Expert Knowledge and Its Application in Landscape Ecology

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Editors

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Foreword

In the years since its emergence as a widely recognized scientific discipline a quarter-century or so ago, landscape ecology has become increasingly quantitative and analytically rigorous. Technological advances have made it possible to obtain empirical information about landscape configuration, movements of animals through a landscape, human land uses, landscape change, and a host of other interesting things about landscapes. Landscape ecology, like other sciences, has become data-driven.

Yet, landscapes are much more complex than the simple patch-matrix diagrams some of us have become fond of. Landscape structure, function, and dynamics interact in myriad ways over multiple scales. We do not have, nor will we ever have, data on everything that is important or interesting. Gaps in data, and uncertainties accompanying the data we do have, pose particularly difficult problems when landscape ecology is applied to practical issues in urban planning, resource management, sustainable agriculture, fire ecology, and the like.

Of course, people knew things about landscapes long before landscape ecology came into being, and even now not everything landscape ecologists know is embodied in digital bytes. These sources of knowledge – expert knowledge – can help to fill the data gaps and reduce the uncertainties. That is why the approaches developed in this book are so important.

But the phrase "expert knowledge" immediately conjures up a variety of possibilities. Expert knowledge might be anything from "It's true because I'm an expert and I say so" to highly formalized systems of knowledge elicitation or expert systems software. An "expert" might be someone who knows more about something than someone else who wants to know about it. Some have suggested that an expert is someone who knows more about a topic than the average person, but this does not mean much because most people know nothing about the topic, bringing down the average. By this definition, even a passing knowledge of, say, quantum physics or the epidemiology of AIDS might qualify one as an expert. This is why "experts" are usually defined by the regard with which they are held by their peers. But there is a sociological element at play here: people who know a lot about a topic but challenge the conventional wisdom of a discipline may be called “iconoclasts” rather than “experts,” and the value of their knowledge is often correspondingly diminished.

In the legal arena, expert witnesses are highly qualified people who are called upon to provide objective testimony about the state of knowledge related to an area of their expertise. Because of their expert status, their testimony may carry inordinate weight. But good lawyers know that it is not difficult to find well-credentialed experts who present diametrically opposed views of the same issue. The open, questioning nature of scientific investigation virtually assures this. As an example, expert witnesses for the plaintiffs and the defendants often gave conflicting statements about the effects of the *Exxon Valdez* oil spill on marine ecosystems in Prince William Sound. The jury hearing the case was unable to evaluate the merits of the arguments presented by the “dueling scientists” and ended up ignoring the experts on both sides in making their decision. The scientific evidence was largely ignored.

The point of this is that the knowledge of experts is not necessarily pure and unbiased. It is a product of their experiences and their training – the “facts” are colored by one’s perceptions of the world from which they came. It is easy to see this if the individual is, say, a tribal elder or a long-time fisherman with deep knowledge gained from decades of experience and insights extending back for generations. Such knowledge can provide invaluable perspectives on landscape dynamics and history, but it is clearly influenced by the cultural context in which it was gained. We tend to think of scientific knowledge as somehow being less swayed by context, and perhaps it is. But science has its cultures, too, and scientists are susceptible to the judgments of their peers, which can influence how they interpret data as well as the kinds of data they collect. “Knowledge” always has cultural overtones.

All of this is to say that, although any discipline, perhaps especially landscape ecology, must draw knowledge from multiple sources, there is a real need to ensure that this knowledge is as accurate and reliable as possible. How we accomplish that is the focus of this book. It is much needed.

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Chapter 7
An Expert-Based Modeling Approach to Inform Strategic and Operational Land Management Decisions for the Recovery of Woodland Caribou

R. Scott McNay

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7.1 Introduction

Ungulates are a valuable natural resource due to their contribution to biodiversity (Ray 2005) and to their value as game animals for aboriginal peoples, guide outfitters, and hunters. For the past decade in British Columbia (BC), forest practices have been regulated to conserve the wildlife range that provides for the overwinter survival of ungulates. For the purposes of the regulations (http://www.env.gov.bc.ca/wld/frpa/uwr/), ungulates include moose (*Alces alces*), mule (or black-tailed) deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginiana*),

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elk (*Cervus elaphus*), caribou (*Rangifer tarandus*), Stone sheep (*Ovis dalli stonei*), Dall sheep (*Ovis dalli dalli*), bighorn sheep (*Ovis canadensis*), and mountain goats (*Oreamnos americanus*). Wildlife range has also been regulated in BC to conserve areas used during other seasons by wildlife species considered by the BC government to be at risk of local extinction.

Woodland caribou (*Rangifer tarandus caribou*; hereafter, "caribou") throughout Canada have undergone a history of range reduction (de Vos and Peterson 1951; Spalding 2000; Thomas and Gray 2002), and populations in many herds are currently in decline (Rettie and Messier 1998; Schaefer et al. 1999; McLoughlin et al. 2003; Wittmer et al. 2005). The BC government considers caribou to be at risk (http://www.env.gov.bc.ca/atrisk/), therefore the BC conservation measures apply to caribou winter ranges as well as to their other seasonal ranges. Caribou have dynamic range requirements due to their broad distribution (the species is potentially found in as much as 30 million ha in BC alone), and wildlife managers lack the tools and specific understanding of how to manage for that set of dynamic requirements, let alone how to manage landscapes to assist the recovery of declining populations. Common responses to such uncertainty have included deferral of decisions, implementation of long-term research programs, development of strategic plans, and participation in a variety of management debates (Thomas 1985). These responses essentially delay or preclude effective management actions by consuming an enormous amount of time and resources.

