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# Decision-support model to explore the feasibility of using translocation to restore a woodland caribou population in Pukaskwa National Park, Canada

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*Abstract:* The distribution and abundance of woodland caribou (*Rangifer tarandus caribou*) have declined dramatically in the past century. Without intervention the most southern population of caribou in eastern North America is expected to disappear within 20 years. Although translocations have reintroduced and reinforced some populations, approximately half of caribou translocation efforts fail. Translocations are resource intensive and risky, and multiple interrelated factors must be considered to assess their potential for success. Structured decision-making tools, such as Bayesian belief networks, provide objective methods to assess different wildlife management scenarios by identifying the key components and relationships in an ecosystem. They can also catalyze dialogue with stakeholders and provide a record of the complex thought processes used in reaching a decision. We developed a Bayesian belief network for a proposed translocation of woodland caribou into a national park on the northeastern coast of Lake Superior, Ontario, Canada. We tested scenarios with favourable (e.g., good physical condition of adult caribou) and unfavourable (e.g., high predator densities) conditions with low, medium, and high numbers of translocated caribou. Under the current conditions at Pukaskwa National Park, augmenting the caribou population is unlikely to recover the species unless wolf densities remain low (<5.5/1000 km$^2$) or if more than 300 animals could be translocated.

**Key words:** Bayesian belief network; decision-support; endangered species; expert opinion; process model; protected areas; reintroduction; species at risk; structured decision-making; threatened species; woodland caribou.

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## Introduction

Boreal populations of woodland caribou (*Rangifer tarandus caribou*) (hereafter "woodland caribou") historically occupied the boreal forest across North America but are now extirpated from the southern limits of that range (Bergerud, 1974). Due to the declines in the distribution and abundance of this species, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Committee on the Status of Species at Risk in Ontario (COSSARO) assessed woodland caribou as Threatened (2000, 2005 and 2014, respectively). Between 1900 and 1950, boreal caribou retracted northward from Lake Superior (Cringan, 1957). They disappeared from the western shore of Lake Superior between 1905 and 1912 (Riis, 1938a, b, c, d) and were declining and scarce on the Sibley Peninsula by 1914 (Cringan, 1957). Three unconnected populations around northeastern Lake Superior persist as the species' most southern representatives in the eastern half of North America. These populations became disjunct from the northern herds in the 1950s or 1960s (Bergerud, 1988). Today, two populations are located on islands (Slates and Michipicoten); they were the products of translocations and are considered to be persistent with >200 individuals that fluctuate with the availability of vegetation (Environment Canada, 2012). The natural population on the mainland is now restricted to a narrow band along Lake Superior coast that includes Pukaskwa National Park (48°N, 85°W). Biennial surveys in the Park since the late 1970s have revealed a steady decline from 30 individuals to only 4 in 2009 (Bergerud *et al.,* 2007; Patterson *et al.,* 2014). With little to no recruitment for over a decade, Bergerud *et al.* (2007) suggested that extirpation is the likely outcome for this population by 2018. Parks Canada must decide between a costly intervention or risk extirpation of a species from a national park.

Translocation has been proposed to augment the population; however, translocations have mixed success as a management tool to recover caribou. Wildlife translocation is one of the more complex management actions used to restore or reinforce populations of species at risk (Decesare *et al.,* 2011). The long-term success of translocations requires managing the behaviour, habitat, metapopulation, and ecosystem level issues that initially led to the decline of the population (Armstrong & Seddon, 2008). Since 1982, the Ontario Ministry of Natural Resources and Forestry has restored or introduced woodland caribou from the Slate Islands to a number of islands and the shoreline of eastern Lake Superior with little success (G. Eason, personal communication; Gogan & Cochrane, 1994).

Failures of caribou translocation projects have been attributed to disease, predation, anthropogenic disturbance and/or insufficient and fragmented habitats (Bergerud & Mercer, 1989; Gogan & Cochrane, 1994; Compton *et al.,* 1995). In a review of 33 caribou introductions in eastern North America from 1924 to 1985, introductions inevitably failed when animals, released in proximity to white-tailed deer (*Odocoileus virginianus*), contracted meningeal brain worm (*Parelaphostrongylus tenuis*) and died (Bergerud & Mercer, 1989). For example, a herd of 51 caribou, released in Cape Breton Highlands National Park, Nova Scotia in 1968 and 1969, was extinct by 1973 due to meningeal brain worm (Dauphiné, 1975). Similar results occurred on Anticosti Island, Quebec (145 reindeer introduced in 1924), Great Cloche Island, Ontario (12 caribou released in 1970), and southern Wisconsin (14 caribou in an enclosure with white-tailed deer) (Bergerud & Mercer, 1989).

