Deh Cho Cumulative Effects Study

Phase 1:
Management Indicators and Thresholds

Prepared for:

Deh Cho Land Use Planning Committee
Fort Providence, Northwest Territories

by:

Salmo Consulting Inc.
in association with

Axys Environmental Consulting Ltd.
Forem Technologies
Wildlife & Company Ltd.

Calgary, Alberta

April, 2004

EXECUTIVE SUMMARY

The Deh Cho Land Use Planning Committee (DCLUPC) is developing a land use plan for the nearly 210,000 square kilometre Deh Cho territory. Land use planning is undertaken to provide guidance on whether, where, and how human activities should be located, encouraged, or restricted to provide appropriate balance between economic, social, environmental, and cultural values. Limited time and resources make it impractical for a land use plan to consider all socio-economic and ecological factors in equal detail.

The DCLUPC initiated a two part Cumulative Effects study to identify cumulative effects indicators appropriate for the Deh Cho Plan area and, where possible, to recommend science-based candidate thresholds or limits for these indicators. The first phase of this Cumulative Effects study also evaluated and integrated available data to document the current status of land use indicators and identify ‘hot-spots’ where cumulative effects risk is elevated. Additional work is planned in Phase 2 to develop projections of future land use activities and associated trade-offs among cumulative effects indicators, and to refine the candidate indicators and thresholds.

Deh Cho Plan Area Setting

Readily available Geographic Information System (GIS) data and reports for the entire Deh Cho Plan area were obtained and evaluated. This information was used to identify regional resources, issues, and values for subsequent work. The DCLUPC has described and mapped resource conditions and potential of the Deh Cho Plan area. This region area offers both pristine boreal wilderness and thriving aboriginal culture and communities. A diverse group of physical landscapes and vegetation communities are present in the region. Ten valued wildlife species have been identified and fish are important for subsistence and recreational harvest. Approximately 10.1 million hectares of the Plan area has been included in a network of key cultural and protected areas.

There are 11 communities in the Deh Cho Plan area with a combined population of approximately 6,700. Aboriginal people within the Plan area are descendants of the Dene and represent several cultures. The regional population has grown by 35% over the last 30 years, but this trend has been accompanied by dramatic and unpredictable fluctuations. Traditional lifestyles are still pursued in smaller Deh Cho communities, and the wage employment rate is low relative to the rest of the NWT and Canada as a whole. Most residents are employed in the government, education and health sector. Opportunities exist to increase wage employment through sustainable use of renewable and non-renewable resources.

The most important renewable and non-renewable resources in the Deh Cho Plan area are tourism, forestry, petroleum exploration and production, and mining. Tourism is a relatively small economic sector in this region, but there are several well known sites, particularly the Nahanni National Park Reserve. The Mackenzie, Yellowknife, and Liard highways link this region to Alberta and British Columbia and provide tourism

opportunities for 'rubber tire' visitors. Productive forest is distributed throughout the Plan area but commercially viable timber stands are largely restricted to the Liard River watershed in the southwest corner of the Plan area. Evaluations suggest that the annual allowable cut in this region can be increased from past levels. Petroleum activity is currently centred in the Fort Liard and Cameron Hills areas adjacent to the Alberta and British Columbia borders. The region is thought to contain large quantities of undiscovered natural gas reserves and energy exploration and production activity is projected to increase. The proposed Mackenzie Gas Project pipeline route passes through the Deh Cho region; this project will create business and employment opportunities as it moves into the construction and operational phases.

Preliminary maps of current conditions were generated to verify the quality and accuracy of the dataset and identify 'hot-spots'. A licenced copy of the ALCES II® landscape simulation model was obtained and modified to allow data from the Deh Cho Plan area to be incorporated. This computer model allows the potential effects of future development to be visualized. ALCES will be a key component in establishing specific management objectives and evaluating socially-appropriate limits and thresholds for Cumulative Effects Phase 2.

Management Indicator Framework

The Deh Cho Land Use Plan will establish the 'vision' and 'rules' for future development and utilization of land and resources in this region. To be most effective, residents and developers should be able to relate their local actions and activities directly to defined land management visions. Regulators should be able to translate these same visions into rules and decision-making processes. This report reviews several existing approaches that have been used in Canada and elsewhere to build links between regional, sub-regional and local plans and decisions. These include the: 'Limits of Acceptable Change' (LAC) system; 'Tiered Thresholds' approach; Sustainable Forest Management criteria and indicators; and 'Results-based Framework'.

