Grizzly Bear Habitat Supply Modelling and Landscape Modelling

Workshop #1

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Workshop Objectives

In support of the project's goals, the objectives of this first workshop were:

- To introduce the project's goals, objectives and components to resource managers and interested parties within the project's initial study area (east Kootenays).
- To introduce habitat supply modelling frameworks that are under development within the province.
- To review and discuss similar or complementary research and management activities within the east Kootenays and other jurisdictions.
- To describe, in rank order of impact, the threats to grizzly bears and their habitat at local and provincial scales.

- To introduce approaches and applications of spatially explicit landscape modelling to explore how to capture threats to grizzly bears within a spatially explicit landscape model.
- To determine the management levers that can be used to manage the threats to grizzly bears.
- To review habitat classification and mapping tools available for development of habitat supply models.
- To review pilot areas to conduct model development and testing.
- To examine what information and presentation format would be most useful to people using the results of the project.

Agenda Topics

Day 1	**Speaker**
Introduction and review of the day's agenda	Rick Ellis
Project affiliation, objectives and overview	Fred Hovey
Chase – a habitat supply modelling framework	Rob McCann
The Mackenzie grizzly bear habitat supply model	Rob McCann
Grizzly bear research in Alberta	Gordon Stenhouse
Grizzly bear population delineation	Michael Proctor
Threats to grizzly bears	Fred Hovey and
	Rob McCann
Day 2	
Review of the day's agenda	Rick Ellis
Summary of day 1	Fred Hovey
Landscape modelling	Don Morgan
Management and research applications	All
Management tools and levers for grizzly bears	Don Morgan
Habitat classification and mapping	Tony Hamilton

Project affiliation, objectives and overview:

The Development of Analytic and Decision Models for Assessing Grizzly Bear Needs from Forest Management Objectives is a project funded by the British Columbia Forest Sciences Program. Key players include members of the Ministry of Forests Research Branch and independent consultants. The broad goal is to provide generalized models of habitat and mortality risk for grizzly bears, based on empirical data (where applicable) and expert judgement. Collectively, these models define a cumulative effects model. Specific project objectives include: 1) the development of predictive models relating the effects of forest management activities and resultant landscape conditions to grizzly bear mortality, 2) to develop and integrate predictive models of habitat use with the mortality models, and 3) to integrate these models with landscape models of forest management policies in a framework that encourages policy assessment and supports the management decision process. Products of this research project should appeal to planners, managers, and policy makers, as well as local and international organizations concerned with grizzly bear conservation. The modelling framework has the potential to support adaptive management initiatives, aid in the certification of forest licensees, support forest stewardship plans, contribute to conservation area designs, provide direction to research initiatives, and provide insights into access management and multiple land use planning.

This project will take advantage of recent provincial initiatives that define habitat supply modelling and provide guidance and standards to this emerging field. Within this context, habitat is viewed as an area that provides the necessary set of biotic and abiotic resources to permit successful (self-sustaining) occupancy by individuals of a species while habitat supply is a spatial-temporal measure of the quality and quantity of such habitats. In particular, we will build upon modelling approaches that have proven effective elsewhere in the province and US. Central to these approaches is the use of a workshop environment to build and evaluate habitat supply models and the use of flexible and intuitive modelling tools that facilitate stakeholder participation and the incorporation of diverse data from diverse disciplines.

Modelling grizzly bear mortality:

Modelling the probability of grizzly bear mortality as a function of landscape conditions represents the primary data driven, or empirically based, modelling aspect of this project. It is expected that empirical mortality models will be widely applicable over both space and time due to effects of human activities on grizzly bear mortality. These human influences can be indexed via measures of human presence such as roads, trails, and camps. Additional explanatory variables that may reference where grizzly bears occur on the landscape (i.e., habitat measures) will also be evaluated during model development. The functional relationship between the probability of mortality, human presence, and habitat quality is of fundamental importance in ultimately providing the linkage with spatial-temporal habitat supply models (HSM) that predict habitat capability, suitability, and effectiveness.

A previous meta-analysis of grizzly bear mortality rates and causes across studies in the Rocky and Columbia mountains substantiates the importance of human-mediated mortality of grizzly bears. For grizzly bears >2 years of age, 77 - 85% of mortalities were caused by humans, and all recorded mortalities of adult males were human caused. Wildlife managers need accurate estimates of reported mortalities, but the meta-analysis showed that without being informed by researchers, managers would have been aware of only 46 - 51% of the grizzly bear mortalities recorded by the studies. Provincially, estimated annual mortality rates of 1.5 - 2.0% are attributed to unknown and unrecorded causes. Access, provided primarily by roads to support timber harvest and other resource-extraction industries, figures prominently in grizzly bear mortality as does increased levels of settlement, and the extension of settlements into occupied grizzly bear range.