Predation was also a key factor in failed translocations. Wolf (*Canis lupus*), cougar (*Felis concolor*), and occasionally bear (*Ursus americanus*) predation were credited with the loss of translocated caribou in Ontario, Quebec, and British Columbia in Canada and Maine in the United States (Bergerud & Mercer, 1989; Gogan & Cochrane, 1994; Compton *et al.,* 1995). Cougar predation was the primary cause of death for 60 woodland caribou translocated from British Columbia to northern Idaho between 1987 and 1992 (Compton *et al.,* 1995). Wolf predation caused the failure of translocations in the Lake Superior region, Ontario, including the Gargantua Peninsula (39 caribou released in 1989) (Gogan & Cochrane, 1994) and Bowman Island (6 caribou released in 1985) (Bergerud & Mercer, 1989). Predation is also the primary limiting factor for almost all natural woodland caribou populations (McLoughlin *et al.,* 2003; Wittmer *et al.,* 2005; Festa-Bianchet *et al.,* 2011). Wolves and white-tailed deer are absent from Newfoundland, which has the highest rate of successful translocations (Bergerud & Mercer, 1989). From 1961 to 1982, 384 caribou were released at 22 sites and 17 of these releases were successful. The failures in Newfoundland were attributed to illegal hunting and anthropogenic disturbance (Bergerud & Mercer, 1989).

The failure of caribou translocations is consistent with reintroductions in general. An early review of reintroduction projects suggested that the majority failed to establish viable populations due to poor planning and insufficient consideration of the biological and ecological factors needed for success (Griffith *et al.,* 1989; Wolf *et al.,* 1998). A more recent review (1990-2005) of 454 projects found most reintroduction programs to be *ad hoc* rather than an organized attempt to assess risk, advance understanding in the field of reintroduction biology, or to improve reintroduction success (Seddon *et al.,* 2007). The authors described most research in the field of reintroduction biology to be retrospective, that is, opportunistic project evaluations and *post hoc* interpretation of monitoring (Seddon *et al.,* 2007). They recommended an increased role for formally planned projects that identify knowledge gaps and address uncertainty coupled with multidisciplinary teams of resource managers and scientists (Seddon *et al.,* 2007).

The planning, documenting, and decision-support for translocation is well served by structured decision analysis (Pérez *et al.,* 2012; Converse *et al.,* 2013). With such a tool, planners and advisors can explore the factors expected to influence the success of a caribou translocation and examine various combinations of environmental settings and introduction scenarios. Federal programs to recover species at risk also benefit from clear communication with stakeholders and the public. The framing of protection and recovery of species at risk is critical because it alters the way we think, talk, and approach the issue (Nie, 2001). Decision support tools are transparent, repeatable, and help conceptualize the key factors and their relationships – all of which facilitates framing and understanding the issue. It was under this premise that we developed a Bayesian belief network to explore the feasibility of a successful translocation of woodland caribou into Pukaskwa National Park.

Bayesian belief networks (BBNs) are graphical models that represent a set of variables linked by conditional probability relationships (McCann *et al.,* 2006; McNay *et al.,* 2006; Rumpff *et al.,* 2011; Conroy & Peterson, 2012). They facilitate communication at the interface of science, politics and community to enhance the decision making process (Reckhow, 1999). A BBN starts with an influence diagram, which is an intuitive graphical representation of the probabilistic dependence among variables (or nodes). In a BBN, a node leading to another one is a parent node, and the dependent node is a child node; the most external nodes (with no parent nodes) are used as the input to the model. Those diagrams are an effective method of modeling potential causal relationships/conditional dependencies (Reckhow, 1999).

Bayesian belief networks can also incorporate the uncertainty inherent in ecology. For example, experts may be uncertain about their own knowledge, there may be uncertainty inherent in the relationships being modeled (functional uncertainty), or uncertainty about the accuracy and or availability of information (epistemic uncertainty) (Kujala *et al.,* 2013). They are particularly useful for articulating the uncertainty that propagates between management actions (such as translocation) and eventual outcomes (such as species persistence).

## Methods

### *Model development*

We developed and quantified a BBN iteratively, with expert contribution and review at each stage, and used the freely downloaded software GeNie 2.0 (http://genie.sis.pitt.edu/). The initial graphical model was based on key variables and processes identified at a workshop with ten experts in caribou management, wolves and genetics, as well as regional biologists, local First Nations and park staff (Parks Canada, 2010). Next, experts crafted the "influence diagram", using as nodes the variables and processes identified at the workshop, and setting as input the parent nodes that describe the local environment as well as the variables that can be manipulated. That provided an intuitive presentation of the ecological relationships and a rapid scoping of the management issue (McCann *et al.,* 2006).

The influence diagram contributions were largely supported by scientific literature. Thresholds for each of the nodes are given in Appendix and include a citation when based on scientific literature. Where knowledge gaps existed, particularly with running scenarios specific to Pukaskwa National Park, we relied on expert opinion and identified predictions that could be tested in the event of a translocation. The influence diagram went through six major and several minor iterations before the team

