts between viewing and hunting appear to be minimal, as most viewing is on the coast, where hunters are sparse, and thus have little effect on bear density or behaviour. However, hunters might be more likely to kill an especially habituated bear that presents a prime opportunity for viewing. Following on the Panel's recommendation, we recommend that management objectives for each GBPU should work to minimize conflicts between grizzly bear viewing and harvest.

D. Habitat issues related to grizzly bears

1. The Panel recommends that the MWLAP aggressively address human access into BC's wild lands, not only to reduce grizzly bear mortality more effectively, but also to manage other species of wildlife that are sensitive to human activity such as elk and caribou. A program established cooperatively by the Ministry of Forests and MWLAP to manage access by motorized vehicles is needed. Restrictions of motorized vehicles in time and space should be a part of this program. When timber harvest is contemplated in largely roadless areas, programs to restrict access are needed.

This issue is addressed to some degree through the Natural Resource Roads Act. Some access restrictions are in place with regard to hunting (e.g., motor vehicle closed areas, motor vehicle

for hunting closed areas). There is also legislation to implement road closures in areas of grizzly bear recovery. However, there has not been much progress with regard to managing road densities within landscapes occupied by grizzly bears. Roads and habitat loss are the biggest threat to the future of grizzly bear populations and a larger threat than harvest in the long-term.

2. The Panel recommends that the MWLAP pursue opportunities to encourage use of prescribed burning of some portions of logged areas to enhance habitat for grizzly bears. Intensive forest management activities that expedite conifer regeneration and minimize the amount of time that associated shrubs and herbs are present following logging reduce the habitat potential for grizzly bears; this should be considered in the development of forestry programs. This recommendation is particularly applicable to interior forests.

This is occurring in some areas of the Province, and is reviewed in the current cumulative effects work, which is assessing landscape seral stage distribution for grizzly bears. There are also two berry research projects underway in southeastern BC and an experimental burn was done there last autumn.

3. The Panel recommends that the MWLAP implement the provision of the Grizzly Bear Conservation Strategy relative to the establishment of a Grizzly Bear Management Area within each bioclimatic region of the province. This should include provisions for maintaining connectivity between grizzly bear populations to facilitate movements.

Whereas 3 GBMAs were established on the coast, they were not pursued for the other ecoprovinces, for a number of reasons: (1) FWB biologists indicated that they were concerned that conservation initiatives would rely too much on GBMAs (e.g., that harvest rates might be increased in areas neighbouring GBMAs, knowing that there is a margin of safety). (2) It is generally felt that this strategy is no longer necessary, given what is perceived to be a conservative harvest strategy (low harvest rate, protection of females with young). (3) Some parks are already closed to hunting, or have very little hunting. (4) The quality of the surrounding matrix of land, not falling within GBMAs, might be ignored, or worse yet, developed more, rationalized by the creation of GBMAs. (5) GBMAs would prohibit hunting, but not protect habitat per se. In fact, the coastal GBMAs are now called "Grizzly Bear No Hunting Areas", in recognition that Grizzly Bear Management Area more properly refers to the entire range of grizzly bears, and not just to places where they are not hunted.

E. Research needs regarding grizzly bears

1. The Panel recommends that the MWLAP pursue efforts to develop an efficient method for monitoring population trend with limited resources. Such trend data would be most important for populations at elevated risk of decline due to over-harvest, severe habitat loss, or isolation.

FWB has increased efforts to monitor trend, but trend information is still limited. Some trend information has been obtained from mark–recapture estimates. Apps (2010) summarized 29 surveys to estimate grizzly bear abundance (through 2009), and identified 5 that produced estimates of population trend. A monitoring program has been established in the Southern

Rockies and Flathead (Mowat, Heard & Schwarz 2013; Mowat & Lamb 2016). Other than these cases, the main trend information is gleaned from analyses of the harvest sex-age structure (Hatter 2015). If population trends were monitored more closely, then uncertainty in parameter estimates would be less of a concern. Monitoring, however, is an optimization process and should be targeted especially at those populations that have identifiable conservation concerns (e.g., high non-hunting mortality or reduced food supply). There are no efficient methods for monitoring population trend and the power to detect trends is generally low with most methods. Maintaining a conservative harvest level is the most precautionary approach possible given resource limitations.

2. The Panel recommends that the MWLAP initiate a study to quantify the representation of cubs-of-the-year in population estimates based on DNA from barbed wire hair-snags.

Recent analyses indicate that although cubs-of-the-year have a low probability of capture, they are included in DNA hair-snaring estimates. This issue requires additional research to assess the possible effects of capture heterogeneity on population estimates.

3. The Panel recommends that the MWLAP attempt to assess the magnitude and sex ratio of unreported human-caused bear mortalities.

This has been investigated and updated by McLellan (2015) for the Flathead. Data from outside the Flathead are still largely lacking. This is especially important for GBPUs with high rates of non-hunting human-caused mortality (Ministry of Environment 2012), because an underestimate of this parameter can lead to significant population declines (Mowat & Lamb 2016).

4. The Panel recommends that the MWLAP undertake further risk assessment analyses to guide grizzly bear management policies, taking into account uncertainty in population parameters. In particular, there is a need to evaluate the actual relationship between grizzly bear productivity (which is directly related to maximum allowable human-caused mortality) and average habitat quality in a MU.

This has not been directly done using quantitative risk assessment techniques. However, a meta-analysis using the numerous population surveys conducted across the Kootenay Region of southeastern BC and adjacent portions of Alberta has been conducted to better understand the relationship between grizzly bear abundance and both foods and human-related mortality risks (Apps et al. 2016). Nevertheless, no studies have been undertaken to explore differences in the density-dependent response of harvested bears in areas that support vastly different bear densities (i.e., different carrying capacities).

4. Management System Uncertainty

Ecological systems are inherently variable, and all wildlife management is steeped in uncertainty. Existence of such uncertainty in the context of grizzly bear harvest management was profiled in a paper by Artelle *et al.* (2013) that contributed to the decision to conduct this review of grizzly bear harvest management in BC. Artelle *et al.* (2013) focused on limits and thresholds of mortality addressing “outcome uncertainty” and “biological uncertainty.” They then offered a “general method” for exploited species to maintain the probability of exceeding mortality limits below some threshold. They stated that harvesting for sustainable yield, in theory, is “a maximum number of bears that can be killed each year by humans without causing population declines.” However, this statement is inconsistent with the fundamental principle of sustainable yield in biological populations whereby harvest is expected to lower population size to exploit the underlying density dependence that provides a sustainable yield (Boyce, Sinclair & White 1999). Otherwise there can be no optimization for sustainable yield (Mendelssohn 1976).

As noted by Artelle *et al.* (2013), uncertainty exists at several levels in the grizzly bear harvesting scheme. To place the bear harvesting scheme into context, we organize our discussion around management strategy evaluation (MSE; Milner-Gulland 2010; Milner-Gulland *et al.* 2010; Boyce, Baxter & Possingham 2012). In Figure 2 we illustrate a MSE for grizzly bear management, identifying (1) an operating harvest model for the population, (2) an observation model where estimates of population parameters are obtained from field observations (e.g., Mowat, Heard & Schwarz 2013; Apps *et al.* 2016) (see section on population estimation), (3) the manager who is responsible for making decisions on the number of hunting licences to be issued using (4) an assessment model for making rules based on alternative quotas, and then (5) monitoring the harvest to feed back into (1). Any management scheme will be faced with uncertainty in each component of the system including sampling error, measurement error, environmental stochasticity, choice of models, and unknown behaviour of managers and hunters.

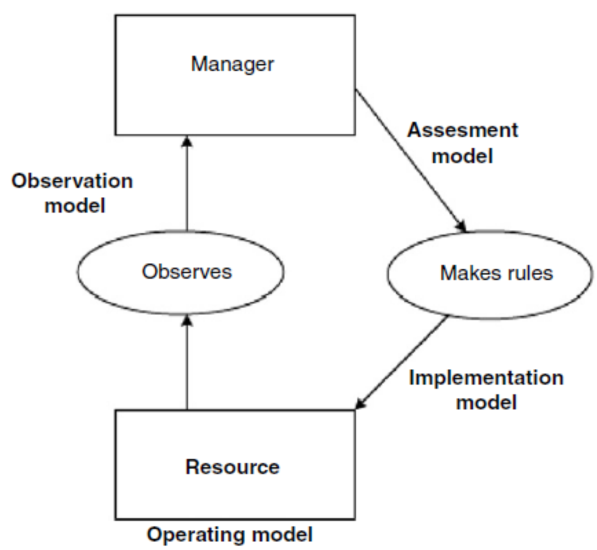

Figure 2. A simplified Management Strategy Evaluation similar to that used in fisheries (adapted from Milner-Gulland 2010).

Management decisions must be made whether or not all sources of uncertainty can be measured or identified. This does not imply that the management decisions are flawed simply because error and uncertainty exist. The manager must decide where to focus limited resources available for conservation. For example, in BC an important source of funding for research and monitoring comes from the Habitat Conservation Trust Foundation (HCTF) that is funded in large part from a surcharge on hunting, guide/outfitter, trapping and fishing licences. The amount varies from year to year, but averages $4.2 million. These funds can be used to support grizzly bear population monitoring but there are competing demands for funding to purchase lands for conservation, and to study, monitor, and manage all of the other components of BC's environment. Of course, the BC provincial government also could make direct financial allocations.