In 2004, to eliminate this inefficient use of resources and to provide the information required to implement effective conservation regulations, the BC government produced legally binding, expert-based management guidelines for the amount, distribution, and attributes of the range required by each ungulate species in the province, including caribou. Managers were instructed to implement the interim guidelines until areas could be legally designated as Ungulate Winter Ranges (UWRs) or Wildlife Habitat Areas and until specific management actions for these designated areas could be provided. In 2005, the BC government also brought together a science team to provide expert technical advice specifically on how to promote the recovery of caribou in the southern portion of their range. Although such expert opinion may at times lack complete empirical scientific support, the implementation of guidelines based on expert advice may be justified because the potential consequence of inaction can be local extinction of a species (Hebblewhite et al. 2010). Hebblewhite et al. (2010) suggested that taking some action, even if it is based only on interim study results (e.g., expert-based information), could benefit the species and possibly lead to effective management.

In north-central BC, managers have used scenario modeling (Daum 2001), expert-based information, management simulations, and empirical testing to provide insights into the probability that woodland caribou, mountain goats, and mule deer will occupy a given range. This probabilistic approach was used to inform strategic decisions about recovery planning for woodland caribou and the formal operational identification of UWRs for all three species, and to provide a transparent framework for adaptation of current management regimes and tools for monitoring the effectiveness of the new management regimes. Using woodland caribou in north-central BC as a case study, my objectives in this chapter were to demonstrate the use of expert-based information at strategic and operational levels of management, and to reveal why the expert-based approach can help to resolve complex and important ecological problems.

7.2 Ecological and Management Context

My case study focused on threatened caribou herds that range over 3.7 million ha in north-central BC, and specifically the Chase (~550 animals), Wolverine (~375 animals), Takla (~125 animals), and Scott (~50 animals) herds (Giguère and McNay 2007; Wilson et al. 2004; Wildlife Infometrics, Inc., Mackenzie, BC, unpubl. data). Caribou in the area generally use lodgepole pine (*Pinus contorta*) forests at mid- to low-elevations (700–1,300 m asl) during the fall and early winter, and use alpine and subalpine areas (>1,300 m asl) during the late winter, spring, and summer (Terry and Wood 1999; Wood and Terry 1999; Johnson 2000; Poole et al. 2000). Except during the spring, their diet consists primarily of terrestrial forage lichens (*Cladina mitis*, *Cladina rangiferina*, *Cladina arbuscula* ssp. *beringiana*, *Cladonia uncialis*, and *Cladonia ecmocyna*), with an increased use of arboreal forage lichens (*Bryoria* spp.) during the late winter (Johnson et al. 2000). Because the early-winter range is located on relatively flat terrain at low elevations, it is at risk of significant anthropogenic disturbance; for example, extensive industrial development began in the study area after construction of the W.A.C. Bennett hydroelectric dam in 1961. Caribou also experience predation risk throughout their range, and predation is the most proximate factor in the general decline of caribou in BC (Seip 1992; Wittmer et al. 2005; Bergerud 2007). Landscape change as a result of anthropogenic disturbance is considered to be the ultimate cause of the decline in caribou populations through the resulting alteration of the relationships between predators and their prey (Golder Associates 2010).

The tendency for caribou to frequent high-elevation range, dispersed to create a low population density, is a common tactic for avoiding predators (Bergerud et al. 1984, 1992; Bergerud 1992), which in the study area are mostly wolves (*Canis lupus*). Aboriginal people have reported seasonal use of the area by wolves, but also described an increase in wolf abundance and a more persistent presence following the first appearance of moose in the early 1920s (McKay 1997). Other predators of caribou in this area include grizzly bear (*Ursus arctos horribilis*), black bear (*Ursus americanus*), and wolverine (*Gulo gulo*). The BC government considers the impact on caribou populations caused by hunting to be minor.

Although the Committee on the Status of Endangered Wildlife in Canada considered the herds in this case study to be at risk of a population decline (COSEWIC 2002), the BC Government did not consider the herds to be a priority for recovery planning. Strategic objectives to conserve caribou range were described in local land use plans (BCMSR 1999, 2000), but there was no legal authority provided to implement any management consistent with the strategic objectives. In 2003, an *ad hoc* caribou Recovery Implementation Group (RIG) initiated a “grass roots" agenda to provide the BC government with the information required to develop a recovery plan for caribou in the area (McNay et al. 2008a). Specific information about the RIG's function, including its meeting agendas and minutes, is available at the Recovery Initiatives Web site (http://www.centralbccaribou.ca).

7.3 Gathering and Formalizing Information

The RIG members chose a modeling approach to make spatially explicit predictions about the quality of seasonal ranges for caribou, using existing environmental conditions as well as those that would presumably occur under a variety of hypothetical simulated landscape disturbance scenarios. The scenarios were based on the disturbances expected to be caused by land management or by natural, unmanaged disturbances such as wildfire (McNay et al. 2006). The intent was to compare the results of the disturbance scenarios as a way to inform RIG members about the potential utility of alternative management regimes. However, no model of caribou seasonal ranges existed at that time, and although information was available from previous research, RIG members recognized the limitations of the information and the lengthy and costly research process that would be required to address those limitations. As an alternative to inaction while awaiting this research, the RIG members chose to develop an interim model and address its data limitations by eliciting information from knowledgeable professionals (hereafter, "experts").

7.3.1 Identifying Experts and Eliciting Their Knowledge

The RIG hosted professionally facilitated, 1- to 2-day workshops approximately every 2 months from January 2000 to January 2003 to gather and formalize information about caribou and their range requirements. Professional facilitation was deemed necessary by the RIG to effectively elicit information from the experts and to move the discussion as efficiently as possible through the initial steps of developing a model. Experts in relevant domains (e.g., ecosystem mapping, population dynamics, lichen ecology, climate, and land management) were chosen by RIG members based on their reputation and their ability to support the model development process. Some experts had primary roles in research projects that had been conducted on caribou herds in the study area or in adjacent areas. Other experts, although knowledgeable about their domains, knew relatively little about caribou or caribou habitat.

