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8 Understanding the Cumulative Effects of Human Activities on Barren-Ground Caribou

Anne Gunn, Chris J. Johnson, John S. Nishi, Colin J. Daniel, Don E. Russell, Matt Carlson, and Jan Z. Adamczewski

CONTENTS

INTRODUCTION

In Canada, the techniques and methods necessary for measuring cumulative effects have developed slowly despite introduction of the concept in the 1970s when Justice

Berger referred to cumulative effects of the proposed Mackenzie Valley pipeline (Berger 1977). From a regulatory perspective, cumulative effects are the aggregate stresses from past, present, or future human activities on a valued ecosystem component. Although there are other definitions—and one might differentiate between cumulative effects and impacts—this is an intuitive concept (Johnson and St-Laurent 2010). Despite this simplicity, application of the concept to resource management and conservation continues to remain a "mystery to most EIA [environmental impact assessment] practitioners" (Duinker and Greig 2006, p. 157). Progress toward effective cumulative effects assessment (CEA) is being questioned, despite having been a requirement for environmental impact assessments in Canada for three decades (Kennett 1999; Dowlatabadi et al. 2004; Duinker and Greig 2006).

In the Northwest Territories (NT), the lack of progress on cumulative effects was apparent during public hearings for open-pit diamond mining. For example, the environmental assessment panel for the Ekati diamond mine concluded that ". . . further work is needed on the cumulative effects of exploration activities on wildlife in the region" (MacLachlan 1996, p. 68). Similar concerns were echoed during the assessment of Diavik, the second diamond mine in the NT (Canadian Environmental Assessment Agency 1999a). Since the mid-1990s, the diamond mines in the NT focused attention on project-specific EIA, and now government agencies must interpret these individual EIAs in a broader regional context. Additionally, people in northern communities express concerns about how even small-scale exploration projects such as diamond drill operations may affect caribou (*Rangifer tarandus*). These small land-use operations typically fall below the criteria for environmental assessment. Logically, they have to be considered as part of the cumulative footprint of human activities on caribou ranges.

The challenge of undertaking and applying CEA partly stems from lack of clear policies, regulations, and terms of reference (Chapter 3). This is the case in the NT, despite a multi-stakeholder, consensus-driven process that was initiated in 1999 to develop a framework for assessing cumulative effects (NWT CEAM Steering Committee 2007). The absence of systematic approaches to identify, evaluate, and respond to regional/territorial cumulative effects has been identified in recent regulatory reviews (Government of Northwest Territories 2009) and environmental assessment hearings especially where the management or conservation of caribou is an issue. Caribou are highly valued across northern Canada and Alaska, and the responses of caribou to mining and oil and gas development are highly visible and controversial. Disagreement surrounds the effects of even large and well-studied developments such as the Prudhoe Bay oil fields, and the indirect or cumulative effects of human developments, including climate change (Joly et al. 2006; Noel et al. 2006).

The "mystery" of cumulative effects is also a consequence of technical shortcomings. Environmental assessment in general, and cumulative effects assessment in particular, has been a slowly emerging field of applied ecological science and has lagged behind other areas of conservation biology and landscape ecology. There have been relatively few published efforts to design and test approaches to measure cumulative effects. With a few exceptions (Schneider et al. 2003; Johnson et al. 2005; Sorensen et al. 2008) past studies have dealt more with the "process" and policy reviews

(Chapter 3), or particular aspects such as the failure to include aboriginal traditional knowledge, different values, and world views (Usher 2000; Paci et al. 2002).

Studies designed to measure the influence of human activities on wildlife tend to deal with individual effects such as behavioral or physiological responses (Seip et al. 2007; Stankowich 2008; Thiel et al. 2008; Fahrig and Rytwinski 2009) or, less frequently, demographic responses such as changes in calf survival (Shively et al. 2005). Few authors have described responses to multiple disturbances or measures of population productivity (Nellemann et al. 2000, 2003; Johnson et al. 2005). Reimers et al. (2003) cautioned that interpreting shifts in animal distribution without understanding underlying ecological conditions is difficult. Behavioral, physiological, or distributional responses should be linked to population dynamics (Vistnes and Nellemann 2008) requiring measures such as energetic cost or change in reproduction and survival across a range of disturbance levels. These studies are methodologically difficult (Johnson and St-Laurent 2010), thus, the bias toward simpler response indices. We found only one published account that links the behavioral, energetic, and demographic responses of caribou to human disturbance (Murphy et al. 2000).

The technical challenge for defining and estimating cumulative effects is threefold. First, scaling up from project-specific to regional effects requires estimating the likelihood of additional industrial projects that are plausible but do not yet exist. Second, spanning the gap between assessing effects at the project-specific scale up to the regional scale requires identification of appropriate temporal and spatial scales and study boundaries (Vistnes and Nellemann 2008). Third, an assessment of cumulative effects requires pathways that integrate individual and population-level wildlife responses to single and multiple projects. Consequently, the science of cumulative effects assessment in northern Canada has often lagged with a reliance on a "check box" approach using qualitative summations of individual categorical ratings (simple addition of single effects) and little consideration of development scenarios and scale issues.

In this chapter, we describe a conceptual framework and supporting methods for assessing the cumulative effects of industrial development for the Bathurst caribou herd, a migratory herd of barren-ground caribou (*R.t. groenlandicus*) in the NT (Figure 8.1). We focused at the regional rather than the project-specific level because aboriginal communities and northern governments are struggling with process and information needs that occur across broad areas, and time frames that exceed the development of single projects. The lack of well-defined regional and strategic environmental assessment processes that support project specific assessments is one of the current CEA deficiencies in the NT (NWT CEAM Steering Committee 2007).

The chapter is organized into five sections. Following the introduction in the first section, we describe characteristics of industrial development in the Canadian central Arctic, briefly describe the regulatory and policy framework in the NT, and outline the significance of migratory barren-ground caribou to cumulative effects assessment. In the third section, we describe and introduce the concept of resilience because it conceptually grounds our understanding of cumulative effects for caribou. In the fourth section, we describe a collaborative research project designed to develop an integrated modeling framework that will help regulators, industry, and northern communities to better understand the potential cumulative effects of

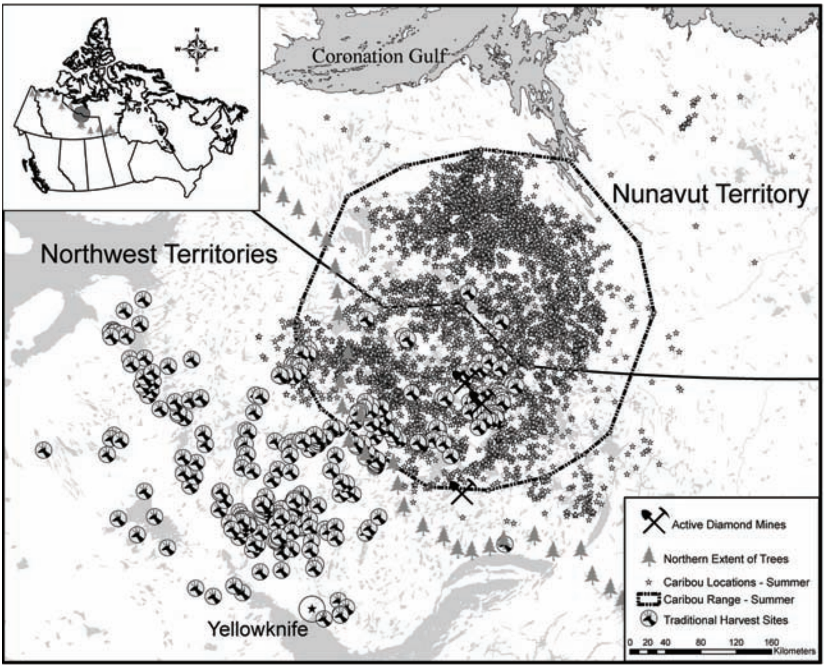

FIGURE 8.1 Extent of summer range, illustrated within inset map, and locations of individual caribou of the Bathurst herd collared from 1996 to 2008 in the Northwest Territories and Nunavut, Canada. Location and use of harvest sites by the Tlicho people was documented for the period 1935–1998. (From Legat, A. et al. 2001. Caribou migration and the state of their habitat. Final Report, Yellowknife, Northwest Territories, Canada.)

development for the Bathurst caribou herd. In the final section we provide a brief discussion and concluding remarks.