5. Uncertainty in Population Estimates

Perhaps the most crucial source of uncertainty in BC's harvesting scheme is for population size (McLoughlin 2003; McLoughlin & Messier 2004) to feed into a harvest model. One approach for reducing some of this inherent uncertainty in abundance estimates would be to increase the intensity of monitoring so that we have a stronger basis for harvest quotas. Investment in monitoring can be viewed as an optimization problem with costs competing for alternative conservation needs such as habitat management and protection (Nichols & Williams 2006; McDonald-Madden *et al.* 2010; Possingham *et al.* 2012). There is little question that management decisions would be improved by better population estimates. These data feed directly into a process of active adaptive management to iteratively enhance management (Nichols & Williams 2006; Williams 2011; Possingham *et al.* 2012).

Population estimates in recent years have focused on mark-recapture methods from DNA surveys (Mowat & Strobeck 2000). Although mark-recapture methods permit the calculation of population estimates, these estimates invariably suffer high uncertainty with large confidence intervals surrounding the estimates. Mark-recapture estimators are notoriously data hungry and the sample sizes necessary to obtain high precision with such a ratio estimator can be greater than the population size.

Another serious source of uncertainty exists for areas where no DNA sampling has been conducted. Abundance for these areas is estimated by a regression model (Mowat, Heard & Schwarz 2013), sometimes adjusted by "expert opinion." Generally any data-based estimate will outperform expert opinion (Johnson & Gillingham 2004) although protocols for standardizing expert opinion might improve reliability (Drescher *et al.* 2013). In previous harvest allocations the BC government used the Fuhr & Demarchi 1990) method based on extrapolated density associated with habitat classifications. Indeed, BC has a highly detailed forest inventory so that they had reasonably good data on which to base the Fuhr-Demarchi method (F-D). Peek *et al.* (2003) noted concerns related to the "step-down" method for adjusting F-D estimates for logging roads and other human developments. Garth Mowat (Kootenay/Boundary Region, MFLNRO) commented that the step-down process was too subjective and this motivated the development of his regression method (Mowat, Heard & Schwarz 2013), and abandoning of the F-D method. A more sophisticated regression model, which predicted abundance in southeast BC with excellent accuracy (Apps *et al.* 2016), might replace the Mowat, Heard and Schwarz (2013) model for this region.

Habitat determines spatial variation in population density (Mowat, Heard & Schwarz 2013; Boyce *et al.* 2016; Apps *et al.* 2016). Instead of abandoning the habitat-based methods, more research can help to refine habitat-selection models (e.g., Ciarniello *et al.* 2007a; Ciarniello *et al.* 2007b; Proctor *et al.* 2015) although caution is necessary when attempting to extrapolate

Resource Selection Functions (RSF) into areas beyond the source of data for the estimation of the model. Methods exist for evaluating the spatial robustness of RSF models (Wiens *et al.* 2008), facilitating the evolution of stronger population estimates. Continuing cutting-edge research on habitat models and mark-recapture models based on grizzly bear data from BC refines and improves our ability to use habitat distribution in population context.

In particular, spatially explicit capture-recapture (SECR) models offer advantages over conventional mark-recapture methods because they automatically allow for capture heterogeneity, are more robust to the violation of the population closure assumption, and derived abundance estimates relate to a specified geographical region (Efford, Dawson & Robbins 2004; Borchers & Efford 2008; Obbard, Howe & Kyle 2010; Efford & Fewster 2013). And SECR methods can be married to RSFs allowing population distribution to be tied to habitat (Royle *et al.* 2013; Royle *et al.* 2014; Efford 2014). MFLNRO is actively engaged in the development of these cutting-edge SECR methods (Efford, Borchers & Mowat 2013; Efford & Mowat 2014).

6. Estimation of Sustainable Harvest Rate

Harvest optimization in the MSE occurs in the context of a population model. For a long-lived species such as the grizzly bear, structured population models are required to capture the dynamics of the stage- and sex-structured population and to assist in the identification of harvest quotas. Indeed, such a structured population model was used by Harris (1986) when he conducted the harvest simulations that form the basis for BC's allowable human-caused mortality quotas.

Harvest modelling is often focused on questions of sustainable yield, but the same model structure can be used to evaluate population control (Guillaumet, Dorr & Wang 2012) or viability (Boyce 1992; Boyce 1993). Fundamental to any harvesting model is density dependence and indeed it is the density-dependent structure of the population that allows the harvesting of a sustainable yield (Harris 1986; Harris & Metzgar 1987; Boyce, Sinclair & White 1999; Xu, Boyce & Daley 2005). Structured population models cannot be used to model sustainable yield without density dependence (Mendelssohn 1976). The same applies to populations capped by a ceiling carrying capacity; these are actually geometric growth models with an upper threshold for population size (Lacy 1993). Population models with a ceiling carrying capacity warrant mention because several software packages for conducting population viability analysis (PVA) use a ceiling carrying capacity to limit population size (Lacy 1993; Mills *et al.* 1996).

Harvest optimization requires identification of the density-dependent function that regulates population size. The exact nature of density dependence varies substantially among species, and even among populations of the same species. For large mammals juvenile survival is usually the first vital rate to change as populations approach carrying capacity (Eberhardt 1977; Eberhardt 2002), and indeed both Miller, Sellers & Keay (2003) and Schwartz *et al.* (2006) found population density to affect grizzly bear cub survival. Adult survival is usually less responsive to density.

Another important consideration in the design of a population model for grizzly bears is an appropriate structure for accommodating uncertainty (Artelle *et al.* 2013). Age-structured population models for a long-lived species such as the grizzly bear would require at least 25 age-specific survival estimates and about 20 age-specific fecundity or recruitment estimates. Such longevity buffers population fluctuations from variation in vital rates (Morris *et al.* 2008), yet it renders intractable the sampling and estimation of vital rates. Reliably estimating 45 vital rates and associated variances is untenable for small populations of long-lived species such as grizzly bears (Boyce 1992; 1993). However, a simplified model with key life-history stages such as cubs, subadult, and adult males and females is much more tractable (Boyce *et al.* 2001; Boyce, Baxter & Possingham 2012), making it feasible to estimate vital rates with their associated variances.

Below we model the distribution of grizzly bears in 4 categories or stages: COY = cubs-of-the-year, SA = subadults pooled for both males and females of ages 1, 2 and 3, adult ♀♀, and adult ♂♂. We have designed a 4×4 stage-projection matrix containing the density-dependent recruitment, $R(N)$, in the top row; density-dependent survival of COY to the SA class, S_{COY}, and survival of subadults that remain as subadults, S_{SA} in the second row. In the third row we have the probability of survival for SA females, S_f, times the proportion of subadults that are females, 1- δ; and the probability of survival for adult ♀♀, $S_♀$. Then the bottom row of the projection matrix contains two elements: the proportion of subadults that are male, δ, times the probability of survival and maturation for subadult males, S_m; and the probability of survival for males already classified as adults, $S_♂$. When this projection matrix is post-multiplied by a column vector containing the number of individuals in each stage class i, n_i, at time t, the product is the composition of the population, n_i at time t+1:

$$\begin{bmatrix} n_{COY} \\ n_{SA} \\ n_♀ \\ n_♂ \end{bmatrix} = \begin{bmatrix} 0 & 0 & R(N) & 0 \\ S_{COY} & S_{SA} & 0 & 0 \\ 0 & (1-\delta)S_f & S_♀ & 0 \\ 0 & \delta S_m & 0 & S_♂ \end{bmatrix} \times \begin{bmatrix} n_{COY} \\ n_{SA} \\ n_♀ \\ n_♂ \end{bmatrix} \tag{1}$$

In standard matrix notation, we will label the time-varying projection matrix, $\boldsymbol{A}_t$, and column vectors of the number of individuals in each stage class as $\boldsymbol{N}_t$:

$$\boldsymbol{N}_{t+1} = \boldsymbol{A}_t \cdot \boldsymbol{N}_t$$

We assumed adult survival to be density independent (Eberhardt 2002) but with density-dependent functions influencing the probability that a subadult will transition to the adult stage, surviving $S_{f,t}$ and $S_{m,t}$ as follows:

$$S_{i,t} = S_i / \exp[\alpha_i (N_t/K_t)^{\gamma_i}] \quad (i = f,\ m) \tag{2}$$

Here $N_t = \Sigma n_i$ is the total population size at time t; K_t scales for a time-varying carrying capacity; γ_i is the density-dependence nonlinearity exponent for recruitment and survival; and α_i are coefficients for density dependence potentially relating to the relative abundance of the 4 stages at K_t (Xu & Boyce 2010). Justification for the stage-specific density-dependent functions comes from the literature (McCullough 1981; Boyce, Sinclair & White 1999; Eberhardt 2002; Bonenfant *et al.* 2009); the form of the survival function is that used by Clutton-Brock *et al.* 2002) and Boyce *et al.* (2012); illustrated in Figure 3.

Adult male bears kill cubs thereby influencing both recruitment and the survival of cubs to the subadult stage (Swenson 2003; McLellan 2005). We presume that this functions as a density-dependent mechanism that we modelled using the following equations:

$$R_t = \alpha_0 \cdot \exp[p(1 - (N_{♂}/\delta K_t)^{\gamma_0}] \quad (3)$$

$$S_{COY},_t = S_i / \exp[\alpha_i (N_{♂}/\delta K_t)^{\gamma_i}] \quad (4)$$

As above, S_{COY} is the time-varying survival rate of cubs at low population density. Harvest thereby increases recruitment and population turnover (Czetwertynski, Boyce & Schmiegelow 2007). The highest recruitment, $R^* = \alpha_0 \cdot \exp(p)$, occurs when there is no density dependence, i.e., $\lim N \downarrow 0$.

Stochastic variation in vital rates (Nations & Boyce 1997) is imposed with normally distributed perturbations drawn from a random number generator. Process variance for adults is assumed to be 50% of that for COY and subadults.

