REVIEW OF LAND COVER DATA AND SUITABILITY OF ALCES© FOR EVALUATING CUMULATIVE EFFECTS ON BOREAL CARIBOU IN THE DEHCHO REGION

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ABSTRACT

ALCES© is a computer-based strategic-level simulation tool that has been used extensively by resource managers, the scientific community, and industrial landusers to understand cumulative effects of human land uses. In December 2006, a small working group – the Northwest Territories ALCES© working group (WG) - was established between the Government of the Northwest Territories and Indian and Northern Affairs Canada, to develop and undertake a pilot project to better understand the utility of ALCES© in a northern context. The proposed approach was to develop a case study within the Dehcho region because of the extensive work on land use planning and associated background research on resource potential and cumulative effects management. In this report, our objectives were to 1) assess the suitability of land cover classification datasets that are available for the proposed study area, and 2) provide an overview of how ALCES© simulates the response of caribou to land use changes in a boreal forest landscape. We suggest that the Earth Observation for Sustainable Development of Forests (EOSD) dataset provides the most appropriate landcover classification for the pilot project because of its consistency across the proposed study area. The EOSD land cover classification will take minimal time and additional work to incorporate into ALCES© because it will not require additional filtering and mosaicking across satellite images. The EOSD land cover classification also presents a realistic option for extension into northern Alberta and northeastern British Columbia (or further down the Mackenzie Valley), should it be deemed necessary to expand the study area in the future. With respect to modeling the impacts of land use on boreal caribou, we think that the Boreal Caribou Committee (BCC) equation developed for boreal caribou in northern Alberta provides a simple and technically-defensible approach that would be easily used by the WG. Using ALCES© as a learning tool in a comparative and not a predictive sense will help the WG understand the potential cumulative effects of land use scenarios on regional landscapes and boreal caribou specifically. A likely benefit of using the BCC caribou model in ALCES© is that it will lead to specific questions about how the boreal caribou submodel could be improved and made more relevant to the Northwest Territories. Other options to develop an alternate boreal caribou submodel in ALCES© include 1) using boreal caribou habitat research on the Snake-Sahtaneh herd in north east British Columbia and/or 2) develop specific Dehcho boreal caribou habitat models based on radio-telemetry data from the southern NWT and analytical approaches currently being developed for caribou in the lower Mackenzie Valley. In any case, the main benefit of using ALCES© is that it provides a logical framework to link boreal caribou and land use, and a modeling structure with which to test old assumptions and incorporate new knowledge and research findings.

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INTRODUCTION

Background

Resource extraction is a crucial driver for economic development in the north (Brackman 2001) and future economic growth in the Northwest Territories (NT) is intrinsically tied to the exploration and extraction of non-renewable resources such as minerals, oil, and gas. With three operational diamond mines and a fourth under review (GNWT 2006a), proposed extraction of natural gas in the Mackenzie Delta and construction of an associated pipeline delivery system for southern markets (see http://www.mackenziegasproject.com/index.asp), extensive exploration activities for minerals and hydrocarbons, and interest in developing hydro-electric facilities, the potential for economic growth is strong.

In addition to these unfolding industrial land uses, the Northwest Territories also has an important traditional economy, which is functionally based on the land use activities of subsistence harvesters of aboriginal ancestry and northern residents. The activities of these harvesters are focused around subsistence, cultural, and medicinal values of renewable resources and include hunting, trapping, fishing, and gathering of wild plants (Parlee et al. 2005). The land use activities associated with the traditional economy are undertaken by individuals and families, and represent important socio-economic, cultural values and nutritional sources to northern communities. Together with the tourism and outfitting industries, these "traditional" land use activities are reliant on healthy ecosystems and abundant renewable resources.

The challenge for northern governments, land use boards and communities is to understand tradeoffs and find a balance that facilitates i) economic growth and prosperity through extraction of non-renewable resources and ii) adequate protection of the environment and renewable resources. Within an informed decision-making framework, it is increasingly important to understand and incorporate values of natural capital and ecosystem services (Anielski and Wilson 2007), as well as the socio-economic implications of development in the north (MVEIRB 2002 and 2006). Since extraction of non-renewable resources and the traditional economy rely on the same land base, it is critical to understand the potential for cumulative effects[1] due to overlapping land uses over meaningful space and time (Duinker and Greig 2006). In other words, we should understand cumulative effects in the context of large regional landscapes (Johnson et al. 2006b) and over time frames that extend over multiples of decades.

In order to understand the implications of cumulative effects on large landscapes and to develop useful management strategies, resource agencies are realizing the importance of engaging in multi-stakeholder processes that utilize computer models as tools to forecast realistic land use scenarios (see Duinker and Greig 2007). Indeed the true value of using models is not to predict the future, but rather to facilitate shared learning by forecasting multiple land

[1] Cumulative effects are defined as

- the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, cumulative impacts can result from individually minor but collectively significant actions taking place over time;
- changes to the environment that are caused by an action in combination with other past, present, and future human actions.

uses and actively looking for the hidden opportunities, challenges, and new insights in to the dynamics and sustainability of regional resource systems (Hudson 2002). One such modeling tool that has gained intensive scrutiny (Alberta Environment and Alberta Forest Products Association 2002, Gendron 2002, Hudson 2002, van Laake 2002) and consequently extensive acceptance by government, academia, and industry (Macleod Institute 2002, North Yukon Planning Commission 2005, Regional Steering Group 2003, Salmo Consulting et al. 2001, Schneider et al. 2003) is the land use simulation tool called ALCES© (see Appendix 1).

Scope

In December 2006, a small working group – the Northwest Territories ALCES working group (WG) - was established between the Government of the Northwest Territories (GNWT), and Indian and Northern Affairs Canada (INAC). The group's purpose was to develop and undertake a pilot project to better understand the utility of ALCES© in a northern context. The proposed approach was to develop a case study within the Dehcho region (see Figure 1), because of the extensive work on land use planning (DLUPC 2006) and associated background research on resource potential and cumulative effects management (Salmo Consulting Inc., et al. 2004) in the region. The initial focus of the project was on one valued ecosystem component (VEC) –boreal-ecotype woodland caribou *(Rangifer tarandus caribou)*. Boreal caribou were chosen as a focal species because they are currently listed as threatened[2], there are ongoing concerns about the potential cumulative effects of landscape change on caribou (GNWT 2006b), and there is baseline (Gunn et al. 2005) and new research on boreal caribou within the Dehcho region (N. Larter and D. Johnson unpublished data).

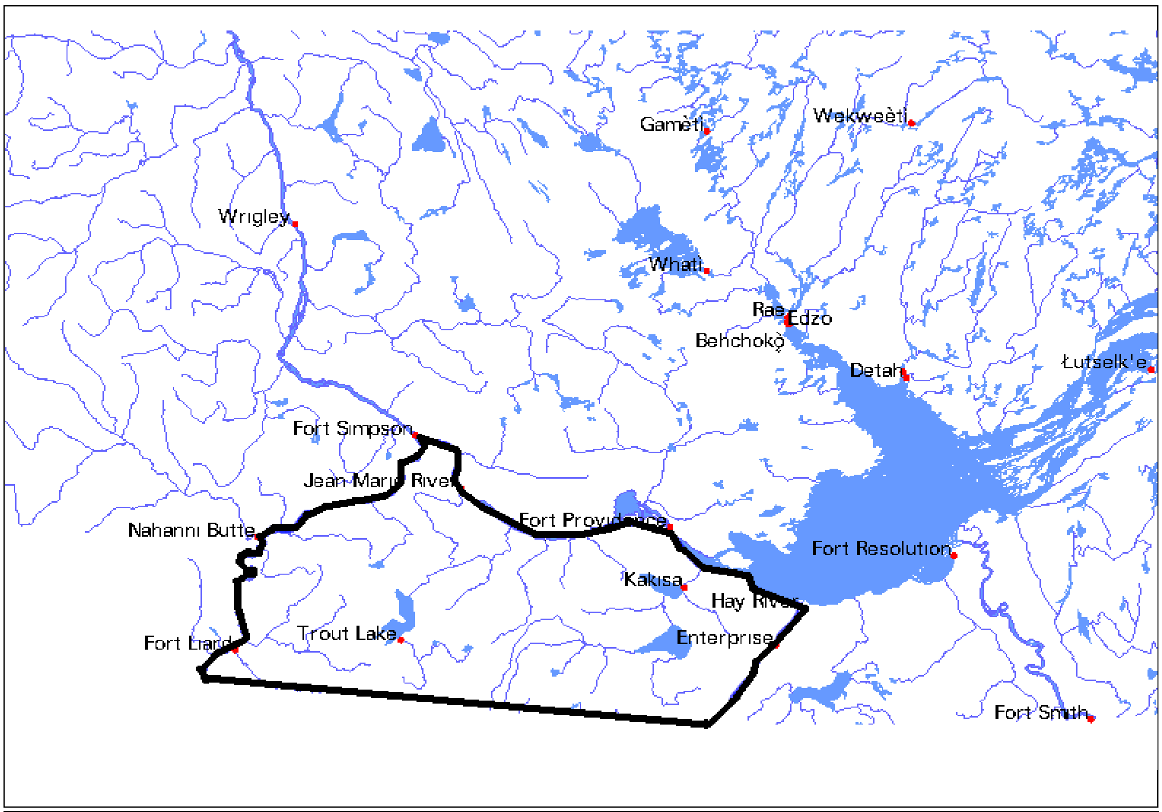

Figure 1. Proposed study area for the Dehcho - ALCES© pilot project

The intention of the pilot project was not to conduct a full scale cumulative effects assessment with engagement of all stakeholders, but rather for agency staff to develop the necessary first hand experience and familiarity with