Once selected, experts became members of the RIG and attended each workshop, except when there was a need for unique or specific information that was not central to developing the model (e.g., provincial timber-supply modeling). Workshops were usually attended by 10–15 members, including 1 facilitator, 3 modelers, and 6–11 domain specialists or experts. There was no specific intent to balance specific affiliations or types of professional endeavor (e.g., academia versus government or consultants), but groups with a vested interest (i.e., government and industry) tended to have the strongest representation.

The elicitation of information followed a series of steps that began with the definition of seasonal range types. Within each seasonal range, the group then identified the most important life requisites that should be represented by the model and the ecological or biophysical factors (e.g., environmental conditions) most likely to be functionally related to these life requisites. The relationships among the life requisites were then depicted as "influence diagrams". The modeling team distinguished between environmental conditions that would or would not be changed by management in order to address the eventual need for simulating landscape disturbance. The conditions that would be changed were then termed "management levers." The elicited information was summarized and reviewed as each meeting progressed. When a difference in opinion arose among the experts, it was resolved by discussion leading to a consensus, guided by the facilitator; all final results were recorded in the meeting minutes for review by workshop participants subsequent to the meeting.

The resulting influence diagrams were then represented as Bayesian belief networks (BBNs; Cain 2001; Chap. 5), which were developed by a three-person modeling team and prepared for presentation to the RIG members at the next workshop. This approach was chosen to maximize the efficiency of the consultation time with experts during the RIG meetings. BBNs can be used to derive and visualize predicted responses (i.e., model outputs) based on information on the influence of environmental conditions (i.e., the model inputs). The nodes of BBNs are linked by conditional probability tables. Marcot et al. (2006) provided a detailed description of the use of BBNs in ecology. The specific probabilistic nature of each of the identified ecological relationships was elicited from the experts as another step in the model development process. Although it was possible for RIG members to misrepresent probabilistic relationships, and for the modeling team to misrepresent expert knowledge (Kuhnert and Hayes 2009), these potential errors were usually avoided by following specific guiding principles. These principles were developed by Bruce Marcot, and eventually become the basis for a journal paper (Marcot et al. 2006). Errors that were identified by the modeling team were corrected through subsequent consultation with the experts.

7.3.2 Ecological Relationships

McNay et al. (2002, 2006, 2008a) summarize the specific ecological relationships and associated conditional probabilities that resulted from this process. The BBNs covered the following seasonal-range combinations: high-elevation winter, pine-lichen winter, calving and summer, post-rut, and migration. Each range prediction was modified by accounting for a BBN based on predation risk. BBN outputs were expressed as the expected probability of occupancy of a site by caribou, which was subsequently classed for convenience into three states: low (0.00–0.33), moderate (0.34–0.66), or high (0.67–1.00). The modeling team felt that this summary would be easy for experts to understand and use to judge the fit of the model results to their expectations. The modeling team used equidistant division points among the classes because the experts were unable to provide a better alternative. Maps of the classified ranges were used by the modeling team to demonstrate the BBN results to the RIG members. Although it was possible to derive a measure of uncertainty in the model output, model developers did not provide this information, mostly due to perceived time constraints and real funding constraints.

7.3.3 Ecological Stressors

The RIG facilitator elicited information from experts and other RIG members regarding the stressors expected to alter environmental conditions and thereby change the probability of range use by caribou. Although the stressors were generally well documented in the scientific literature, their perceived importance and degree of interaction varied because their relative strength is still being debated. The work on stressors therefore tended to be a confirmation among the experts about their relative ranking of the known stressors as applied to the conditions of the study area. The debate and conclusions that resulted from this discussion were largely based on the published literature, but set within the context of the personal observations of the experts.

The RIG experts believed that where timber harvesting occurred, the resulting early-seral forests would support abundant moose interspersed through the adjacent older forest (Franzmann and Schwartz 1998) and, in turn, abundant wolves (Messier et al. 2004). Compounding the predation risk from increased wolf numbers was the development of roads associated with timber harvesting operations, which provide wolves with easier travel and potentially increase hunting efficiency (James and Stuart-Smith 2000). The experts assumed that caribou populations would generally experience greater mortality in areas where moose are interspersed throughout their range (Wittmer et al. 2005); this source of greater mortality therefore became a stressor, which was assessed using a BBN for predation risk.

A second stressor was the hydroelectric development in the area. Subsequent flooding of the Finlay, Peace, and Parsnip Rivers created BC's largest body of freshwater, which experts considered a barrier to caribou migration. This barrier has likely contributed to reductions of caribou populations, particularly for the Scott herd. The barrier effect of the reservoir was included as a variable in the migration BBN.

Timber harvesting and similar disturbances were considered to be a third group of stressors through their ecological effect on natural succession of vegetation communities, and hence on the abundance of terrestrial forage lichens. Forage lichens tend to dominate the understory of pine forests during distinct (but not all) stages of natural vegetation succession (Coxson and Marsh 2001). Winter ranges were therefore considered to require regular natural (i.e., wildfire) or managed (e.g., timber harvesting) disturbance to sustain the lichen supply; consequently, these disturbances had varying effects on the BBN results for the pine-lichen winter range.

7.3.4 Management Scenarios

Seasonal ranges for caribou were predicted and evaluated using five land-management scenarios defined by the RIG members:

1. The *potential range* was estimated by setting all input nodes to their most favorable condition for caribou.
2. The *current range* was estimated by setting the input nodes to use the existing environmental conditions.
3. The *managed range* was estimated based on forest management, such as timber harvesting and road construction, conducted under rules specifically intended to conserve caribou range.
4. The *natural unmanaged range without elevated predation* was estimated based on assumed natural patterns of wildfire without accounting for the moose–wolf predator–prey system.
5. The *natural unmanaged range with elevated predation* was estimated based on the same natural disturbance patterns as in scenario 4, but accounting for the moose–wolf predator–prey system.

