13th Arctic Ungulate Conference
Yellowknife, Canada
22-26 August, 2011

Brief Communication

CARMA's approach for the collaborative and inter-disciplinary assessment of cumulative effects

Anne Gunn[1], Don E. Russell[2], Colin J. Daniel[3], Robert G. White[4] & Gary Kofinas[4]

[1] Salt Spring Island, BC, V8K 1V1, Canada (Corresponding author: gunnan@telus.net).
[2] Yukon College, Whitehorse, YT, Y1A 5K4, Canada.
[3] Apex Resource Management Solutions Ltd., 937 Kingsmere Ave,, Ottawa, ON, K2A 3K2, Canada.
[4] Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, 99775, USA.

Rangifer, 33, Special Issue No. 21, 2013: 161–166

Introduction

One of the most frequent concerns about the future of migratory tundra caribou, *Rangifer tarandus groenlandicus or granti,* are the impacts of the cumulative effects of changing climate and land-use activities across herd's ranges. Assessing cumulative effects is typically a requirement in environmental assessment of industrial developments but policy and technical limitations have hindered development of assessment methods (Duinker & Greig, 2006). Johnson & St.-Laurent (2011) commented on the lack of a methodological framework as one of the reasons for slow progress on cumulative effects. They suggested a framework based on the scaling from individual to population, the relative frequency, and magnitudes of effects and their regulation.

We know quite a bit about individual caribou responses to human activities – interruptions to foraging and displacement of individuals at various distances from the disturbance (Aastrup, 2000; Cameron *et al.,* 2005; Boulanger *et al.,* 2012). However, to scale up from the behavioral responses of individual caribou to the population scale (Johnson & St.-Laurent, 2011) requires baseline information on the 'state' of the individual and population giving consideration to, for example, climate, population density, and genetic structure. At both the individual and population scale, we also have to consider environmental influences, especially weather and climate, which will be additive or compensatory to impacts imposed by human activities.

To scale up the individual's behavioral responses to the population requires being able to estimate the costs to the individual and whether those costs will affect its reproduction and survival. Estimating the costs of a behavioral response is not straight forward; as well as the energy costs of movement and interruption in foraging time, there may also be an effect on diet (energy protein intake) if a displacement puts the individual in a different habitat. Understanding and integrating those relationships between behavior, habitat selection, energy and protein intake relative to reproduction and survival is data intensive and interdisciplinary as the understanding is based on ecology, nutritional ecology, and modeling.

Collaborations among researchers and an interdisciplinary focus are among the strengths of the CircumArctic *Rangifer* Monitoring and Assessment (CARMA) which is a network of shared expertise (Russell *et al.,* 2013). CARMA has worked to develop an approach and associated tools for cumulative effects assessment. The principle tools are currently a spatial climate database scaled to herd seasonal ranges, an individual-based energy/protein (E/P) model (Russell & White, 2000; Russell *et al.,* 2005; White *et al.,* 2013) and a population model. CARMA, through international cooperation and collaboration, has also compiled herd-specific databases on caribou condition and health that is essential as input for modelling cumulative effects.

We have two objectives in this brief communication. Firstly, to describe the conceptual approach of using CARMA's tools and secondly, to briefly describe how the different types of input feed into the models and how the two models work together. The model generates corresponding outputs which are subsequently used to project cumulative effects.

Conceptually, the approach is to track how environmental conditions and movements affect the energy and nitrogen intake of a female caribou. The model tracks energy/protein input (*i.e.,* diet and foraging time) and then the model projects how a cow allocates her energy and protein balance for the probability of pregnancy, fetal growth during gestation, and calf growth during lactation. The pregnancy rates and calf survival are linked to a population model, which in turn tracks vital rates and trends in abundance.