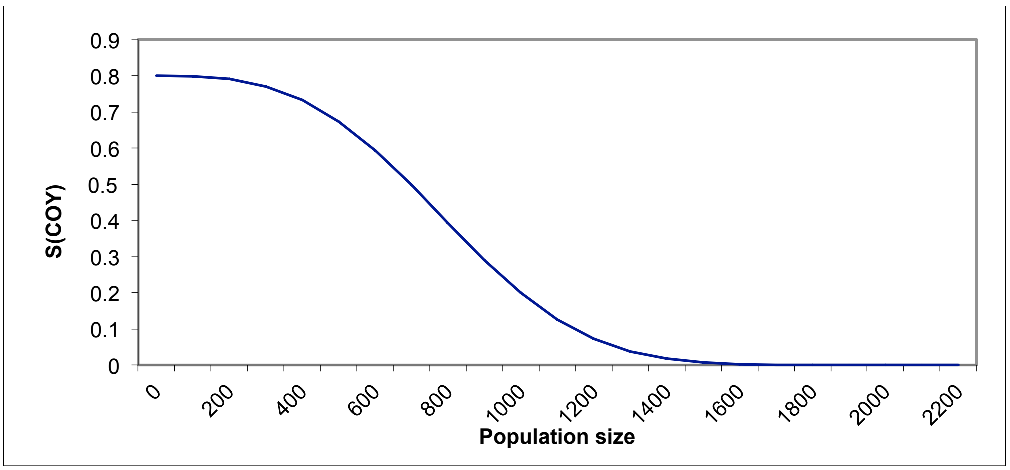

Figure 3. Survival of cubs-of-the-year (COY) as a function of population size. Sexually selected infanticide appears to contribute to this function (Swenson 2003; McLellan 2005). The same shape, eq. 2, is assumed for recruitment and pre-reproductive survival in our simulation model.

Human-caused mortality could affect all stage classes, with removals organized into a column vector of H_is that is subtracted from the column vector of stage classes before post-multiplication by the projection matrix. In matrix notation,

$$\boldsymbol{N}_{t+1} = \boldsymbol{A}_t (\boldsymbol{N}_t - \boldsymbol{H}_t)$$

In practice, harvest of cubs (in fact all bears <2 years old) is illegal but other sources of human-caused mortality such as road or railway collisions can occur such that H_{COY} is sometimes greater than 0. For our simulations we assumed that $H_{\mathrm{COY}} = 0$. Conducting simulations using vital rate estimates from BC, we identified the human-caused mortality quota that could yield maximum sustained yield.

Although the details of model structure are quite different, our simulation results substantiate the often-cited sustainable yield value of 6% (Harris 1986), that has used by the FLNRO to determine the target number of bears to be killed by hunters in BC (McLellan *et al*., in prep.). This model structure makes it easy to simulate alternative rules for determining harvest quotas, and as additional data are collected parameter estimates can be refined, i.e., adaptive management (Boyce 1993).

7. Grizzly Bear Population Units

The range of grizzly bears in BC is partitioned into 56 population units (GBPU) used for monitoring, assessment, conservation, and management (Figure 1). Some GBPU boundaries follow natural (e.g., large rivers) or human-caused (e.g., settled mountain valleys and major highways) that reduce connectivity. The boundaries in southern BC reflect varying degrees of genetic isolation from adjacent areas (Proctor *et al.* 2012). In northern and coastal BC where few barriers to movement exist, GBPU boundaries follow natural and ecological boundaries or transition areas (e.g., heights of land between watersheds).[4]

7.1 Delineation of Grizzly Bear Population Units

A management unit is generally considered to be a biologically meaningful area of ecological integration where population growth rate is largely determined by local reproductive and survival rates rather than immigration (Cole 1957; Caughley 1977; Palsboll, Berube & Allendorf 2007). The degree of connectivity should be sufficient to provide gene flow but low enough that each population that monitoring and management could be conducted independently (Taylor & Dizon 1999; Palsboll, Berube & Allendorf 2007). There is little evidence that many of BC's GBPUs act as true populations and thus, the issue of immigration and emigration are of critical importance to population trend. Few of the GBPU are fully isolated from adjacent populations and thus, the GBPU function as management units with some ecological differentiation. To some extent, the whole Province could be considered a meta-population. Specifically, a GBPU might not function as a population and thus population trend may be driven as much by external processes than by internal birth and death rates. A consequence of such delineated populations (e.g., low closure) is that management should consider adjacent GBPUs and their status given the high likelihood of movement between population units. Effective management and conservation of species or ecotypes require an understanding of how populations are structured in space and over time (Nagy *et al.* 2011).

- *Recommendation*

Spatially explicit capture-recapture models may reduce the need for careful delineation of populations (Borchers 2010) but management should be based on biologically meaningful units. This is a precursor to any population inventory. Integration of telemetric data where available, genetic structure, and stable isotopes should be applied to improve the GBPU boundaries.

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[4] BC Ministry of Forests, Lands, and Natural Resource Operations. 2012. 2012 Grizzly bear population estimate for British Columbia.

8. Grizzly Bear Population Assessment in BC

Peek *et al.* (2003) noted three distinct approaches to maintaining sustainable harvests: "One is to estimate population size and sustainable harvest rates and based on this information, calculate a sustainable yield. A second is to make a best guess at a sustainable harvest, using historic records, and then adjust this harvest year to year in accordance with estimates of population trend. Population trends may be assessed through counts or other surveys of the living population, through analysis of harvest data, or through population modeling linked to field data. A third approach is to restrict the number of hunters to such a low level that it would be highly unlikely that they would ever exceed a sustainable harvest. As populations rise, the hunter success rate will climb, and as populations decline, so will the hunter success rate, but population estimation or trend monitoring would be unnecessary because the harvest would always be far below the maximum sustainable yield (MSY). The choice of which of these approaches to use depends on: (1) how close to MSY the population will be harvested, (2) the feasibility of obtaining either population estimates or trend data, and (3) the reliability of these data." FWB utilizes the first approach, basing allowable harvests on estimates of population size and estimates of sustainable human-caused mortality rates.

A great deal of effort and expense has gone into producing population estimates for each GBPU. Undoubtedly, BC has produced more mark–recapture population estimates for grizzly bears than any similar jurisdiction (province, state) for any bear species, anywhere in the world. BC also has used these many estimates (and others from neighboring jurisdictions) to model population density (Mowat *et al.* 2013b; Apps *et al.* 2016). The goal of this modelling was to produce population estimates for areas where mark–recapture-based estimates were not available. In some cases, though, managers felt that model-based estimates were incorrect and the estimates were adjusted using expert opinion.

Errors in model-based estimates stem from inadequate models and imperfect measurement of the variables used in the model. Whereas we understand and appreciate that "experts" may perceive flaws in the model, variables, or model predictions, there seems to be no clear criteria for the use of expert opinion over-riding model predictions, nor clear documentation of how experts derived their estimates. Because expert-opinion-based abundance estimates are being used in about 39% of the Province as a whole (34% of the areas with a grizzly bear hunt – information provided by MFLNRO), it seems possible that over-harvests could occur in some places simply as a result of misperceptions of bear abundance by managers (or incorrect model predictions). However, there is evidence that managers have, at least in some cases, correctly recognized biases in model-based or mark–recapture-based population estimates, and made appropriate corrections (e.g., Mowat *et al.* 2013). We disagree with the contention of Artelle *et al.* (2014) that science-based management must exclude subjective inputs such as this. Wildlife management invariably includes non-scientific factors. The role of the wildlife manager is to review the full range of inputs including cultural, social, First Nations' traditional ecological knowledge, local knowledge, and economic considerations. The key, however, is to provide clear documentation how such non-scientific aspects were considered in the decision-making process. Having said that, we also support efforts to generate population estimates for each GBPU based on less-subjective procedures, or to at least include more sophisticated model-based estimates (e.g., Apps *et al.* 2016) in the decision-making.

Estimation of sustainable human-caused mortality is another potential source of over-harvest. The currently-used rate of 6% was derived by Harris 1986), using limited data, and with little understanding at the time of how this rate varies with habitat conditions and bear density. Artelle *et al.* (2013) showed that this sort of uncertainty could, in itself, increase chances of over-harvest. However, this would be less apt to be true if the maximum allowable mortality rate of 6% tended to be an underestimate of the true maximum sustainable offtake, as claimed by FWB, based on studies conducted since Harris (1986). These more recent studies indicated that natural mortality for adult grizzly bears (1–3%/year) is much lower than assumed by Harris (1986)(5–10% for age 4–20 years), so sustainable rates of human-caused mortality are likely to be higher (McLellan *et al.* in prep.).

The dangers of over-harvest stemming from incorrect assessments of abundance or sustainable mortality, or from mortalities that are unaccounted for, may be guarded against to an extent through trend monitoring and commensurate adaptive management (adjustments based on population trend). FWB has implemented some forms of trend monitoring, falling basically into two categories: (1) population estimates, and (2) analysis of harvest data.

8.1 Population estimates

Although BC has invested heavily in producing reliable population estimates, few cases exist where these data have been used to examine population trend. Artelle *et al.* (2013, Appendix S3) summarized changes in population estimates by GBPU from 2004 to 2008 to 2012, but these changes were due to modifications deriving from new data, not changes in actual bear density.

The Flathead has the longest and best records of population change (based on radio-collared animals, 1978–2010; McLellan 2015). The density of hunter kills in this GBPU is the highest in BC. Despite this, the population doubled over a period of 2 decades, due to high reproductive rates, driven by an abundance of food (huckleberries). As the food supply diminished, the reproductive rate halved (to the lowest known in North America), and the population declined precipitously (2–5%/year). Continued monitoring of this population using DNA mark-recapture (2010–2014) indicated a population recovery (Mowat & Lamb 2016). The dynamics of this population followed the food supply, and not changes in human-caused mortality. Non-hunting human-caused mortality was low, and total human-caused mortality (including hunting) did not exceed the maximum target of 6%, even during the decline phase (McLellan 2015; Mowat & Lamb 2016).