The rules for conservation of caribou range were adopted from the local land-use plans (BCMSR 1999, 2000), which stated that 50% of the potential pine-lichen winter range should be in a condition usable by caribou at all times. The natural disturbance scenarios were based on historical patch sizes and return intervals for wildfire within the study area (Delong 2002). All scenarios were simulated over 290 years in 10-year time steps using the Spatially Explicit Landscape Event Simulator (Fall and Fall 2001), and the natural disturbance scenarios were repeated with random start positions to generate a range of results over those conditions. These scenarios are described in more detail by Fall (2003).

7.3.5 Validation and Verification of the Results

The modeling team considered *validation* to be an assessment of the model's implementation and *verification* to be an assessment of its accuracy. Validation assessments conducted by the modeling team included reviewing the mapped output for obvious errors (e.g., missing data, apparent background noise, unnatural boundaries between range classifications) and manually inspecting data and relationship calculations to confirm that the model inputs at specific, random locations led correctly to the specific output.

Preliminary verification of the model's performance was limited to a simple visual inspection of the mapped seasonal range predictions by the RIG caribou experts to verify that classified seasonal range results met with their expectations or knowledge of how caribou used their range. Peer reviewers were solicited to review the BBN structures and the associated conditional probability tables. The RIG members considered this limited verification to be sufficient for use in strategic planning (i.e., development of management actions to promote caribou recovery). In contrast, a more formal verification of the model's results was conducted before the results were used in operational planning (i.e., UWR identification). The original mapped results were first smoothed to facilitate their application to the landbase. An aerial reconnaissance was then conducted to verify the spatial locations of the predicted range. Relocations of radio-collared caribou were also used to help assess model validity using either a statistical test of range selection (Chesson 1983) or a simple measure of inclusion (the proportion of animals that used the range). The selection test was based on an analysis of winter (1 January to 30 April) relocations with the hypothesis that caribou would choose to use modeled ranges in direct proportion to their availability (i.e., selection was equivocal). Alternatively, we assumed that caribou selected the modeled range if they used the modeled range more than expected, and that caribou did not select the modeled range if use was less than expected. To assess correspondence to the hypothesis, the modeling team also used a confusion matrix (Provost and Kohavi 1998) of the selection observations to calculate standard performance criteria for the model. The proportion of inclusion was a simple and less formal measure of the relative proportion of relocations that could be enclosed by the modeled range while attempting to minimize the total amount of range predicted by the model.

7.3.6 Interpretation and Use of the Expert-Based Information

Following the workshops that were used for model building, the RIG hosted a second series of ten professionally facilitated workshops between December 2003 and February 2007. The purpose of these workshops was to develop a set of management actions intended to promote the recovery of caribou populations using the expert-based modeling results. At this stage, new members were added to the RIG who had a vested interest in how land management might unfold in the future (e.g., First Nations, recreational snowmobilers, guide-outfitters – "stakeholders" Chap. 1). As was the case for selecting the experts, the new members were chosen based on their reputation for being knowledgeable professionals and their perceived ability to support the planning process. The workshops proceeded using the following series of steps:

1. Confirm stakeholder dedication to the process and define the extent of the area in which recovery would be promoted.
2. Review the available knowledge for each herd, including the modeled range predictions.

3. Determine the general goals to set boundaries on the scope of the recovery planning.
4. Confirm the stressors identified by the previous series of workshops and identify potential mitigation measures.
5. Compose a set of specific management actions to promote recovery of the caribou populations.
6. Establish a basis to review the socioeconomic impacts of the anticipated management direction.

Each workshop was conducted following a standard protocol, which began with a meeting announcement and request for attendance. Agendas were then developed and final meeting arrangements were established based on the responses of the members. The RIG attempted to have all members attend, and this was usually achieved. Maps were used to help RIG members interpret the spatial results of the expert-based seasonal range models. Further, without specific information on seasonal range carrying capacity, the modeling team created a habitat index so RIG members could conveniently and consistently compare quantitative model results among seasonal ranges. The index, which was calculated by multiplying the amount of seasonal range by a seasonal range value weight (SRVW), effectively standardized original model results for each seasonal range based on a constant, hypothetical density of caribou that might be expected under conditions of sustainability (McNay et al. 2008a). The SRVW was calculated as:

$$\mathrm{SRVW} = -0.53 + 0.04\mathrm{RV} + 0.79\mathrm{RT} - 0.35\mathrm{RT}^2 + 0.04\mathrm{RT}^3,$$

where RT is the range type (i.e., pine-lichen winter, post-rut, high-elevation winter, or calving and summer) and RV is the range value (i.e., high, medium, or low) predicted by the BBN. Minutes were recorded by an RIG secretary and salient points (e.g., decision points and action items) were recorded by the facilitator. Minutes were prepared and sent to RIG members for review.

7.4 Results of the Expert-Based Modeling

Clear differences were revealed in the results for each herd area by applying the expert-based BBNs for the seasonal ranges. For example, whereas the potential for calving and summer range exceeded the potential for any other range in all areas, the potential for pine-lichen winter range was generally the lowest, though not in all herd areas (Fig. 7.1). Furthermore, the potential effect of predation risk varied across seasonal ranges and areas (Table 7.1), and the different scenarios also produced results that varied over the forecasted conditions for the simulation period (Fig. 7.2). In general, the results for seasonal ranges, herd areas, and management scenarios successfully provided the RIG members with opportunities to compare the existing availability of caribou range to the caribou range that would result from a variety of hypothetical forecasted future conditions.