THE NORTHERN PERSPECTIVE

Characteristics of Mineral Resource Extraction in the Northwest Territories

The NT is a large area (1,346,106 km^2) with a small human population. Based on the 2008 national census (www.stats.gov.nt.ca), there were 43,283 people living in 29 communities and only Yellowknife has more than 4,000 people. The NT has a low density and clumped distribution of human activities including industrial exploration and developments. Compared to Canadian provinces, the NT is sparsely developed with few roads, and relatively little landscape-scale change due to agriculture or forestry. Mining exploration typically follows boom and bust cycles with highs in exploration activities in the 1970s (mostly uranium) and the 1990s (diamonds). The discovery of diamonds in 1991 at Lac De Gras resulted in the largest staking rush in Canadian history leading to the construction of two open pits and one underground mine. The collective operations of the three diamond mines produce 15% of the world's rough diamonds, and the annual production in 2007 was worth $1.4 billion (www.iti.gov.nt.ca).

Although developments such as mines are relatively few (i.e., about 35 mines since the 1930s) people have long memories; concerns about past practices and abandoned mines have influenced public perception of recent mining activities. The lack of all-season roads means that fly-in operations are typical, although the cold winters allow the use of seasonal ice roads to service remote camps and developments. Tourism is important for the NT economy; however, it is mostly confined to the larger communities serviced by roads or to lakes and rivers. On the central barrens, human activity other than mining exploration and development occurs mostly as guided hunting based out of seasonal camps. The majority of oil and gas development is found in the western Mackenzie Valley region while mining activities are more frequent in the central and eastern NT.

Regulatory and Policy Framework in the Northwest Territories

The NT regulatory regime has greatly changed since the early 1990s. Currently, governments (i.e., federal, territorial, aboriginal) participate in comanagement relationships, accepting shared responsibilities for resource development and management. The emphasis on comanagement of land and resources was formally recognized through enactment of the Mackenzie Valley Resource Management Act in 1998. The act was a result of commitments made by Canada during the negotiations of the Gwich'in and Sahtu comprehensive land claim agreements settled in 1992 and 1993, respectively (Donihee 1999).

The Mackenzie Valley Resource Management Act is counterpart to an environmental assessment act, and gives aboriginal people a greater say in resource development and management through an institutional framework that emphasizes comanagement, collaboration, and inclusion of indigenous knowledge (Armitage 2005; Ellis 2005; Christensen and Grant 2007). The Mackenzie Valley Resource Management Act resulted in the establishment of the Mackenzie Valley Environmental Impact Review Board (www.reviewboard.ca/), which is a comanagement board that has shared aboriginal and government roles, and is responsible for the environmental impact assessment process in the Mackenzie Valley, including areas used by the Gwich'in, Sahtu, Deh Cho, Akaitcho, and Tlicho aboriginal peoples. The Review Board considers cumulative effects during its assessments. The Mackenzie Valley Resource Management Act also established a requirement for monitoring cumulative impacts on the environment. Adopting a community-based approach, this work is directed by the NT Cumulative Impact Monitoring Program (NWT-CIMP) working group, which is a partnership among NT aboriginal governments, the Government of Canada, and the Government of NT.

Concerns about cumulative effects during the comprehensive review for the Diavik Diamond mine prompted the regulatory agencies to commit, in 1999, to a regional cumulative effects assessment and management framework (NWT CEAM Steering Committee 2007). The framework is meant to formally involve federal, territorial, and aboriginal governments, regulatory agencies, nongovernmental organizations, and industry in the design and implementation of a monitoring, management, and planning framework that addresses limits on regional cumulative effects (Chapter 3). The framework was slow in development as the requirement for consultations was time consuming. By February 2008, the CEAM Steering Committee recognized that cumulative effects were only one component of the framework, which more properly involved management of human activities through stewardship. Formally recognizing the broader role of the framework, it was renamed the NT Environmental Stewardship Framework.

The Significance of Migratory Barren-Ground Caribou

Caribou are of profound cultural, spiritual, and economic value to aboriginal peoples who have hunted the herds and depended on them for food and clothing (Kuhnlein and Receveur 1996; Legat et al. 2001). Indeed, the present-day relationships between northern peoples (aboriginal and nonaboriginal) and caribou is more accurately described as a complex, adaptive socioecological system (Berkes et al. 2003, 2009), where social capacity for responding to and shaping ecosystem dynamics is a powerful feedback mechanism (Folke et al. 2005). Consequently, one of the strongest public concerns expressed during the environmental review of diamond mines in the 1990s was for the migratory barren-ground caribou herds, especially the Bathurst herd that ranges across the majority of staked kimberlite deposits.

Within the context of formal environmental assessments, caribou are considered a valued ecosystem component due to their importance to northern people. The Bathurst herd is one of the seven herds of migratory barren-ground caribou in the NT and Nunavut. The winter range of Bathurst caribou is below treeline, and the herd can migrate over 1,000 km to the tundra for calving and summer habitats. The migrations are the caribou's evolutionary strategy to cope with variable environmental conditions (Bergerud et al. 2008), suggesting that barren-ground caribou may be especially vulnerable to human activities that interfere with or interrupt movement behavior. The migratory tundra caribou are also gregarious, especially during calving and postcalving, which can increase their vulnerability to human activities.

One of the difficulties for cumulative effects assessment is selecting and rationalizing spatial and temporal boundaries (Vistnes and Nellemann 2008). The boundaries are important because the definition and application of any thresholds for regional development will be largely dependent on scale. The seasonal and annual distribution of barren-ground caribou can help identify and justify boundaries for cumulative effects assessments across regional areas. The definition and application of any thresholds for regional development will be largely dependent on scale, and therefore the assessment has to be defined as or nested within the annual range of the study herd. A consequence of migratory behavior is the dilution and transfer of effects across regional areas that can complicate CEA between neighboring jurisdictions.

Less attention is paid to the logic for selecting temporal boundaries (Vistnes and Nellemann 2008). Typically, the timescale for less intensive activities such as exploration is years and for fully developed mineral deposits is often 20–30 years, although failure of reclamation can extend the time period. The abundance and distribution of caribou changes at the decadal scale (30–60 years) with relatively regular phases of increase, decrease, and low numbers (i.e., cyclic behavior; Gunn 2003;

Zalatan et al. 2006). Measures of individual and demographic vigor vary between different phases of the cycle that has implications for baseline, monitoring, and mitigation and describing responses to human activities. For migratory barren-ground caribou, then, the temporal scale for cumulative effects is decades and tied to the period and amplitude of the cycle that represents repeatable changes in abundance and distribution.