Likewise, in the coastal Kwatna-Owikeno GBPU, DNA mark-recapture data combined with helicopter surveys indicated that grizzly bear populations varied directly with local salmon (*Oncorhynchus* spp.) availability: grizzly bear survival and recruitment was low, causing populations to decline, when salmon availability was too low to support them (Boulanger, Himmer & Swan 2004; Himmer & Boulanger 2003). This monitoring effort has been discontinued.

In another coastal area, within the Tweedsmuir GBPU, grizzly bear populations were monitored by helicopter surveys over a period of 13 years. Here again populations varied year to year (but showed no significant trend over time) due to changes in salmon availability. In this case, the number of bears probably did not change, but their visibility, and hence detectability during the helicopter surveys, increased when high salmon escapements attracted more bears to the rivers (Apps & Hamilton 2011). This survey was discontinued due to its inability to detect true trends in grizzly bear abundance.

A grizzly bear trend-monitoring project at Galore Creek in northwestern BC (Lower Stikine GBPU) was motivated by the potential development of a copper-gold-silver mining operation. This monitoring was based on DNA mark–recapture over a 4-year period (2004–2007), although population-monitoring protocols were not instituted until 2006. Anomalous snowpack conditions prevented comparison of spring estimates between 2006 and 2007, but fall estimates were similar. The investigators concluded that they would have been able to detect an 8% population change (Rescan Environmental Services Ltd 2008).

The South Rockies GBPU is the only case targeted for population monitoring due to a concern of excessive human-caused mortality. This unit has a number of outfitters and high demand by resident bear hunters, combined with high non-hunting human-caused mortality. As a result, especially of the uncontrolled non-hunting mortality, human-caused mortality was believed to exceed 5% of the estimated population in most years since the 1980s; also, this kill often consisted of >30% females. Notably, road and train-caused mortalities have been on the rise in recent years. The hunt was closed in 2001 (Province-wide) and 2011 (due to overkill in this unit). An initial analysis of DNA mark–recapture data in this unit indicated that despite the relatively high human-caused mortality of females, females comprised over ¾ of the population, and further, that sequential population estimates did not indicate a population decline (Mowat *et al.* 2013). A more recent analysis, however, using an open mark–recapture model showed that the population declined by 40–50% (8% per year) during 2006–2013 (Mowat and Lamb 2015). This finding came to light after the population had been harvested.

Extensive mark–recapture work in this unit demonstrated that:

1. Population density based on "expert opinion" (which was used to correct for lack of closure in previous empirical estimates) was remarkably close to spatially explicit (closure-corrected) estimates. However, expert opinion did not detect the population decline. As a result, mortality rates increased through time because a roughly constant number of bears were being removed from a declining population.
2. Errors in estimating population size and rates of non-hunting human-caused mortality led to harvests that contributed to the continuing population decline: the total kill rate exceeded the target (unknowingly, until this study was completed) for 6 of 8 years.
3. Non-hunting human-caused mortality in this unit was especially high (known non-hunting kills were >60% of known mortality), and unreported non-hunting mortality may be much higher than was estimated using standard correction factors (i.e., doubling the known non-hunting kill).
4. A reduction in natural foods also likely contributed to the decline (through diminished reproduction and increased propensity of bears to seek human-related foods), but since no foods were monitored, this effect was ascertained from indirect evidence (reduced berry production in the adjacent Flathead (McLellan 2015), low estimates of apparent recruitment, and unexplained high rates of population decline).
5. Trend monitoring using this method can effectively detect population declines of this magnitude in as few as 6 years.

6. Trend monitoring targeted in areas with known or suspected high non-hunting human-caused mortality would be a useful approach to averting prolonged over-harvest.

From the pace of ongoing inventory projects, it appears that meaningful monitoring of abundance using this approach will be unlikely for a substantial proportion of the grizzly bear populations in BC. The development of lower-cost monitoring approaches (e.g., occupancy) might be necessary to develop long-term trend indicators. Occupancy-abundance relations are among the most fundamental patterns in ecology (He & Gaston 2003).

8.2 Analysis of harvest data

McLellan (2012b) and McLellan *et al.* (in prep.) examined the sex-age structure of the harvest in each GBPU to look for indications of over-harvest. Here, over-harvest means that it is causing an unwanted population decline, not that it exceeds what is presumed to be sustainable. For example, a declining age of harvested bears could be indicative of over-harvest. Likewise, a declining age at which an equal number of males and females are harvested might indicate that the harvest rate has increased. Fraser (1984) and Paloheimo & Fraser (1981) showed that if one sex (i.e., males) are consistently more vulnerable to harvest, then the proportion of living animals of that sex will decline with increasing age; therefore, at older ages, there will be many fewer males than females, so despite their continued higher vulnerability to harvest, fewer males than females will be harvested among these old bears. The age at which the harvest of males and females becomes equal is proportional to the harvest rate.

McLellan (2012b) and McLellan *et al.* (in prep.) found that in most GBPUs, males exceeded females among harvested bears of all ages. That is, not only was there no age at which an equal number of males and females were harvested, but there was no evidence of a decline in the proportion of males with increasing age. One interpretation of these results is that the harvest has been light, so that older-age males remained abundant. An alternate interpretation is that non-hunting mortality rates for older females are higher than for males. Or, it could be that the protection of females from hunting while they are cub-rearing (essentially 2 of every 3 years) has prevented many old females from being shot.

Beston & Mace (2012) used this same sort of analysis based on changing sex ratio with age of harvested black bears (*U. americanus*) in Montana to show that harvest rates were sustainable, and that populations were not declining. Notably, this result was consistent with subjective estimates of population trend ascertained by managers (Garshelis & Hristienko 2006), and counter to results of a meta-analysis of vital rates of black bears in western U.S. states, which indicated that they should be declining (Beston 2011). Indeed, Beston's (2011) predictions of population trend across the U.S. based on vital rates do not match the weight of evidence that black bear populations are increasing numerically and expanding geographically across this entire region (Garshelis *et al.* in press).

Modelling approaches, like Beston's (2011) for black bears and Artelle *et al.*'s (2013) for grizzly bears help to highlight possible management problems (or at least possible deficiencies in management approaches), but direct evidence of population status could indicate that the modelling predictions were wrong. In depth analyses of populations with high human-caused rates of mortality, as done for the South Rockies (McLellan 2012a; Mowat *et al.* 2013; Mowat &

Lamb 2016), seems like a prudent approach, and would be warranted in other areas. The age at harvest approach provides an additional check on population status for most of the Province, where mark–recapture based monitoring is absent, and seems to indicate that grizzly bears are not being over-harvested. However, more investigation is necessary to explain why males (despite their higher vulnerability to harvest) are more common than females for every harvested age class.

A related approach is to use age-at-harvest data, number of harvested bears, and ancillary data such as a reliable population estimate and estimates of non-harvest mortality to "reconstruct" population sizes over time. Various reconstruction methods have been used to assess changes in population size, especially in fisheries and increasingly for big game species, where modern versions are now commonly called Statistical Population Reconstruction (SPR). Hatter (2015) used a new SPR approach (Gast, Skalski & Beyer 2013; Lady & Skalski 2015) to investigate trends in male grizzly bears in three large regions of BC (each composed of multiple Wildlife Management Units), and detected significant population trends (both increases and decreases) in two of them (sample sizes of harvested bears were insufficient to detect trends in the coastal region). He concluded that this method, which uses data that are already available, should become a part of the normal monitoring system. We strongly agree with this recommendation.

9. General Issues Pertaining to Grizzly Bear Harvest Management

This section addresses a variety of grizzly bear harvest management issues that pertain to effective management.

9.1 Resources and staffing

Effective management of wildlife is a costly undertaking. Whereas the BC grizzly bear management program is working at a high level with highly qualified staff, additional staff would improve the management of this highly-valued species. Grizzly bears are considered to be a keystone, umbrella, and flagship species (Noss *et al.* 1996; Helfield & Naiman 2006) and thus public interest is high.

It was clear throughout our consultations that resources were a limiting factor in grizzly bear management in BC. Lack of resources reduced effective management planning and resulted in excessive dependence on extrapolation methods and greater uncertainty about GBPU trends and sustainable harvest levels. The population of BC is projected to increase from 4.68 million people in 2015 to 6.12 million in 2041[5] and therefore, pressures on grizzly bears and their habitat are likely to increase.

Whereas a population inventory and monitoring strategy has been developed for BC (see Apps 2010), it is clear that adequate resources are unavailable for full implementation of the strategy.

[5] British Columbia Population Projections: 2014 to 2041 by BC Stats September 2014

This has resulted in an *ad hoc* inventory program largely driven by other resource development (e.g., oil, gas, mines, pipelines, hydro).

- *Recommendation*

Resources available for grizzly bear management and research should be increased to an adequate level necessary to fund proper population monitoring and assessment. Given the complexity and costs associated with such inventory programs, predictability of funding is of paramount importance.