[2] Boreal caribou are classified as Threatened (i.e., a "species likely to become endangered if limiting factors are not reversed" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2005).

developing and conducting ALCES© simulations, so that they might better assess the utility of ALCES as a landscape simulation tool for application across the Northwest Territories. The pilot project was designed to occur in two phases, with the first to be completed by March 2007 and the second by March 2008. Phase I was focused on project initiation, team building, data gathering and evaluation, and culminated with a 2-day workshop in Hay River (26-28 March 2007) to introduce the project to a larger group of stakeholders. Phase II would see the WG become engaged in developing realistic land-use scenarios and populating and running the ALCES© model.

There were four main objectives of the pilot project:

1) Evaluate adequacy of current datasets.
2) Explore the utility of ALCES© in a Northwest Territories study area as a tool for cumulative effects analysis and regional/landscape planning.
3) Examine effects of landscape change (both natural and anthropogenic) on boreal caribou habitat and population trends. Landscape changes/uses might include (but are not limited to) variations in:
   - Forestry and logging
   - Protected areas
   - Wildfire
   - Oil and gas exploration and development
   - Mining exploration and development
   - Insect outbreaks
   - Climate change

- Wildlife harvesting.

4) Examine the effectiveness of industry best practices on simulations of boreal caribou habitat and population trends.

Objectives

In this report, our aim was to address two issues related to the adequacy of current datasets. Our first objective was to assess the suitability of land cover classification datasets that are available for the proposed study area (see Figure 1), because a first step in using ALCES© requires the initial composition of the landbase to be summarized and entered in to the model. ALCES© uses a spatially stratified approach to track the area and length of each natural or agricultural landscape type (e.g., forest, cropland) and anthropogenic footprint type (e.g., wellsite, city). The definition of each cover type is user-defined, with a maximum of 20 landscape types and 15 footprint types permissible. Landscape types that can be input in to ALCES© would be derived from an existing land cover classification for the study area.

Our second objective was to provide an overview of how ALCES© simulates the response of caribou to land use changes in a boreal forest landscape. Since the boreal caribou modeling component within ALCES© has evolved since it was first developed and is based largely on the extensive caribou research conducted in northern Alberta, the WG thought it was particularly important to consider whether the model would be appropriate for simulating boreal caribou habitat and population trends in the Dehcho study area.

METHODS

Land cover classification (LCC) datasets

We evaluated two satellite imagery-based land cover classification datasets available for the proposed study area (Figure 1). Our evaluation of the prospective land cover data was largely qualitative and descriptive, and we used general criteria to evaluate which land cover classification would be suitable for initializing ALCES©. A suitable land cover classification dataset for the pilot project should:

- cover the entire proposed study area;
- exhibit consistent interpretation of land cover types across scenes;
- provide good resolution of land cover types; and
- ideally contain minimal cloud cover, shadow and image noise[3].

We evaluated two land cover classifications for the study area using data provided by A. Cassidy, ENR Forest Management Division, Hay River, NT:

1) Northwest Territories land cover classification (NWT LCC) (RWED 2002); and the
2) Earth Observation for Sustainable Development of Forests (EOSD) land cover classification (Wulder 2002, Canadian Forest Service 2007).

[3] "Image noise is any unwanted disturbance in image data that is due to limitations in the sensing, signal digitization, or data recording process. The potential sources of noise range form periodic drift or malfunction of a detector, to electronic interference between sensor components, to intermittent 'hiccups' in the data transmission and recording sequence. Noise can either degrade or totally mask the true radiometric information content of a digital image. Hence, noise removal usually precedes any subsequent enhancement or classification of image data" (Lillesand et al. 2004, p. 503).

We also considered Ducks Unlimited Canada's earth cover classification (DU ECC) projects in the southern NT. No formal assessment of DU ECC data was completed because they were not available at the time of writing, and the spatial extent of the classification did not extend across the entire proposed study area (discussed below in the Results section).

Mapping and comparing land cover classifications

Land cover data classifications were analyzed and displayed using ArcView 9.1 (ESRI Corporation). In order to compare the area of land cover classes between the NWT and EOSD datasets, both datasets were projected using an Albers Equal Area Conic projection with the following parameters:

Central meridian: - 120º
Standard parallel: 55º
Standard parallel: 65º
Latitude of origin: 50º
Datum - NAD83

The EOSD data covering the study area consisted of two scenes (UTM Zone 10 and Zone 11). The scene covering UTM Zone 11 was reprojected with a UTM Zone 10 projection and a mosaic was created from the two scenes. This mosaic was then reprojected in Albers Equal Area Conic. For each classification, raster data within the study area boundary (shapefile) were extracted. An attribute table comprising cell counts for each land cover class was exported as a database file. The area (km^2) of each landcover class was calculated in Microsoft Excel by multiplying cell counts for each land cover class by cell size. Land cover classes in the NT LCC dataset were based on the main vegetation types (Main_Veg_T field) (RWED 2002). Wulder and Nelson (2003), and Wulder et al. (2004) described the development of land cover classes for the EOSD classification.

<u>Land use and boreal caribou</u>

We describe evolution of the ALCES model, and describe the history of model development and supplement this with a brief summary of the pertinent literature on caribou. We also draw on recent experiences and unpublished data from a 5 year study on the Snake-Sahtaneh boreal caribou herd in northeast British Columbia (Antoniuk et al. in prep).

RESULTS

Ducks Unlimited Canada's Earthcover Classification (DU ECC)

Ducks Unlimited Canada is using TM satellite imagery as the basis for baseline earthcover inventory projects in the Dehcho. This work is part of a larger earthcover classification initiative to provide recent, regional scale baseline inventory on various upland and wetland cover types in east central Saskatchewan and Manitoba, east central Alberta, northeastern British Columbia, and various locations in the NT and Yukon (Smith et al. 2004). The purpose of the earthcover classification is to provide recent, regional scale baseline inventory on the various upland and wetland cover types found within project areas. The earthcover classification will provide a basis for selecting basins for the waterbird and water chemistry inventories as well as the foundation for future modeling exercises and monitoring potential landscape changes (Smith et al. 2004).

The DU ECC projects currently being conducted in the Dehcho are shown in Figure 2, and include the Pehdzeh Ki Ndeh (PKD), Dehcho Central, and Trout Lake study areas. Unfortunately, the spatial extent of these classifications covers only a portion of the proposed study area (Figure 1). The PKD and Trout Lake classifications/user guides will be complete and ready for distribution (pending data-sharing agreements) by the end of the April 2007 while the Central Dehcho classification will not be available until late summer or fall 2007 (S. Haszard pers. comm.).