Ecological Characteristics of Migratory Barren-Ground Caribou

Understanding the ecological characteristics of caribou ranges is necessary because "cumulative effects have to be identified and assessed within the framework of a variable natural environment" (Cameron et al. 2005, p. 7; Wolfe et al. 2000). Natural environmental variability is an ecological driver of population dynamics and influences the resilience of caribou in the context of additional stresses that can be imposed directly through natural predation and hunting mortality, or indirectly through anthropogenic disturbance or displacement associated with industrial development and infrastructure (Figure 8.2).

There are several important ecological characteristics of the tundra and taiga seasonal ranges used by barren-ground caribou that can interact directly or indirectly with human activities. First, a highly seasonal pulse of annual plant productivity occurs during the relatively short and warm summer, interspersed with long cool winters when most ecological processes are dormant or slow (Bliss et al. 1973).

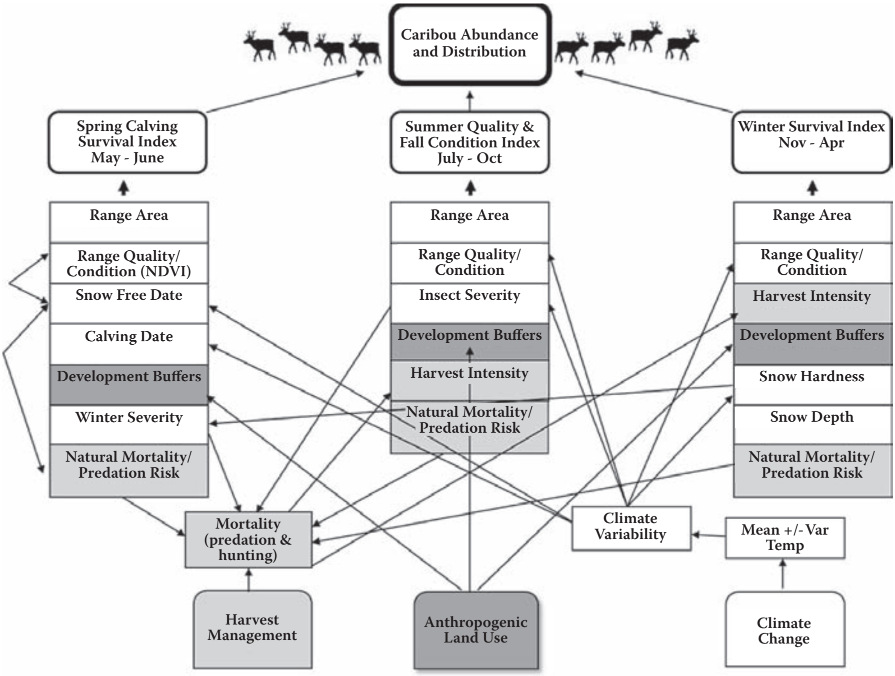

FIGURE 8.2 General factors and associated interactions influencing the abundance and distribution of barren-ground caribou populations found across North America.

Second, weather patterns that affect timing and length of the plant growing season are annually variable and unpredictable. The timing of new plant growth in spring, and forage production through the growing season are essential elements in the survival and growth of calves, and in the ability of females to meet the demands of lactation and regain body condition sufficiently to breed in autumn (Russell et al. 1993). Summer weather also influences the abundance of parasitic and biting insects, which in turn influences caribou body condition (Russell et al. 1993; Hagemoen and Reimers 2002).

Third, climate variability influences the frequency and size of fires on the taiga range that may burn large areas of winter foraging habitat, and effectively remove lichen biomass for decades (Thomas et al. 1996; Rupp et al. 2006). Finally, snow cover (i.e., depth, hardness, and duration) and freeze-thaw cycles reduce access to forage and may limit energetic and nutritional intake of caribou during winter (Adamczewski et al. 1988).

Barren-ground caribou are hunted by wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), and less frequently by wolverine (*Gulo gulo*) and lynx (*Lynx canadensis*). Newborn calves are especially vulnerable to avian predators such as golden eagles (*Aquila chrysaetos*). Many of the evolutionary strategies of caribou, including migration, are shaped by predation (Bergerud et al. 2008). Caribou are gregarious and migrate in groups that range from a few individuals to tens of thousands. Group size can affect the average behavioral response level of individuals in the group (Roberts 1996; Manor and Saltz 2003). Gregarious behavior of caribou varies seasonally. During calving, all breeding females of a herd congregate on the calving ground, and during postcalving, caribou form large aggregations of thousands to tens of thousands of individuals. Thus, sampling designed to measure cumulative effects must be robust to variation in the relatively low probability that caribou will encounter a site of human activity, while each encounter can include a large proportion of a herd.

Caribou responses to human activities are likely influenced by their reaction to predators (Frid and Dill 2002). Indirectly, hunting may modify the responses of caribou to other human activities including habituation (Haskell and Ballard 2008) or avoidance responses (Coleman et al. 2001; Reimers et al. 2003). Prior to European settlement, aboriginal peoples accessed barren-ground caribou by anticipating and following the movements of the migratory herds on foot and establishing seasonal hunting camps; their traditional knowledge of water-crossing sites, over-winter areas and other aspects of caribou migratory movements were a key aspect to aboriginal hunting strategies (Legat et al. 2001; Stewart et al. 2004; Parlee et al. 2005). Today, people use trucks, off-highway vehicles (i.e., snowmachines, all-terrain vehicles), boats, and aircraft to access barren-ground caribou from late summer through winter. Access for caribou hunting from winter or all-season roads associated with industrial exploration and development is a key aspect for cumulative effects.

RESILIENCE IN THE CONTEXT OF CUMULATIVE EFFECTS

Our approach to cumulative effects is premised on the concept of resilience. Resilience captures the ability of caribou (individuals and populations) to cope with natural and anthropogenic environmental variation and stressors. For caribou, ecological resilience is measured by the amount of disturbance that is absorbed (coped with) before the individual (or herd) changes behavior (Holling 1973, 1986; Gunderson 2000). Natural environmental variation such as level of insect harassment can reduce or increase resilience of a caribou, which then changes the impact of the same individual's response to human activities. Gunn et al. (2001) explored the concept of resilience for caribou to integrate responses to human activities and the effect of insect harassment and snow conditions. The application of resilience as a concept allows us to integrate project-specific CEA and range-wide monitoring to offer testable predictions about the cumulative effects of human activities on the Bathurst caribou herd.

Considering human–caribou interactions, the concept of resilience also applies to the socioecological system's ability to build and increase the capacity for learning and adaptation by people (Berkes et al. 2003). Resilience in socioecological systems is closely tied to the concept of sustainability and the challenge of meeting current demands without degrading the potential to meet future requirements (Ludwig et al. 1997; Walker and Salt 2006). The concept of resilience shifts perspective from the anthropogenic desire to control change in systems assumed to be stable, to sustain and enhance the capacity of socioecological systems to adapt to change (Folke et al. 2002). This definition of resilience is similar to how Tlicho elders view respect and knowledge as a cornerstone of their relationship with caribou (Legat et al. 2001).