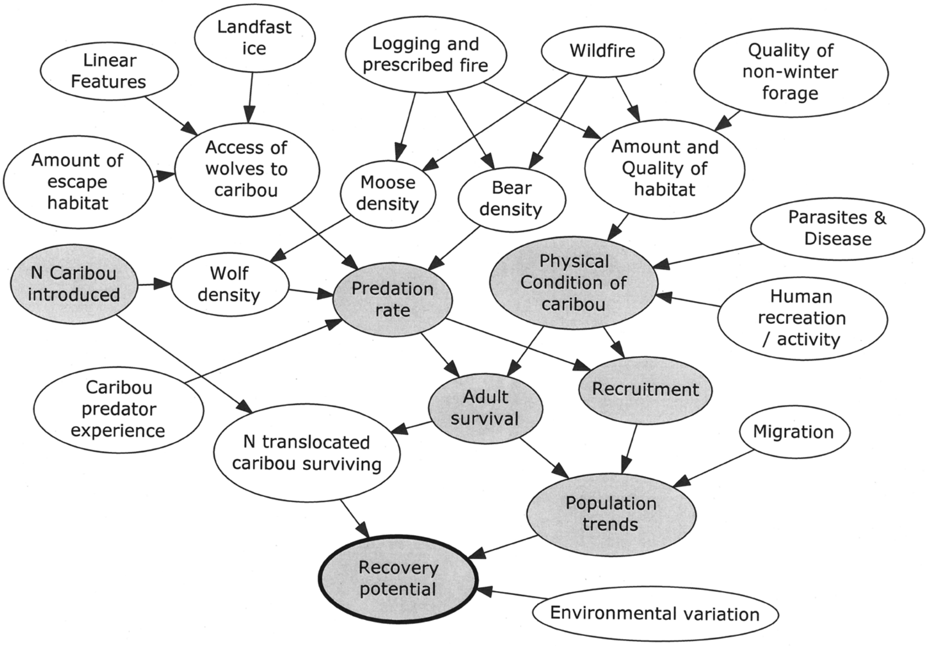

Figure 1. Influence diagram underlying a Bayesian Belief Network for a proposed woodland caribou translocation into Pukaskwa National Park. Grey shaded nodes are those presented in Table 1; the resultant (outcome) node has a thicker border.

reached a consensus (Fig. 1).

Whenever possible we were parsimonious with the model because the conditional probability table (CPT) of a child node becomes difficult to parameterize with increasing numbers of parent nodes. Also, the more links there are among nodes, the less tractable the model becomes (Marcot *et al.,* 2006). Parsimony was also appropriate given the degree of precision available for each node.

Developing the influence diagram (Fig. 1)

The general structure of the BBN is consistent with other efforts to identify key variables for caribou in Ontario (Rodgers *et al.,* 2008). Caribou declines are ultimately caused by habitat alterations and proximately caused by predation. More specific divisions can be traced back to these two broad effects (Festa-Bianchet *et al.,* 2011).

The most external parent nodes of the BBN, also called "input nodes" herein, are the key ecosystem variables and processes that affect caribou persistence and that either are determined by the local conditions or can be modified through management. These include descriptors of the caribou's environment, such as amount of escape habitat, the extent of linear features, and landfast ice, which all influence the access of wolves to caribou (Bergerud *et al.,* 2007). Other parent nodes include "logging and prescribed fire", "wildfire" and "quality of non-winter forage", which all influence moose and bear density and the amount and quality of habitat for caribou (Rodgers *et al.,* 2008; Environment Canada, 2012; Pinard *et al.,* 2012) (Fig. 1). For details on each node's states, thresholds used to separate states, and conditional probability values, see tables in the Appendix.

The child nodes are key variables and processes that influence population dynamics more or less directly, such as rate of predation and adult survival, which in turn are a main determinant of the population recovery potential. The rate of predation was primarily determined by the densities of wolves and bears (Ballard, 1994), and the accessibility of caribou to wolves, which are considered their most significant predator (Bergerud *et al.,* 2007). Predation rate is also likely to be affected by the experience the introduced animals have with predators (Frair *et al.,* 2007). If caribou translocated into Pukaskwa National Park were sourced from nearby predator-free islands, these individuals would be naïve and more susceptible to predators. Given that the experience of translocated animals with predators could affect their persistence, predator-experienced vs. predator-naive caribou was a factor included as a parent (input) node in this model.

Wolf density is in turn affected by the density of their main prey species, which could be moose or caribou depending on their relative availability (Bergerud & Elliott, 1986). For the period 1974–1988, the dynamics at Pukaskwa National Park suggested that wolf predation depended on caribou density (Bergerud, 1996). Caribou recruitment declined and adult mortality increased when wolf numbers increased beyond 20 individuals (Bergerud, 1996). Predation dynamics can partly offset the effect that a larger initial population of caribou would have on recovery potential. This is why the model includes the intermediate child node "number of translocated caribou surviving" between the nodes "number of caribou introduced" and "recovery potential" (Fig. 1). The number of surviving animals (over ~ 5 yrs) is modulated by the survival rate of adults, and therefore links the short-term dynamics to the longer-term projection.

Vors and Boyce (2009) reviewed a variety of potential responses by caribou to climate change, such as indirect, density-independent effects of extreme weather events that cause unpredictable access to forage, or freezing rain events that eliminate access to grazing due to an impenetrable layer of ice. Therefore, we included physical condition (or body mass) as a qualitative biological integrator of key environmental variables: amount and quality of habitat, parasites and diseases, and human disturbances through recreation and resource extraction. Those key environmental variables are determined by the local conditions and/or can be altered through management, so they are set as external parent nodes in the model.

The physical condition of caribou has implications for determining adult survival and recruitment, as relationships between body mass and survival and fertility have shown (Taillon *et al.,* 2012). Caribou may skip reproduction if they are in poor physical condition due to insufficient food resources (Bergerud *et al.,* 2007; NCASI, 2007; Taillon *et al.,* 2012). Caribou are also susceptible to anthropogenic disturbances; they avoid resorts and recreation activities (Nellemann *et al.,* 2000; Carr *et al.,* 2011), active logging (Schaefer & Mahoney, 2007), and are subject to increased bear predation near campsites (Pitt & Jordan, 1996). In Pukaskwa National Park, human recreational activities could include tourists on foot and in boats around islands and coastlines.