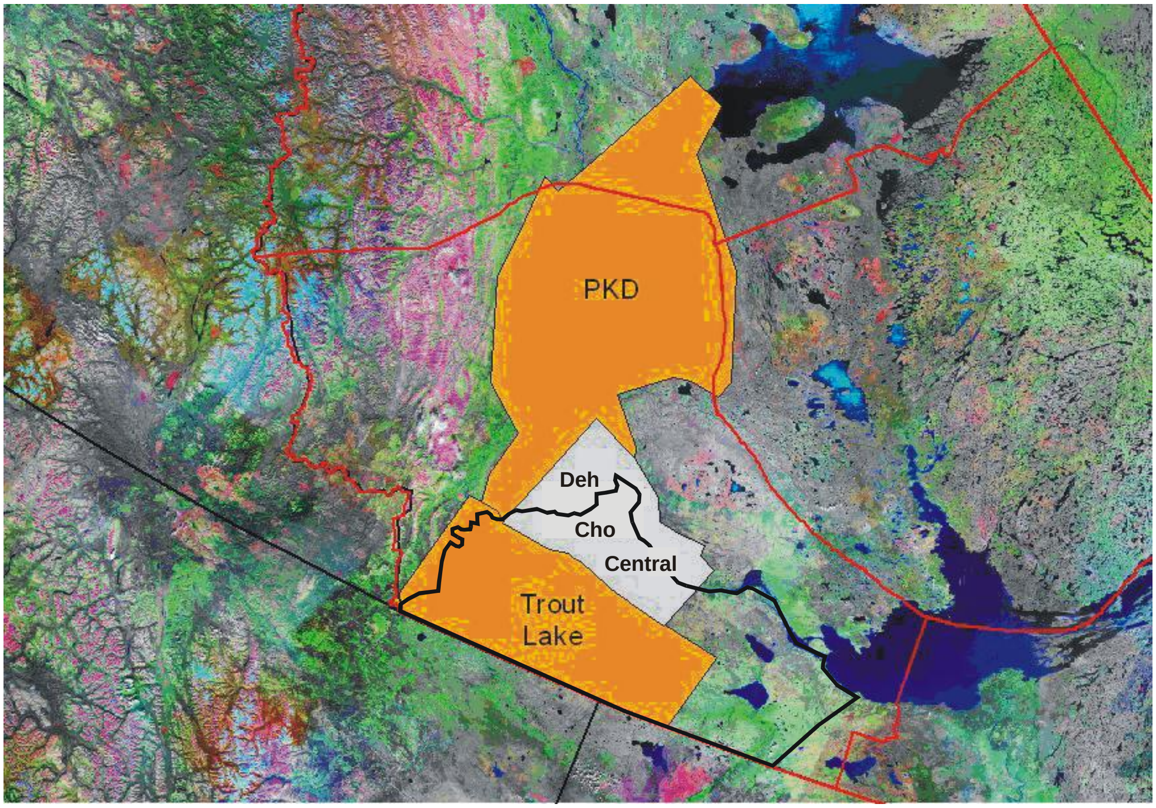

Figure 2. Spatial coverage of land cover classification projects by Ducks Unlimited Canada. The red boundary encompassing the majority of the classification projects is the boundary for the Dehcho territory. The black boundary indicates the proposed study area.

<u>Northwest Territories land cover classification (NWT LCC)</u>

The NWT LCC was developed by the Forest Management Division, Department of Resources, Wildlife and Economic Development, primarily as a means to allow conversion of different vegetation classes into a fuel type database to enhance fire behavior capabilities (RWED 2002). A subsequent objective of the project was to develop a first level of wildlife habitat mapping (RWED 2002). Black spruce (*Picea mariana*) and low shrub habitats dominate the Dehcho Plan area. Less common habitats include white spruce (*Picea* *glauca*), jack pine (*Pinus banksiana*), deciduous, and mixed forest (Gunn et al. 2002).

The NWT LCC is based on the classification scheme used by the National Forest Inventory (NFI), and is interpreted from Landsat TM 5 imagery, with a pixel resolution of 30 m (Table 1). The overall accuracy of the classification is estimated between 75-80% with the exception of the non-forested wetland classes which varies from 50-75% (RWED 2002). Within the proposed Dehcho study area, the land cover classification is based on Landsat TM images from the 1990s (Figure 3). It is visually apparent that the classification is affected by inconsistency across images (Figures 3 and 4), with an observed degree of noise – described as “speckle” by Salmo Consulting Inc. et al. (2004).

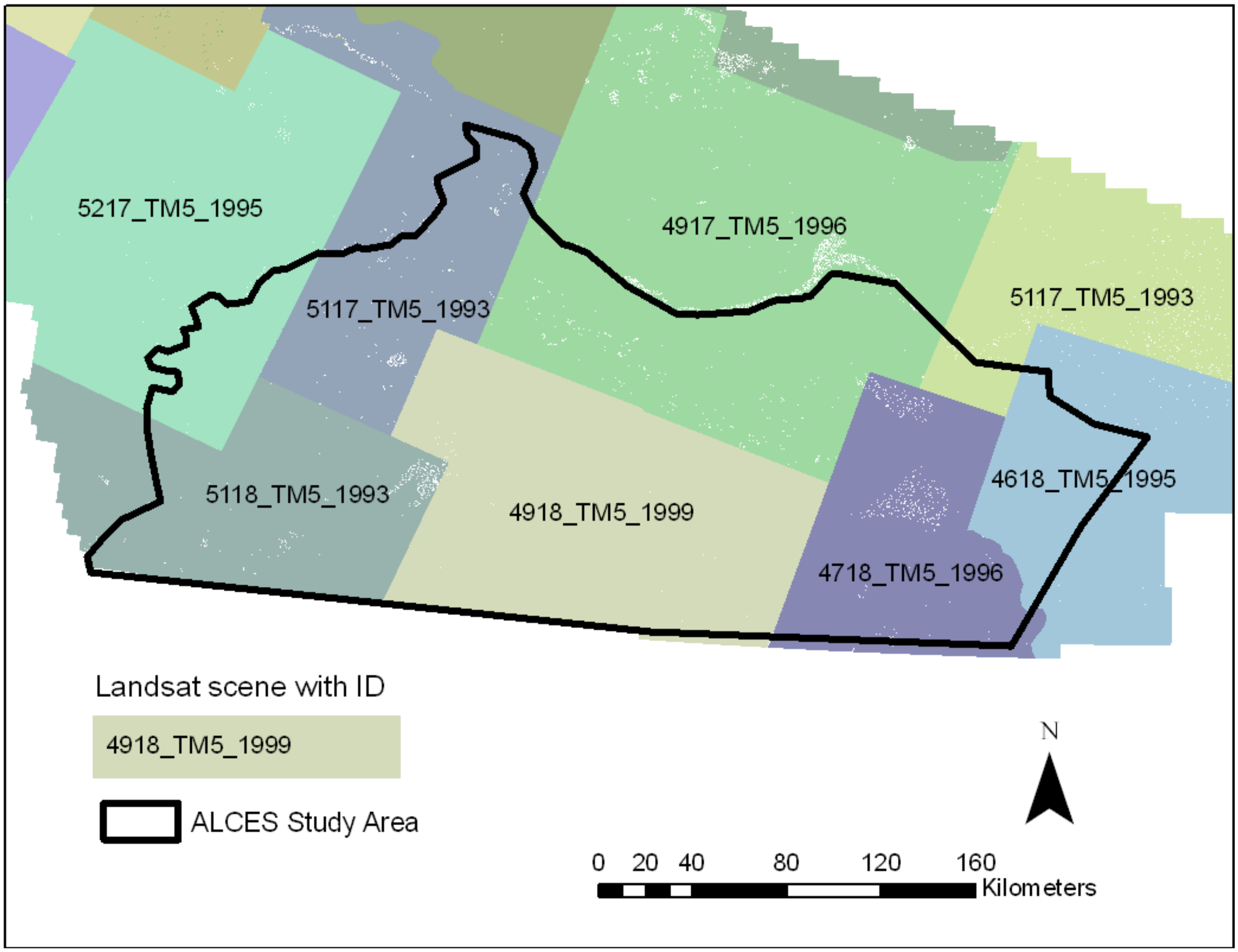

Figure 3. Coverage and date for Landsat-5 TM scenes used to develop the Northwest Territories land cover classification in the proposed study area for the Dehcho - ALCES© pilot project.