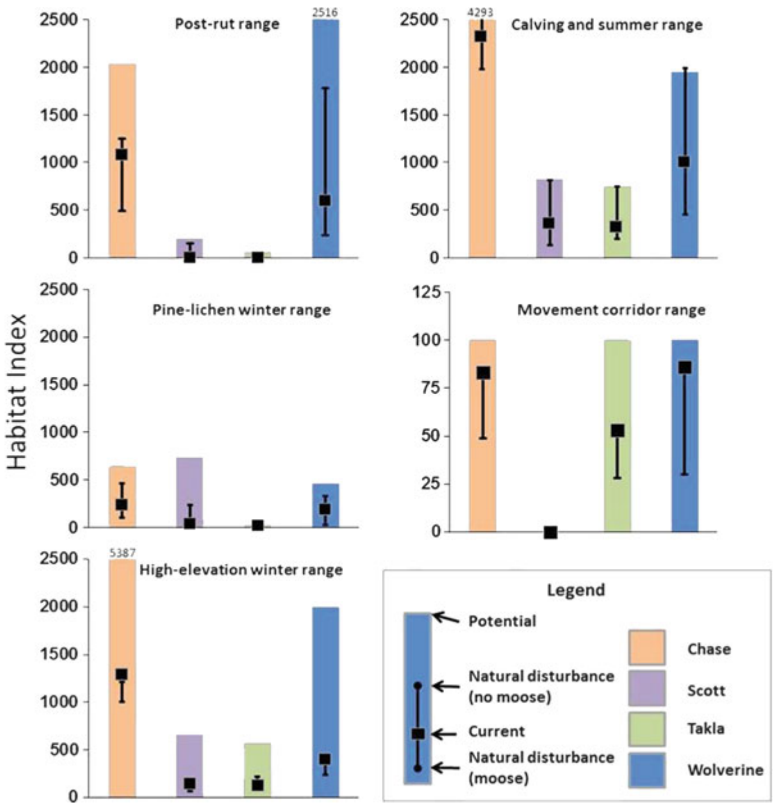

Fig. 7.1 The relative amount of seasonal range (i.e., the habitat index; see Sect. 7.3.6 for a description) modeled for conditions in four caribou herd areas (Chase, Scott, Takla, and Wolverine herds) of north-central British Columbia (from McNay et al. 2008a). Predictions were made for hypothetical simulated landscape scenarios representing the potential best conditions for caribou, current environmental conditions, and two natural disturbance scenarios (with and without accounting for elevated predation based on the abundance of moose as primary prey for wolves). A hypothetical management scenario was modeled but is not presented here because that scenario was dynamic through time and could not be characterized using a static estimate. The actual habitat index is placed above histograms whenever they exceed the limits of the Y-axis

7.5 Validation and Verification of the Modeled Results

The RIG arranged for an aerial reconnaissance that intersected 54 of 74 available patches of pine-lichen winter range in the Chase and Wolverine herd areas (Fig. 7.3). Terrestrial lichens were not abundant in nine of the 54 patches. In eight other cases along the flight line, false negatives were observed (i.e., there was abundant terrestrial lichen even though the BBN did not predict its occurrence). Winter relocations of 40 and 33 radio-collared caribou in the Wolverine herd area ($n = 3{,}239$) and Chase herd area ($n = 5{,}207$), respectively, were collected and used in the selection tests for the pine-lichen winter range. Selection or avoidance of range was stronger in the

Table 7.1 Area and percentage of total area (in parentheses) for different seasonal ranges in north-central British Columbia modeled as having a high or medium probability of occupancy by woodland caribou (from McNay et al. 2008a)

	Area of seasonal range (ha) and % of total area			
Herd area (Scenario)	Post-rut range	Pine-lichen winter range	High-elevation winter range	Calving and summer range
Chase herd (Scenario 1)	22,500 (1%)	17,184 (1%)	208,505 (12%)	1,094,879 (63%)
Percentage reduction 1–2	26	28	71	2
Scenario 2	16,679	12,407	59,462	1,069,999
Percentage reduction 2–4	56	63	21	47
Scenario 4	7,343	4,587	47,078	579,012
Percentage reduction 4–5	41	54	24	15
Scenario 5	4,324	2,100	35,997	492,419
Scott herd (Scenario 1)	2,319 (<1%)	21,883 (4%)	26,069 (4%)	204,831 (34%)
Percentage reduction 1–2	13	70	56	0
Scenario 2	2,009	6,525	11,419	204,060
Percentage reduction 2–4	100	86	53	56
Scenario 4	0	929	5,354	90,172
Percentage reduction 4–5	0	98	52	64
Scenario 5	0	21	2,556	32,312
Takla herd (Scenario 1)	492 (<1%)	835 (<1%)	22,420 (4%)	186,322 (38%)
Percentage reduction 1–2	3	3	53	0
Scenario 2	477	812	10,529	186,122
Percentage reduction 2–4	97	55	56	57

(continued)

Table 7.1 (continued)

Herd area (Scenario)	Area of seasonal range (ha) and % of total area			
	Post-rut range	Pine-lichen winter range	High-elevation winter range	Calving and summer range
Scenario 4	12	374	4,613	80,635
Percentage reduction 4–5	0	100	17	40
Scenario 5	12	0	3,827	48,741
Wolverine herd (Scenario 1)	26,703 (3%)	11,722 (1%)	78,785 (9%)	484,830 (57%)
Percentage reduction 1–2	30	6	68	1
Scenario 2	18,762	10,981	24,918	478,449
Percentage reduction 2–4	83	59	38	48
Scenario 4	3,101	4,545	15,430	249,703
Percentage reduction 4–5	35	87	41	55
Scenario 5	2,001	595	9,141	111,754