Empirical mortality models are being generated with data collected from 2 adjacent study areas (North Fork and South Fork grizzly bear research projects) within the Flathead River drainage. The study areas share general similarities in habitat components and resource extraction history, but diverge with respect to levels of human presence on the landscape, grizzly bear population density, and population status. Specifically, the North Fork study area has an extensive road network but little human settlement and a high density, increasing grizzly population while the South Fork study area is adjacent to relatively higher human densities and has a low density, stable to declining grizzly bear population.

The strength of this data lies in the diverse levels of human activity between the 2 studies used to develop relationships, resulting in a wide range for these explanatory variables. Additionally, the available data is unbiased as to source and location as all recorded mortalities were from a sample of radio-monitored bears and includes data from areas where hunting is permitted - other predictive models of grizzly bear mortality have generally relied on reported mortalities, or have been limited to park environments. Challenges with the analyses lie in issues related to trans-jurisdictional aspects of data availability. Since the North and South Fork studies areas are within BC and the US, respectively, significant differences exist with respect to forest inventory planning data (FIP), terrestrial and predictive ecosystem mapping variables (TEM and PEM), and biogeoclimatic variants (BEC) available as digital coverages. While variables such as elevation and greenness are universally available and may index grizzly bear habitat, they are not readily amenable to projections over space and time - trans-jurisdictional relationships between grizzly bear mortality, habitat quality, and human-use variables will have to be recast using habitat variables that are amenable to spatial-temporal forecasting (i.e., FIP, TEM, PEM, and BEC) and available provincially. Final models will be validated against data from a third BC study area (West Slopes project). Collectively, data available for model fitting and validation represents >40 years of research on >250 individual, radio-monitored grizzly bears. Even this extensive data set, however, will not likely allow sex- or age-specific models of mortality.

The development of predictive models of grizzly bear mortality relies on logistic regression and an information-theoretic approach to define a set of candidate models based on prior information of grizzly bear ecology and mortality factors. Models are being fit as a function of where bears die versus where they live, in addition to models of where bears live versus random points (i.e., resource selection functions) and where bears died versus random points. Seasonal differences in habitat quality and where humans occur on the landscape necessitate exploration of seasonal mortality models. Preliminary results suggest that while variables related to habitat quality may be important in some seasonal models, much simpler models predicated on human-use variables may be good candidates for other seasons.

CHASE - a habitat supply modelling framework:

CHASE (Caribou Habitat Assessment & Supply Estimator) is an example of a habitat supply modelling framework that was developed in Mackenzie, British Columbia (Scott McNay, formerly of Canadian Forest Products, Inc.). This modelling framework was developed as a multi-stakeholder initiative that included local forest licensees, provincial ministries, and the research community. CHASE can be defined as a series of linked, spatial, seasonal habitat models that sequentially evaluate habitat 'value' for single species or guilds. These seasonal habitat models: 1) identify species-specific life requisites, 2) determine the accessibility of these life requisites, 3) evaluate risk of mortality, and 4) link to spatially explicit models of population dynamics. The seasonal habitat models are static but driven by inputs from landscape coverages. Linking the habitat models to a spatially explicit landscape simulator allows scenarios that express different management policies, or different potential futures, to be evaluated within a decision support context.

More broadly, CHASE can be viewed as a suite of complementary models and tools that address issues of habitat supply, timber supply, adaptive management, and the evaluation of competing management policies. To complete these functions the CHASE framework incorporates several modelling platforms and tools including: 1) Norsys Netica® - a Bayesian Belief Network (BBN) modelling shell, 2) Gowlland Technologies SELES - a Spatially Explicit Landscape Event Simulator, 3) Environmental System Research Institute ArcGIS® Desktop and ArcView® with Spatial Analyst, 3) Microsoft Access®, and 4) VDYP - British Columbia Ministry of Forest Variable Density Yield Prediction program.

The framework embodied by CHASE incorporates several elements deemed essential to habitat supply modelling. Given that habitat supply is a spatial-temporal measure of the quality and quantity of a species' habitat, spatial and temporal resolutions as well as spatial and temporal relationships must be specified. Current applications of CHASE have utilized a 1 ha spatial resolution over large (>1,000,000 ha) landscapes with temporal resolutions of 1 (stand age succession, natural disturbance events), 5 (forest harvesting events), 10 (model time steps for habitat supply evaluations), and 200 (2 harvest rotations) years. Spatial relationships are represented either as simple buffers or moving window algorithms such that the habitat value at a location is the result of the location's spatial proximity to factors (e.g., mortality risk) that influence value. Temporal relationships are mediated through stand age (forest species succession is not currently modelled) and incorporate stand age succession, disturbances related to forest harvesting, and episodic events such as fire. To support the comparison of management scenarios that entail trade-offs between timber and habitat, a base case scenario of habitat supply through time is desirable. CHASE employs a stand-initiating fire model consistent with fire ecology information and history for the study area to generate thresholds or targets for habitat supply. Comparisons between the amounts of seasonal habitats available under management scenarios with those that would occur under natural conditions provide the basis for evaluation of the effectiveness of management options. In keeping with established metrics of habitat (e.g., capability, suitability, and effectiveness) CHASE employs a sequential evaluation of habitat that expresses an inherent habitat quality for a site and subsequent step-downs in quality due to defined and measurable influences. Evaluating habitat at different points in this step-down process permits quantification of the impact of specific events and policies. The specification of several seasonal habitat models for a species, while essential to effectively modelling habitat, complicates the final assessment of habitat supply. Tracking the balance of season range supply through time is informative; however, seasonal range supply is linked in a spatially-explicit approach to population dynamics within CHASE to achieve a more tangible and holistic evaluation of risks associated with management policies.