Timber volumes harvested in Ontario over the last decade have declined by more than 40%, including from lands adjacent to the park (Ontario Ministry of Natural Resources, 2012). Although wildfire and prescribed fires are permitted in some circumstances in the park, the fire cycle has departed significantly from what it would have been without human influence, and as a result, an older-than-usual forested landscape prevails. Fires are infrequent (Perera & Baldwin, 2000) and typically smaller in size along the coast (C. C. Drake, unpublished data), which is largely believed to be beneficial for caribou (Environment Canada, 2012). Fire improves habitat for moose, which attracts predators. The predators consume moose but also caribou, when they encounter them (Bergerud *et al.,* 2007). These factors were included in the model, incorporating the circumstances more to less favourable for caribou.

Presently, disease is not considered the primary limiting factor in the Lake Superior range mainly because white-tailed deer, the vectors of brain worm, which is lethal to caribou (Anderson & Strelive, 1968), were not historically abundant (Whitlaw & Lankester, 1994). Nonetheless, we included disease as an input node in the model because white-tailed deer are expanding their distribution (Thompson *et al.,* 1998) and have been increasingly detected in Pukaskwa National Park (C. C. D., unpublished data).

The terminal child node of the model is the recovery potential. It is defined as the long-term probability of persistence of the population (i.e., whether a population will be self-sustaining). As such, the node has as parent nodes the population trends, the environmental variation (which drives the random variation in population trends), and the number of translocated caribou surviving. A high recovery potential could be defined as a time to extinction longer than 50 yrs, or a 95% chance of persistence over the next 50 yrs. Although the time scale of the processes included in the model is short-term (~5 yrs), the end result is a projection into the future. When the result of a BBN scenario is a high probability for "high recovery potential", it suggests that this scenario will produce a successful translocation.

Other factors that might be relevant for other caribou populations, such as predation by felids (Compton *et al.,* 1995), vehicle collisions, or avalanches (Hebblewhite *et al.,* 2007), were not relevant at Pukaskwa National Park. Genetic diversity was not included in the model because, although it is lower in isolated populations, there is no immediate concern for conservation (Courtois *et al.,* 2003; McLoughlin *et al.,* 2004) nor did participants at the 2010 caribou workshop feel this was a significant factor in the success of a translocation (Parks Canada, 2011).

Parameterizing the model

The links among the model's nodes reflect the knowledge we have about the probable influence that a given parent node has on one or more child nodes. These links are assumed to be causal. All the links in this BBN are through CPTs, which we conceived as contingency tables. For example, the probabilities of a population decline were determined by the number of observed cases in which a decline was observed under each combination of two states of adult survival, recruitment, and three states of migration (positive, negligible, negative).

For the node "Population trends", we used data from population surveys and modeling, categorized each case, and compiled a contingency table (Appendix). For all other child nodes, data were less available so we first asked experts to determine what threshold values could be used to tell each state apart. Wherever possible, these thresholds were drawn first from the literature. We then asked the experts to consider how nodes would interact so that we could parameterize the CPTs. For example, we asked, "among all the possible cases where number of caribou introduced were high, in how many cases would the wolf density have remained low?". Experts were asked to consider the breadth of the caribou literature, not specifically caribou in Pukaskwa National Park. Experts were also invited to review each other's assessments. Most often there was consensus or suggestions for additions, fine-tuning of the model, or increased precision in a threshold based on a new literature reference.

Exploring scenarios

To explore the properties of the model and to apply it specifically to caribou translocation at Pukaskwa National Park, we set evidence in all the most external parent nodes according to these 10 scenarios: least favourable vs. most favourable environmental conditions with two levels of translocation effort (4 scenarios), current conditions at Pukaskwa National Park with three levels of translocation effort (3 scenarios), and current conditions at Pukaskwa National Park with low wolf densities with three levels of translocation effort (3 scenarios) (Table 1).

The decline in logging, less frequent wildfire, combined with limited prescribed fire in the park over the last decade (Kuchta, 2012), has created older growth forests adjacent to and within the park that are favourable to caribou. Therefore, the probability of limited logging and prescribed fire and wildfire was set at 100%. Terrestrial lichen, a year-round food source for caribou (NCASI, 2007), is abundant at Pukaskwa National Park but entirely absent on Michipicoten Island (Bergerud *et al.,* 2007) where caribou numbers are high. Therefore the probability of good "quality of non-winter forage" was set at 100%.

Several nodes have high levels of uncertainty or show important variation among years, so virtual evidence was used as input for those nodes. Parasites or disease being transmitted by deer is unlikely to seriously threaten the physical condition of caribou in the near future because of the current low density of deer in the park and surrounding landscape, but the situation could change rapidly. Therefore, the probability of low "parasites and diseases" was set at 90%.

In Alberta, human activities alter caribou behavior and mediate the effects of wolf predation on caribou (Hebblewhite *et al.,* 2005; Wasser *et al.,* 2011). However, Pukaskwa National Park has low human use at sensitive times (calving/rutting), so the probability of low "human recreation/activity" was set to 80%.