Predictions were made for hypothetical simulated landscape scenarios derived based on expert consultations: Scenario 1, potential best conditions for caribou; Scenario 2, current environmental conditions; Scenario 4, natural unmanaged conditions without accounting for elevated predation; and Scenario 5, natural unmanaged range accounting for elevated predation. The percentage reduction in range area compares the results in Scenarios 2 and 1 and the results in Scenarios 4 and 2. Scenario 3 was a dynamic forecast of managed range conditions over time and therefore could not be characterized by a static estimate

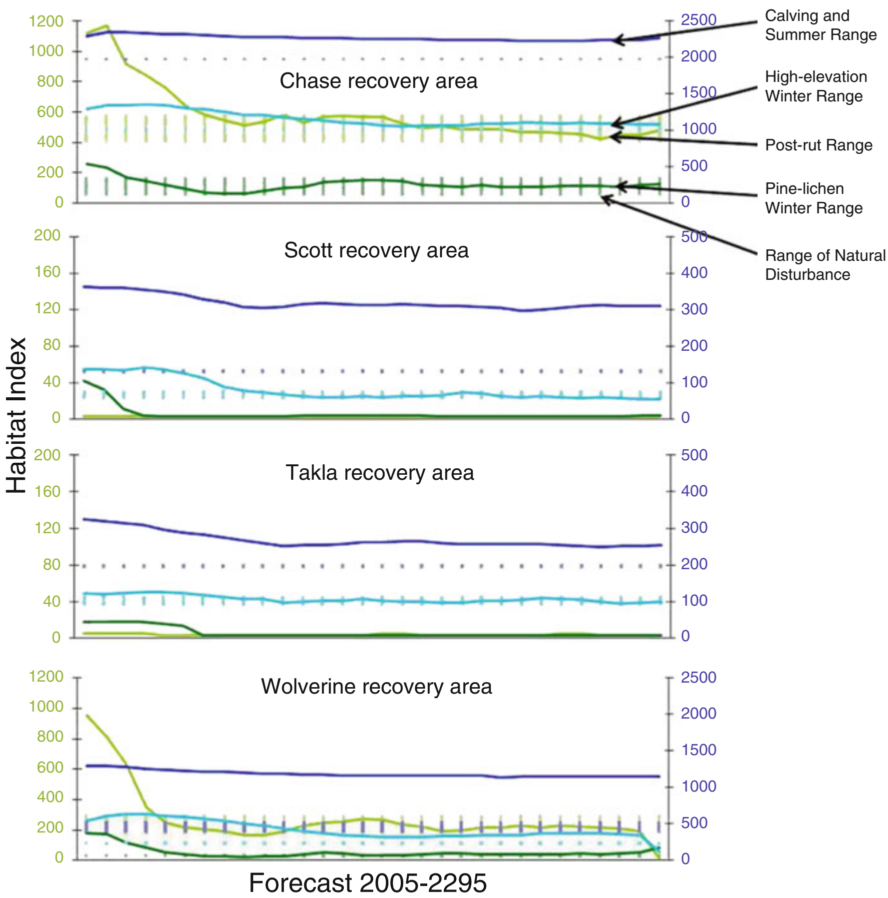

Fig. 7.2 The relative amount of seasonal range (i.e., the habitat index; see Sect. 7.3.6 for details) modeled to represent hypothetical simulated environmental conditions [a conservation scenario (*solid lines*) and a natural disturbance scenario (*vertical bars*)] in four caribou herd areas (Chase, Scott, Takla, Wolverine) of north-central British Columbia (from McNay et al. 2008a). See the text for a description of the modeling and landscape scenarios

Chase area than in the Wolverine area, although the rate was acceptably high (>70%) in both cases (Table 7.2). Overall accuracy was ≥75% in both areas (Table 7.3), but the prediction error in the Wolverine area was marginal (i.e., a false negative rate of nearly 30%).

In comparison with the relatively successful tests of pine-lichen winter range, the test of caribou selection for high-elevation winter range revealed a poor and inconsistent fit of the relocation data to the original modeled range. Reconnaissance surveys of the high-elevation winter range suggested that arboreal forage was not being predicted properly (Rankin and McNay 2007). This led to a more detailed study of the abundance of arboreal forage lichen in subalpine habitats within the study area,

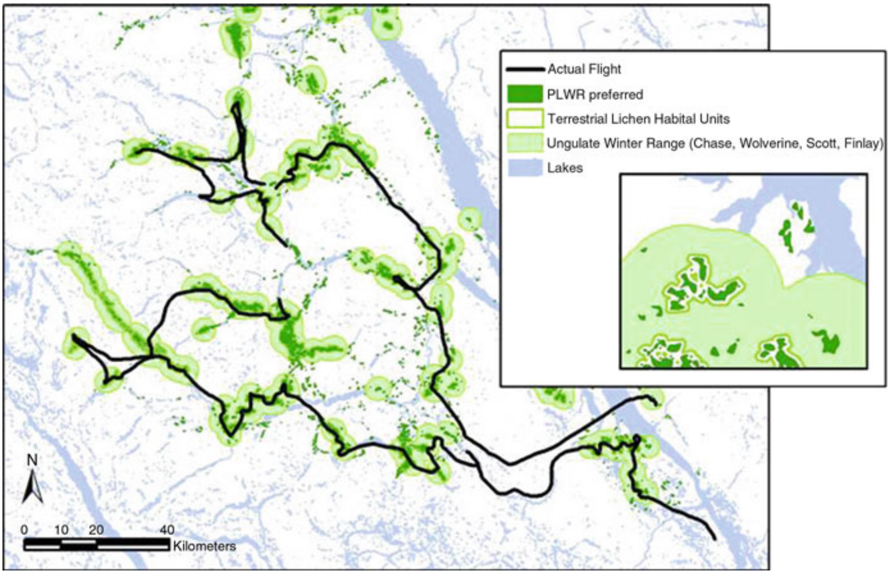

Fig. 7.3 Management units [ungulate winter ranges, terrestrial lichen habitat, and preferred pine-lichen winter range (PLWR)] for caribou in the Scott, Wolverine, and Chase herds of north-central British Columbia and the flight line depicting an aerial reconnaissance of the management units conducted in late 2003 (from McNay and Sulyma 2003)