Two other essential elements of a habitat supply modelling framework embodied within CHASE include model building principles and the model building process. The principles for model building are centered about known or assumed species-habitat relationships expressed as causative relationships between landscape variables, or proxies for such variables. These expressed relationships should be comprehensive, explicit, measurable, testable, and have clear linkages to management policy through model factors that represent management levers (i.e., points in the models where policy-driven activities explicitly influence species-habitat relationships). Development of the seasonal habitat BBNs within CHASE were guided by 4central concepts of habitat (life requisites, risk of mortality, disturbance and competition) in recognition of their ecological importance and susceptibility to resource development activities. CHASE's strengths stem from the model building process, specifically the use of consultative workshops during which Netica is employed as an intuitive, rapid, and interactive platform for the development of seasonal habitat models or BBNs. As an ecological modelling tool and decision support aid, BBNs have been widely used by the USDA Interior Columbia Basin Ecosystem Management Project and the USDI Bureau of Land Management. Favorable characteristics of BBNS include: 1) intuitive representation of key environmental factors and causal relationships, 2) easy incorporation of diverse data and professional judgment, 3) explicit accounting of uncertainty and variability, 4) representation of model outcomes as probabilities and support for sensitivity analysis that encourages risk analysis and management, 5) inference of the most likely causes of model outcomes that aids in understanding the model and defining which environmental conditions will likely generate desired a outcome, and 6) fits well with adaptive management concepts.

Within the context of developing analytic and decision models for grizzly bears and forest management, the value of CHASE is in the established framework that it provides and in the benefits that have been realized from applying this framework in north and south central BC. These benefits include enhanced land use decisions and enhanced insights into long-term consequences of competing management policies.

The Mackenzie grizzly bear habitat supply model:

As part of Slocan (now Canadian) Forest Product's FIA funding, a habitat supply modelling project for grizzly bears was initiated during 2003-2004 on the Mackenzie TSA. The general approach to model development was predicated upon that of CHASE and involved a series of 3, professionally facilitated, consultative workshops that brought together stakeholders from industry, government, and the research community. Proximate reasons for initiation of the project stemmed from: 1) recognition that habitat mapping for grizzly bears on the TSA is too general to guide forest practices, 2) concerns that development of the Williston Reservoir may have impacted some seasonal ranges, 3) population level evidence that human activities may have already negatively impacted grizzly bears, and 4) recognition that ongoing development activities create roads and alter natural vegetation patterns. Specific objectives of the modelling project were to: 1) provide a comprehensive definition of grizzly bear habitat, 2) refine existing habitat mapping, 3) provide tools to facilitate resource inventory, 4) quantify and forecast development, disturbance, and mortality impacts on habitat supply, 5) incorporate spatially explicit habitat supply into timber supply analyses, and 6) provide a spatial-temporal framework for informed strategic, tactical and operational decision-making. The Mackenzie HSM will provide an initial approximation of a habitat supply model for grizzly bears for the current project.

As with CHASE, the grizzly bear HSM started with a comprehensive view of habitat that incorporated species-specific life requisites (primarily food), displacement in response to human presence, anthropomorphic mortality factors, and resource competition (food competition with black bears and humans). For grizzly bears' active portion of the year, 3 preliminary seasonal models that sequentially evaluate habitat in a fashion analogous to capability, suitability, and effectiveness were developed and intersected with 2 seasonal mortality models to generate predictions of habitat value. Seasonal habitat models were cast broadly as spring, summer, and fall while the 2 mortality models encompassed spring and summer/fall seasons combined. All models were developed as BBNs and followed a systematic approach of developing a layered influence diagram followed by the definition of states for each model node, and finally assignment of conditional probabilities to express the nature of the relationships between linked nodes.