A results-based framework including elements of all four approaches is recommended for the Deh Cho Plan area. The critical component of a results-based framework is explicit land and resource management **objectives** set for the Deh Cho Plan area and smaller zones (landscapes, watersheds, sub-regions). Specific **indicators** are then used to measure progress in achieving these objectives. Wherever possible, **limits of acceptable change** or **thresholds** are established for the Plan area and smaller zones to describe acceptable, unacceptable, and desired future conditions of each indicator.

Management objectives for the Deh Cho Plan area have not yet been developed. These should describe the ideal future condition of each management zone. Independent specialists cannot identify these objectives, but they can help inform the residents and stakeholders who must define them.

'Indicators' are characteristics of the social or ecological setting that can be used to describe, measure, manage, and report on factors that are of value to the public. They have been classified into four types for this report: **Physical-Chemical**; **Ecological**;

Land and Resource Use; and **Social**. A suite of complementary indicators is generally believed to be the most appropriate for both project and resource management purposes because a single indicator is not capable of tracking all pertinent factors. Eighteen candidate cumulative effects indicators are identified for the Deh Cho Plan area.

Indicators provide a good idea of what's happening in the Deh Cho Plan area, but provide no direct measure of the acceptability of those changes. 'Thresholds' are used to define the point at which an indicator changes to an unacceptable condition, with acceptability defined either from an ecological or social perspective. Setting a numerical value on indicators has been one of the most challenging aspects of land and resource management. 'Limits of acceptable change' and 'tiered thresholds' are two approaches that have been used to develop socially defined endpoints or thresholds that reflect the desired balance between human activities and ecological and social sustainability.

Physical-Chemical Indicators and Thresholds

To date, the best examples of management indicators and thresholds are established air and water quality guidelines. Air quality is a recommended indicator for the Deh Cho Plan area. Candidate Critical and Cautionary thresholds are proposed for regional and local ambient air quality. These are based on the approved NWT standards and the presence of local, regulated emission sources.

Two water quality indicators are recommended for the Deh Cho Plan area. Project-specific and sub-regional effects can be evaluated using one or more parameters of interest such as total suspended sediments. The established federal water quality guidelines for protection of aquatic life represent an appropriate Critical Threshold applicable to the entire Plan area. Cautionary thresholds are proposed where a local, regulated discharge source occurs. Intermediate Target thresholds should be considered in areas where pristine water quality is the defined management objective.

A 'Relative Water Quality Index' incorporated in ALCES is recommended as an indicator for simulation of future land use conditions to allow relative effects of nutrient and total suspended sediment levels to be tracked over time. Candidate Critical and Target thresholds are provided for this index.

Ecological Indicators and Thresholds

Ecological indicators describe ecosystem conditions such as habitat availability and quality, animal abundance, and biodiversity. Both species-specific and generalized indicators proposed and used elsewhere are discussed. A suite of five candidate ecological indicators is identified for the Deh Cho Plan area to track both regional and local conditions. These include three generalized terrestrial habitat indicators, one aquatic habitat indicator, and one species-specific indicator for woodland caribou.

'Habitat availability' for key wildlife species (woodland caribou, moose, marten, and grizzly bear) is a useful indicator because it can be readily measured and is assumed to be biologically meaningful. Other species can be considered in zones where they are the primary management objective. Regional candidate Critical and Target thresholds are proposed. Cautionary thresholds and more restrictive Critical and Target thresholds should be considered in areas where wildlife values are the primary management objective. Habitat availability is currently within candidate Critical and Target thresholds.

'Specialized terrestrial habitat features' such as dens and mineral licks are a candidate indicator that complements the general habitat indicator. These local features are important, and must be considered during planning and reviews. Regional candidate Critical and Target thresholds are proposed. Cautionary thresholds and more restrictive Critical thresholds should be considered in areas where wildlife values are the primary management objective.

'Minimum core area' is a widely used indicator of areas with relatively limited human activity. This is defined to be those areas greater than 500 m from high use features such as roads, industrial and recreational facilities, and communities. Two sets of candidate Critical, Target, and Cautionary thresholds are proposed: one for areas where resource development is the primary management objective; and one for areas where wildlife values are the primary management objective. Large core areas are currently present in the Deh Cho Plan area. Almost 99% of the region where analyses could be completed is classified as medium or larger core areas.