DEVELOPING AND DEMONSTRATING A SPATIALLY EXPLICIT DEMOGRAPHICS MODEL FOR MIGRATORY CARIBOU

Since 1980, the efforts of governments, industry, and independent researchers have contributed greatly to the understanding of the distributional and population dynamics of barren-ground caribou. With the development of oil reserves on Alaska's North Slope and the discovery of diamondiferous kimberlite deposits in the Canadian central Arctic, much of the recent emphasis on research and monitoring has been placed on understanding the impacts of human activities (Cronin et al. 2000; Johnson et al. 2005; Joly et al. 2006). For the Bathurst herd, three diamond mines and associated exploration activities have served as the impetus for a number of innovative cumulative effects studies (Gunn et al. 2001; Legat et al. 2001; Johnson et al. 2005). None of these works, however, captured the full range of hypothesized interactions between industrial development and the long-term dynamics of caribou. Likely the greatest limitation of these studies was their inability to interface effectively with decision-making frameworks focused at herd management, regulatory approval for new development, and strategic land-use planning.

Despite a considerable amount of research and a number of overlapping federal and territorial review and approval processes, aboriginal communities remain concerned about the impacts of development on caribou. The precipitous decline of Central Arctic and other caribou herds (Vors and Boyce 2009) has increased the pressure on government agencies and comanagement boards to better understand and, if possible, halt the decrease in the number of caribou. Recognizing the limitations of past research and approaches, we suggest a suite of interacting and complementary methods that provide a more complete perspective on the distribution and population dynamics of terrestrial mammals. Considering the current declines in caribou populations and the increasing level of development across the Arctic, this approach is timely and well illustrated using barren-ground caribou as an example species. This is especially the case for the Bathurst population, where nearly 15 years of distribution data, decades of past studies and knowledge of the biology, population status, and traditional uses of the herd, and recent concerns around a new and expanding industry suggest that further advances in cumulative effects analyses are warranted and likely fruitful.

We are developing an integrated and adaptive modeling framework that draws on the learning, data, and approaches developed for the Bathurst and other migratory caribou herds. This includes distribution data of Bathurst caribou collected at the mines through aerial census and across the annual range using satellite collars; activity data as part of a number of behavioral studies; and traditional ecological knowledge describing the long-term distribution of caribou. These data are being applied to a set of simulation and statistical models that have shown good utility for Bathurst caribou and other taxa, but to date have not been integrated to understand changes and interactions in (1) caribou distribution and (2) abundance in the context of (3) long-term and large-scale anthropogenic activities and environmental variation.

A team of experts in spatial, nutritional, and population models, caribou biology, and aboriginal knowledge of the historical distribution and behavior of caribou are working collaboratively to develop a set of models that will provide some perspective on future outcomes in the distribution and abundance of the Bathurst caribou herd in the context of global change and more localized development scenarios. This project is meant to be larger than a 2- to 4-year research endeavor, serving as a long-term planning framework that is adaptive and reflexive to changing knowledge, development pressures, government and community needs. As the starting point, we envision a collection of interconnected models that are premised on the distribution and avoidance responses of caribou to human disturbances (Figure 8.3). This includes spatial avoidance of human features, with inherent consequences for habitat use and the behavioral and ultimately nutritional costs of such decisions. These habitat relationships are then integrated within a mechanistic nutrition-population model to forecast the demographic consequences of avoidance behaviors and habitat change associated with the current human footprint. Finally, the products of these models will interface with a regional cumulative effects simulator (A Landscape Cumulative Effects Simulator [ALCES®], Schneider et al. 2003) that will allow the research team to engage local communities, government, and industry in a formal discussion of the possible implications of future land use and environmental change across the range of the Bathurst herd.

One of the initial objectives of the project was to illustrate the utility and benefits of the integrated modeling process. As such, the scope of the project is limited to the summer range of the Bathurst herd, the area with the greatest concentration of industrial activities. Through successive iterations, the research team will increase the detail and specificity of the models, accuracy and precision of input data, and the total area of application, including the annual range of Bathurst caribou and other herds of caribou in the Central Arctic. Thus, we are pursuing an iterative modeling process with no set end-point. Model predictions will be posed as tentative hypotheses that help engage the public, stimulate discussion and consideration of regional development thresholds

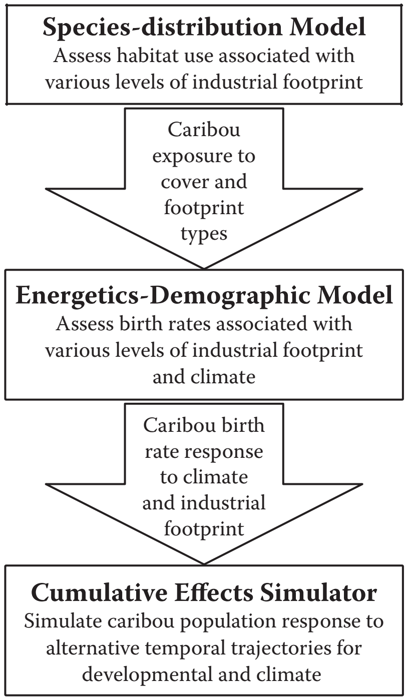

FIGURE 8.3 Integrated modeling framework for documenting and understanding the impacts of human developments for barren-ground caribou found across northern Canada. The analytical role of each model and information flows between models are presented.

for caribou, and direct further learning of limiting or regulating factors for the distributional and population dynamics of the species (Starfield 1997). Below, we discuss the conceptual framework and supporting research for developing and interpreting the three foundational elements for the cumulative effects demonstration project: distribution model, nutritional-demographic model, and cumulative effects simulator.

Understanding the Distributional and Avoidance Responses of Caribou

The first step in developing the integrated modeling framework was to use species-distribution models to describe the distribution and avoidance response of caribou relative to sites of industrial exploration and development. Defined by Guisan and Thuiller (2005, p. 994) as "...empirical models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surfaces," species distribution models are now a well-accepted technique for quantifying and spatially representing the response of plant or animal species to variation in important resources.

Mace et al. (1996, 1998) were pioneers in applying species distribution models to the question of cumulative impacts. Working with grizzly bear locations, they demonstrated that bears had a lower probability of occurrence in areas with a high density of roads and that human activity resulted in a cumulative reduction in the availability of bear habitat. Similarly, Carroll et al. (2001) used species distribution models to quantify the impacts of human-caused landscape alteration on the distribution of carnivore species across the Rocky Mountain region of western North America.

Species distribution models are useful for identifying zones of influence. These zones represent the static area and perhaps time of year when wildlife demonstrate measurable responses as a result of an existing development such as an avoidance response, altered behavior in the vicinity of a facility, or changes in the types or quality of habitat used by animals. The zone of influence can determine the area of effect, serve as a metric for regional measures of cumulative effects, or help guide monitoring and mitigation strategies. For example, Nelleman et al. (2003) reported a zone of avoidance of 2.5–5 km for reindeer (*R. t. tarandus*) responding to powerlines, resorts, and roads.

Although an intuitive concept, the zone of influence and measures of significance are difficult to quantify (Quinonez-Pinon et al. 2007). This is especially apparent where multiple developments interact. Also, the zone of influence should be premised on the type of response that is measured, and there may be multiple zones depending on the source of effect. Direct mortality via road access, for example, is normally restricted to the area in the immediate vicinity of the road corridor or road density across a larger area. Habitat alteration or avoidance responses relative to noise or human presence may occur over a larger spatial extent. Recent research has focused on developing techniques that indicate statistically meaningful responses of animals to human activities or facilities that can then be translated to zones of influence used in regulatory frameworks (Bennett et al. 2009). When empirical data are absent, expert opinion is used to estimate probable zones (AXYS and Penner 1998). Often, the processes to collect such ecological data are flawed (Johnson and Gillingham 2004), making a strong case for the application of formal and repeatable species distribution models for such purposes.