The spring habitat model incorporated both pre- and post-green-up foraging on roots, emergent grasses and forbs, and ungulate calves. Summer habitat was modelled as primarily a berry-economy but with some provisions for secondary foods in the event of berry failures. The fall habitat model was similar to spring in the use of forbs and roots but also included carrion from sport hunting and residual or persistent berries. All 3 models were fully approximated with respect to the influence diagram and node states; however, assignment of conditional probabilities for each seasonal model was limited to the top portion (or sub-model) that defined vegetative capability due to time and funding constraints. Each of these sub-models shared an identical structure in terms of the influence diagram and node states and differed only in the conditional probability tables of 2 nodes that summarized the percent cover of vegetative foods under forest canopies and in persistently non-forested sites. Primary inputs to these sub-models are derived from digital land inventory coverages and include biogeoclimatic zone, soil moisture regime, stand age and stand initiating event (for forested sites), and broad seral stage classification (non-vegetated, herb, shrub) for non-forested sites. Management levers for the sub-models are contained within the stand age and stand initiating event nodes.

The 2 seasonal mortality models are also similar to each other in structure and share input nodes that reference proximity to settlements, access (roads, trails, navigable rivers, pipelines, seismic lines, hydro lines, firebreaks), hunter density, and highways and rails (differentiated from other access due to likelihood of vehicular kills). Differences between the 2 mortality models are with respect to definitions of hunter densities (only bear hunters in the spring model but bear, bird, and ungulate hunters in summer/fall), and the presence of a node in the summer/fall model denoting hunter-killed carcass remains. All input nodes also represent potential management levers via various policies to manage access, problem wildlife control responses, hunter density, and hunter success. The second layer of the models (i.e., immediately below the input nodes) represent summary nodes that reveal how inputs influence grizzly bear mortality types (e.g., limited entry & resident hunting kills, poaching kills). The mortality models represent an alternative approach to the empirical modelling of mortality and also provide a heuristic representation of how factors influence mortality.

Grizzly bear research in Alberta:

Grizzly bears are currently listed as a species of special concern within Alberta although a review process is underway to determine if they should be listed as threatened. Also awaited is a ministerial decision on a provincial grizzly bear recovery plan that has been prepared and submitted to government. Additionally, the province's current Bear Management Area boundaries are under review pending results of three DNA population censuses being conducted in western Alberta between Highways 3 and 16 to determine genetically based population boundaries. Presently, it is expected that the DNA censuses will be repeated every 5 years. Under current management regulations, a spring limited entry hunting season was scheduled for 2005.

The Foothills Model Forest Grizzly Bear Research Program (FMFGBRP) is currently in phase 2 of a long-term study. Field research for phase 1 extended from 1999 to 2003 and was limited to a relatively small study area (10,0000 km^2 with habitat mapping progressively extended to ≈30,000 km). The initial scope of the research program was to provide the necessary regional data on grizzly bear status, demography, habitat associations, and responses to current landscape conditions to permit a cumulative effects analysis of the Cheviot open pit coal mine project. More generally, the focus of the FMFGBRP is to provide managers with knowledge and planning tools that integrate the long-term requirements of grizzly bears into the decision-making framework for land management. Results of this research has provided managers with insights into the location of high quality grizzly bear habitat, where mortality risks are greatest, where major movement corridors are located, and revealed that provincial grizzly bear populations differ with respect to health and demography.

The current phase of research extends to 2010 during which the development of remotely sensed landsat-based habitat map products, and resource selection functions (RSF) of grizzly bear occurrence, will be progressively extended to cover all provincial grizzly bear habitat (228,000 km^2). Currently, seamless habitat mapping extends over 100,000 km^2 in west-central Alberta. Subsequent to habitat mapping, mortality risk surfaces following RSF analytical procedures and delineation of movement corridors based on graph theory will be generated. These products represent the primary management tools for grizzly bear conservation in Alberta. Understanding the relationships between environmental and landscape characteristics and grizzly numbers and health, however, is still in development. The important question of to what degree landscapes can be altered by anthropogenic impacts and still support viable populations of grizzly bears can not yet be answered. As such, sampling grizzly populations under differing regimes of landscape change and human use, and detection of landscape changes over time, is of fundamental importance to managers.

Map products to support habitat mapping, RSF and graph theory analyses, and change detection have relied on the development of new remote sensing techniques applicable to large areas. These products incorporate land cover maps of anthropogenic entities (e.g., clear-cuts, roads, rails, pipelines, well sites, urban areas) and natural cover types (e.g., rock, water, alpine, shrub, open and closed conifer or deciduous forest) as well as derivative continuous variable surfaces (e.g., leaf area index, crown closure, and species composition). Annual change detection methodologies rely on Enhanced Wetness Difference Index and MODIS satellite sensor imagery. For example, changes detected between 1999 and 2001 in west-central Alberta include 284 km of road, 297 ha of mines, 128 well sites, and 6012 ha of cut-blocks. In general, outside of protected lands, a general trend of landscape change is towards increased human use (that increases mortality risk for bears) and increased amounts of early seral habitats (that increases the food base for bears). Grizzly bear response to these changes appears to be towards younger bears due to high mortality risk that exhibit higher fecundity due to enhanced food base.