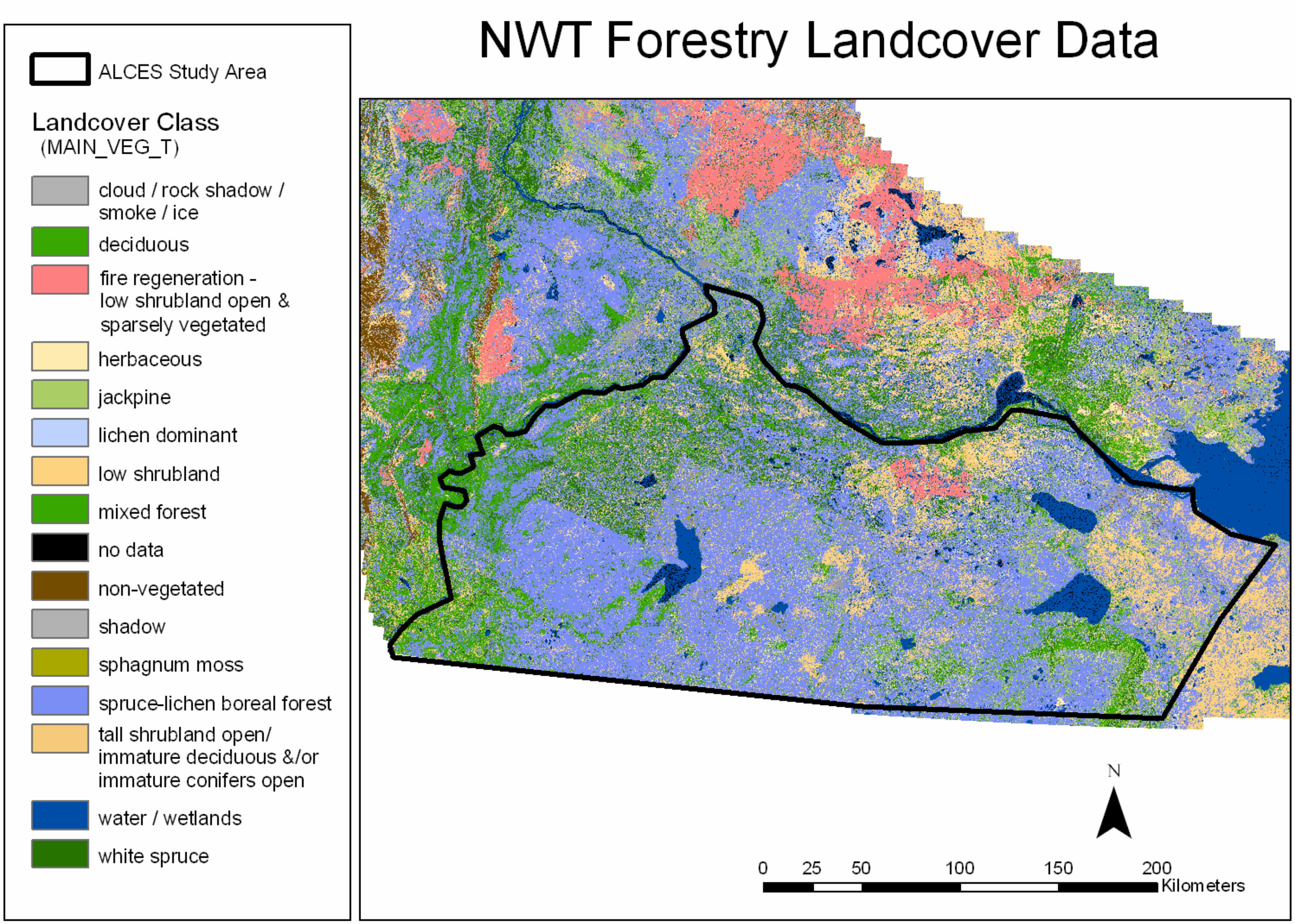

Figure 4. Northwest Territories land cover classification for the proposed study area of the Dehcho - ALCES© pilot project

Earth Observation for Sustainable Development of Forests land cover classification (EOSD LCC)

Monitoring of Canada's forests is required for internal monitoring and reporting and for participation in international programs related to climate change and sustainable forest management (Wulder 2002). The EOSD is a joint project between the Canadian Forest Service and Canadian Space Agency with a primary objective of producing a land cover map of the forested area of Canada based upon Landsat data representing circa 2000 conditions to meet those monitoring needs (Wulder 2000). The EOSD land cover classification has been developed through a partnership of federal, provincial, and territorial governments, universities, and industry. The EOSD utilizes the National Forest Inventory class structure as a base, so it is able to standardize classified image products, and integrate with provincial and territorial mapping agencies (Wulder 2002). While under final developments, EOSD data and products are freely available to the public and accessible through i) the National Forest Information System (NFIS) and ii) SAFORAH (System of Agents for Forest Observation Research with Automation Hierarchies), through the EOSD website (http://eosd.cfs.nrcan.gc.ca/index_e.html).

The EOSD LCC is interpreted from Landsat TM 7 ETM+ imagery, with a pixel resolution of 25 m (Table 1). Coverage across the proposed Dehcho study area appears consistent (Figure 5). The recommended target for classification accuracy is 85% overall and across all classes. Although the overall accuracy assessment for the EOSD product has not been completed, a protocol for addressing accuracy based upon a stratified random sample has been proposed and is being tested (Wulder et al. 2006).

Table 1. Characteristics of Northwest Territories (NWT) and Earth Observation for Sustainable Development of Forests (EOSD) land cover classifications for the proposed Dehcho study area.

Imagery	Resolution (m)	Year(s) of imagery	Projection (source data)
EOSD			
Landsat-7 ETM+	25	circa 2000 (Wulder 2002)	UTM Zones 10 & 11 NAD83
NWT			
Landsat-5 TM	30	1993, 1995-97, 1999	Lambert Conformal Conic NAD83

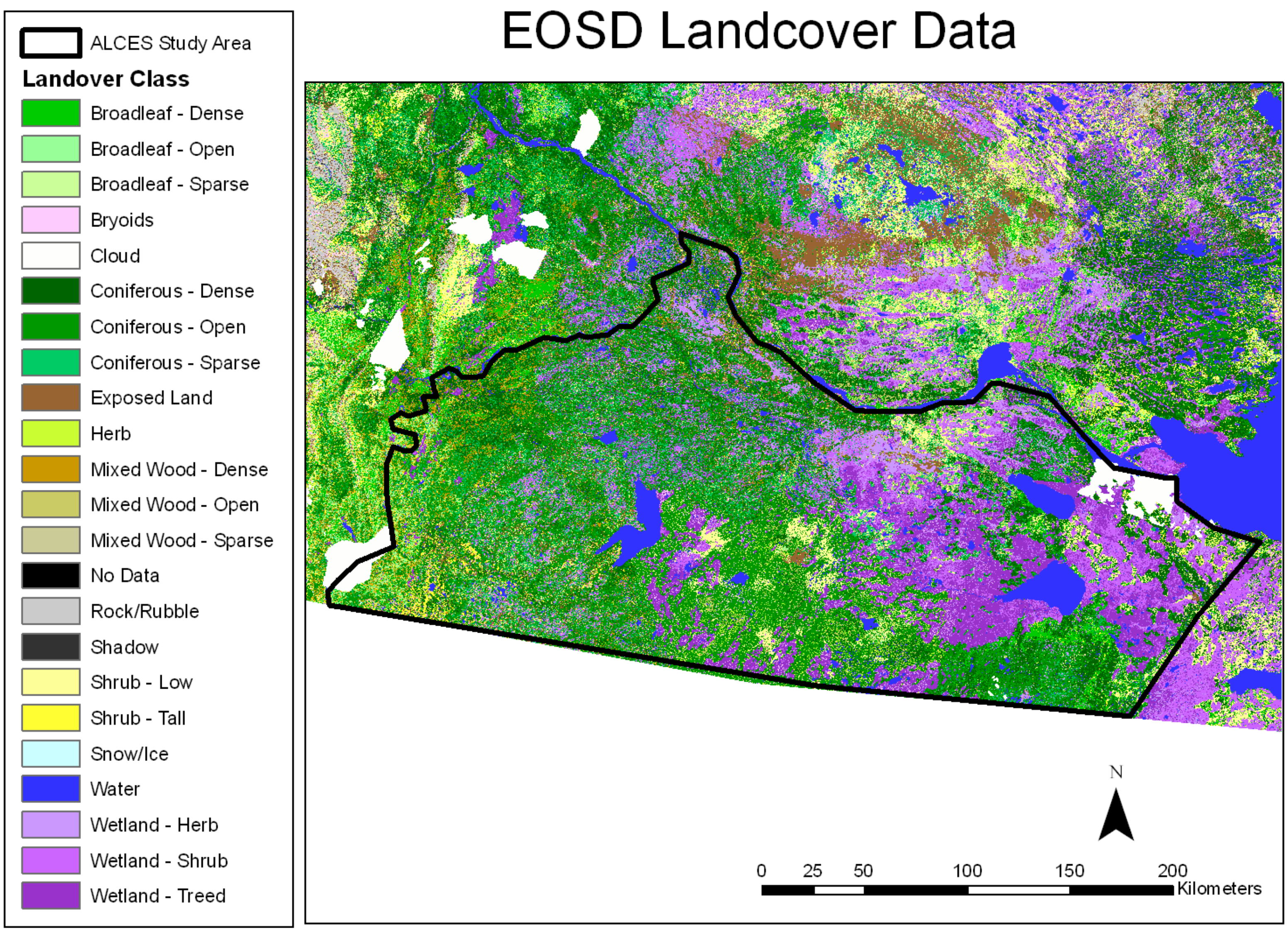

Figure 5. Earth Observation for Sustainable Development of Forests (EOSD) land cover classification for the proposed study area of the Dehcho - ALCES© pilot project

Comparison Between NWT and EOSD Landcover Classificaions

A comparative assessment of the NWT and EOSD landcover classifications for the proposed Dehcho study area is summarized in Table 2. The comparison showed that the study area, when described by the NWT LCC, was comprised primarily of spruce-lichen boreal forest vegetation type (29,245 km^2 / 57,086 km^2 = 51.2%), while the Coniferous – Open habitat class represented the greatest coverage when the EOSD classification was applied (18,833 km^2 / 57,203 km^2 = 29.5%). A more direct comparison of general landcover classes for the two LCCs indicated that the ‘coniferous’ class represented 65.5% of the study area for the NWT LCC and comprised 48.3% of the same study area classified by the EOSD LCC (Table 2). Conversely, ‘wetlands’ comprised 26.4% of the study area using the EOSD LCC, and only represented 1.1% of the area when the NWT LCC was applied (Table 2).