Methods

The energy-protein model integrates the state of an individual caribou (*e.g.,* body size and condition) on a particular landscape which has specific attributes (*e.g.,* vegetation type, forage biomass, snow cover, and insect harassment). The approach accommodates responses to human activity as measured through displacement and/or daily activity budgets (*i.e.,* behavioral responses). Those responses can include a reduction in foraging time for caribou close to the development based on measured activity budgets, increased activity costs (*e.g.,* due to avoidance of human activity), and displacement away from the development that may result in foraging in different plant communities which affects diet quantity and quality for the individual caribou. The energy-protein model converts the diet to protein and energy reserves by tracking the physiological steps of digestion and metabolism and then allocates protein and energy to maintenance, protein and fat reserves, body growth, fetal growth, and calf growth (based on milk production).

To describe the different types of input we use the example of a population on its post-calving summer range. The first set of data input relate to the landscape. To describe forage quantity, the model input starts with the relative abundance of plant cover types derived from a vegetation classification typically based on Landsat satellite imagery. The frequency of the caribou's use of those plant cover types is derived from habitat selection modelling such as resource selection functions (Manly *et al.,* 2002). Estimates of above-ground green biomass available in the plant cover types during the growing season are available from satellite imagery (*i.e.,* the normalized vegetation difference index (NDVI)). The energy-protein model tracks 10 plant groups in the caribou diet (moss, lichens, mushrooms, horsetails, deciduous shrubs, evergreen shrubs, forbs, graminoids, standing dead graminoids, and cotton grass heads). The relative abundance of those plant groups among the plant cover types has been described using field measurements which can then be applied to other landscapes on the tundra.

The inputs to the model for forage quality (*e.g.,* nitrogen concentration, digestibility including secondary compounds of shrubs) are based on a relationship that associates published plant nutrients with phenological stage based on growing degree-days and biomass. The model can use as input field measurements of diet or if those data are unavailable, the model can generate a likely diet based on known nutrient requirements, forage biomass, and forage quality.

Growing degree-days, as well as other climatic variables that affect caribou activity patterns (*e.g.,* index of insect harassment) or diet (*e.g.,* mushroom growth index), as input to the energy-protein model are derived from one of CARMA's other tools. We downloaded the retrospective spatial data at the scale of seasonal ranges for all circumpolar caribou herds and developed caribou-relevant variables (Russell *et al.,* 2013). The climate data are available as a spreadsheet and a searchable database organized at the level of seasonal ranges for individual herds. The herd database is available on request to CARMA. The climate data themselves are from NASA's Modern Era Retrospective-analysis for Research and Applications (MERRA) website (http://gmao.gsfc.nasa.gov/merra/).

The next set of model inputs include daily activity budget, which can include those budgets when caribou are responding to disturbances by reduced time spent foraging and increased energy costs of walking or running away. The model inputs also require an assessment of the individual caribou's initial body condition. This is an advantage offered by CARMA which has compiled from historic sources, extensive herd-specific data and metadata on condition. The same databases are also useful as a validation of the model's projected probabilities of pregnancy which the model generates from fall body condition of the cow.

With these inputs, the energy-protein model can run scenarios to examine the possible range of effects of industrial development and or climate. The scenarios can include the degree of changes in distribution as a result of displacement which are tracked through shifts in habitat type (thus diet quantity and quality) and changes in density (tracked by plant biomass) if the displacement changed the relative density of the caribou.

Results and Conclusion

There is complexity in the modelling approach but the integration of spatial data using the habitat selection models has been successfully incorporated into the energetic model during a demonstration project for the Bathurst herd (Nishi *et al.,* 2009; Gunn *et al.,* 2011; Adamczewski *et al.,* In press). A significant advantage of the ability to integrate spatial data is that it allows the inclusion of longer-term datasets such as those held by aboriginal elders. For the demonstration project on the Bathurst herd's range, we were able to work with the Tlicho to include longer-term information on caribou distribution across the landscape based on knowledge from the elders (Legat *et al.,* 2001).