In the Lake Superior range, caribou remain vulnerable because escape habitat is limited and, importantly, habitat in their range has been altered by human disturbance (Vors *et al.,* 2007). Near-shore islands may serve as a primary escape habitat from predators (Ferguson *et al.,* 1988; Carr *et al.,* 2011) and limited linear features likely keeps predator access low in the area (Bergerud, 1985). Trends toward warmer winters resulting in less landfast ice may have further limited the access of wolves to caribou in the coastal region (Thompson *et al.,* 1998). To take into account the variation and uncertainty in those factors, the probability of plenty vs. little for the node "amount of escape habitat" was set to 20:80; the probability of limited "linear features" was set to 90% and to 50% for limited "landfast ice". This set of values gives a probability of low "access of wolf to caribou" of about 50% (Appendix).

Based on population size time series, environmental variation (i.e., the long-term yearly random fluctuation in population growth rate due to variation in survival, recruitment, and migration), remains low; therefore, the probability of low "environmental variation" was set at 80%.

Once the values for the input nodes were set, we examined how the probability of recovery potential would increase following the introduction of an increasing number of caribou: less than 50, 50–300, and >300. These values were drawn from a non-spatial population viability analysis which concluded that a population of 300 animals with moderate calf and adult female survival had a 10% probability of quasi-extinction, and that large populations (≥ 300) had a high probability of persistence under favourable demographic conditions (Environment Canada, 2012). It could be argued that introducing such large numbers of animals is unrealistic, but one has to consider the (conceptual) 5 year time frame of the model, which would allow for a lower number of animals to be introduced annually over 5–10 yrs rather than all at once during a one-time translocation event. We also assumed that caribou that were "available" for a translocation into Pukaskwa National Park would originate from islands where caribou are abundant, such as the nearby Slate and Michipicoten Islands and many of those naïve individuals would be lost annually.

## Results

The least favourable scenario produced only a 1% probability of population recovery (Table 1). The most favourable scenario resulted in 58% probability of population recovery when fewer than 50 animals were translocated and 90% when more than 50 animals were translocated (Table 1).

Under current conditions in Pukaskwa National Park, the chance of high recovery potential increased with the number of translocated animals to a high of 46% (Table 1). When we set the probability of high "wolf density" to 100%, regardless of its parent nodes, the probability of high predation rate reached 72%. This combination of inputs suggests that even introducing 300 caribou would not increase the probability of population recovery beyond 50% (Table 1). With the same set of evidence, but with probability of low wolf density set at 100%, introducing more than 50 caribou raised the probability of population recovery above 50% (Table 1).

## Discussion

Interestingly, the probability of high recovery potential under the current conditions, and with even a large translocation effort, are roughly consistent with the 50% failure rate of caribou translocations in eastern North America (Bergerud & Mercer, 1989; Gogan & Cochrane, 1994) as well as estimates of translocation success in western North America (Decesare *et al.,* 2011). However, the mechanisms leading to that result vary from one application to another, so we cannot claim that our model emulates or explains the more general result of many historic translocations.

Table 1. Probability of recovery potential (%) under different model scenarios and number of caribou introduced. Percent probability of five child nodes are also presented.

| Model scenario | # of caribou introduced | Predation rate | Physical condition of caribou | Adult survival | Recruitment | Population trends | Recovery Potential |
|---|---|---|---|---|---|---|---|
| | | Low/High | Good/Bad | Low/High | Low/High | Decline/Stable/Increase | High/Low |
| Least favourable[1] | <50 | 0/100 | 0/100 | 90/10 | 100/0 | 96/2/2 | 1/99 |
| Most favourable[2] | <50 | 99/1 | 100/0 | 1/99 | 1/99 | 0/25/75 | 58/42 |
| Most favourable[2] | 50-300 | 99/1 | 100/0 | 1/99 | 1/99 | 0/25/75 | 90/10 |
| Current[3] | <50 | 30/70 | 91/9 | 38/62 | 72/28 | 47/32/21 | 21/79 |
| Current[3] | 50-300 | 30/70 | 91/9 | 38/62 | 72/28 | 47/32/21 | 38/62 |
| Current[3] | >300 | 30/70 | 91/9 | 38/62 | 72/28 | 47/32/21 | 46/54 |
| Low wolf density[4] | <50 | 87/13 | 91/9 | 7/93 | 17/83 | 29/28/43 | 35/65 |
| Low wolf density[4] | 50-300 | 87/13 | 91/9 | 7/93 | 17/83 | 29/28/43 | 58/42 |
| Low wolf density[4] | >300 | 87/13 | 91/9 | 7/93 | 17/83 | 29/28/43 | 67/33 |

[1] Input nodes adjusted to the least favourable environmental conditions or worst case scenario

[2] Input nodes adjusted to the most favourable environmental conditions or best case scenario

[3] Input nodes adjusted to reflect the current conditions at Pukawska National Park, based on best available information. For those scenarios, wolf density node is input as 100:0 high, regardless of the value of its parent nodes.

[4] A hypothetical scenario with same input as current, but in which wolf density node is set at 0:100 low, regardless of the value of its parent nodes.