Table 2. Comparison* of Northwest Territories (NWT) and Earth Observation for Sustainable Development of Forests (EOSD) land cover classifications for the proposed Dehcho study area.

NWT Landcover

Landcover Class	Area (km^2)
mixed forest	2272.8
deciduous	3311.0
jackpine	3476.3
spruce-lichen boreal forest	29245.2
white spruce	4650.3
lichen dominant	117.0
sphagnum moss	777.1
tall shrubland open/immature deciduous and/or immature conifers open	2522.6
low shrubland	4282.2
herbaceous	2225.0
fire regeneration/low shrubland open	392.9
non-vegetated	126.4
wetlands	614.6
water	2145.3
cloud or rock shadow	90.8
clouds or smoke or ice	457.7
shadow	78.7
no data	299.8
TOTAL	**57085.7**

EOSD Landcover

Landcover Class	Area (km^2)
Mixed Wood - Dense	1111.7
Mixed Wood - Open	950.0
Broadleaf - Dense	1291.8
Broadleaf - Open	455.7
Broadleaf - Sparse	3.4
Coniferous - Dense	7081.7
Coniferous - Open	16833.3
Coniferous - Sparse	3726.4
Bryoids	521.5
Shrub - Tall	1067.9
Shrub - Low	2676.8
Herb	701.3
Rock/Rubble	4.4
Exposed Land	1802.8
Wetland - Treed	7429.1
Wetland - Shrub	4674.3
Wetland - Herb	3013.5
Water	2938.9
Cloud	840.4
Shadow	77.6
No Data	0.2
	57202.6

General Landcover Class	NWT Landcover Area (km^2)	EOSD Landcover Area (km^2)	NWT Landcover Proportion	EOSD Landcover Proportion	Relative Difference %
mixed forest	2272.8	2061.7	4.0%	3.6%	9.7%
deciduous	3311.0	1750.9	5.8%	3.1%	61.6%
coniferous	37371.9	27641.3	65.5%	48.3%	29.9%
bryoids	894.1	521.5	1.6%	0.9%	52.6%
tall shrubland	2522.6	1067.9	4.4%	1.9%	81.0%
low shrubland	4282.2	2676.8	7.5%	4.7%	46.1%
herbaceous	2225.0	701.3	3.9%	1.2%	104.1%
exposed land	519.3	1807.2	0.9%	3.2%	-110.7%
wetlands	614.6	15116.9	1.1%	26.4%	-184.4%
water	2145.3	2938.9	3.8%	5.1%	-31.2%
cloud	548.5	840.4	1.0%	1.5%	-42.0%
shadow	78.7	77.6	0.1%	0.1%	1.5%
no data	299.8	0.2	0.5%	0.0%	199.7%
	57085.7	**57202.6**	100.0%	100.0%	

*Note: Color coding shows which landcover classes from the NWT and EOSD classification were summed together into general landcover classes, so that direct comparisons could be made.

Land Use and Boreal caribou in ALCES©

The wildlife interface panel within ALCES© (Figure 6) allows the user to define and track the modeled response of different wildlife species and communities to landscape change from human land use and/or natural disturbances. With respect to modeling species – habitat relationships, ALCES© is configured to use two general approaches including i) habitat suitability indices (HSI) (see USFW 1980a, 1980b, and 1980c, Juntti and Rumble 2006), and ii) resource selection functions (RSF) (see Manly et al. 2002) and logistic regression (see Johnson et al. 2006a, Keating and Cherry 2006).

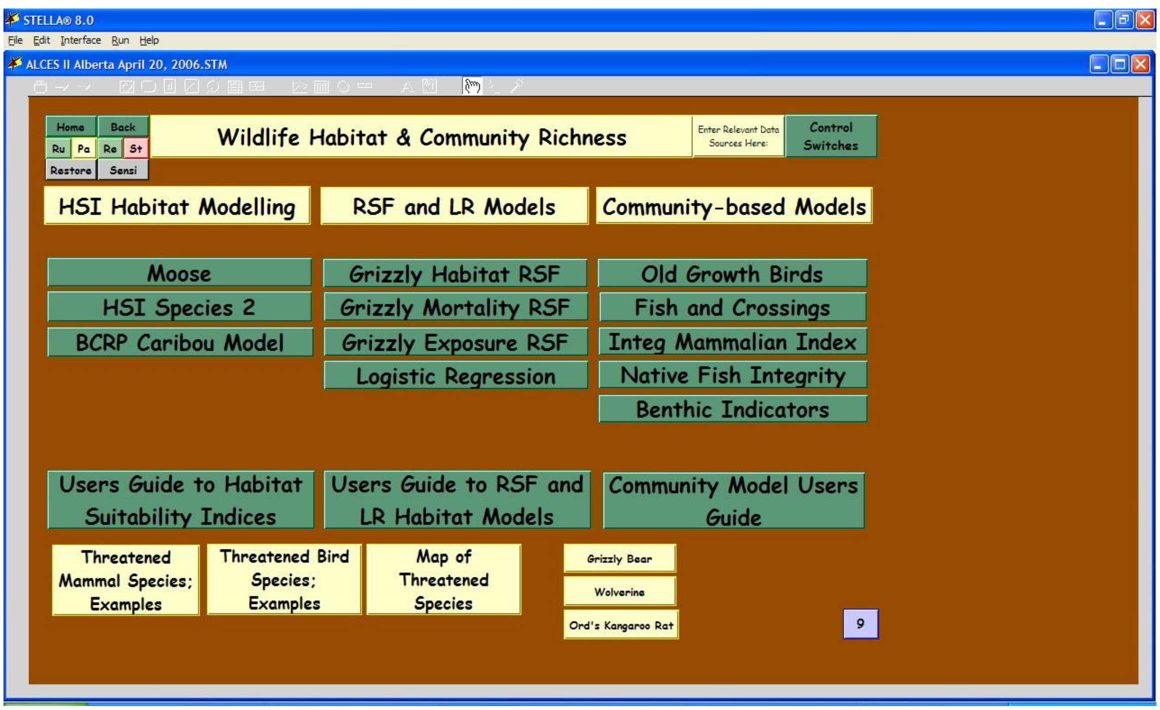

Figure 6. The Wildlife Habitat and Community Richness interface panel in ALCES©, which allows the user to determine the relationships between land use footprints and wildlife habitat and populations.

The current version of ALCES© also includes a specific boreal caribou submodel developed with data from northern Alberta. This submodel was included because of concern over woodland caribou population declines in northern Alberta (Edmonds 1998, Dzus 2001, Thomas and Gray 2002, McCloughlin et al. 2003, Hervieux et al. 2005), and the need for a tool that would allow managers to understand the potential cumulative effects on caribou (Wynes 1998). Accordingly, the evolution and development of the boreal caribou submodel in ALCES© is intrinsically tied to the dynamic interests and support of the Alberta Boreal Caribou Committee (BCC)[4] and the extensive research results generated by its Boreal Caribou Research Program (BCRP), and industry and university collaborators (see Bradshaw 1994, Bradshaw et al. 1995, Bradshaw and Hebert 1996, Bradshaw, et al. 1997, Stuart-Smith et al. 1997, Anderson 1999, Dyer 1999, James 1999, James and Stuart-Smith 2000, Schneider et al. 2000, Dyer et al. 2001, Weclaw 2001, Dyer et al. 2002, Dunford 2003, McLoughlin et al. 2003, James et al. 2004, Weclaw and Hudson 2004, McLoughlin et al. 2005, Tracz 2005, Dunford et al. 2006, Dalerum et al. 2007, McCutchen 2007).