9.2 Management objectives for each GBPU

Specific objectives are not available for each GBPU (e.g., harvest levels, habitat protection, habitat trends, problem bear hotspots). Grizzly bears are affected by roads because roads cause effective habitat loss, habitat fragmentation, alter body condition, increased stress, vehicle strikes, and higher mortality from hunting and poaching (e.g., McLellan & Shackleton 1988; Nielsen *et al.* 2004 ; Bourbonnais *et al.* 2013; Boulanger *et al.* 2013; Boulanger & Stenhouse 2014). Higher mortality is a primary concern for population management. Setting of management objectives for each GBPU has been identified as a priority; such goals have not been developed in a standardized manner and should be addressed and made publicly available. In some areas, (e.g., the Flathead), management of a population unit will require an international and inter-provincial collaboration as recommended in the Alberta Grizzly Bear Recovery Plan (http://esrd.alberta.ca/fish-wildlife/wildlife-management/grizzly-bears/documents/GrizzlyBear-RecoveryPlan2008-13-revJuly23-2008.pdf). Periodic review of GBPUs may be required to refine units as the landscape and connectivity changes.

The British Columbia Grizzly Bear Harvest Management Procedure Manual does not outline a clear plan for population inventory. Specifically, in 2010, a list of priority population inventory or re-inventory was developed based on 10 criteria (Apps 2010). Consideration for re-inventory and the criteria for identifying when a population should be re-inventoried are lacking. Apps (2010) proposed that a rigorous population survey should be conducted with reassessment in 5-10 years. The peril of this approach is that it fails to identify specific conditions for an inventory at 5 or 10 years. Presumably development or concerns about excess harvest would produce a higher priority for re-inventory but such criteria are lacking. The interval of re-inventory is not quantified nor assessed in a meaningful manner. Re-inventory every 5-10 years might be appropriate but given the paucity of current inventories, the interval seems challenging to obtain.

- *Recommendation*

Clear management objectives are required to facilitate management actions. Trends in habitat (e.g., harvest, industrial development, ruralisation), critical resources (e.g., berries, salmon), and access (e.g., roads) need to be monitored and accurately reflected in management decisions. Remote sensing makes habitat monitoring relatively inexpensive, but the ramifications of habitat change to population change can be anticipated only if habitat-selection studies have been done in the area.

The development of GBPU reports produced periodically and made publically available on the Grizzly Bear Population Status in BC website would be beneficial and aid in transparency of the management procedures. This recommendation also was noted by Gallus (2014: pg. 28).

9.3 Self-reporting of hunter-killed bears

Reporting of the sex of harvested bears is an essential component of the management of BC grizzly bears (specific quotas exist on female harvests); thus, it is essential that such reporting is accurate. Since 1976, hunters have been required to present harvested grizzly bears for a compulsory inspection to ascertain sex and remove a tooth for age determination. However, the tooth collection is not complete and there was no independent monitoring of the inspection process, which is a privatized fee-for-service business.

An analysis of the reliability of sex reporting for polar bear (*U. maritimus*) hunter harvests in Alaska using genetic testing found that sex was incorrectly reported for 13.7% of the kills; more females were reported as males, than vice versa, resulting in a 12% under-estimate of harvested females (Schliebe *et al.* 1999).

- *Recommendation*

Efforts should be made to increase full data submission during the compulsory inspection process. This should include, as a minimum: a tooth with intact root attached, accurate location fixed by GPS, sex (verified by DNA sample, baculum, and visual inspection), and DNA sample for population structure and other analyses (e.g., hair with roots, blood, skin, muscle). An assessment of the accuracy of the self-reporting system would aid confidence in the management of grizzly bears.

10. Ecological Issues Pertinent to Population Management

The following sections provide an overview of specific issues pertinent to the management and conservation of grizzly bears in BC. Several of the issues pertain to population carrying capacity and vital rates as reflected by possible changes in grizzly bear habitats.

10.1 Resource selection functions

Habitat loss due to continuing industrial development and human settlement is probably the most serious threat to the future of grizzly bears in BC. To anticipate the consequences of habitat loss or alteration, new methods are available using geographical information systems (GIS) and habitat modelling. Remote-sensing technology permits documentation of changes in landscapes that can be related to grizzly bear habitats (Huettmann, Franklin & Stenhouse 2005), and enhanced technology makes it feasible to monitor habitats at low cost.

Habitat selection can be characterized using resource selection functions (RSF), and the density of grizzly bears can be related to habitats using RSFs (Boyce *et al.* 2016). A variety of methods have been used to estimate RSFs for grizzly bears, and often involve monitoring habitats used by bears from radiotelemetry data and contrasting these with random landscape locations (Johnson *et al.* 2006). Several RSFs have been estimated for grizzly bears in BC and adjacent areas of Alberta, including most of southeastern BC (Proctor *et al*. 2015), upper portions of the Columbia River basin (Apps *et al.* 2004; Apps, McLellan & Woods 2006), and the Hart Mountains and Parsnip River area north of Prince George (Ciarniello *et al.* 2007a; Ciarniello *et al.* 2007b). Focused RSF models have been estimated to characterize grizzly bear den-site selection (Ciarniello *et al.* 2005), and use of avalanche chutes for foraging (Serrouya *et al.* 2011).

RSF models have been shown to predict the distribution and abundance of grizzly bears when applied in the area where they were estimated (Boyce *et al.* 2002). However, when applied in areas where the available habitats are different, these habitat-selection models may not be reliable. Interpolation is often possible, however, and metrics are available to evaluate the robustness of RSFs in new areas (Wiens *et al.* 2008). Similarly, RSFs can be used to scale the distribution of abundance in a manner similar to the regression approach of Mowat, Heard & Schwarz (2013) and Apps *et al.* (2016). Habitat selection coefficients (betas in the models) can be modelled as a function of availability (Knopff *et al.* 2014).

RSF models permit evaluation of the consequences of habitat alteration, but to do so will require that RSFs be estimated in those ecosystems that have received little study. Generally, the Coastal Range and the Pacific coast are areas where grizzly bear habitat research is needed most to enhance the ability to monitor and document future grizzly bear habitats.

- *Recommendation*

Additional habitat selection studies should continue with priority on estimating RSFs for western portions of BC. These should then be used to monitor habitats relative to anticipated consequences for grizzly bear distribution and abundance.

10.2 Access management

Industrial development for timber harvest, oil/gas extraction, or mining usually requires road construction. Roads are not necessarily bad for bears, especially when attractants such as clover or vetch are planted in roadside ditches for bank stabilization (Roever, Boyce & Stenhouse 2008). But when roads remain open for public use they attract recreational users of the landscape and this increased traffic invariably results in higher grizzly bear mortality (Northrup *et al.* 2012). Industry use sometimes has little consequence for the bears (Wielgus, Vernier & Schivatcheva 2002), especially if use is <12 vehicles per day (Northrup *et al.* 2012). In general, however, human access is an important factor explaining landscape selection and survival of grizzly bears in BC (Apps *et al.* 2016).

- *Recommendation*

Roads constructed for resource extraction should be closed to recreational users and decommissioned when they are no longer required by industry. Gating can be effective at reducing road use, especially if the road has never been open for public access.

10.3 Whitebark pine as grizzly bear food

Whitebark pine (*Pinus albicaulis*) is an important grizzly bear food in parts of the United States and is associated with the seasonal distribution of grizzlies and their reproductive output (Schwartz *et al.* 2006; Bjornlie *et al.* 2014; Costello *et al.* 2014). Whitebark pine has an extensive distribution through coastal and interior habitats in BC and its distribution might increase in BC with a warming climate (McLane & Aitken 2012). COSEWIC lists whitebark pine as endangered; it is listed as imperilled/vulnerable under the BC Conservation Data Centre listing. Identification of the importance of this species in the diet of grizzly bears could be a component for understanding long-term population dynamics. Whitebark pine, however, is susceptible to mortality caused by mountain pine beetle (*Dendroctonus ponderosae*) and infections from white pine blister rust (*Cronartium ribicola*) (Logan, Macfarlane & Willcox 2010; Jewett *et al.* 2011). Thus, the distribution is predicted to change under a warming climate with range contraction in the south (Chang, Hansen & Piekielek 2014) and could disappear as a principal dietary component in some areas. There is evidence from the Yellowstone ecosystem that grizzly bears can accommodate to the loss of whitebark pine seeds (Fortin *et al.* 2013) but understanding key resources would improve long-term monitoring and assessment of sustainable harvest.

The use of whitebark pine by grizzly bears in BC is poorly understood. Changes in population growth rates associated with changes in whitebark pine use might affect the long-term sustainability of grizzly bear harvest levels. Sulphur isotopes can be used to assess whitebark pine use (Felicetti *et al.* 2003 but see Schwartz *et al.* 2014) and application of this technique might be useful for long-term monitoring and identification of changes in resources that affect survival or reproductive rates.

- *Recommendation*

If whitebark pine is found to be a significant food source for grizzlies in BC, monitoring this resource should be considered. There are no specific procedures in the GBHM procedures that identify how or when resource abundance inputs are to be implemented. Similar monitoring of key foraging species such as *Vaccinium* spp. or *Shepherdia canadensis* could be considered in setting harvest levels. The particular concern would be for long-term loss of key food resources that might alter carrying capacity. Monitoring abundance of bear foods, specifically to relate to bear population dynamics, has been accomplished for many years by other management agencies (Noyce & Coy 1990; Noyce & Garshelis 1997; Obbard *et al.* 2014).

10.4 Salmon monitoring in grizzly bear habitat

Grizzly bears in coastal ecosystems as well as many inland areas of BC make extensive use of salmon (Van Daele *et al.* 2013). Studies have linked energy intake to population productivity (Hilderbrand *et al.* 1999). Both salmon and grizzly bears have been described as keystone species for their roles in ecosystem processes and nutrient cycling (Helfield & Naiman 2006). However, in general, salmon management has focussed on the maximum sustainable yield for commercial purposes with little consideration of other resources or ecological factors (Levi *et al.* 2012). From a harvest management perspective, changes in the availability of a key resource such as salmon should be integrated into population management. Grizzly bear management in BC does consider reduced food resources. For example, salmon escapement levels that were too low to sustain the grizzly bear population near Owikeno Lake (Boulanger, Himmer & Swan 2004) resulted in a reduction in harvest levels in the Kwatna-Owikeno GBPU. However, the process for assessing key food resources is unclear and not articulated in the GBHMPM.