Another primary objective of FMFGBRP is to detect and evaluate the impacts of environmental stress on grizzly bears via molecular and biochemical indicators, and through analyses of existing datasets that may reveal associations between health and environmental conditions.

Grizzly bear population delineation:

Meta-population (i.e., interacting sub-populations) structure may develop from combinations of natural fractures and anthropogenic induced population fragmentation. The detection of population boundaries and their causes is necessary to understand and effectively manage these fragmented systems. Human-induced meta-population structure of grizzly bears in southwestern Canada has been derived through genetic analyses. This research used 15 locus microsatellite genotypes of 826 wild grizzly bears from a 100,000 km² area of southwestern Canada and two levels of analysis that provided insight into the structure and genesis of population boundaries in this area. The first level used a Bayesian Monte Carlo Markov Chain algorithm designed to detect population boundaries with no *a priori* assumptions of group membership. The second level used individual-based population assignment methods and multiple linear regression to measure sex-specific movement rates and fragmentation in relation to human disturbance. Together these results suggested where spatially explicit discontinuities existed in the regional distribution of grizzly bears sufficient to detect and explain the presence of population and sub-population units. These discontinuities roughly correspond to the human-settled valleys associated with major highways in the region (Highways 3, 1, 6, 95 in southern BC). Seven immediately adjacent sub-populations characterized by limited female and varying degrees of male inter-change and one isolated population were identified. Two of these sub-populations were small and vulnerable: the female-isolated south Purcell population south of BC Highway 3 and the completely isolated south Selkirk population south of BC Highway 3A.

To further explore the factors associated with fragmentation, a multiple linear regression in 16 geographic areas that compared only immediately adjacent populations was used. It was found that reductions in male inter-population movement was significantly associated with human-caused mortality, human settlement, and geographic distance. Reductions in female inter-population movement were significantly associated with human-caused mortality, traffic volume, and geographic distance. The future of grizzly bear persistence in southwestern Canada is likely dependent on management actions that promote and ensure meta-population function (inter-change of males and females) between these fragmented sub-units. To this end, current research is designed to provide management solutions to the fragmentation problems in the south Purcell and Selkirk areas. That research involves DNA surveys and GPS radio collaring of grizzly bears from these areas with the objectives to identify and develop linkage zones that foster secure inter-population movement of grizzly bears, reduce human-caused mortality, improve habitat quality and security, and educate government, industry, and the public about grizzly bear conservation in the region.

Threats to grizzly bears:

Long-term threats to grizzly bears in British Columbia ultimately stem from economic, ecological, sociological, and political drivers that introduce uncertainty into 1) resource conservation objectives and policies, 2) political support and funding, and 3) our ability to forecast the type and magnitude of natural (beetles) or global processes (global warming). Some of these drivers are clearly inter-dependant and as the provinces' human population increases in size and changes in composition, needs and values will change and be reflected in conservation objectives, policies and funding. While desirable futures can be defined and the uncertainty surrounding the probability of obtaining these futures explicitly handled within the context of risk analysis and management, the uncertainty associated with long-term stability of human values, political will, and management objectives will always be difficult to capture within models. Ultimately, the onus will lie with decision makers, domain experts, and modellers to continually consider which informational, value, or policy uncertainties are not incorporated into a model. For example, cumulative effects models may explore the effects of varying road closure policies on habitat supply, but managers may frequently be unable or unwilling to enact such policies given the political climate.

Delineating threats to bears is a necessary first step in deriving management levers and policies (permutations of levers) that will 1) function as input variables in the habitat models, 2) be incorporated into dynamic landscape simulations, or 3) be evaluated subsequently via post processing of resultant spatial coverages. Modelling threats to bears is directed towards factors that serve either as sources of direct or indirect mortality and may be cast against a backdrop of ecological processes for which we have an understanding of stochastic natural events (e.g., wildfire, berry crop failures). Such threats serve to impact established sequential habitat metrics as follows:

> Capability refers to the optimal natural ability of a site to provide for a species requirements. Human impacts and activities such as settlements, agriculture, and road surfaces permanently alter a site's inherent capability.
>
> Suitability refers to the sites' current ability to provide species requirements and reflects successional and structural stages or site conditions that are less than optimal, but also transient such that the site can return to its inherent capability at some point. Human activities such as forestry (harvest, silviculture, and herbicides) and grazing represent non-permanent anthropogenic impacts while forest species and age succession, wildfires, and beetle outbreaks represent natural processes that may deflect a site away from its capability. In general, anthropogenic effects result in a site's suitability being less than its capability, but intensive activities (e.g., agriculture) may increase suitability above capability.
>
> Effectiveness incorporates the effects of displacement and disturbance of grizzly bears from habitats due to human presence such as vehicle traffic, industrial equipment, and hikers.