The BCC purchased a licensed copy of ALCES© in 2000, for the purpose of evaluating and comparing the relative effectiveness of various future land use practices on caribou range; it emphasized that the value of ALCES© was in comparing mitigative strategies rather than for predicting an absolute measure of

[4] In 2005, the BCC was amalgamated with the West-Central Alberta Caribou Standing Committee (WCACSC) to establish a single Alberta Caribou Committee (ACC). The ACC combined the responsibilities of the two existing caribou committees and the Provincial Caribou Recovery Team. The ACC comprises government, industry, academic and stakeholder interests, and its main purpose is to coordinate management activities for caribou at a provincial scale. For more information see the following websites:

- BCC: http://www.deer.rr.ualberta.ca/caribou/bcrp.htm
- WCACSC: http://www.rr.ualberta.ca/research/caribou/
- ACC: http://www.albertacariboucommittee.ca/index.htm

future habitat value (Wynes 2000). Using ALCES© helped the BCC evaluate cost effectiveness of industry practices for achieving caribou conservation objectives as well as understanding knowledge gaps and prioritizing research initiatives (Wynes 2000). ALCES© was determined to be the principal model by which the BCC would i) project future disturbances to habitat overlain on the current footprint, while accounting for recovery, and ii) strategically evaluate alternative industrial practices that minimize their effects on the landscape (BCC 2001).

In 2001, the BCC released guidelines and recommendations on best practices for managing and reducing linear and non-linear disturbances related to the forestry industry, horticultural peat harvesting, oil and gas industry, and seismic acquisition (BCC 2001). An emphasis of these guidelines was a definition of habitat effectiveness targets that would be required to maintain caribou population stability. The BCC recommended that available data on population trends “be correlated with the proportion of habitat that is rated fully or partially effective in each range in order to establish the habitat effectiveness target” (BCC 2001. Section 3.1. p. 7). The intent was to develop one habitat effectiveness target for northern Alberta, and then apply the target to each caribou range during a subsequent range planning process (BCC 2001). The BCC’s process of trying to define habitat effectiveness targets (BCC 2003) was tied to the caribou submodel development in ALCES©. This initial work was functionally based on an HSI approach to define the relationship between boreal caribou (i.e., population rate of increase) and habitat quality.

HSI Approach:

An HSI is a numerical index that represents the capacity of a given habitat to support a selected species. The HSI has a minimum value of 0.0 which indicates that the habitat is totally unsuitable, and a maximum value of 1.0 which indicates optimum habitat. A general HSI is reflective of the following conditions:

HSI = Study Area Habitat Conditions / Optimum Habitat Conditions

HSI models are generally based on hypothesized species-habitat relationships (USFWS 1980b). HSI models represent interactions of habitat characteristics and how each habitat relates to a given wildlife species. An HSI model can be constructed in a variety of ways with a basis on a theoretical framework, or empirical models based on mechanistic relationships, multivariate statistical relationships or a combination of methods (USFWS 1980c). The intent and value of HSI models is to provide a logical basis for improved decision making and improve our general understanding of species-habitat relationships.

Through a user-defined HSI approach, ALCES© calculates the availability and quality of habitat for specific wildlife species by tracking the area and area-weighted value of different landscape types. ALCES© requires the user to define the distribution of wildlife among landscape types and to define the response curve of habitat quality as a function of different habitat attributes such as stand age, forest structure, herbaceous vegetation, linear disturbance, etc. As ALCES© simulates a land use scenario over time (with or without natural disturbances), it accounts for several indices including:

- a rank of importance values of different habitat elements to wildlife;
- changes in habitat quantity and quality through time; and
- effects of buffered footprints (i.e., roads, seismic, cutblocks, wellsites) on quantity and quality of wildlife habitat (buffers may be areas of complete exclusion by wildlife or can support a gradient response defined by the user).

During the early development of a specific boreal caribou submodel that incorporated habitat quantity and quality, there were no empirically based relationships and responses that could be incorporated directly into ALCES©. Consequently, a Delphi process was used to incorporate expert opinion from biologists and caribou specialists on appropriate coefficients that would describe habitat quality and habitat effectiveness[5] (BCC 2003).

The BCC analyzed existing spatial data on individual caribou ranges to estimate current landcover and footprint extents, and then the habitat quality and habitat effectiveness coefficients were applied. The final step was to use linear regression to evaluate the relationships between rate of increase and habitat quality and effectiveness respectively. However, once the linear regression was calculated, “the underlying differences in habitat quality did not seem to affect population trend (P = 0.440, R^2 = 0.153). The results also suggested that habitat effectiveness (as defined by the workgroup) was a very poor predictor of population trends (P = 0.90, R^2 = 0.0045). The inability of habitat effectiveness to

[5] “Effective” habitat is the usable habitat for caribou that remains after subtracting the portion that is reduced in quality directly by a footprint or indirectly by a buffer.

explain population trend was likely a result of inaccurate assumptions set by the workgroup" (BCC 2003).

BCC Boreal Caribou Equation:

Since the relationship between caribou population trends and habitat quality/effectiveness was statistically weak, an alternative method that directly correlated the amount of footprint in a population range against its trend was applied (BCC 2003). This approach was more parsimonious because it was based on the statistical properties of the available data, and used a multiple regression approach to find the best combination of footprint-based variables to predict rate of increase. Although this method would not allow managers to calculate a habitat effectiveness target *per se*, it could still be used to determine and model the impacts of industrial activities, reclamation activities, wildfires, etc., on population trends of caribou. For this analysis, industrial footprint and forest age were the variables that were initially chosen because these were two common factors that influenced habitat selection by boreal caribou (Stuart-Smith et al. 1997, Dyer 1999, Dyer et al. 2001, Dyer et al. 2002, Dunford 2003, Dunford et al. 2006).

These two factors were used in a multiple regression to predict finite rate of increase for six boreal caribou populations in northern Alberta. The model (Figure 7) explained 95.9% (R^2) of observed variation in actual population growth among population units ($F_{2,3}$ = 35.4, P = 0.008) (BCC unpublished data). The equation that describes this relationship is:

Y = 1.191 - (0.314 * IND) - (0.291 * FIRE)

Where:

- Y = Predicted population growth (lambda)
- IND = percentage (%) of caribou range area within 250 meters of anthropogenic footprint[6]
- FIRE = percentage (%) of caribou range naturally disturbed by wildfire within the last 50 years (i.e. % of range of recent (≤ 50 yrs) fire origin).
-

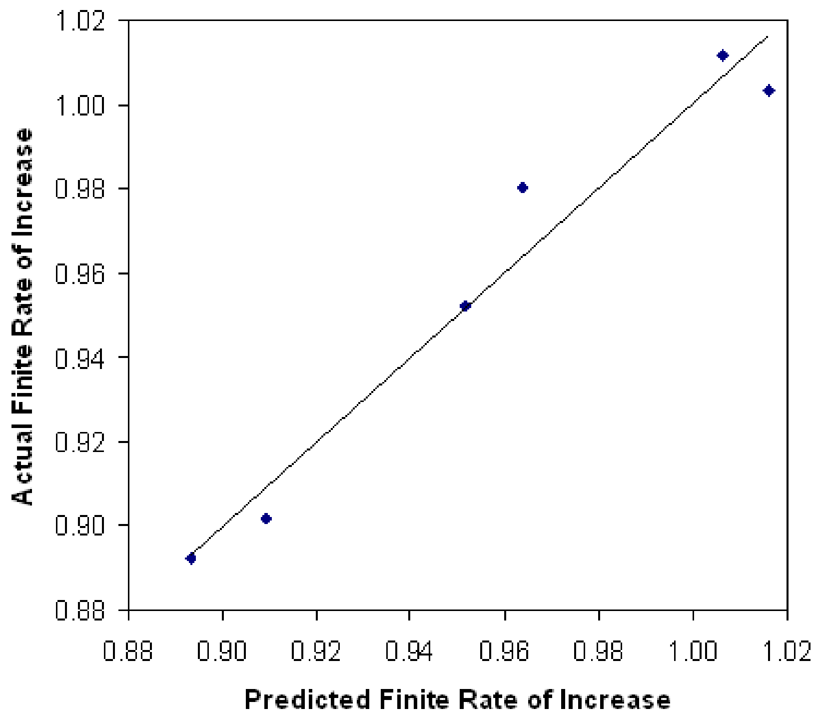

Figure 7. Regression of Predicted Population Growth (x axis) and Actual Population Growth (y axis) for boreal caribou in northern Alberta (Boreal Caribou Committee unpublished data). Actual population growth is based on annual adult female survival of collared caribou and recruitment data for 6 caribou ranges in the province including the East Side of the Athabasca River (ESAR), Cold Lake Air Weapons Range (CLAWR), West Side of the Athabasca River (WSAR), basin of the Little Smoky River (LS), the Caribou Mtns (CM), and Red Earth (RE). See Dzuz (2001) for geographic locations of these caribou herds.

[6] Anthropogenic footprint included roads, cutblocks, pipelines, seismic lines (irrespective of width), peat & gravel mines etc. Cutblock edge was buffered by 250m, but in-block roads were not buffered to avoid double-counting. Fires overwrote seismic lines. Salvage harvest blocks within fire boundaries were not buffered (as the fire component was counted in the second half of the predicted population growth equation) (A. Hubbs pers. com.).