- *Recommendation*

Given the reliance of grizzly bears on salmon in many populations, integration of salmon escapement data with grizzly bear habitat assessment and planning is an important part of long-term trend monitoring. Although salmon abundance is considered in harvest management there are no specific GBHM procedures that identify how or when such inputs are to be implemented. Loss of protein sources for a population should be included in metrics initiating harvest review and possible reductions. Escapement data from Fisheries and Oceans Canada (i.e., NuSEDS – New Salmon Escapement Database System) could be used to identify changes in salmon resources available to grizzly bears in a GBPU. For long-term population sustainability of grizzly bear harvest, there is merit to ensuring adequate escapement of salmon for grizzly bears in GBPU management plans in cooperation with Fisheries and Oceans Canada and for adjusting grizzly bear harvest levels relative to escapement data over the longer term in those ecosystems where salmon are an important dietary component.

10.5 Climate change issues

Climate change is altering ecosystems globally and is expected to result in significant changes across a diversity of taxa (Walther *et al.* 2002; Parmesan & Yohe 2003; Parmesan 2006). Grizzly bears are likely to face habitat alterations associated with climate change, but given their wide ecological niche and varied diet, they are not considered particularly sensitive to projected changes (Roberts, Nielsen & Stenhouse 2014). Nonetheless, various aspects of grizzly bear life history might be affected (e.g., Graham & Stenhouse 2014; Fisher, Wheatley & Mackenzie 2014). Climate change has the potential to negatively affect some key resources (e.g., salmon: Finney *et al.* 2000) and therefore, this issue needs to be considered in grizzly bear harvest management.

- *Recommendation*

While climate change has not been identified as a major risk factor for grizzly bears conservation and harvest management in BC, in the longer term, climate change should be integrated into management plans and assessed when GBPU management objectives are set. Climate warming associated changes in habitat are likely to be a major concern affecting harvest sustainability over the longer term (i.e., decades).

10.6 Problem bear management

Grizzlies clearly are in conflict with humans in many areas. For example, in the Tweedsmuir GBPU, animal control kills of grizzlies greatly exceeded the hunter kill[6]. While problem bear kills are not directly related to harvest mortality, they are factored into harvest calculations through the predicted non-hunting mortalities (Section 3.2.3 b. of the GBHMPM) and then subtracted from the AAM.

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[6] http://www.env.gov.bc.ca/soe/indicators/plants-and-animals/grizzly-bears.html

• *Recommendation*

With an increasing population in BC and an expanding human footprint, it is necessary to reduce problem kill mortality throughout their range. Efforts should be focused on those areas where problem bear mortality is high and chronic. Identification and control of attractants should be a priority for improving the long-term conservation of grizzlies in BC.

11. Procedure Manual – Grizzly Bear Harvest Management (12-11-21)

The following section deals with the details of the Ministry of Forests, Lands and Natural Resource Operations Procedure Manual (Volume 4, Section 7, Subsection 04.04, 14 pages) for Grizzly Bear Harvest Management (12-11-21). The stated purpose of the Procedure Manual is "To establish a sound and transparent approach for developing management objectives and harvest regulations for Grizzly Bears province-wide."

11.1 Issue: Harvest targets versus limits

Artelle *et al.* (2013) discussed the distinction between grizzly bear harvest targets and limits. In particular, they state "by allocating mortality right up to mortality limits, BC managers treat limits as targets, conflating the two; we hereafter refer to true targeted mortality levels (whether or not they are conflated with mortality limits by managers) as 'targets' and true, biologically determined mortality limits as 'limits'." (Artelle *et al.* 2013: page 2). With the terminology used in the Grizzly Bear Harvest Management (GBHM) procedure manual, there is a distinction between the annual allowable mortality rate (AAM), which includes bears killed by hunting, illegal (reported harvest), control kills, and road kills but excludes unreported First Nations harvest and unreported harvest versus the annual allowable harvest (AAH), which is just the maximum number of harvested bears. The AAH was not viewed as a target because the harvest can be adjusted over the "allocation period," which is the 5-year period to which an allocation share applies. The GBHM clearly identifies how harvest management is to be adjusted following the "yellow flag" and "red flag" procedures (see GBHM 3.2.7 a. and b.). The issue of managers treating limits as targets seems to be a semantic issue.

• *Recommendations*

The term "annual allowable mortality" could be reworded as the "average annual mortality" to recognize the role that adjustment of harvest plays in instances where excess mortality from all sources exceeds the annual allowable harvest.

The AAM definition makes no mention of railroad kills and these should be explicitly included in the calculations (although acknowledging that there are few areas where this is significant).

11.2 Issue: Scale of management

1.1. Grizzly bear populations generally will be managed at the level of the GBPU. In particular circumstances, approval can be sought from the director to manage population at another spatial scale (e.g., MU).

There are several reasons why management would be more appropriate at the scale of MUs. In particular, areas with significant habitat loss, problem bears, or declining population size may warrant a finer scale of management.

- *Recommendation*

There is merit to outlining the circumstances under which management at another spatial scale may be appropriate. There is no specific mention of management at scales larger than the GBPU. For clarity and transparency, there is merit to providing conditions under which management may be imposed at a different spatial scale.

11.3 Issue: Avoiding a population decline

2.1 Management objectives: populations "should be managed to avoid a decline… unless formal management objectives specify otherwise." In reality, most GBPUs are managed to allow a sustainable harvest. Other small populations are not harvested and are managed for a population increase, and potentially, some over-abundant populations could be targeted for a reduction.

- *Recommendation*

This issue could be addressed by developing specific objectives for each GBPU. The procedure would benefit from guidance on the situations in which a population would be managed for a decline. At the very least, examples of situations where a managed decline would be permitted should be identified (e.g., excessive depredation, human-bear conflicts, protection of other resources).

11.4 Issue: Cub segment of population

3.1.3 "Population estimates, developed for the purposes of harvest management, will:
a. Include grizzly bears of all ages" This means that the population size and harvest calculations include a segment of the population that cannot be legally harvested but may be under-represented in the population estimates. It would be useful to explore methods that allow information on the number of cubs included in mark-recapture analyses. It is likely that detection probabilities of cubs are a source of heterogeneity in analyses of abundance.

- *Recommendation*

Consider a) hair size for cubs-of-the-year (COYs), b) isotopic signature differences of cubs in mark-recapture analyses, c) using cameras to identify COYs. If cubs-of-the-year are trap shy because of association with their mothers, they may be underestimated.

Including dependent young in the population estimate may inflate the allowable harvest levels and they should be removed, or at least their abundance considered, before harvest calculations are made.

11.5 Issue: Maximum harvest rate

3.2.2 a. Maximum allowable mortality rate of 6% - written rational allows a higher or lower %.

- *Recommendation*

Specific guidelines should be developed for when a higher or lower maximum mortality rate is allowed in a GBPU. The justification should be stated in each GBPU management objective document. Areas with high recruitment and low non-harvest mortality can sustain higher human-caused mortality (McLellan *et al*., in prep).

11.6 Issue: First Nations' harvests

3.2.2 b. "Estimating First Nations' harvest rate" – this appears to be a weakness in the current management system. Trends in First Nations' harvests and other unreported mortality could affect population trends.

- *Recommendation*

While we acknowledge that obtaining reliable data on this issue will be challenging, we believe it is important to work toward increased consultation and collaboration to increase the accuracy of reporting. Co-management of grizzly bears will be necessary in those areas where First Nations harvest grizzly bears and in those areas where non-consumptive use of grizzlies is a priority.

11.7 Issue: Unreported mortality

3.2.2 c. "unreported mortality rate" – The assumptions around unreported mortality could have significant implications for long-term population trends, but the current estimate is tenuous given the spatial and temporal limitations of the data. Austin *et al.* (2004) estimated this parameter to be 2% based on data from a single population (McLellan *et al.* 1999), and this benchmark rate of unreported human-caused mortalities was adjusted for other GBPUs based on variation in 4 indices (hunter density, density of large ungulate harvest, road density and humans within 50 km). The adjusted unreported mortality was bounded by 0.3 and 3%.

- *Recommendation*

Further work is needed to investigate unreported mortalities. Some insights might be gained by pooling telemetry data across regions and this is an area of possible additional research because it is fundamental to the long-term management of the harvest.

11.8 Issue: Protecting small populations

3.2.5 The basis for a GBPU to be harvested if it contains ≥100 bears is unclear and arbitrary. A GBPU <100 bears or close to this number may not represent a minimum viable population size and, as such, this value should be re-assessed as a minimum for ensuring long-term conservation and a sustainable harvest.

Under this same point, "there is limited connectivity to larger populations" – concerns are 1) no clear definition of "limited connectivity" and 2) no definition of "larger populations" (is this more than 1 population and >100 bear minimum or larger in the context of being significantly larger?)

- *Recommendation*

A population of ca. 100 bears may or may not be viable and thus, review and reconsideration of this number to a more conservation-based population size is warranted. Additional rigor in the methodology is required. Connectivity, adjacency to protected areas, rate of development and habitat alteration, and population demographics should be considered within the context of developing specific population numbers where hunting would be allowed for each GBPU. Such objectives should be stated in the management objectives for each GBPU.