Capability, suitability, and effectiveness collectively influence population processes of grizzly bears. and can be mediated through habitat effects (displacement, degradation) and associated reductions in reproductive potential. A final habitat metric recognized by workshop attendees was habitat value that incorporates direct mortality impacts on bears due to human activities or sources such as vehicle collisions, hunting, poaching, mistaken species identification, and defence of life and property kills.

Table 1. Threats to grizzly bears that can be explicitly addressed within HSMs.

Habitat Metric	Threat	Impact
Capability	• Settlements • Agriculture • Recreational developments • Fragmentation • Hard/permanent road surfaces • Rail lines • Reservoirs • Global warming	Threats to capability are those that result in a permanent loss or reduction of the habitat's inherent optimal ability to provide resources required by bears. The effect of global warming is equivocal.

Suitability	• Resource extraction
	    • Soft/temporary road surfaces
	    • Forest harvesting
		Threats to suitability represent agents that reduce a habitat below capability without restricting return of the habitat to its inherent capability. Some anthropogenic impacts may increase suitability above capability.

	- Silvicultural practices
	• Fire suppression
	• Wildfires
	• Beetle outbreaks
	• Forest pathogens
	• Competition
	  - Livestock grazing
	  - Commercial berry harvest
	  - Black bears	

Effectiveness	• Access - Habitat avoidance
	  - Highways
	  - Forestry mainlines
	• Access - Disturbance
	  - All access types
		Threats to habitat effectiveness operate either through avoidance or disturbance issues. Avoidance results in complete (bears never use the habitat) or partial (bears temporally restrict use of habitat) 'loss' of habitat. Disturbance refers to disruption of critical activities with concomitant energetic effects.

Value	• Access
	  - Roads
	  - Rails
	  - Trails
	  - Navigable rivers
	  - Seismic lines
	  - Firebreaks
	  - Power-lines
	  - Pipelines
	• Hunting
	• Settlements
	• Camps
	• Grazing
	• Garbage dumps
		Threats to habitat value incorporate direct mortality agents that exert their influence through increasing the lethal encounter rate between grizzly bears and humans. Some threats serve simply to increase human presence and increase the background encounter rate, while other threats involve attraction (roadside seeding, hunter kills, garbage dumps) of bears into close proximity to humans or entry of humans into highly suitable habitats.

Landscape modelling:

Landscape models simulate landscape change over time, and project implications of land-use policies on timber supply, coarse filter biodiversity and habitat for species of interest such as grizzly bears. Landscape models can be used to examine scenarios such as:

- future trends if current forest practices continue unchanged,
- estimate landscape patterns that would result from natural disturbances in the absence of industrial forestry, and
- experimentally examine consequences of alternative forest practices.

Spatially-explicit simulation modelling tools can be used to represent knowledge about an area. SELES is one such tool that is widely used in BC. It can allow an interacting suite of models to be constructed so that alternate assumptions about future landscape and habitat condition can be evaluated. For example, a base landscape module could combine spatial timber supply projections with road building, forest species succession and natural disturbance. It can project specific locations where roads are built and logging undertaken, and simulate forest succession and growth. The model could apply forest-replacing disturbances (including fire and insect outbreaks) in Biogeoclimatic Variants based on disturbance history information and simulate disturbances patches across the landscape. These models typically project landscape conditions at scales of one hectare and allow both temporal and spatial consequences of management policies and decisions to be explored and contrasted with natural disturbances.

A landscape model does not in itself evaluate biodiversity or rate wildlife habitat suitability. Instead, the indicators of landscape state are exported, that is then either interpreted directly by domain experts, or used to drive separate computer models that rate habitat suitability for species of interest. Biodiversity data can be exported including: forest age, patch size, patch connectivity, and other related landscape metrics. Interpretation of biodiversity data is intended to be undertaken by a planning group with the assistance of a domain expert.

Landscape models can export other landscape data such as forest age, canopy closure, tree height, et cetera to species models that use the data to evaluate habitat suitability. Models for species such as grizzly bear, woodland caribou, and American marten can be modelled in separate applications such as a Bayesian belief networks. Since landscape models provide landscape data both over time and space, the combination of the landscape model and species models can estimate how the spatial distribution of habitat changes over time.

Effective interpretation of landscape model projections are best accomplished with the assistance of relevant domain experts. A landscape model cannot examine all potential management decisions, nor are they designed to directly undertake necessary social choices among competing land use options. Ultimately, human judgment on the parts of both planning groups and expert advisors are critical supplements to the information provided by a landscape model.