'Fish habitat' is the candidate aquatic indicator, with no net loss identified as the Critical threshold to conform to existing federal policy.

Woodland caribou is the candidate focus species for the Deh Cho Plan area because it is the sensitive to cumulative land use effects. Total corridor density, including all cutlines, roads, and pipelines wider than 3 m, is the candidate indicator for this species. Caribou herd survival has been shown to decrease as total corridor density increases. Two sets of candidate Critical, Target, and Cautionary thresholds are proposed: one for areas where resource development is the primary management objective; and one for designated caribou management areas. Current corridor crossing density in the Deh Cho Plan area is low. At present, 98% of the region where analyses could be completed is below the candidate Cautionary threshold, 99% is below the candidate Target threshold, and 99.5% is below the candidate Critical threshold.

Land and Resource Use Indicators and Thresholds

Land and resource use indicators measure the direct and indirect footprint of human disturbance or the amount of human activity. One class of resource use indicators – harvest limits and mortality thresholds – has been commonly used by fish and wildlife management agencies. A suite of four land use indicators is identified for the Deh Cho Plan area. Combined, these indicators can be used to gauge how the landscape and its features are being affected by land and resource uses.

'Total cleared/disturbed area' is recommended as an indicator to evaluate cumulative effects risk to rare and unique physical and vegetation features in the Plan area. Regional candidate Critical and Target thresholds are proposed. Cautionary thresholds and more restrictive Critical and Target thresholds should be considered in areas where environmental or biodiversity values are the primary management objective.

'Significant environmental features' such as hotsprings and hoodoos are a candidate indicator that complements the disturbed area indicator. These local features are important, and must be considered during planning and reviews. Regional candidate Critical and Target thresholds are proposed. Cautionary thresholds and more restrictive Critical thresholds should be considered in areas where environmental or biodiversity values are the primary management objective.

Road density is the best known and most widely used land use indicator. All season access is limited in the Deh Cho Plan area however, and the 'total corridor density' indicator previously described for caribou is considered to be a more appropriate indicator for this region. Candidate thresholds are based on available cause-effect relationships for woodland caribou, the most sensistive species in the region. Current corridor crossing density in the Deh Cho Plan area is low.

'Stream crossing density' – the number of times that roads, trails, pipelines, and railways cross streams in a watershed – is the candidate watershed indicator. This index is easily calculated and provides the most direct indicator of cumulative erosion and mortality risk. Watersheds with many crossings are more likely to have increased erosion, water temperature, angling pressure, and temporary or permanent barriers to fish movement. Regional candidate Critical and Target thresholds are proposed. Cautionary thresholds and more restrictive Critical and Target thresholds should be considered in areas where fisheries or watershed values are the primary management objective. Current stream crossing density in the Deh Cho Plan area is low. The candidate Critical threshold was not exceeded, and the candidate Target threshold was exceeded on less than 0.01% of the region where analyses could be completed.

Social Indicators and Limits of Acceptable Change

Social indicators that describe the condition of communities, economies, or cultures have been more widely used than ecological indicators. A suite of six candidate ecological indicators is identified for the Deh Cho Plan area. This includes three community health and wellness indicators, one economic indicator, and two resource use indicators.

'Signficant cultural features' such as traditional and archaeological sites are a recommended cultural indicator. These local features are important, and must be considered during planning and reviews. Regional candidate Critical and Target thresholds are proposed. Cautionary thresholds and more restrictive Critical thresholds should be considered in areas where cultural values are the primary management objective.

'Population change' and 'wage-based employment' are the two other health and wellness measures that can be estimated or measured at both regional and community levels using existing data. Ideally, subsistence activity participation rate would be a more appropriate indicator than wage employment because it reflects current conditions and values.

However it is difficult to measure and predict; wage-based employment was therefore identified as an indirect measure. Candidate thresholds are not identified because these must be developed with community and stakeholder input.

'Regional revenue created by each economic sector' is the candidate economic indicator and 'total area available for each resource use' is a candidate resource use indicator. These indicators can be estimated or measured at both regional and community levels and can be related to current and potential future activities. While it is assumed that revenue growth of each sector is desired, candidate thresholds must be developed with community and stakeholder input.