The original energy model (Russell *et al.,* 2005) was linked to a population model to explore the impacts of climate change and development on the Porcupine caribou herd (Kruse *et al.,* 2004). We are presently in the process of linking the current energy-protein model to a "Caribou Estimator", a model that projects populations into the future with the focus on assessing the impacts of harvest policies on the productivity of herds. That linkage will allow decision-makers to consider the health of populations into their harvest management planning.

In the context of cumulative effects, CARMA's approach offers four key features. Firstly, it allows the scaling up from individual to population responses to environmental changes including climate and industrial exploration and developments. Secondly, the energy-protein model is flexible in data input. Predicting the body condition of the individual uses monitoring data or values through literature review and expert opinion. For those inputs with significant uncertainty in their values, a range (or distribution) of values can be provided. Thirdly, the model is adaptive in that it incorporates recent data about typical caribou responses to human development (*e.g.,* a large open pit mine). Fourthly, during an environmental assessment, the approach can assist with decisions about cumulative effects by allowing the relative ranking of the relative effects of different response scenarios based on, for example, degrees of displacement across seasonal and annual ranges (Russell, 2012).

The adoption of individual- to population-scaled modelling in cumulative effects is a recent development although the need for the approach has been long recognized. There are other energy-based models for caribou (White *et al.,* 1975; Boertje, 1985; Camps & Linders, 1989; Fancy, 1986; Bergerud *et al.,* 2008), and Boertje's (1985) model is being used in the recent environmental assessment for a diamond mine in the Northwest Territories (Mackenzie Valley Environmental Impact Review Board public registry http://www.reviewboard.ca/). However, we are not aware of any model that tracks complete energy-protein balance and no other modeling approach designed to address both the cumulative effects of climate change and incremental human activity.

CARMA's tools for cumulative effects assessment work together to couple the state of an individual or population to the cumulative effects of climate change, industrial development, and harvest on circumpolar *Rangifer* herds. To be useful as tools, CARMA's models have to be relatively available and so CARMA is working to ensure that the models are web-based and accessible. Steps such as graphical comparison of alternative model scenarios, modular approach for sharing parameters between herds, built-in capability to edit model inputs in Microsoft Excel®, the ability to make multi-year runs, and the capability for stochastic Monte Carlo simulations are all underway.

References

Aastrup, P. 2000. Responses of West Greenland caribou to the approach of humans on foot. — *Polar Research* 19: 83-90.

Adamczewski, J., Nishi, J., Gunn, A., Antoniuk, T., Johnson, C., Russell, D., Blondin, T., Legat, A., Beaulieu, D., Virgl, J., Chocolate Pasquayak, M.& Wooley, B. *In press. Modeling Cumulative Effects in Barren-ground Caribou Range: Proceedings of a Workshop in Yellowknife, February 2008.* Department of Environment and Natural Resources, Government of the Northwest Territories, Yellowknife. Manuscript Report 233. 74pp.

Bergerud, A.T., Luttich, S.N. & Camps, L. 2008. The return of the caribou to Ungava. McGill-Queen's University Press. Montreal, Quebec. 586pp.

Boertje, R.D. 1985. An energy model for adult female caribou for the Denali herd, Alaska. — *Journal of Range Management* 38: 468-73.

Boulanger, J., Poole, K.G. & Gunn, A. 2012. Estimating the zone of influence of industrial developments on wildlife: a migratory caribou and diamond mine case study. —*Wildlife Biology* 18: 164-179.

Cameron, R.D., Smith, W.T., White, R.G. & Griffith, B. 2005. Central Arctic caribou and petroleum development: distributional, nutritional, and reproductive implications. — *Arctic* 58: 1-9.

Camps, L. & Linders, A. 1989. *Summer Activity Budget, Nutrition and Energy Balance of George River Female Caribou.* M.Sc. thesis. Katholieke Universiteit Nijmegan, Nijmegan. 156pp.