11.9 Issue: Inclusion of dependent bears in population estimates

3.2.6 b "Known human-caused mortalities of grizzly bears < 2 years (24 months) old will not be included." This seems to counter point 3.1.3, where grizzly bears of all ages are included in the population estimate. The net effect is a mismatch between the bears that are included in population estimates versus the removals coming from those populations.

- *Recommendation*

There is a need to harmonize the known human-caused mortalities with the population estimates; both should either include or exclude dependent young.

11.10 Issue: Exclusion of translocated bears in population estimates

3.2.6 c "Translocated bears will not be added to the population estimate for harvest purposes of the area of relocation." Whether a translocated bear would or would not be included if sampled during a population inventory is unclear. This is likely only an issue for small populations but a potential concern if small populations were augmented.

- *Recommendation*

Clarify the text to explicitly state how to treat translocated animals in a population inventory (assuming genetic identity of translocated animals is known).

11.11 Issue: Bears of unknown sex

3.2.6. d " Reported mortalities for which the sex is unknown will be assumed to have a sex ratio of 50:50 to estimate the number of female mortalities (i.e., a reported kill of unknown sex will be recorded as a 0.5 of a female bear)." This approach is less conservative than desired. Bears of unknown sex, while representing a small number of individuals, may underestimate the removal of females.

- *Recommendation*

All reported mortalities of unknown sex should be classified as females to increase the conservative nature of the harvest.

11.12 Issue: Reduced hunting if mortality exceeded

3.2.7 b. "A "red flag" will be raised if the total annual mortalities or annual female mortalities… averaged over the course of the allocation period, exceed the AAM or female AAM, respectively. …the director should recommend that hunting opportunities be reduced so that mortalities return to a level at or below the AAM and female AAM." This directive has logical inconsistencies and lacks clarity. If the total annual allowable mortality is exceeded over the 5 year allocation period, the director cannot take any actions that would keep the AAM to the proposed level. Further, there is no requirement to consider what adjustment or reduction of hunting opportunities would be made nor does the policy address the need to recover the lost individuals to the population (i.e., population recruitment).

- *Recommendation*

We recommend clarifying the wording to indicate that the director would take actions to reduce AAM for the next allocation period. Further, the actions by the director should adjust the AAM to allow recovery of the population equivalent to the number of animals that exceeded the AAM or female AAM. The intent is to carry forward the excess harvest to bring harvest to the estimated sustainable level over the longer term.

11.13 Issue: Harvest management spreadsheet

3.2.8 "…using the Grizzly Bear Harvest Management Procedure Spreadsheet" These spreadsheets are not available publicly yet form the basis of harvest decision-making process.

- *Recommendation*

These spreadsheets should be made available on the Grizzly Bear Population Status website. While these are complex and require significant knowledge to fully implement the process, there is no obvious reason for lack of openness.

11.14 Issue: Over-mortality

3.2.12 "…the carryover of over-mortality from previous years may be discarded if results suggest a sufficient density of bears remain." The wording is unnecessarily vague.

- *Recommendation*

A sufficient density is undefined and should likely reference the population size on which the previous AAM level was calculated. The over-mortality may be discarded if the population size remains unchanged from previous estimates or the population size has achieved a given GBPU objective.

11.15 Issue: Success rates over 5 years

3.3.3 "Success rates used to determine the number of LEH authorizations will generally reflect the most-recent five years that were open to grizzly bear hunting." The wording is vague.

- *Recommendation*

Clarification for why the success rate would not reflect the most recent five years is needed. There is a conservative benefit to stating that the "success rate cannot exceed…" rather than "generally reflect".

11.16 Issue: Success rates after closure

3.3.4 "…LEH success rates will be limited to a minimum of 10%." This seems generally reasonable but in areas where populations were depleted, LEH success rates may be artificially low, particularly following a period of closure to hunting.

- *Recommendation*

Clarification of the wording would be useful to note that re-opening harvest for populations following closure may have more conservative LEH success rates until new success rates are determined. The objective would be to reduce the likelihood of exceeding AAM.

11.17 Issue: Spring and fall hunting

Spring and autumn harvest periods are permitted in BC in some GBPUs. Autumn hunts put pregnant females at higher risk of harvest because they are not associated with offspring and thus, legal for harvest.

- *Recommendation*

Data on the sex ratio of spring and autumn harvested bears should be analyzed to assess the potential for reducing female harvests. Should evidence of seasonal difference in female harvest be noted, the open seasons could be changed if there is a need to reduce female harvest.

11.18 Issue: GBPU-specific population objectives

Austin, Heard & Hamilton (2004) state that "population objectives will be approved for all GBPUs." (page 7)

- *Recommendation*

Each GBPU should have explicit goals that pertain to harvest management or mortality reduction, and to population recovery, where necessary.

11.20 Issue: Clarification of "additional information"

APPENDIX A: Additional information to be considered before significantly reducing harvest opportunities

- *Recommendation*

The average age of males "should be >7.5" – the basis for this designation is unclear and exploration of this harvest age warrants further consideration and research.

11.21 Issue: Trends in ages of harvested bears

APPENDIX A – 2. b. "The average age of male and female grizzly bears killed by hunters in GBPU over time with the regression lines weighted by number. There should not be a decreasing trend of either male or females ages over time." This same issue is present in 2. c. using weighted regressions. Appendix A states that "regression lines weighted by number" should be used. This means: i) years with more harvest are weighted heavier in the regression than those years with lower harvests, ii) a declining population is likely to have lower harvest (i.e., less data in a regression), iii) long time series with long periods of stability may mask declines at the end of the time series (i.e., ongoing declines).

A) The generality of the non-declining trend is broad with the exception of the situation where there is limited recruitment in a population. In such cases, an increasing age of bears could occur in a declining population. If such a decline was ongoing, associated information such as increasing hunter effort in a catch-per-unit-effort (CPUE) approach may yield additional insights. An increasing CPUE and increasing or stable age trend over time suggests further investigation or monitoring is warranted.

B) The regression should consider/explore the appropriateness of transformation of the raw age structure data. Due to the non-normal nature of age structures, it is likely that the removals are not normally distributed. Further, in a declining population, the variance of the data over time may not be constant. Moreover, the changes in a population may not be linear so consideration of alternate models of decline may be appropriate.

C) Use of a weighted regression may be problematic in a declining population as less emphasis is placed on the less precise measurement (these are likely to occur if harvest levels are low). In periods when harvest is high, the data variance is low and thus, the least square approach will "fit" to those values disproportionately. The "best fit" to the data may occur but long periods of high harvest with low variance may mask lower levels of harvest with higher variance in a weighted regression. Specifically, the method may be less likely to identify a decline at the end of a time series.

The statement that "Preferably, the average age of males should increase over time." While this is generally acceptable, the procedure should be clarified that there should be either "no trend in average age of males or it should increase over time" (similar to wording in 2.c. for proportion of females). While likely obvious, it is not possible to have long-term increase in age and at some point, it will plateau. Further, for this aspect to be of use, there must be consideration of recruitment to the population. Increasing mean age in a population also can occur from very low levels of recruitment and an aging population. Given analytical issues is it unlikely to know whether the average age of males increases or not given lack of independence in the time series.

- *Recommendation*

The trends should be explored with weighted and non-weighted regression. Analyses could consider the use of a moving average (weighted and unweighted). Wording should be revised to note specific issues above. There are 2 major issues: 1) Lack of independence in the series meaning that statistical inference is compromised, and 2) Sample sizes are usually so low that the error will overwhelm the results, resulting in high probability of committing a Type II error. We note that this is an interesting approach for exploratory data analysis, but we do not support that it be used for making management recommendations.

11.22 Issue: Spatial analysis of mortalities

APPENDIX A 3. "A spatial analysis of male and female, hunting and non-hunting mortalities to identify any changes in distribution." This directive is lacking in specific direction and is thus, either of limited value.

- *Recommendation*

Spatial distribution of kills could be useful for identifying problem locations for non-hunting mortalities and possible locations of sinks at specific locations, with appropriate analysis: for example, the distribution of nearest neighbour distances, kernel analyses for hotspots, and resource selection function analyses (see Nielsen *et al.* 2004). Of particular concern, albeit likely challenging given small sample sizes, would be the analysis of kill locations of adult females. Ultimately, if the goal is to minimize female harvest, analysis of female kills should be considered independently of all kills. Further, usefulness of these data would be improved with mandatory reporting of GPS locations of all kills. Increased rigor of analyses is required.

11.23 Issue: Anecdotal trend information

APPENDIX A 5. "Submission of credible anecdotal information from regional wildlife staff and stakeholders on relative abundance and trends of grizzly bears within the GBPU."

While such a procedure allows flexibility in the management procedures, the process lacks transparency, repeatability, and documentation suitable for public review. In the context of science-based management, use of anecdotal information might result in a loss of credibility in the management process. Use of the term "credible" is impossible to assess and the process hinges on an interpretation on this point.

- *Recommendation*

Stakeholders should be allowed to comment on harvest procedures and such input should be made available so there is a public record of the information being used for decision-making. While stakeholders might have information of use to the management process, for purposes of transparency and replication of management decisions, such input (within a defined consultation period) should be allowed from anyone considering himself or herself a stakeholder.

11.24 Issue: Density threshold for maintaining a hunt

APPENDIX A "Specific outputs from #1-#5 that will be considered in a recommendation to maintain a hunt that, under this policy, would normally be closed include:"
"f) Current bear density ≥ 20 bears/1000 km^2 (or other density as specified by the Provincial Carnivore Ecologist)."

This section identifies ≥20 bears/1000 km^2 yet the basis for this density is undocumented. In particular, it is unclear why this density would be required to maintain a hunt that would normally be closed. The density appears to be flexible and can be set by the Provincial Carnivore Ecologist but the scientific underpinnings for such an adjustment lacks guidance and thus repeatability. Several of the GBPUs are well below the level of 20 bears/1000 km^2 (e.g., Nation, Hyland, Taiga, Hart, Central Purcells) and others well above (e.g., Tatshenshini, Kitlope-Fiordland, Kwatna-Owikeno).