'Visual quality' is a candidate resource use indicator for management units such as highway corridors and tourism areas where visual values are the primary management objective. Candidate thresholds must be developed with community and stakeholder input.

Refining Indicators and Thresholds

Although the Deh Cho Plan area is largely undisturbed, experience in other boreal forest areas indicates that it is important to have clear management objectives for future land use decisions. This Cumulative Effects Phase 1 study provides a suite of candidate indicators and tiered thresholds that, when considered together, can be used for land use planning and resource management.

This framework is an important first step, but experience in other jurisdictions clearly demonstrates that it is important to conduct formal evaluations of the indicators and thresholds to give all affected groups and individuals the opportunity to help define limits of acceptable change. Implementation is a shared responsibility that will be most effective when indicators and limits are accepted as both reasonable and based upon accepted science and traditional knowledge. The adaptive management approach also suggests that proposed management actions should be rigorously tested before they are widely applied. A recommended stakeholder implementation process is presented to test and refine indicators, thresholds, and limits of acceptable change in Cumulative Effects Phase 2.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

List of Acronyms

AAC	Annual Allowable Cut
AENV	Alberta Environment
ALCES	A Landscape Cumulative Effects Simulator®
AVHRR	Advanced Very High Resolution Radiometry
AVI	Alberta Vegetation Inventory
BCC	Alberta Boreal Caribou Committee
BCE	British Columbia Environment
BCF	British Columbia Forestry Service
BCIRPC	British Columbia Integrated Resource Planning Committee
CASA	Clean Air Strategic Alliance
CCFM	Canadian Council of Forest Ministers
CCME	Canadian Council of Ministers of the Environment
CE	Cumulative Effects
CEM	Cumulative Effects Model
CEQ	Council on Environmental Quality
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPI	Consumer Price Index
CSA	Canadian Standards Association
CZC	Canadian Zinc Corporation
DC	Disturbance Coefficient
DCFN	Deh Cho First Nations
DCLUPC	Deh Cho Land Use Planning Committee
DFO	Department of Fisheries and Oceans
DIAND	Department of Indian Affairs and Northern Development
EBA	EBA Engineering Consultants Ltd.
ELI	Environmental Law Institute
ESGBP	East Slopes Grizzly Bear Project
FEARO	Federal Environmental Assessment Review Office
FMF	Foothills Model Forest
GDP	Gross Domestic Product
GIS	Geographic Information System
GNWT	Government of the Northwest Territories
GRI	Global Reporting Initiative
HEP	Habitat Evaluation Procedures
IFIM	Instream Flow Incremental Methodology
IRS	Indian Resource Satellite
IWAP	Interior Watershed Assessment Procedure
IWMS	Identified Wildlife Management Strategy
LAC	Limits of Acceptable Change
LCC	Land Cover Classification
LIS	Low Impact Seismic
LRSY	Long-Run Sustainable Yield
MELP	British Columbia Ministry of Environment, Lands and Parks
M-KMA	Muskwa-Kechika Management Area
MSRM	British Columbia Ministry of Sustainable Resource Management
MVEIRB	Mackenzie Valley Environmental Impact Review Board
MVLWB	Mackenzie Valley Land and Water Board
NBIOME	Northern Biosphere Observation and Modelling Experiment

List of Acronyms (cont'd).

NCGBRT	North Cascades Grizzly Bear Recovery Team
NEB	National Energy Board
NNSL	Northern News Services Limited
NRTEE	National Round Table on the Environment and the Economy
NWT	Northwest Territories
OGC	British Columbia Oil and Gas Commission
PACTeam	PACTeam Canada
PM	Particulate Matter
RCMP	Royal Canadian Mounted Police
RIC	British Columbia Resources Inventory Committee
RSF	Resource Selection Functions
RWED	Resources, Wildlife and Economic Development
SRUNA	Sustainable Recreational Use of Natural Assets
TSP	Total Suspended Particulate
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
VEC	Valued Ecosystem Component
WHA	Wildlife Habitat Areas
WKSS	West Kitikmeot/Slave Study Society
YRRMMT	Yukon Renewable Resources Moose Management Team
ZOI	Zone of Influence

Glossary

Access corridor – a linear feature created by humans (road, trail, pipeline, powerline, railway line, cutline) that may be used by pedestrians, vehicles, hunters, anglers, or animal predators.