Species distribution models and their associated outputs are easily adapted and applied to resource management or conservation models. These multimodel approaches often integrate maps, illustrating the location and amount of selected habitats, with predictive movement models, population viability analyses, or habitat supply models. Johnson et al. (2005), for example, used maps of the distribution of high-quality habitats for a number of Arctic species, including caribou from the Bathurst herd, to quantify the impacts of hypothesized development scenarios on the distribution and availability of habitats and abundance (Johnson and Boyce 2004). Similarly, Carroll et al. (2003) linked species distribution and spatially explicit population models to understand the relative value of a range of reintroduction strategies for wolves under current and predicted future landscape conditions.

Building on previous research (Johnson et al. 2005), we are using Resource Selection Functions (RSF), one type of species distribution model, to investigate the responses of Bathurst caribou to broad-scale vegetation patterns (i.e., habitats) and human disturbances. We hypothesize that after statistically controlling for variation in the distribution of plant communities, caribou will demonstrate a decreasing avoidance response as distance from human facilities increased. An RSF produces a series of coefficients that quantify the strength of avoidance or selection for specific habitat covariates. When considered additively (Equation 8.1), the series of coefficients indicate the relative probability of caribou using any location from across the study area (Johnson et al. 2006).

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i) \quad (8.1)$$

When normalized, the RSF score $w(x)$ equals the relative probability of the occurrence of caribou; this is a function of the weighting coefficients (β_i) and the magnitude of the covariate at that site (x_i). Using simple image arithmetic, the RSF equation can be applied to GIS data for each covariate resulting in spatially explicit habitat predictions; these maps can then be used to further develop population, movement, or habitat supply models.

We are using one form of a broad range of models capable of quantifying species–habitat relationships (Elith and Leathwick 2009). Alternative species distribution models may provide a quantitative perspective on caribou distribution. The exponential form of the RSF, however, is inherently flexible, accommodating a range of habitat covariates; is grounded in statistical theory and has a number of proven methods for validation; results in a predictive metric, relative probability of use, that is easily understood and transferable; and is insensitive to data imprecision and choice of formulation (Johnson et al. 2006; Johnson and Gillingham 2005, 2008).

An RSF is constructed using point data that illustrate the spatial location of an animal across some defined area and time period, a comparison set of random locations that represent the amount and distribution of resources or features, and a number of habitat or disturbance covariates that describe or model the observed pattern of animal locations relative to the set of random locations. For this project, we drew upon 13 years of location data collected by satellite collars deployed on 67 female caribou (Gunn et al. 2002). Recognizing longer-term dynamics in caribou distribution and the need to directly involve aboriginal communities in the project, we derived additional point locations from an extensive Traditional Use Study focused on the harvesting of caribou (Legat et al. 2001). Here, Tlicho elders documented locations where they had hunted caribou since 1932 and trails used by caribou. Each hunting location was considered as a separate datum, and the trails were converted into point locations with a 5-km interval to ensure independence. Because the traditional ecological knowledge information was located on the western extremity of the study area, these data were used to model vegetation covariates only (Figure 8.1).

We are using the RSF to investigate two vegetation and three human disturbance covariates. Because of the large study area, vegetative habitat variables were derived from two independent mapping projects based on Landsat Thematic Mapper images, but different legends and classification routines. Variation in green plant biomass and phenology influences caribou distribution (Griffith et al. 2002). Thus, we used the Normalized Difference Vegetation Index (NDVI) to measure the response of caribou to seasonal changes in plant productivity. We selected a number of types of human disturbance features that would aggregate cumulatively to influence the distribution of caribou. Drawing from the methods of Johnson et al. (2005), the distance of each caribou and random location was calculated from existing diamond mines and a gold mine. Recognizing that not all mines were in operation during the study period, distances were relative to active mines, on an annual time scale. We also calculated the distance to areas of the summer range where mineral exploration activities occurred. This included known locations of exploration camps and activities, buffered by 10,000 m, and broader areas for which an active mineral lease was on record. Previous work (Johnson et al. 2005) suggested that Arctic wildlife may avoid outfitter camps. We buffered camps by 500 m to represent the broader area of influence of such activities. Outfitters often hunt caribou from lake shorelines; therefore, we buffered lakeshores 5 km inland when situated within 20 km of a hunt camp.

Through the modeling, we are identifying combinations of resource and disturbance variables that serve as hypotheses that might explain patterns in the distribution of Bathurst caribou. We are generating candidate models for three time periods of distinctive behavior across the summer range: post-calving (June 14–July 5), early summer (July 6–July 18), and late summer (July 19–August 22). Then, we use an information-theoretic approach to guide model development and selection (Anderson et al. 2000).

Understanding Changes in Abundance of Caribou with an Energetics–Demographic Model

The second model explores how caribou integrate their behavioral responses to human activity and environmental variation (e.g., insect harassment, foraging conditions) from the individual to the herd scale (Nicolson et al. 2002; Kruse et al. 2004). The model (Russell et al. 2005) predicts the change in daily body mass and body composition of a female caribou, her milk production, and the daily body mass change of her calf as a function of milk intake. The variables driving these outcomes are daily activity budgets, forage quality, and forage quantity. The energetics model consists of two submodels (Figure 8.4 and Figure 8.5). The first is the energy submodel (Figure 8.4), which predicts daily changes in a female's metabolizable energy intake (MEI) by calculating her food intake and then simulating the functioning of the female's rumen and her digestive kinetics on an hourly basis. Using MEI as the index of change, specific objectives of the energy submodel are as follows: to show effects of environmental conditions and movement patterns as reflected by changes in activity budgets, forage quality, and forage quantity; to evaluate effects of human and natural disturbance such as mining activities and insect harassment; and to evaluate winter severity as reflected by snow depth.

The MEI predicted by the energy submodel is transferred to the second model. The growth submodel calculates the female's energy expenditure, her energy balance, and the subsequent daily change in her mass, milk production and hence the daily change in mass of her calf. The growth submodel evaluates effects of changes in seasonal activity budgets and MEI on the energetic and reproductive status of a female caribou. The growth submodel's specific objectives: to evaluate the impact of changing activity costs, maintenance costs, and MEI on the female's energy balance and subsequent change in body composition and growth; and to evaluate effects of the female's energy balance on the growth of her fetus during pregnancy and her calf during lactation.