Duinker, P.N. & Greig, L.A. 2006. The importance of cumulative effects assessment in Canada: ailments and ideas for redeployment. — *Environmental Management* 37: 153-161.

Fancy, S.G. 1986. *Daily Energy Budgets of Caribou: A Simulation Approach.* Ph.D. dissertation. University of Alaska Fairbanks, Fairbanks. 452pp.

Gunn, A., Johnson, C.J., Nishi, J.S., Daniel, C.J., Carlson, M., Russell, D.E. & Adamczewski, J.Z. 2011. Addressing cumulative effects in the Canadian central Arctic – understanding the impacts of human activities on barren-ground caribou. — *In:* Krausman, P.R. & Harris, L.K. (eds.). *Cumulative Effects in Wildlife Management: Impact Mitigation,* pp. 113-133. Taylor and Francis, New York. 274pp.

Johnson, C.J. & St.-Laurent, M.-H. 2011. Unifying framework for understanding impacts of human developments on wildlife. — *In:* Naugle, D.E. (ed.). *Energy Development & Wildlife Conservation in Western North America*, pp. 23-54. Island Press, Washington D.C. 305 pp. http://www.springerlink.com/content/1432-9840/7/8/" \o "Link to the Issue of this Article"7: 815-828.

Legat, A., Chocolate, G., Gon, B., Zoe, S.A. & Chocolate, M. 2001. Caribou *Migration and the State of their Habitat* Dogrib Treaty 11 Council and West Kitikmeot Slave Study Society, Yellowknife. 96pp. http://www.enr.gov.nt.ca/_live/documents/content/WKSS_Caribou_Migration_and_Habitat_2001.pdf.

Manly, B. F. J., McDonald, L. L., Thomas, D. L., McDonald, T. L. and Erickson, W. P. 2002. Resource selection by animals: statistical analysis and design for field studies. Second Edition. Kluwer, Boston, Massachusetts,USA.

Nishi, J., Gunn, A. & Adamczewski, J. 2009. *Modeling Cumulative Effects on Summer Range of the Bathurst Caribou Herd: A Demonstration Project.* Unpublished report. NWT Cumulative Impact Monitoring Program: Capacity Building & Monitoring Projects 2008-2009. Yellowknife. 10pp. http://www.nwtcimp.ca/documents.

Russell, D. 2012. Appendix 6H: energy-protein modeling of north Baffin caribou in relation to the Mary River mine project. *In: Mary River Project Final Environmental Impact Statement*, *Volume 6 – Terrestrial Environment.* 41pp. Baffinland Iron Mines Corp., Toronto. ftp://ftp.nirb.ca.

Russell, D.E. & White, R.G. 2000. Surviving in the north- a conceptual model of reproductive strategies in arctic caribou.— *Rangifer* Special Issue 12: 67 (abstract only).

Russell, D.E., White, R.G. & C. J. Daniel. 2005. *Energetics of the Porcupine Caribou Herd: A Computer Simulation Model.* Technical Report Series No. 431. Canadian Wildlife Service, Ottawa. 64pp.

Russell, D., Whitfield, P., Cai, J. & Gunn, A. 2013. CARMA's MERRA-based caribou range climate database. — *Rangifer,* 33, Special Issue No. 21: 145–152.

White, R.G., Daniel, C.J. & Russell, D.E. 2013. CARMA's integrative modeling: historical background of modeling caribou and reindeer biology televant to development of an energy/protein model. — *Rangifer*, 33, Special Issue No. 21: 153–160.

White, R.G., Thomson, B.R., Skogland, T., Person, S.J., Russell, D.E., Holleman, D.F. & Luick, J.R. 1975. Ecology of caribou at Prudhoe Bay, Alaska. — In: Brown, J. (ed.). Ecological Investigations of the Tundra Biome in the Prudhoe Bay Region, Alaska, pp. 151-201. Biological Papers of the University of Alaska, Special Report No. 2, Fairbanks. 215pp.