To use the BCC caribou equation, the user needs to complete the following steps in ALCES©:

- Identify the proportion of each landscape type used by caribou.
- Identify those footprints that need to be buffered, and the buffer width to be applied to each side of the footprint.
- Identify those footprint types that need to be dissolved from the landbase in the event that they are burned by fire.
- Identify those footprint types whose buffers need to be included in the "zone of influence" (ZOI) metrics even after they have been reclaimed. Enter the number of years following reclamation that each footprint buffer is to be included.

In addition, two modeling features have been added to ALCES© to assist the BCC in seeking solutions for maintaining caribou populations. These added features include:

1. the ability to conduct pulse reclamation events that allow a user-defined portion of all footprint types to be dissolved at a defined year, with reclamation events repeated at a defined interval thereafter; and
2. the ability to examine the consequences to caribou lambda of an "imaginary" reduction in the percent of those footprint types that contribute to the "Zone of Influence" (ZOI). This variable is called the ZOI % reduction modifier. A value of 0 indicates that none of the footprint type is dissolved, whereas a value of 0.5 would suggest that 50% of the ZOI is removed. Using sensitivity analyses with this variable, it is possible for the

user to quickly ascertain the proportion of footprint that needs to be removed if she wants to maintain caribou populations on the landscape.

Once the above steps are completed, ALCES© is able to simulate changes in population growth of boreal caribou.

RSF Approach:

"Resource selections functions (RSFs) are statistical models defined to be proportional to the probability of use of a resource unit by an organism" (Boyce 2006). RSF's are often used by wildlife biologists to describe use of habitat by individuals or populations, relative to availability of habitat (Manly et al. 2002). With appropriate scaling RSF's can be used to link populations to their habitats, and distribute individuals in a population across the landscape (Boyce & McDonald, 1999).

ALCES© users can compute RSF values based on user-defined RSF models for selected wildlife species using different combinations of biophysical variables tracked within the ALCES© model. ALCES© assumes the model structure for the RSF equation to be based on a vector *x* of *k* predictor habitat variables:

$$RSF = w(\boldsymbol{X}) = \exp(\beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k)$$

where $w(\boldsymbol{X})$ is the RSF value, β_i is the RSF coefficient for the k^{th} habitat variable, and X_k represent independent variables. For the RSF and logistic regression models, the user must enter the proportion of each land cover type used by the species and the proper coefficients that apply for each land cover type, footprint type, or RSF variable.

In the current version of ALCES, the RSF submodel has been built around the extensive grizzly bear habitat use dataset generated by the Foothills Model Forest Grizzly Bear Project[7] (see Nielsen et al. 2004a, 2004b). However, ALCES© may be customized to include RSF variables not currently in the model, and accommodate other species for which RSF data are available.

[7] For further information on the Foothills Mode Forest Grizzly Bear Project, please visti the following website: http://www.fmf.ca/pa_GB.html#overview

DISCUSSION

Land cover classifications

Although an accuracy assessment has not been completed for the southern Northwest Territories, the EOSD dataset is the most appropriate landcover classification for the pilot project because of its consistency across the proposed study area. The EOSD LCC does not seem to suffer from the problems that appear in the NWT LCC which are related to image noise, and inconsistent class labeling across satellite images. Salmo Consulting Inc. et al. 2004 (p. 25) also raised similar concerns over the quality of the NWT LCC. The EOSD LCC also presents the following important advantages over the NWT LCC:

- it will take less time and additional work to incorporate into ALCES© because it will not require additional filtering and mosaicking across satellite images; and
- it presents a realistic option for extension into northern Alberta and northeastern British Columbia, should it be deemed necessary to expand the study area.

The EOSD LCC provides much higher area estimates of wetland community types when compared to the NWT LCC. Although we cannot comment on which classification is more accurate, the inclusion of wetland community types is likely an important biological consideration for boreal caribou since studies in northern Alberta have shown that peatland complexes are preferred (Andersen 1999, Schneider et al. 2000).

From a wildlife research perspective, it would be valuable to use the DU ECC once it is available, to conduct finer scale comparative work on caribou habitat use. Since the DU ECC will have accuracy assessments completed and its emphasis is on a finer scale classification of wetland community types, it would be useful to compare habitat selection patterns for boreal caribou locations with both EOSD LCC and DU ECC coverage (i.e., Dehcho Central and Trout Lake project areas). However, the results obtained from this type of analysis would occur at a smaller spatial domain (sensu Boyce 2006) than that required for a strategic level evaluation of the influence of future land use scenarios on boreal caribou.

To maintain strategic generality, it is important to consider that the spatial domain of a regional land use exercise will require a tradeoff against an emphasis on fine scale accuracy and refinement of habitat selection patterns. For example, Gunn et al. (2000) took a regional landscape approach to assess boreal caribou habitat; this had higher strategic value for land use planning, versus a finer-scaled approach that would have emphasized research to develop a spatially-explicit predictor of habitat use by caribou. Similarly, although Nagy et al. 2006 (in Leroux et al. 2007) developed fine scale RSF models for boreal caribou in the lower Mackenzie Valley, Leroux et al. (2007) rescaled and reclassified the 30 m resolution 34-category earth cover map of the study area to 500 m resolution and 10 cover types respectively. This coarser grained approach was commensurate with the resolution at which other conservation features were being addressed, and was sufficient for caribou habitat models because it was able to minimize the aggregation and loss of unique earth cover types (Leroux et al. 2007).

Multi-scale approaches are valuable and complementary, and should not be considered mutually exclusive. As suggested by Van Horne (2002), it is critically important to “match the questions we ask to the scale at which we gather information and model.” In this context, the EOSD should provide the best regional scale landcover classification to use in ALCES© because it is provides continuous coverage across the southern Northwest Territories and in to northern British Columbia and Alberta.

As mentioned above, a drawback of the EOSD dataset is that an accuracy assessment of the data has not been done for the southern Northwest Territories. Although we do not propose using caribou habitat selection as a surrogate for a proper LCC accuracy assessment, there is considerable value in analyzing current caribou telemetry data relative to the EOSD LCC. Such an analysis would provide useful insight in to the applicability of the EOSD LCC, and would allow knowledgeable biologists to evaluate whether the defined habitat use patterns are at least plausible.

Application of the Alberta Boreal caribou equation to the southern Northwest Territories

The BCC caribou equation provides a simple and technically-defensible approach that could be easily used by the NWT ALCES© WG. Using ALCES© as a learning tool in a comparative and not a predictive sense will help the WG and other users understand the potential cumulative effects of land use scenarios on regional landscapes and boreal caribou specifically. A likely benefit of using the BCC caribou model in ALCES© is that it will lead to specific questions about how the boreal caribou submodel could be improved and made more relevant to the Northwest Territories. The advantage of using ALCES© is that it provides a logical framework and modeling structure with which to test old assumptions and incorporate new knowledge and research findings.

From a comparative perspective, the boreal caribou data that have been collected by ENR biologist from ongoing boreal caribou research in the southern NT (N. Larter and D. Johnson unpublished data) may be used to augment and evaluate the BCC caribou equation. In this example, we would expect that the southern NT caribou data should be consistent with the BCC linear regression, and the data points should plot out in the upper right hand side of the regression plot (see Figure 7).

Although the Alberta experience suggests that the HSI approach may not be helpful in modeling impacts of landuse on boreal caribou, it is worth developing regionally-specific RSF and HSI inputs to the ALCES© model using available telemetry data from the Dehcho and South Slave regions. This analysis would require the development of functional relationships between boreal caribou and habitat through the RSF and/or HSI modeling approaches, and would address concerns that the existing caribou modeling assumptions in ALCES© are not pertinent to the Northwest Territories. A sensitivity analysis using different caribou responses to footprint density, risk of predation, or some other ecologically important metric, would likely provide useful insights into the functional relationships between caribou and land use and provide direction on future research needs. In addition, development of a boreal caribou habitat RSF models for the southern Northwest Territories should be conducted within a similar context and approach that is being developed elsewhere in the territory (see Nagy et al. 2005 and 2006, in Leroux et al. 2007). This would evaluate boreal caribou-habitat relationships on a territorial scale, and add consistency and robustness to use of landscape simulation models like ALCES© in the Northwest Territories.

Applicability of Snake-Sahtaneh Herd RSF modeling to the southern Northwest Territories

Findings of the recent multi-year study from the Snake-Sahtaneh boreal caribou range located east of Fort Nelson, British Columbia (BC) are relevant to boreal caribou in the southern NWT. Available habitat and boreal caribou habitat use is similar in both regions (Gunn et al. 2004; Culling et al. 2006).