The differences among the probabilities of high recovery potential for the most favourable scenario (90%) and the current conditions (38%) at Pukaskwa National Park suggest that the translocation of caribou into Pukaskwa National Park would be highly risky unless some of the unfavourable conditions were altered. Although reducing predation would increase the probability of recovery potential by 12–21%, this increase may be insufficient to warrant a potentially unpopular and ecologically harmful management option such as predator control, particularly in a national park. Alternatively, Parks Canada could try managing the predation rate on caribou indirectly. For example, the park could manage habitat to reduce alternate prey (moose and deer) that attract predators, improve escape habitat, limit linear features that facilitate access of wolves to caribou, and provide safe sites for caribou to calve.

Typical of species at risk, elements of uncertainty remain that affect recovery potential. The probability of recovery and persistence of translocated caribou in Pukaskwa National Park hinges on key uncertainties such as the risk of parasites and disease, human disturbance, and the ability of predator-naïve caribou successfully eluding predators. The complexity of the relationships among the nodes of this BBN coupled with knowledge gaps highlights the importance of uncertainty. Complexity and uncertainty are “familiars” in ecology; the advantage of a BBN over *ad hoc* decision-making is that it identifies and prioritizes research needs. The parts of our BBN that are based mainly on expert experience can be used to generate testable hypotheses and can be advanced with iterative testing and updating of the model (Marcot *et al.,* 2006; Martin *et al.,* 2012).

Our BBN is a representation of a collectively agreed upon reality as opposed to a test of causal relationships. We could not formally estimate the predictive accuracy of the model since observation data are unavailable to compare predictions with observations. This may be an unsatisfying outcome for those who value the precision of quantitative models; as data become available, this model can certainly be improved. However, a network of variables with numerical probabilities is not an intuitive way to interpret results for all stakeholders (Renooij & Witteman, 1999). Eliciting expert input for BBNs requires experts to express their beliefs in probabilistic terms that describe dependencies among different factors. It has been argued that inferential reasoning is the mechanism by which people integrate and interpret subjective and incomplete data from various sources (Pearl, 1988). Some of our experts did not feel familiar enough with the concept of probability or they felt it was too difficult to quantify their beliefs. As a result, the probabilities of the outcomes in this BBN are generally described in a relative sense. The model's precision could be improved in the future; presently, it is consistent with available data and the level of uncertainty of the experts.

The translocation of caribou is logistically difficult and expensive to implement. Recovery of caribou requires public funds and so it is important to have local support for caribou translocation programs (Schneider *et al.,* 2010). In this area, the majority of regional residents support conservation actions for caribou in Pukaskwa National Park, however, only 51% would support translocation (Parks Canada, 2011). The lack of strong support may be driven, in part, by local hunters. Over the past century, caribou have declined and moose have increased and local hunters in this region have shifted their harvest to moose. Hunters are aware that managing for caribou habitat does not favour moose habitat, which could result in lower moose densities and fewer moose tags (C. C. Drake, personal observation). The social challenges of translocations can be even more daunting than the biological ones (Reading & Clark, 1996), and successful programs benefit from approaches that integrate the social and biological sciences (Miller *et al.,* 1999). BBNs are well-suited to incorporating social and economic analyses by including model nodes for costs and utilities (Levontin *et al.,* 2011; Haines-Young, 2011). A future application for this caribou BBN could include the addition of socio-economic factors.

## Conclusion

Species at risk of extirpation or extinction present unique challenges to land managers given their paucity coupled with political scrutiny and economic realities (Armstrong & McCarthy, 2007). It is often necessary to make decisions for species at risk under considerable uncertainty (i.e., limited demographic data and lack of information on dispersal (Beissinger & Westphal, 1998) and failing to acknowledge or address uncertainty can lead to poor decisions and outcomes (Regan *et al.,* 2005). Despite the *ad hoc* nature of these projects, programs to recover endangered species are expected to maximize species survival and minimize financial cost, while under the scrutiny of stakeholders and jurisdictions with divergent opinions (Maguire, 1986). We presented a BBN for a potential caribou translocation in Pukaskwa National Park to provide structured decision support for resource managers.

This BBN suggests that any size of translocation is unlikely to help recover the population of caribou in Pukaskwa National Park under the current conditions. Although the long-term recovery and persistence of an augmented population of caribou in Pukaskwa National Park is unknown, most of the short-term scenarios explored in the BBN resulted in low to moderate success, which suggests that long-term recovery and persistence may be unlikely either with or without translocation. Importantly, long-term recovery and survival of caribou may be hampered by the lack of contiguity with more northern populations and habitat conditions beyond the boundaries of Pukaskwa National Park.

Although this BBN was developed for Pukaskwa National Park's proposed translocation, we also made it flexible enough to be applied to other caribou populations. It represents and combines empirical data with experts' understanding of caribou ecology. It graphically expresses complex relationships and challenges for caribou recovery and management. It addresses, in a structured way, uncertainties that plague attempts to solve these problems. It evaluates alternative decisions within a context of risk assessment to help identify options with caribou translocation. It also fosters communication among ecologists, decision-makers, and stakeholders who may lack common training, terminology, or experience (Cain, 2001).

Regardless of whether the caribou population in Pukaskwa National Park is augmented through translocation, it is apparent that the factors driving the decline of caribou and the fate of their recovery in this region will not be easily resolved. On-going development of this BBN based on empirical data, as it becomes available, could be an important tool in facilitating the decision-making process for caribou management in Pukaskwa National Park and more broadly, as many caribou populations in Canada are declining (Environment Canada, 2012).