Management and research applications of landscape models:

Landscape models can be used to simulate effects of management alternatives on grizzly bear habitat supply. Management plans that encompass the Flathead include the following management tools that relate to grizzly bears:

- Core grizzly bear conservation areas, covering the entire Flathead area,
  - old growth management areas that include:
  - avalanche tracks
- denning areas,
- connectivity corridors that emphasize grizzly bear habitat,
- riparian management and reserve zones, and

- old and mature timber retention targets, that have direction for assigning priority to grizzly bear areas.

Additional grizzly bear management tools can be explored using a landscape model for their impact on timber supply, recreation opportunity, agriculture, urban expansion and conservation. Experiments can be set up to address the following type of questions relating to grizzly bear habitat supply:

- rate and placement of forest harvesting,
  - concentrated vs. dispersed harvesting,
- access management strategies,
- impact of mountain pine beetle disturbance and forest salvage response,
  - climatic effects:
  - distribution of wet and dry years on berry production, and
- impacts of climate change on the disturbance regime and forest productivity.

Management tools and levers for grizzly bears:

Landscape variables and aspects of grizzly bear population ecology that are affected or influenced by human activities have the ability to be used as management levers. Many such levers can be spatially modelled with a stochastic modelling tool such as SELES that provides a language for model specification and a simulation engine for running the models. SELES can model processes responsible for landscape change (anthropogenic or natural, continuous or episodic, spreading or contained) and can be used to predict future landscapes that fall within the range of natural variation, or that represent the impacts of management scenarios, or combinations of the two. SELES can produce output in the form of digital resultant layers that can serve as input data to HSMs.

Not all management levers are amenable to spatially explicit modelling. Some management policies are applied widely or must be locally referenced to specific land tenures, landscape units, or game management units. Pre-processing of SELES output prior to input to the HSMs can be used to invoke particular parameter states that represent the effect of these levers within the HSM. One advantage of this approach is that the same SELES simulation can be used to evaluate a different variant of a global or local policy - an approach that effectively holds spatially explicit policies constant. It is also possible for non-spatially explicit policies to provide feedback from one model time-step to another. For example, a global or local policy on access restrictions or grizzly bear hunter effort (with spatially explicit policies held constant) could be tied to the amount of effective habitat, with access or hunter effort for a time-step dependent on effective habitat levels in the previous time-step.

Table 2. Summary of management levers for grizzly bears.

Threat	Management Levers
Grazing Leases (GL)	• Number

Back Country Recreation (BCR)
Front Country Recreation (FCR)
	• Spatial Location and Proximity
	• Type
	    • Cattle, sheep (GL)
	    • Hikers, heli-access, ATV, horses (BCR)
	    • Golf courses, campgrounds (FCR)
	• Usage
	    • Human use days (BCR, FCR)
	    • Animal Unit Months (GL)

River access	• Access management policies
	    • Fishers
	    • Boaters
	    • Hunters
	• Proximity

Settlements	• Number
	• Spatial Location and Proximity
	• Type
	    • Towns/housing developments
	    • Industrial camps
	    • Commercial farms and ranches
	    • Hobby farms
	• Size
	    • Human density
	    • Areal
	• Garbage and attractants management

Forestry	• Harvesting
	    • Block size and configuration
	    • Species selections
	    • Partial cutting/Variable retention strategies
	    • Placement of Wildlife Tree Patches
	    • Annual timing of activities
	• Silviculture
	    • Burning, scarification
	    • Planting density and arrangement
	    • Planting delays or natural regeneration
	    • Herbicide use
	    • Thinning
	    • Brushing and grazing vegetation control
	• Corridors and Security Areas
	    • Spatially explicit Old Growth Management Areas
	    • Visual buffers and Visual Quality Objectives

	• Riparian buffers • Large leave blocks • Re-entry strategies for basins
Wildfires and fire suppression	Fire management policies
Sport hunting of game species, ceremonial hunting, and management/research removals of grizzly bears	• Agreements with First Nations • Ungulate, bird and bear hunter access policies • Ungulate, bird, and bear hunting season policies • Tracking of ungulate hunter success - bear/human conflicts at ungulate kill sites • Grizzly bear sex/Age harvest policies • Problem bear management policies

Competition	• Berry picker access
	• Black bears
	  • Population management
	  • Creation of large openings
	• Grazing management
	• Ungulate management/enhancement
	• Spawning channel management
	• Kokanee enhancement

Road access	• Spatial location and proximity • Type (industrial, recreational) • Traffic density • Closures/deactivation • Kilometers of road or road density targets • Crossing management for highways/rail • Timing of road use • Visual buffers along roads • Road side vegetation and attractants management