Table 7.2 Observed caribou habitat selection for the modeled pine-lichen winter range estimated from relocations of radio-collared caribou in the Wolverine and Chase caribou herd areas of north-central British Columbia

Caribou herd area and modeled probability of range occupancy		Observed selection[a] Avoided	Preferred	Total selected (avoided + preferred)	Equivocal	Total sample
Wolverine	Low	25	7	32	8	40
	High and medium	7	18	25	15	40
	Total	32	25	57	23	80
Chase	Low	27	4	31	2	33
	High and medium	4	22	26	7	33
	Total	31	26	57	9	66

[a]Estimates of selection were calculated for individual caribou based on the methods described by Chesson (1983)

a variety of updates to the BBN for the high-elevation winter range, and a reapplication of the model; the revised model included 63% of the observed winter relocations of caribou at higher elevations (McNay et al. 2009). Expert and peer review of the modeling and maps resulted in detailed documentation of the model (McNay et al.

Table 7.3 Key performance criteria summarized from a confusion matrix containing information about the observed selection for modeled pine-lichen winter range by radio-collared caribou in the Wolverine and Chase caribou herd areas of north-central BC

	Caribou herd area	
Performance criteria[a]	Wolverine	Chase
Selection rate (%)	71	86
Recall rate (%)	72	85
Accuracy (%)	75	86
Precision (%)	72	85
False-positive error rate (%)	22	13
False-negative error rate (%)	28	15

[a] Criteria definitions:
Selection rate = [(actual preferred observations + actual avoided observations)/total observations] × 100%
Recall rate = (number of predicted preferred choices that were actually observed as preferred/total actual preferences) × 100%
Accuracy = [(number of predicted avoided choices that were actually observed as avoided + number of predicted preferred choices that were actually observed as preferred)/total selections] × 100%
Precision = (number of predicted preferred choices that were actually observed as preferred/total predicted preferences) × 100%
False-positive error rate = (number of predicted preferred choices that were actually observed as avoided/total actual avoided) × 100%
False-negative error rate = (number of predicted avoided choices that were actually observed as preferred/total actual preferred) × 100%

2002), a user manual for application of the model (Doucette et al. 2004), a published summary of the expert-based approach to modeling (McNay et al. 2006), and a series of herd-specific seasonal range maps that were used by the BC government and other managers to implement management actions that focused on promoting recovery of the caribou (McNay et al. 2008a).

7.6 Practical Applications

7.6.1 Recovery Planning

The use of BBNs allowed a systematic and transparent use of expert-based information to support planning of management actions that would promote the recovery of caribou herds in the study area. The transparency of the method and its reliance on multiple experts helped to establish agreement about this complex problem among land managers and other RIG members, and encouraged a collective approach to the identification of specific management priorities. For example, one important agreement among RIG members fundamental to the recovery plan was the primary assumption that the distribution of moose (and therefore of wolves) in the plan area had likely expanded due to historical processes that encouraged natural colonization of parts of the area by moose, but that a further increase in moose numbers resulted from an abundance of moose forage following recent forest harvesting. Based on this agreed-upon assumption, management actions to promote recovery of the caribou populations were therefore given the following specific priorities:

1. Restore critical range by reducing the extent and value of the range for moose, but not below the level that would be likely to occur normally as a result of natural disturbance regimes.
2. Implement priority 1 and provide interim controls or limits on the abundance of the wolves' primary prey (e.g., implement an aggressive hunting season to control moose populations).
3. Implement priority 1 and provide interim controls or limits on the abundance of wolves.

If range restoration was ultimately found to be unsuccessful within a herd area, and ongoing management of other proximal factors (i.e., moose and wolves) were required to maintain a herd, then the caribou herd was considered to be not self-sustainable and recovery of caribou to self-sustaining levels would not be ecologically feasible (McNay et al. 2008a).

Another complex ecological problem considered by the RIG experts focused on the fact that moose were an important, albeit recent, resource in the area. The change in moose abundance meant that even natural, unmanaged conditions are unlikely to support caribou today as well as they did historically. This is because as moose populations increase (hence, as more wolves enter the study area), the incidental predation on caribou would increase. This logic was supported by the BBN results (Fig. 7.1), so the RIG experts decided that it would not be efficient or perhaps even feasible to artificially create range conditions for caribou that would equate to historical conditions. Therefore, the population levels to which caribou herds may recover would likely be lower than historical levels. Similarly, the irreparable barrier to migration created for the Scott herd by the reservoir meant that high-elevation range was permanently separated from low-elevation range in that herd's area; therefore, RIG experts assumed that this barrier would limit the likelihood and feasibility of recovery by the Scott herd.