ALCES – 'A Landscape Cumulative Effects Simulator' computer model used to forecast changes in landscape patterns and wildlife habitat. This simulator integrates four submodels (habitat availability, population, land use, and natural disturbance) and considers all land use activities likely to occur in the region. It includes both aquatic and terrestrial indicators and is able to incorporate random events such as fire.

AVHRR – Advanced Very High Resolution Radiometry satellite sensor.

Barrier – a barrier is present when it is not possible for animals to move across a corridor, and the habitat on either side of the corridor becomes isolated (e.g., a busy highway is a barrier for small ground-dwelling insects).

Biodiversity – the diversity of plants, animals, and other living organisms in all their forms and levels of organization (BCF and BCE 1995a). The basic goal of biodiversity conservation is to maintain naturally occurring ecosystems, communities, and native species (CEQ 1993).

Cautionary threshold – a threshold established to indicate that additional or more intensive monitoring is required to provide sufficient local data to confirm scientific predictions of both target and critical thresholds.

Core area – an area with minimal human impacts. Core areas are relatively undisturbed, 'unroaded' areas; they are often source areas for plant and animal populations or metapopulations.

Corridor – a reasonably uniform, linear feature that differs from its surrounding landscape. Corridors can occur naturally (e.g., river valley; windrow, aeolian ridge) or as the result of human disturbance (e.g., roads, cutlines).

Criterion - a fundamental standard in the Sustainable Forest Management framework against which progress can be assessed.

Critical threshold – a science-based target reflecting the continuous maximum amount of stress that a sensitive ecosystem, species, or community can support without sustaining long-term harm. This may incorporate economic and social values to determine the acceptable magnitude of change, risk of long-term damage, or level of protection required.

Cumulative effects – changes to the environment caused by collective past, present, and future human actions; most result from the combined effects of simple, routine activities and projects.

DC – Disturbance Coefficient; an index assigned to each feature or activity type that rates the degree to which the disturbance zone of influence remains effectively useable by the species. Ratings are on a scale of 0 to 1 and are used to calculate habitat effectiveness.

Density-dependent – factors that affect population growth and parameters in relation to as animal abundance. These depress population growth as animal abundance increases, and increase growth as animal abundance decreases. Examples include food availability and quality. Predation may be density-dependent or –independent.

Density-independent – factors that affect population growth and parameters regardless of animal abundance. Examples include natural environmental disturbances such as fire, floods, or severe weather. Predation may be density-dependent or –independent.

Disturbance – a natural or human action that affects physical, chemical, or biological conditions.

Disturbance feature – a corridor or patch created by natural random events (e.g., burn or flood) or human action (e.g., cutblock, facility, community, road).

Disturbance trajectory – the calculated or predicted rate of natural or human disturbance.

Drainage - a subset of a watershed, generally less than 1,000 km^2 in size.

Early seral – forest that are younger than 40 years old (BCF and MELP 1999a).

Ecological resilience – the ability of a system or species to absorb natural and human disturbance without altering its fundamental structure (Weaver et al. 1996).

Ecological sink – an area with degraded habitat that has lower survival (or higher mortality) rates, causing local population declines. Although individual animals may continue to use this area, it creates a net loss to the population that may not be detectable for several generations.

Edge area - the area bordering patches and corridors where abiotic conditions (e.g., moisture, light, temperature, wind regimes) and biotic conditions (e.g., predation, mortality, competition, vegetation diversity and structure, species diversity and abundance) may be altered. Examples include the intersection between a cutblock and forest or a trail and native grassland.

Element - A key constituent of a Criterion in the Sustainable Forest Management framework. Elements represent major features of the Criterion with which they are associated; they define the scope of a given Criterion.

Filter, partial barrier, or porous barrier – a type of corridor across which some movement occurs but the rate of movement is less than through intact habitat (e.g., a busy highway is a porous barrier for large mobile wildlife like deer [*Odocoileus* spp.]).

Fragmentation – the process of losing habitat continuity through temporary or permanent conversion of lands for human use (e.g., clearcutting forest, tilling native prairie for agriculture). Three general effects result from habitat fragmentation: (1) original habitat is lost, (2) remaining habitat patches decrease in size, and, (3) patches become increasingly isolated from one another.