This model was developed using the freely downloaded software GeNie 2.0 (http://genie.sis.pitt.edu/). We invite readers to explore their own scenarios. Our inputs are available in Appendix. Contact the authors to request the model.

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# Appendix. Conditional probability tables (Tables A1-A10).

Table A1. Conditional probability table for node recovery potential.

| Parent nodes and their state | | | Recovery potential[1] | |
|---|---|---|---|---|
| Number of translocated caribou surviving | Environmental variation | Population trends | High | Low |
| Large | Low | Decline | 0.25 | 0.75 |
| Large | Low | Stable | 0.75 | 0.25 |
| Large | Low | Increase | 1.00 | 0.00 |
| Large | High | Decline | 0.00 | 1.00 |
| Large | High | Stable | 0.50 | 0.50 |
| Large | High | Increase | 1.00 | 0.00 |
| Medium | Low | Decline | 0.00 | 1.00 |
| Medium | Low | Stable | 0.75 | 0.25 |
| Medium | Low | Increase | 1.00 | 0.00 |
| Medium | High | Decline | 0.00 | 1.00 |
| Medium | High | Stable | 0.50 | 0.50 |
| Medium | High | Decline | 0.75 | 0.25 |
| Small | Low | Decline | 0.00 | 1.00 |
| Small | Low | Stable | 0.25 | 0.75 |
| Small | Low | Increase | 0.70 | 0.30 |
| Small | High | Decline | 0.00 | 1.00 |
| Small | High | Stable | 0.10 | 0.90 |
| Small | High | Increase | 0.50 | 0.50 |

[1] Thresholds for recovery potential:

| | |
|---|---|
| Low | Probability of extinction >5% over 50 yrs OR: time to extinction <= 20 yrs |
| High | Probability of extinction <5% over 50 yrs OR: time to extinction > 20 yrs |

Table A2. Conditional probability table for node population trends.

| Parent nodes and their state | | | Population Trend | | |
|---|---|---|---|---|---|
| Migration[1] | Survival[1,2] | Recruitment[3] | Decline | Stable | Increase |
| Negligible | Low | Low | 0.875 | 0.125 | 0.000 |
| Negligible | Low | High | 0.571 | 0.286 | 0.143 |
| Negligible | High | Low | 0.200 | 0.600 | 0.200 |
| Negligible | High | High | 0.250 | 0.250 | 0.500 |
| Positive | Low | Low | 0.000 | 0.875 | 0.125 |
| Positive | Low | High | 0.200 | 0.500 | 0.300 |
| Positive | High | Low | 0.100 | 0.600 | 0.300 |
| Positive | High | High | 0.000 | 0.250 | 0.750 |
| Negative | Low | Low | 1.00 | 0.000 | 0.000 |
| Negative | Low | High | 0.800 | 0.200 | 0.000 |
| Negative | High | Low | 0.600 | 0.200 | 0.200 |
| Negative | High | High | 0.500 | 0.250 | 0.250 |

[1] States for migration: Positive: immigration accounts for >10% of the population size over 5 years; Negative: emigration accounts for >10% of the population size over 5 years; Negligible: migration is less than or equal to 10% over 5 years.

[2] Survival (annual rate): Low: $S < 0.88$; High: $S >= 0.88$.

[3] Recruitment (calf:adult ratio): Low: $R < 0.105$; High: $R >= 0.105$.

Table A3. Conditional probability table for nodes adult survival and recruitment.

| Parent nodes and their state | | Adult Survival | | Recruitment | |
|---|---|---|---|---|---|
| Predation Rate | Physical Condition | Low | High | Low | High |
| Low | Good | 0.0 | 1.0 | 0.0 | 1.0 |
| Low | Bad | 0.1 | 0.9 | 0.5 | 0.5 |
| High | Good | 0.9 | 0.1 | 1.0 | 0.0 |
| High | Bad | 0.9 | 0.1 | 1.0 | 0.0 |

Note: Probability values assume that predation affects recruitment much more than it affects survival of adults.

Table A4. Conditional probability table for node translocated caribou surviving.

| Parent nodes and their state | | Translocated caribou surviving | | |
|---|---|---|---|---|
| Adult Survival | N caribou introduced[1] | Large | Medium | Small |
| Low | Large | 0.0 | 1.0 | 0.0 |
| Low | Medium | 0.0 | 0.0 | 1.0 |
| Low | Small | 0.0 | 0.0 | 1.0 |
| High | Large | 0.9 | 0.1 | 0.0 |
| High | Medium | 0.0 | 0.9 | 0.1 |
| High | Small | 0.0 | 0.0 | 1.0 |

[1] N caribou introduced: Small <= 50 animals, Medium 50-300 animals, Large >300 animals.