Consistent application of the expert-based BBNs across the herd areas revealed two results that otherwise might have been considered counterintuitive (Table 7.1): a general lack of potential for low-elevation range in the Takla herd's area and a high risk of predation in low-elevation range in the Scott herd's area, even under natural disturbance conditions. The RIG members therefore de-emphasized restoration of caribou range in these areas. In contrast, the BBN results indicated that the best recovery opportunities existed for caribou in the Chase and Wolverine herd areas (Fig. 7.1). Without considering metrics other than the seasonal range habitat index (i.e., other metrics might include patch size and connectivity), the conservation policy that was modeled for these areas appeared able to provide for a sustainable supply of caribou range consistent with the conditions expected under an assumed natural disturbance regime (Fig. 7.2). That said, the pine-lichen winter range and post-rut range were likely to decrease from their current levels and undergo some decline over the next 2–3 decades. If this occurs, the caribou populations will decline as well, but RIG experts were uncertain whether the decline could be mitigated by the caribou by increasing their use of high-elevation range. Another uncertainty that became obvious to the RIG experts pertained to the feasibility of implementing the recommended policy given the pending outbreak of mountain pine beetle (*Dendroctonus ponderosae*). This expected episodic rather than chronic forest disturbance had no apparent precedent in BC's natural systems, and it was unclear whether forest licensees could manage their forests in the manner intended by the caribou conservation policy in the context of the insect outbreak. Since the original study was conducted, the episodic nature of mountain pine beetle disturbance has killed most of the overstory tree layer in many of the UWRs.

7.6.2 Designations of Ungulate Winter Range

The first submission to the BC government for conservation of UWR was made by the RIG for pine-lichen winter range in 2005 using the expert-based BBN results. The submission was preceded by a collaborative workshop to develop management actions for the UWR (which totaled 360,029 ha). Because workshop participants were mostly RIG members, the participants were familiar with the background to the submission and the meeting progressed with little preamble. A subsequent submission to the BC government for conservation of UWR is still being prepared for high-elevation winter range totaling 877,087 ha. This second submission was developed under contract rather than during a collaborative workshop. The difference in approach was largely due to the BC government's perception that the contract would be more efficient. Although it is too early to say for sure, it seems as though the anticipated efficiency may not be realized because the consultation phase of the process has yet to begin.

7.7 Discussion

In general, planning for the recovery of endangered wildlife is a difficult problem with no easy solutions, particularly where the availability and future supply of natural resources are fundamental to the species as well as to the economic or recreational development undertaken by licensed stakeholders, aboriginal peoples, and the general public. Competing demands on natural resources may mean that insufficient management options exist to allow for full implementation of desirable actions to promote recovery of animal populations. Also, incomplete understanding of key ecological relationships may add to management uncertainty and to the perceived risk of failure. However, in the example described in this chapter, several intended mechanisms and a variety of unintended coincidental activities led to almost universal acceptance of using expert-based modeling as the foundation for planning and implementing management actions to promote the recovery of local caribou herds.

Expert-based information was depicted using influence diagrams and later quantified using BBNs through a series of workshops that were inclusive rather than exclusive of participants. In competitive social or economic settings, exclusion is common, but the "grass-roots" nature of the RIG initiative led to a more inclusive team environment. Professional facilitation insured that debate among experts was welcome and expected, but that consensus was eventually achieved. The graphical nature of the influence diagrams assisted this process by allowing the participants, regardless of their education or experience, to grasp at least the conceptual nature of the ecological relationships. The inclusiveness led to a sense of shared ownership of the results by stakeholders and scientists alike. Ownership was important because all stakeholders could claim pride in the product while also being in a position to defend its implementation. Open discussion and peer review enabled consensus on the final form of the BBNs for the seasonal ranges and acceptance of the mapped results. The systematic approach provided by regular workshops and formal modeling, combined with the transparent use of the expert information by using the influence diagrams, instilled confidence in and understanding of a complex ecosystem, leading to a more rational and focused discussion than what might otherwise have occurred. The BBN approach to depicting expert information provided the ability to discuss and model a comprehensive description (i.e., not limited by incomplete empirical data) of how caribou relate to their environment and of how stressors may affect their populations and their use of seasonal ranges. Although we recognized that the results could likely be sensitive to the inherent properties of the BBN (Kuhnert and Hayes 2009), the modeling team did not have time to fully evaluate the potential implications. Rather, the RIG members relied on recommended BBN construction standards (Marcot et al. 2006). Nonetheless, this combination of a formal approach with transparency led to acceptance of the expert knowledge and subsequently allowed workshop participants to identify, discuss, and make decisions about the potential implications of certain management actions (or lack thereof).

There are many alternative approaches to the implementation of management actions for conservation of seasonal range for ungulates. For example, government biologists could have simply taken the results from recent studies, determined a habitat-use model that best fit the observed relocation data (e.g., resource-selection functions; Johnson et al. 2006), and used those results to designate conservation areas (e.g., UWRs and Wildlife Habitat Areas). Such an inductive modeling approach may provide more precise identification of seasonal ranges, but the accuracy is restricted to the environmental conditions under which the animal relocations were observed. Such models are not particularly well suited for scenario planning in which the environmental conditions change, because the interactions among the descriptor variables in the model are not robust across all environmental conditions. Also, in the specialized case of declining populations, it's unlikely that inductive model results are a desirable representation of habitat-use patterns; moreover, the resulting algorithms rarely offer transparency about the actual causal ecological relationships, making it difficult for some stakeholders to understand (and therefore accept) the model. Lastly, the application described by the inductive model excludes other resource-use interests and is therefore unlikely to address the multiple-use objectives of a broader government agenda. For all these reasons, expert judgment and deductive or abductive thinking may be more suited to addressing complex environmental problems (Douglas 2006; Martin 2007).

Although the use of expert-based information may be expedient and well suited to resolving complex problems, mistakes can be made (e.g., the high-elevation winter range model was initially inadequate). Protocols for the use of expert-based information should therefore include a dedication to testing (validating and verifying) the models prior to use, at least at operational management levels (e.g., Chap. 5 and Chap. 14). Future applications of the expert-based approach used in north-central BC would benefit from a prior understanding of the potential influence of the inherent structure of the BBNs and by making measures of uncertainty more explicit in the information provided to decision-makers. Although it is sometimes impossible to envision future catastrophic changes, the RIG process would have benefited from a more serious consideration of the potential effects of the mountain pine beetle outbreak (McNay et al. 2008b).

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