- *Recommendation*

Consider removing the ≥20 bears/1000 km^2 and revise the text to represent a value based on historic density or perhaps a projected density (e.g., following Mowat, Heard & Schwarz 2013; Apps *et al.* 2016) for each GBPU. Documentation of the bear density being used to maintain a hunt, and the science or professional judgment behind this density, would aid transparency in management and should be made available online.

11.25 Issue: Clumping of harvested females for maintaining a hunt

APPENDIX A also notes the following condition that could be used to maintain a hunt: "g) Lack of clumping of hunter-killed females: clumping of non-hunted human-caused mortalities suggest conflict areas that should be appropriately addressed."

Analysis of kill locations requires greater rigor and repeatability: "clumping" has little meaning beyond being non-random unless spatial patterns are quantitatively analyzed using constant criteria for what is meant by "clumping". The population level impacts of a clumped harvest may be minimal or non-existent and are likely of minimal merit as a criterion for maintaining a hunt. The issue of clumping of killed females is a topic suitable for further research.

- *Recommendation*

The criteria of clumping should be reviewed, metrics for analyses defined, and interpretation for management assessed and noted in the Procedure Manual. Analysis of nearest-neighbor distances might yield insights but harvest data are often clumped due to hunter access and habitat preferences of bears so the utility of this metric is questionable. As a means of assessing conflict areas, the approach has merit at the visual inspection level, but again, lacks rigor.

11.26 Issue: Decline in bear populations for maintaining a hunt

APPENDIX A also notes the following condition that could be used to maintain a hunt: "h) Lack of regional wildlife staff and stakeholder concern with decline in bear population." Lack of concern with decline in a bear population appears to be counter to the long-term conservation of grizzly bears. The definition of "stakeholder" is undefined.

- *Recommendation*

The term stakeholder requires clarification. Stakeholder input should be documented and made publicly available for each GBPU. The reasons for lack of concern should be documented and made available for public input.

12. Other Management Issues

12.1 Issue: Problem bear mortalities

Problem bears mortalities affect the AAH. While the numbers of problem bears recorded is highly variable throughout the Province, some areas (e.g., Bella Coola) have significant problem bear mortalities.

- *Recommendation*

Analysis of problem bear locations, timing, factors, sex/age, causes, and an assessment of the effects of problem bear removals on grizzly harvest levels should be undertaken for those GBPUs where problem bears are a significant concern. Identification of measures to reduce problem bear mortality would aid long-term conservation efforts.

12.2 Issue: Railway kills and collisions with grizzly bears

Railway kills of grizzly bears are noted in the removals in BC and are not a major conservation concern relative to other threats. Further, the distribution of railway kills seems limited although this may be from a lack of reporting. This issue is being addressed in the National Parks but not beyond. Longer term, this source of mortality could become more important in some areas.

- *Recommendation*

Implementation of mandatory reporting for grizzly bear collisions or suspected collisions on railways. The role of different attractants should be addressed, particularly in high-collision areas, but more broadly across the Province.

Use of stable isotopes (carbon, nitrogen and sulphur) may provide insights into grizzlies that forage along railways (Hopkins *et al.* 2014). Further, application of quantitative fatty acid signature analysis could be considered as an additional means of documenting the importance of rail-associated foods (Thiemann *et al.* 2008).

Canadian Pacific Railway is funding a $1 million study in Banff National Park to assess means to reduce rail-related mortalities of grizzly bears (www.pc.gc.ca/eng/pn-np/mtn/ours-bears/conservation/cp.aspx_.). Grain spillage from trains provides food for bears, is an attractant to other wildlife that are killed and thus become an attractant to grizzly bears both in and out of the parks. We recommend that the rail cars transporting grain be upgraded/modified to prevent all spills so as to reduce rail-related mortalities.

12.3 Issue: Grizzly bear kills in National Parks

Kills in National Parks are not coordinated with the Provincial database. Given population connectivity and the need to understand the source sink-dynamics, it is important to understand all sources of mortality regardless of jurisdiction. Given the importance of metapopulation dynamics, it is essential that removals in National Parks (i.e., Glacier, Kootenay, Mount Revelstoke, and Yoho) and given the presence of shared populations in the mountain parks in Alberta (i.e., Banff, Jasper) be included in the Provincial database and considered in the broader management of a GBPU.

- *Recommendation*

At the very least, age, sex, location, reason for kill, and date of kill should be recorded and reported to the Province. Samples from kills for isotopes and DNA should be collected. Likewise, for populations that cross provincial borders such as in the Flathead and Peace, there should be increased collaboration and sharing of data.

13. Other issues raised during consultations[7]

The authors were encouraged to seek opinions about grizzly bear harvest management in BC to broaden the scope of the review. Several individuals well versed in grizzly bear ecology and management were consulted during the review process (Appendix II). The following is a general synthesis of points raised during conversations. The focus is on issues that are not covered elsewhere in the report.

The point of transparency in grizzly bear management was raised repeatedly. Accessing data used to support management decisions was at times unavailable or unsupported. It was noted that the website “Grizzly Bear Status in BC (2012)” (http://www.env.gov.bc.ca/soe/indicators/plants-and-animals/grizzly-bears.html) was an improvement in openness. The website, however, did not allow for high-resolution exploration of the data or trends due to the pooling of information into GBPU. Many individuals expressed a desire for more information to be posted on the website. It was also noted that reasoning behind changes in management decisions were difficult to ascertain and that such changes could make assessing harvest data difficult to interpret. The issue of repeatability in the management system was raised as a concern as the decision making process was unclear or unavailable. The view that grizzly bears are a public resource was noted and that the public has a right to know how their resources are being managed. Part of the concern seemed

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[7] This section reflects issues raised during discussions but do not necessarily reflect the views of the authors of this report. The individuals consulted for this section are noted in Appendix II.

to centre on a lack of clear management goals for each grizzly bear population. Further, public input to the process of grizzly bear harvest was minimal and largely after decisions were made.

The capacity of the management system for grizzly bears was perceived to be inadequate. Many had high praise for the biologists associated with harvest management yet felt that the level of staffing was inadequate to address the diversity of issues across the Province. Timeliness of addressing conservation concerns, the level and frequency of inventory, data verification, data analysis, data verification, data availability, and the collection of harvest information (e.g., are kill locations accurate?) were all raised as concerns that were associated with inadequate resources and staffing levels.

Reflecting developing issues in other species, concerns were raised that the effects of harvesting grizzly bears was unknown and required further study. The issue of learned behaviours and cultural transmission within a population of bears was noted as an area possibly affected by harvest. Concerns about destabilization of social structure were also a concern.

Several noted that most grizzly bear studies in BC were of short-term nature relative to the time frame in which harvests were being adjusted. Inventories were generally viewed as out-dated yet harvest levels were being set using the data. The lack of a monitoring plan that could detect changes was noted. The issue of how population boundaries were set was raised as a concern and thus, the validity of population estimates. It was noted that some GBPUs seemed to lack rigorous ecological boundaries. Overall, concerns were raised about uncertainty in the methods applied to grizzly bear harvest management.

The issue of other resources and the role that salmon escapement might have on grizzly bear populations was raised as a concern. The core concern appeared to centre on possible changes in carrying capacity (e.g., whitebark pine). The issue of climate change likely lowering carry capacity was also raised.

Some were concerned by statements made by grizzly bear managers that the harvest was "science-based" yet the process lacked repeatability and that decisions were made based on other issues (e.g., economic, social, political factors) but these were not openly stated. In contrast, some directly involved with the harvest allocation process felt that the spreadsheets used to calculate harvest, while complex, were repeatable. Centralization of many decisions to Victoria meant that regional decisions had less influence on the process. For example, the decision to have any grizzly bear harvest in BC is made in Victoria.

Problems with unreported mortality were raised based on periodic observations. The concern was that unreported mortality was being inadequately considered in harvest management and thus harvest levels may be too high. There was a sense from some that unreported mortality might be changing over time.

The reliability of harvest data collection through the self-reporting process was raised as a concern. The issue of identification and correction of data errors was raised. Concerns were raised that changes in how unreported mortality is addressed make long-term trends difficult to assess.

Opinions were expressed that hunting conducted under properly managed game management principles rarely poses a threat to bear populations; chronic habitat changes and increased human access, however, can have serious deleterious effects.

The GOABC usually find agreement with the number of grizzly bears estimated by MFLNRO, but not always. Guides and outfitters would like an opportunity to offer their expert opinion, especially when they might have better information on resource abundance in remote areas (e.g., fish and berries). Concerns were raised that the "rainfall model" (Mowat, Heard & Schwarz 2013) was inadequate in the Peace region that does not receive much rainfall.

Throughout the Province guides and outfitters have been reporting increased numbers of bears except in the Kootenays where grizzly bear populations appear to have declined. Bears are occurring in areas where they have not been found before (e.g., some north coastal areas and the north end of Vancouver Island). It was estimated that there might be 30-50 grizzly bears on Vancouver Island. In some areas in the interior of BC guides and outfitters have noted substantial increases in bear abundance, especially in the Cariboo Region north of Williams Lake and Quesnel.

The harvest of grizzly bears is low, approximately 2% of the provincial population estimates, recognizing that the Harris (1986) analysis suggested that human-caused mortality should be kept below 6%. And it was acknowledged that in several areas mortality associated with vehicular collisions including trains contributed significantly to human-caused mortality.

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Appendix II Individuals Consulted During the Scientific Review

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