Spatially oriented frameworks such as provided by CHASE and the FMFGBRP, that use models and mapping to 1) assess species - habitat associations, 2) assess or predict landscape change, and 3) provide support to management decisions, are desirable tools for managers. Such management tools are often cast within the context of trade-off analyses between competing resource, social, or economic values that permit a more complete evaluation of management policy consequences. Application of these tools requires post-processing of SELES - HSM outputs. For example, comparisons of habitat supply and timber supply under various management scenarios require post-processing of both SELES harvest outputs and HSM habitat outputs for each time-step to determine the long-term flow of both resources. While some resource trade-off tools have a quantitative basis for comparisons with habitat supply stemming from established modelling approaches (e.g., models of timber growth and yield, spatial models of natural disturbance agents), others require a more conceptual approach to address a broader set of social and economic values. Some potential management tools are:

- Habitat supply vs. timber supply
- Habitat supply vs. “range of natural variation”
- Habitat supply vs. industrial opportunities
- Habitat supply vs. “lifestyle” opportunities
- Habitat supply vs. recreational opportunities

Habitat classification and mapping:

Spatially explicit application of the BBNs, and dynamic landscape modelling that will project ecological and anthropogenic effects through time, require digital base coverages as primary data sources. Several candidate map products are available, each with its own strengths and weaknesses:

Provincial Forest Cover (FC) and Terrain Resource Information Mapping (TRIM) - coverages are at an appropriate scale for habitat modelling (1 /20 000), incorporate roads and hydrology, and are consistent with timber supply modelling (hence data are amenable to projections into the future). Forest cover inventories may be tenure specific, may not be current for roads and openings, have little ecological basis, provide little information for non-forested sites, do not extend beyond provincial boundaries and are not available in jurisdictions such as national parks and protected areas.

Landsat Imagery - cost effective and appropriate for large area mapping and land cover monitoring at resolutions of 30m for most bands, extends beyond provincial boundaries and useful in trans-jurisdictional settings, has some mapping applications in non-forested areas. Landsat can be poor at identifying uniform forest types at the pixel level, coverages do not have clear ecological meanings, and Landsat products like greenness are not easily projected into the future.

Broad Ecosystem Units (BEU) - integrates vegetation, surficial material, topography and soil and is the smallest unit of a hierarchical Broad Ecosystem Inventory. The BEU classification ties the Biogeoclimatic Ecosystem Classification (that incorporates climate, vegetation, and site classes at a regional scale) to provincial scale ecological units or Ecoregions that are defined by climatic processes, physiographic, and plant and animal distributions. The classification system places an emphasis on physical attributes, successional stages and climax vegetation. The Broad Ecosystem Inventory system is a uniformly applied, ecologically based system amenable to successional and structural (temporal) changes. It is, however, mapped at an inappropriate scale (1:250 000) and includes polygons that are complexes of BEU such that resolution over most study areas is poor and is out of date.

Terrestrial Ecosystem and Predictive Ecosystem Mapping (TEM/PEM) - are large scale standardized mapping products (1:5000 to 1:50 000) describing site units and vegetation development stages that hierarchically fit into the smaller scale Ecoregion and BEC zone classification system. TEM/PEM is linked with forest cover and can be melded with Vegetation Resources Inventories to complement data. TEM/PEM provides more extensive data on non-forested sites than forest cover, can provide information as sites undergo changes in structural stage, and is linked to food species through via plot data (Venus database). TEM/PEM data, however, is composed of complex polygons that are problematic when converted to a raster modelling environment and does not provide successional pathways stemming from different disturbance agents (e.g., fire, beetle, harvesting).

Modelling of spatial-temporal habitat for grizzly bears will generally start with maps that depict the occurrence and abundance of important seasonal foods. The favoured approach by workshop attendees stressed use of TEM/PEM in conjunction with FC and TRIM within a SELES environment. Problems with complex polygons in TEM/PEM coverages may be addressed by using the original raster coverages with subsequent coalescing into polygons following a model specific algorithm. TEM/PEM site series can be referenced to a food ratings table developed from VENUS data that provide prominence values for species. Berry species in particular may be difficult to model due to the variety of vaccinium species and their slightly different ecological associations along with differential use by bears. Shepherdia distribution and abundance has also proven difficult to predict, however, some modifications to the TEM/PEM database may be possible to improve on these predictions.

In addition to vegetative foods, faunal sources need to be considered. One option may be to create a "protein" coverage that incorporates existing or modelled data on ungulate densities and winter ranges, ant and ground squirrel colonies, anadromous salmon and kokanee spawning areas and escapement. Stable isotope data from grizzly bear hair samples may be used to delineate small scale protein maps, however, this may be difficult to project through time without reference to changing ungulate populations.

To fully develop a habitat supply modelling framework, additional existing coverages such as Game Management Units, cadastral maps, landscape unit maps, licensee forest development planning maps, road development projection maps, and beetle attack maps are required. Estimates and projections of natural disturbance processes, that provide baseline measures for comparison with various management scenarios will also require development. Particular concerns with fire return cycles derived from BEC coverages were expressed by attendees. BEC variants that are positioned above low elevation Natural Disturbance Type 4 are disturbed by fires more often than their counterparts not so positioned.