We are using nine different scenarios to explore the sensitivity of the body condition model predictions to varying levels of human development and environmental

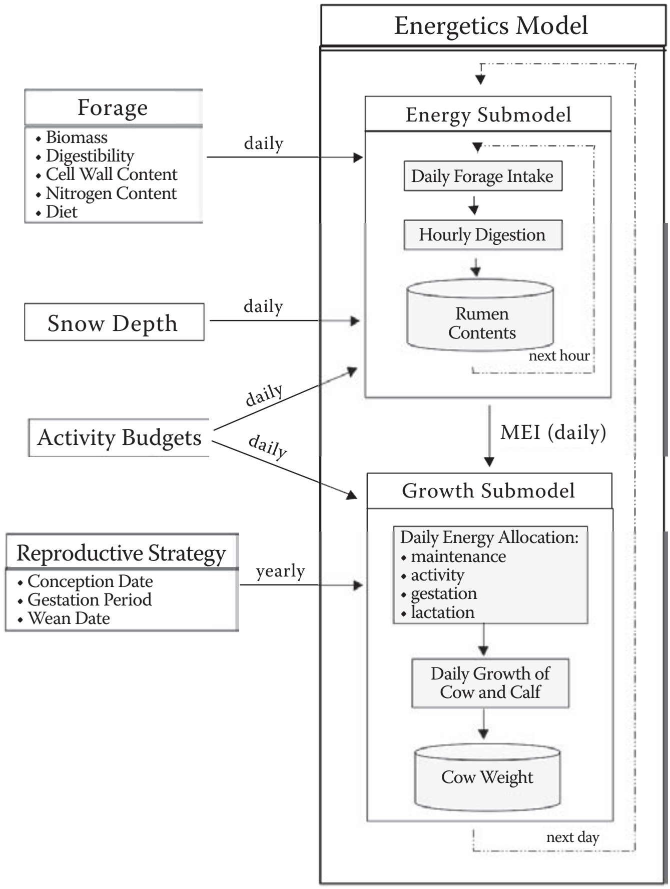

FIGURE 8.4 Generalized structure of the barren-ground caribou energetics model developed by Russell et al. (Used with permission from the Canadian Wildlife Service.)

change. Each scenario has an assumption regarding the level of development (none, current, or double current development) and climate (average, worst case, and best case). Within each scenario, we incorporate two zones of influence: habitats and behavior adjacent to the diamond mines and the area outside the zone of influence. With respect to the level of development, "current" scenarios represent current mining activity on the Bathurst summer range. About 6% of the summer range is within the 30-km zone of influence of mine sites for these scenarios; the no development scenarios assume that no development occurs on the summer range, while the two-times current development scenarios assume that the total area within the development zone is double that of current conditions (i.e., 12% of summer range).

For the climate scenarios, the average scenario represents current average climatic conditions. The worst-case climate scenario represents the worst possible combination of climatic conditions for caribou (i.e., high winter snow levels, high summer insect harassment, and a short green-up period for plant biomass). Similarly, the best-case climate scenario represents the best possible climatic conditions (i.e., low winter snow levels, low insect harassment, and long green-up).

To determine the time-series of forage biomass available to caribou every day, the model requires the annual maximum biomass (kg·ha^{-1}), for plant groups within each of the 10 habitats taken from the RSF analysis (i.e., moss, lichens, mushrooms, horsetails, graminoids, deciduous shrubs, evergreen shrubs, forbs, standing dead, *Eriophorum* heads). Next, the phenology (green-up) of each plant group is characterized using three dates: start of plant emergence, date of maximum biomass, and end of plant senescence. These dates vary as a function of the climate year-type (i.e., average, worst-case, best-case), representing early and late green-up.

The model also requires estimates of seasonal activity budgets for the herd, specifying the proportion of time spent by the animal each day in foraging, lying, standing, walking, and running. The proportion of total foraging time is further broken down into the proportion time spent eating and time spent pawing. We specify activity budgets for each possible climate year-type to account for the differing effects of snow depth and insect harassment on caribou activity. Activity budgets are also varied within and outside the development zone, to reflect changes in caribou activity patterns as a function of human-related disturbance.

The body condition model requires an estimate of the proportion of time spent in each landscape stratum within the summer range, where landscape stratum refers to a combination of habitats and development zone. For the post-calving, early summer, and later summer seasons, this proportional use of each landscape stratum is estimated by simulating caribou movement based on the relative probabilities taken from the RSF. We run the model through each of the three seasons to predict the autumn mass (i.e., on October 15) of a lactating adult female for the nine scenarios. Having run the body condition model for this suite of scenarios, the last step in the analysis is to relate predicted changes in body condition to changes in one or more demographic parameters such as birth rate the following spring, as determined using data from the Central Arctic and Porcupine herds (Cameron and Ver Hoef 1994).

Understanding Implications of Landscape and Environmental Changes on Caribou: A Landscape Cumulative Effects Simulator (ALCES®)

We use ALCES (www.alces.ca), a landscape simulation model, to explore the cumulative impacts of land-use scenarios for barren-ground caribou. Scenarios are plausible, but structurally different descriptions of how the future might unfold (Duinker and Greig 2007; Mahmoud et al. 2009). Although computer-based scenario simulations do not provide quantitative predictions or forecasts of conditions in any particular year, they can be used to assess the influence of assumptions or management approaches, and to explore uncertainties and strategies for mitigating cumulative effects (Schneider et al. 2003; Carlson et al. 2007; North Yukon Planning Commission 2009).

The model ALCES is capable of simulating and tracking changes in land cover types caused by anthropogenic land uses and natural ecological processes at a regional scale (Hudson 2002). The cumulative effects simulator can represent natural disturbance regimes, human land-use trajectories, and climate drivers according to user-defined inputs. Resource development (e.g., mining, hydrocarbon extraction, forestry and agriculture), the ecological composition of the land base, and climate are translated into biological indicators such as the area of a particular plant community that may serve as habitat or the actual abundance of a wildlife species. For example, relationships between rates of increase of boreal caribou and functional habitat loss due to natural and anthropogenic landscape disturbance (Sorensen et al. 2008) have been incorporated in ALCES to simulate and evaluate implications of alternative management strategies for woodland caribou (*Rangifer tarandus caribou*) in northern Alberta (West Central Alberta Caribou Landscape Planning Team 2008, Athabasca Landscape Team 2009).

Effective and transparent application of ALCES for strategic-level cumulative effects modeling of barren-ground caribou systems requires that the model is able to simulate multiple plausible impacts that potentially affect caribou, and the impact hypotheses are grounded in relevant expert knowledge and empirical research. Our goal is to parameterize the model to integrate and simulate the effects of resource development and land use, climatic variability, and hunting and predation for barren-ground caribou (Figure 8.5). As a first step, a population dynamics

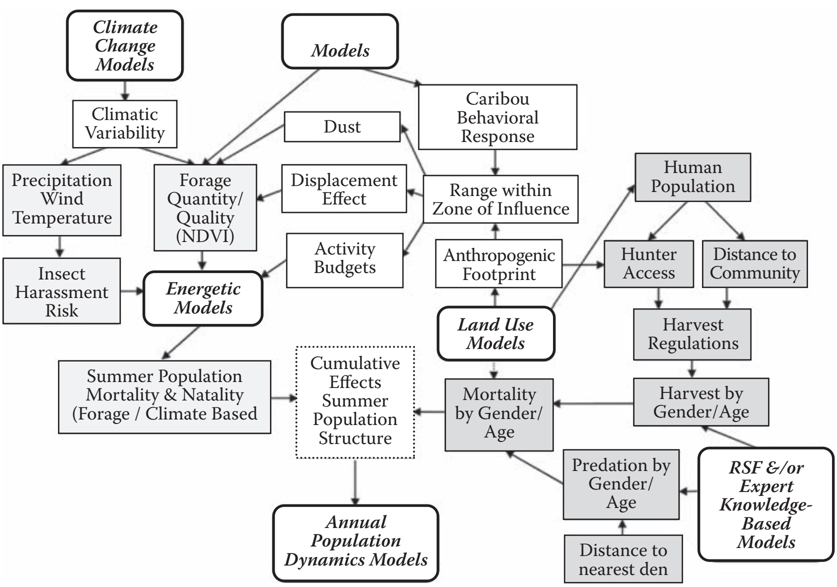

FIGURE 8.5 Structure of a cumulative effects simulation model for barren-ground caribou on the summer range. Submodel components—shown as dark outlined boxes—serve as data sources (e.g., RSF/expert models) and data processors (e.g., energetic and population dynamics models). Regular boxes reflect data themes with arrows showing linkages and flow of information among submodel components. Lightly shaded boxes outline factors that may be generated from climatic variability and are used as inputs to the energetics model, darkly shaded boxes represent factors that directly influence mortality via predation and hunting, and unshaded boxes represent factors that determine the anthropogenic footprint and associated responses of caribou.

submodel was added to ALCES to provide the link between direct and indirect effects of landscape change, and natural and anthropogenic stressors to population performance of caribou. The submodel also facilitates simulation of the direct effects of predation and hunting to sex and age-class specific mortality of a caribou population (Figure 8.5).