Table A5. Conditional probability table for node predation rate.

| Parent nodes and their state | | | | Predation Rate | |
|---|---|---|---|---|---|
| Caribou predator experience | Wolf Density | Access of wolf to caribou | Bear Density | Low | High |
| Yes | Low | Low | Low | 1.0 | 0.0 |
| Yes | Low | Low | High | 0.9 | 0.1 |
| Yes | Low | High | Low | 1.0 | 0.0 |
| Yes | Low | High | High | 0.9 | 0.1 |
| Yes | High | Low | Low | 0.9 | 0.1 |
| Yes | High | Low | High | 0.8 | 0.2 |
| Yes | High | High | Low | 0.4 | 0.6 |
| Yes | High | High | High | 0.3 | 0.7 |
| No | Low | Low | Low | 0.9 | 0.1 |
| No | Low | Low | High | 0.75 | 0.25 |
| No | Low | High | Low | 0.9 | 0.1 |
| No | Low | High | High | 0.2 | 0.8 |
| No | High | Low | Low | 0.5 | 0.5 |
| No | High | Low | High | 0.25 | 0.75 |
| No | High | High | Low | 0.0 | 1.0 |
| No | High | High | High | 0.0 | 1.0 |

Table A6. Conditional probability table for node physical condition of caribou.

| Parent nodes and their state | | | Physical Condition | |
|---|---|---|---|---|
| Parasites & diseases[1] | Amount & quality of habitat | Human recreation/activity | Good | Bad |
| Low | High | Low | 1.0 | 0.0 |
| Low | High | High | 0.9 | 0.1 |
| Low | Low | Low | 0.2 | 0.8 |
| Low | Low | High | 0.1 | 0.9 |
| High | High | Low | 0.3 | 0.7 |
| High | High | High | 0.1 | 0.9 |
| High | Low | Low | 0.0 | 1.0 |
| High | Low | High | 0.0 | 1.0 |

[1] Thresholds for parasite and diseases: based on deer density: Low: < 6 deer/km$^2$; High: > 6 deer/km$^2$ (Bergerud & Mercer, 1989).

Table A7. Conditional probability table for node wolf density.

| Parent nodes and their state | | Wolf density[1] | |
|---|---|---|---|
| Moose density | N of caribou introduced | Low | High |
| Low | Large | 0.75 | 0.25 |
| Low | Medium | 0.9 | 0.1 |
| Low | Small | 1.0 | 0.0 |
| High | Large | 0.0 | 1.0 |
| High | Medium | 0.25 | 0.75 |
| High | Small | 0.5 | 0.5 |

[1] Low: <5.5/1000 km$^2$; High >=5.5/1000 km$^2$

Bergerud and Mercer (1989) have suggested that even in the absence of deer (the source for *P. tenuis*) when wolf densities exceed 10/1,000 km$^2$, caribou re-introductions will fail. Bergerud and Elliot (1986) indicated that generally, in the absence of escape habitat, caribou populations cannot maintain their numbers when wolf densities are >=6.5/1,000 km$^2$.

Table A8. Conditional probability table for nodes moose density and bear density.

| Parent nodes and their state | | Moose Density[1] | | Bear Density[2] | |
|---|---|---|---|---|---|
| Logging & prescribed fire | Wildfire | Low | High | Low | High |
| Limited | Limited | 0.90 | 0.10 | 0.90 | 0.10 |
| Limited | Extensive | 0.75 | 0.25 | 0.75 | 0.25 |
| Extensive | Limited | 0.40 | 0.60 | 0.50 | 0.50 |
| Extensive | Extensive | 0.20 | 0.80 | 0.20. | 0.80 |

[1] Thresholds for moose density: Low : <0.3 moose/km$^2$; High = >0.3 moose/km$^2$

[2] Thresholds for bear density: Low: <10/100 km$^2$; High = >10/100 km$^2$

Table A9. Conditional probability table for node access of wolves (to caribou).

| Parent nodes and their state | | | Access of wolves | |
|---|---|---|---|---|
| Amount of escape habitat | Linear features | Landfast ice | Good | Bad |
| Plenty | Limited | Limited | 1.0 | 0.0 |
| Plenty | Limited | Extensive | 0.8 | 0.2 |
| Plenty | Extensive | Limited | 0.7 | 0.3 |
| Plenty | Extensive | Extensive | 0.5 | 0.5 |
| Little | Limited | Limited | 0.5 | 0.5 |
| Little | Limited | Extensive | 0.4 | 0.6 |
| Little | Extensive | Limited | 0.3 | 0.7 |
| Little | Extensive | Extensive | 0.0 | 1.0 |

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Table A10. Conditional probability table for node amount and quality of habitat.

| Parent nodes and their state | | | Amount & quality of habitat | |
|---|---|---|---|---|
| Quality of non-winter forage | Logging & prescribed fire[1] | Wildfire[1] | High | Low |
| Good | Limited | Limited | 1.0 | 0.0 |
| Good | Limited | Extensive | 0.2 | 0.8 |
| Good | Extensive | Limited | 0.2 | 0.8 |
| Good | Extensive | Extensive | 0.1 | 0.9 |
| Poor | Limited | Limited | 0.5 | 0.5 |
| Poor | Limited | Extensive | 0.0 | 1.0 |
| Poor | Extensive | Limited | 0.0 | 1.0 |
| Poor | Extensive | Extensive | 0.0 | 1.0 |

[1] Logging and prescribed fire node, and for Wildfire node, the threshold for limited *vs.* extensive is 40% of the range. When total disturbance exceeds 40% of the range, the probability that a Woodland Caribou population would be stable or increasing drops below 0.5 (Environment Canada, 2012).

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