Culling et al. (2006) summarized habitat use and ecology of the Snake-Sahtaneh herd and developed seasonal RSF habitat use models based on a DU ECC dataset. Seasonal habitat use and movements of the herd were generally consistent with those reported for boreal caribou in northern Alberta. Adult female use was centred on the largest patches of low relief, treed peatlands. Burned areas (<50 years) were selected for during snow-free periods and mature coniferous habitat was selected during late winter. Upland mixedwood and deciduous habitats were avoided, although they were interspersed within home ranges (Culling et al. 2006).

A second component of the Snake-Sahtaneh study is evaluating two cumulative effect pathways that are of primary concern for boreal caribou. The first is reduced habitat effectiveness (and associated functional habitat loss) caused by the presence of linear corridors and clearings that caribou avoid. The second is increased mortality linked to higher predator numbers or human/predator hunting efficiency caused by habitat conversion and fragmentation. Both pathways can contribute to short- or long-term population declines.

The Snake-Sahtaneh cumulative effects study used RSF modeling to relate caribou use and mortality to cumulative effect variables thought to be most practical for cumulative effects assessment and management (habitat, linear corridors, clearings and facilities, other land use features, and wolf pack ranges). Land use intensity in the Snake-Sahtaneh range was very high relative to other boreal caribou ranges (Dyer 1999; Sorensen et al. in prep.) and corridors and other land use features were concentrated in the most used (core) areas of the range relative to the surrounding landscape. Although female caribou avoided most land use features (but not seismic lines) at the within-home range scale, resource selection at the home range scale was significantly related to habitat, but not to land use variables. Adult female survival was lower than expected in home ranges with more wells, facilities, and area within 250 m of land use features. These conditions indicate that intensively developed areas of the

Snake-Sahtaneh range have become ‘ecological traps’ – in other words, caribou continue to select them even though they increase mortality (Antoniuk et al. in prep.).

Ideally, the WG should modify ALCES© to apply RSF models developed with Dehcho boreal caribou telemetry data to allow the cumulative effects of natural disturbance and land use to be explored. However, these telemetry studies are ongoing and detailed analysis incorporating statistical modeling is not planned for the coming year. In the interim, ALCES© could be modified to apply the RSF habitat use and mortality models developed for the Snake-Sahtaneh herd. This would involve the following steps: 1) link the habitat types developed with the DU ECC dataset and those developed with the EOSD LCC dataset and apply these to the twenty ALCES© Dehcho landscape types; 2) link Snake-Sahtaneh land use variables with the fifteen ALCES© Dehcho footprint types; and 3) modify the existing grizzly bear habitat and mortality RSF models in ALCES© to incorporate the Snake-Sahtaneh boreal caribou coefficients and defined landscape and footprint types. Simulations completed with these preliminary models would complement BCC model simulations and help the WG explore the relationships between future resource development, habitat quality, and survival.

Results of the Snake-Sahtaneh study can also contribute to an evaluation of the influence of avoidance buffer width on future boreal caribou habitat effectiveness by conducting ALCES© simulations using avoidance buffers reported by GNWT (2006b), Dyer (1999), and Antoniuk et al. (in prep.).

Modelling Approaches

The NWT ALCES© WG could apply one of five progressive modeling approaches during Phase 2:

1) 'Basic': use EOSD LCC dataset and the existing BCC model;
2) 'Basic plus BC RSF': use EOSD LCC dataset and the existing BCC model plus RSF models developed for northeastern BC;
3) 'Basic plus HSI': use EOSD LCC dataset and the existing BCC model plus a Dehcho-specific HSI model incorporating ENR expert opinion and traditional ecological knowledge;
4) 'Basic plus Dehcho RSF': use the models developed above, plus analyze Dehcho telemetry data and generate Dehcho-specific RSF models based on the EOSD LCC dataset; and
5) 'Regional': develop a combined regional dataset with NT, Alberta, and BC telemetry data and generate regional RSF models based on the EOSD LCC dataset.

The 'Basic' and 'Basic plus BC RSF' approaches would allow simulations to be completed relatively quickly and inexpensively with existing data from Alberta and BC. This would the simplest method to allow the WG to better understand how ALCES© can be used to evaluate the implication of land use for Dehcho boreal caribou and other sensitive wildlife species.

Experience elsewhere suggests that stakeholders prefer ALCES© models that reflect information from the region. The 'Basic plus Dehcho HSI' and 'Basic plus Dehcho RSF’ approaches would address this issue by incorporating Dehcho traditional and scientific knowledge and/or telemetry data. Finally, the ‘Regional’ approach would be useful to help understand boreal caribou response in the Taiga Plains ecozone.

RECOMMENDATIONS

1) The EOSD land cover classification represents the best classification to use for the pilot project because it provides seamless coverage across the entire proposed study area. Also, the EOSD classification is consistent with northeast British Columbia and northwest Alberta and facilitates extension of the study area in to those other jurisdictions if need be.
2) The spatial extent of the proposed study area should be evaluated with the current caribou movement and location data from the Dehcho. If the current caribou data show substantial range occupation in to either Alberta or British Columbia, than it may be important to adjust the study area accordingly.
3) If further quantitative evaluation of land cover classifications is required, the current boreal caribou telemetry data from the Dehcho should be analyzed to define and compare the relationships between caribou locations and habitat types across each of the candidate land cover classifications. This analysis would help define the specific land cover types that are important for caribou. These land cover types would be input into ALCES©.
4) The BCC equation represents the quickest approach to modeling the response of boreal caribou to landscape changes in the Dehcho. This approach is defendable because it is based on extensive data and relevant experience from northern Alberta.

5) An option for applying an RSF approach would be to use the relationships developed from research in northeast British Columbia on the Snake-Sahtaneh boreal caribou herd. These data are thought to be relevant to the Dehcho region and this approach would minimize Phase 2 costs by avoiding the time and resources needed to develop RSF relationships with Dehcho telemetry data.
6) A comparative approach could also be used to understand the differences and similarities between landscape level caribou responses that are based on the BCC equation, RSF models from northeast BC, and Dehcho-specific HSI and RSF relationships. This will require the development of functional caribou-habitat relationships using one or more of the HSI and RSF modeling approaches with existing caribou data for the Dehcho. The analyses should be conducted so that the resultant caribou-habitat relationships are easily added to the existing ALCES model interface, with minimal customization.

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APPENDIX 1. What is ALCES©?

ALCES© is an acronym for “A Landscape Cumulative Effects Simulator,” and is the tradename for a computer-based landscape simulator developed by Forem Technologies Ltd (for more information, please see www.foremtech.com). ALCES® is a strategic-level simulation tool intended for use by resource managers, the scientific community, industrial landusers, and the general public. Its primary purpose is to facilitate Integrated Resource Management (IRM), which is defined as “an interdisciplinary and comprehensive approach to decision-making for natural resource management. This approach integrates decisions, legislation, policies, programs and activities across sectors to gain the best overall long-term benefits for society and to minimize conflicts. IRM recognizes that the use of a resource for one purpose can affect both the use of that resource for other purposes and the management and use of other resources" (Alberta Environment 2000, p 3.)

ALCES© is a landuse simulator that tracks industrial footprints and ecological processes under alternative management scenarios. These scenarios need to run quickly and must be accurate at a strategic level. As stakeholders run ALCES© into the future (a 100 year run takes ~100 seconds) they can appreciate the range of socio-economic and ecological outcomes of different landuse options and move toward a suite of landuses that optimize societal goals. ALCES© has gained extensive acceptance by industry, government, and the public as an effective simulation tool for exploring the consequences of different landuse strategies and conducting cumulative effects assessment (see Schneider et al. 2003).

An addition to being a powerful tool to understand cumulative effects, the use of ALCES© facilitates a larger process by which diverse stakeholders can gather together and explore the economic, ecological, and social consequences of different landuse trajectories on defined landscapes. The process in which various stakeholders are brought together to provide model inputs in to ALCES©

and develop realistic land use scenarios, increases credibility and leads to a much more effective learning experience than would be gained if one or a few vested interests drove the outcome.

Specific examples of stakeholder's issues that ALCES© has been used to address include:

- forecasting transformations of landscapes subjected to single or multiple human landuse practices and to various natural disturbance regimes;
- tracking flows of natural resources (water, fiber, hydrocarbons, wildlife, livestock, carbon, agricultural products) and identify issues relating to sustainability of flows of natural resources;
- tracking employment, expenditures, royalties and indirect economic benefits associated with flows of landuse resources (timber, hydrocarbon, water, electricity, etc) occurring on landscapes;
- defining trade-offs that exist between landuse practices and environmental resources; and
- seeking mitigation strategies that minimize adverse risk to ecological and economic goals.

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