Our current focus on resource selection and energetic models is a way to define and incorporate empirically based functional relationships that describe responses of barren-ground caribou to changes in landscape composition that may occur due to resource development. Through an additional series of simulation experiments, we will use the resource selection and energetics models to define a suite of functional response curves that link pregnancy rate to varying levels of anthropogenic land use and natural stressors (e.g., summer insect harassment). For example, the RSF is first applied to simulate the distribution of females during the calving and summer seasons, including the amount of time spent in each cover type and the proportion of time spent within a 30-km zone of influence of an active mine. The energetics model is then used to estimate the implications of that avoidance scenario for the body mass of average female caribou and, ultimately, birth rate. This modeling approach is used to estimate birth rates associated with a number of land-use scenarios across a continuum from no active mines to several times the current area of active mines. Results from these scenarios will be used to define a relationship between proportion of the study area within the zone of influence of active mines and caribou birth rate. This relationship will be integrated into the population dynamics submodel within ALCES as a modifier to birth rate.

Because ALCES is able to simulate variation and trends in temperature and precipitation regimes based on user-defined climatic parameters for an ecozone, it is possible to explore potential consequences of climate change scenarios to population performance of caribou. We are developing an approach that would use the energetics model within a factorial simulation experiment, to relate climate variables to female body condition and birth rate. Simulations conducted with ALCES would track relevant climate variables using random variation around user-defined expected climate trends. Based on the array of climate variables simulated for a given year, ALCES would then select the appropriate birth rate from the database of birth rates derived from the energetics model.

The cumulative effects simulator, ALCES, will serve as the integration tool, projecting empirical output from the RSF and energetics model over long time periods (e.g., 50–100 years) under a range of change scenarios, including future climate and land-use development. Such scenarios will be premised on historical or anticipated rates of development, predicted levels of climate change relative to key caribou parameters (e.g., insects, green-up of spring forage), and questions that come directly from the users and managers of caribou. Predicting the possible outcomes of these cumulative impacts for the Bathurst caribou herd will allow for a better understanding of how resilient the herd is to anticipated levels of landscape change that occur over time periods (e.g., 50–100 years) that exceed the current temporal and spatial frameworks of site-specific CEA. Such information is crucial for long-term strategic planning in the context of cumulative effects and may help address many of the shortfalls of the current regulatory and monitoring processes (Chapter 3).

ADDRESSING THE CUMULATIVE EFFECTS QUAGMIRE—CARIBOU AND BEYOND

This research is an ongoing collaborative project between researchers, government, and a comanagement board, and was designed to meet the particular concerns of people in the NT and criticisms about CEA (Kennett 1999; Duinker and Greig 2006). Those concerns and criticisms (Duinker and Greig 2007) also relate to projects that fall below screening requirements, so we developed a practical approach to incorporate potential small-scale effects arising from exploration sites and camps on caribou range. Our integrated modeling approach lends itself to land-use planning that can be an effective approach for considering cross-sectoral developments strategically across regional areas (Chapter 3). Understanding the range of caribou responses to development, from the behavior of individual animals to the demographic changes of the herd, will allow communities, comanagement boards, and government to better manage or plan for cumulative effects. Additionally, this improved understanding will lead to a clearer appreciation of trade-offs between goals for sustainable hunting and persistence of healthy caribou populations in the context of broader goals for landscape management that include industrial development and resource extraction. An example of the trade-offs between sustainable harvesting and industrial development is apparent in the management of the Central Arctic herd that interacts with the Prudhoe Bay oilfield. Here, harvest levels are kept low (<2%) to offset possible detrimental effects of disturbance during calving (Lenart 2007).

As suggested by Vistnes and Nellemann (2008), pre- and post-development studies provide a powerful framework for environmental assessments and for understanding cumulative effects. The benefit of simulation models is that they can be used as learning tools to compare pre- and post-development scenarios to develop testable hypotheses that are derived from a current understanding of caribou ecology and responses to human activities. The goals of current and future modeling work in this project are to better understand the cumulative effects of a range of stressors on the long-term viability of the Bathurst caribou herd. These effects, however, can be considered in the context of economic development for northerners, including aboriginal communities.

If trade-offs are to be considered and integrated into the decision-making process, managers will need to move from command and control strategies (Holling and Meffe 1996) to those that recognize and accept that natural systems are complex and dynamic. Furthermore, people will need to be considered as part of these systems, which requires a shift in thinking and the development of decision support and learning tools. Such a shift has occurred in the NT as the management and regulatory process is premised on comanagement and community involvement. There is still, however, much room for improvement. Agencies and biologists must move from simply including traditional knowledge in science and management to a broader acceptance of other world views and the development of adaptive capacity in these complex socioecological systems (Paci et al. 2002).

Understanding the influences of natural environmental variation is fundamental to moving the science of cumulative effects from correlation to causation (Perdicoúlis et al. 2007). Causality is the link between human activities (actions) and their environmental impacts, although more often than not causality refers to hypotheses rather than facts (Perdicoúlis et al. 2007). Consequently, there is a need to select a design/methodology for CEA that can accommodate natural and industrial changes. Resilience allows one to integrate natural environment variability with the responses of animal populations to human activities. Applying the concept of resilience also emphasizes that there are limits to what caribou (or ecological systems) can cope with and that this limit will depend on naturally varying environmental conditions. This means that we can anticipate thresholds in development levels above which caribou ecology, distribution, or population dynamics will shift to a different state. We have to weigh those impacts in the context of the benefits of the development for local and national economies.

The impact of industrial development on wildlife is a frequent and worldwide concern, especially for migrant species whose traditional routes can be threatened by infrastructure or landscape change (Berger 2004). Although we designed our approach to cumulative effects specifically for migratory tundra caribou in the NT, the approach likely has application to migratory tundra caribou elsewhere. Caribou, such as those in the Bathurst herd, have ecological similarities to other open habitat, gregarious and migratory ungulates in Africa and Asia that face similar threats (e.g., Mongolian gazelles [*Procapra gutturosa*]; Ito et al. 2005). Thus, we suggest the general approach we have developed may be applicable to other species of wide-ranging herbivores.

When asked in 2008 about whether industry and caribou could coexist in the north, Fred Sangris (Chief, Yellowknives Dene) said, “When the buffalo went from the plains, the people of the plains, the Cree, the Dakota—their culture died, their spirit died. Here, we have a chance to save it” (Canadian Arctic Resources Committee 2007, p. 22). His comparison of bison and caribou underscored two important points: there is a strong cultural link between aboriginal peoples, wildlife, and the land, and abundance of wild animals today is no guarantee of their future survival. Bergerud et al. (1984, p. 19) also linked bison and caribou when they concluded: “But, adaptable as the caribou is, it still has the same problems as the buffalo—overharvest and the need for space.” Seasonal migration is an adaptive strategy of caribou to their predators, parasites, and availability of forage. Caribou herds will lose their ability to cope with environmental changes and human activities if their ability to find space is compromised or restricted.

CONCLUSION

The future for caribou populations across the Canadian central Arctic is uncertain. We are currently witnessing historic lows of all populations with extreme curtailments on harvest for all northern residents, including aboriginal communities. The Bathurst herd is a case in point with numbers dropping from a peak of 472,000 ± 72,000 (SE) in 1986 to 128,000 ± 27,300 in 2006, and then a historic low of 31,900 ± 5,300 in 2009 (Government of Northwest Territories Environment and Natural Resources 2009). Continued decline will have consequences for ecosystem integrity and the livelihoods of northern residents with strong cultural and economic ties to caribou (Forchhammer et al. 2002).

Uncertainty for the future of barren-ground caribou arises from the cumulative effects of the types and levels of land-use activities that we permit across their seasonal ranges. Climate change with its positive and negative effects also confronts the use and management of caribou (Brotton and Wall 1997; Gunn et al. 2009). Given these cumulative impacts and uncertainties, governments, caribou users, and industry will have to collaborate to maintain the space that caribou need to cope with landscape changes. Our integrated modeling will help people to work together, and the model outputs provide perspective on the potential risks of development scenarios. Our goal is to move cumulative effects research from the realm of scientists to comanagement and government decision-makers as a step toward sustainable development.

Cumulative Effects in Wildlife Management

Impact Mitigation

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Contents

Preface

Cumulative effects (i.e., the influence on the environment resulting from activities when added to other past, present, and foreseeable future actions) and their influence on fish and wildlife populations have been discussed and incorporated into law and public policy for nearly three decades. Cumulative effects can have serious consequences on fish and wildlife populations, and they should be addressed in land management plans that influence natural resources. Unfortunately, the only attention they often receive is a check-off during an effects analysis indicating they have been considered but without much serious thought or mitigation for possible future altered landscapes. Furthermore, practitioners often address single issues only; after all, how can anyone be responsible for what others are doing, especially when their plans are not available to the public? It is an easy defense to make and much easier to simply address single issues without considering how they will fit into the broader picture. Cumulative effects have been given lip service only, in part, because there is no set guideline to follow in addressing them and it has been difficult to predict what will happen in the future. However, if the only actions that are addressed in relation to environmental influences are those that have direct or indirect effects, information about the most important influence (i.e., cumulative effects) will not be considered. Good examples are river sedimentation as a result of housing developments or forestry practices, and polar ice melting as a result of climate change. In both cases if only direct and indirect effects are considered, serious damage to the landscape would not be recognized initially. Cumulative effects are important and have to be considered seriously if society is to obtain a complete view of how anthropogenic influences affect natural resources.

Over 100 years ago, there were those who recognized that big game would not survive without serious changes to the way society viewed them and their use. The result was the Great American Experiment from which the North American Model of Conservation has evolved and become the envy of countries and conservation organizations worldwide. That period was marked with declining populations, populations that rested on the verge of extinction before our forefather's very eyes. We would argue that over 100 years later we are in the same situation with wildlife habitat. Management has restored big game populations across North America but as the human population increases, wildlife habitat is decreasing before our eyes, in quality and quantity. A housing development here, a shopping mall there, a few more trees cut here, another road put in there, another hectare plowed or grazed, another oil or gas well dug, with a scattering of resorts, ski lodges, off-highway vehicle trails, exurban developments, power lines, airports, and other associated "necessities" of successful societies. At the same time, each of these cuts into the habitat available for wildlife. Unless cumulative effects are recognized and incorporated at the beginning of project development, we will continue to see wildlife habitat disappear at unprecedented rates.

During the 14th Annual Meeting of The Wildlife Society in Tucson, Arizona, in 2007, Dr. Lisa K. Harris and Bruce Pavlick of Harris Environmental Group organized a symposium entitled "Cumulative Effects: Implications and Analysis on Sensitive Resources." Only six papers were presented at the time, and many dealt with endangered species. We realized that there was clearly much more that needed to be presented to push the importance of how and why cumulative effects should be addressed in wildlife management and conservation. Starting with the symposium as the genesis of this book, we expanded the depth and breadth of the topic. In particular, we wanted to bring the importance of cumulative effects to the forefront for managers and practitioners that deal with wildlife, their habitats, and changing landscapes. As humans continue to encroach on wildlands and wildlife habitat, we need to be aware of the actions of our particular projects and those of our neighbors on federal and private lands. Without a conscious knowledge of what is happening around us, we will not be able to incorporate an effective land ethic and natural resources will lose.

The book is divided into two parts. Section 1, Understanding Cumulative Effects, and Section 2, Case Studies. The chapters in Section 1 outline the differences between direct, indirect, and cumulative effects, and address the confusion that can be created by not considering them; the legal aspects of cumulative effects; and how cumulative effects are addressed in Canada. We initially planned a chapter to address cumulative effects in Europe and other countries but there was little to draw upon and many of the countries that did emphasize cumulative effects (i.e., Sweden, United Kingdom, Australia) had laws and policies similar to the United States and Canada. Section 1 also presents the standard means of quantifying cumulative effects as proposed by the Council on Environmental Quality and a final chapter addressing the economics of dealing with cumulative effects.

Section 2 is a series of case studies about border issues with Mexico, scenic resources, and how cumulative effects are dealt with in the Canadian Arctic. The final three chapters addressing the numerous issues that need to be considered when dealing with cumulative effects in suburban and exurban landscapes, freshwater fishes, and the cumulative impacts of energy development on sage-grouse. Each of these chapters is presented to give the reader an appreciation of how anthropogenic influences are interconnected and the importance of understanding how human actions influence our ability to make informed decisions. Many of these chapters point to new and innovative means of addressing cumulative effects in a comprehensive manner. While the state of the art is not yet developed to the degree where there is a standard way to measure cumulative effects, these examples certainly point the way to more efficient means including moving from a project point of view to a landscape approach.

There is a much more to be done and managers and practitioners are at the forefront to ensure that cumulative effects are seriously considered. We hope this text helps resource managers make informed decisions regarding the effects of any proposed action on fish and wildlife and its habitat.

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Organizational assistance was provided by Marisa Franz who spent numerous hours making sure all of the citations were included and the format was consistent. Other day-to-day operations were accomplished by Jeanne Franz, who keeps the Wildlife Biology Program at the University of Montana on an even keel.

The following reviewed the book chapters: Sherry Barrett, U.S. Fish and Wildlife Service (USFWS); Susan J.M. Brown, Western Environmental Law; Andrea W. Campbell, U.S. Forest Service (USFS); Ruth Doyle, USFS; Laura López-Hoffman, University of Arizona; Julie Jonsson, Harris Environmental Group, Inc.; Andrew Laughland, USFWS; John Loomis, Colorado State University; Jason P. Marshal, University of Witwatersrand; Jim Rorabaugh, USFWS; Susan Sferra, USFWS; William Shaw, University of Arizona; and Jeffery Wright, University of Montana.

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