Habitat – the environment in which an organism or biological population lives or grows.

Habitat alteration – habitat alteration occurs with disturbance of original habitat. *Temporary habitat alteration* occurs when pre-disturbance conditions are allowed to re-establish (e.g., forest regrowth after harvest). *Permanent terrestrial habitat alteration* occurs when different vegetation becomes established on the disturbed area (e.g., converting mixedwood forest to domestic grasses for hay production; introducing non-native species). *Permanent aquatic habitat alteration* occurs when substrate or channel conditions are modified, or where flow and sediment transport patterns are modified by upstream activities.

Habitat availability – the amount of usable habitat accessible to a particular species.

Habitat effectiveness – habitat quality, as perceived by a particular species. For instance, when a species uses the area around a man-made facility less than nearby areas of identical habitat, there has been a decrease in habitat effectiveness for that species.

Habitat loss – loss of habitat can occur in either terrestrial or aquatic ecosystems. *Terrestrial habitat loss* occurs when human activities disturb the soil or remove vegetation and regrowth is not allowed to occur (e.g., construction of a city, highway or industrial facility). *Aquatic habitat loss* occurs when water is removed, chemistry is substantially altered, or the structure of the waterbody is substantially altered.

Habitat suitability or **quality –** the ability of a habitat unit, in its current condition, to provide the life requisites of a species. This rating is irrespective of the numbers of that species that are currently using the habitat (RIC 1999).

Habitat unit – a defined terrestrial or aquatic unit with consistent abiotic and biotic conditions.

Human activity – all forms of human actions including land conversion and disturbance, damming, water withdrawal, pedestrian, vehicle and aircraft movements, harassment, harvest, and contaminant input.

Human capital - skills, education, experiences, and general abilities of residents or communities that facilitate the creation of personal, social, and economic well-being (NRTEE 2003).

Index or metric – a numerical value used to represent or monitor the condition of an abiotic or biotic resource.

Indicator – a surrogate measure used to represent or monitor the condition of an abiotic or biotic resource. May be a representative species, an outcome, or an input.

Interior area – also referred to as core area in this report. Interior areas are those beyond the influence of edge effects.

IWAP – Interior Watershed Assessment Procedure; a method developed by the British Columbia provincial government to help forest managers understand the type and extent of current water-related problems in a watershed, and to recognize the implications of proposed activity in that watershed (BCF 1999).

Juvenile – an individual age 1 or older that has not reached maturity.

Landscape – an area of tens to hundreds of square kilometres that includes one dominant background ecosystem. Northeast British Columbia consists of a number of landscape types including the forest landscape, the agricultural landscape, and the alpine/subalpine landscape.

LCC – Northwest Territories Land Cover Classification derived from Landsat TM 5 and 7 images acquired between 1992 and 2000 (mainly 1996-1999; RWED 2002a).

Local population - A breeding group or stock with distinct genetic or life history attributes that interact on a regular basis. May also represent a component of a metapopulation or population found in a discrete or isolated area (Hanski et al. 1996).

Lowest observed effect level – concept from the field of ecotoxicology that represents the lowest concentration of a material used in a toxicity test that has a statistically significant adverse effect on the exposed population of test organisms compared to the controls. Also called lowest observed adverse effect level (LOAEL). This concept is also applicable to behavioural, physiological, and population response.

Matrix – the dominant background ecosystem or land-use type within a habitat mosaic. Within the matrix, patches and corridors are reasonably uniform areas and linear features that differ from their surroundings.

Mature growth/mature seral – forests greater than a specified age (generally >80 years) based on forest zone and dominant species (BCF and MELP 1999a).

Metapopulation - a population of populations. This represents an abstraction of the population concept to a higher level. Metapopulations generally consist of a group of interacting but spatially discrete or isolated populations, subpopulations, or stocks. These subunits are linked by drainage networks but movement between subunits is infrequent and typically takes place across unsuitable habitat or over great distances (Hanski and Gilpin 1991; Dunham and Rieman 1999). An example of a fish metapopulation is a group of isolated headwaters populations found in the same watershed.

Natural capital – the environmental stocks and systems that provide us with the many natural materials and services that we rely on to sustain economic activity, including natural resources, land, and ecosystems (NRTEE 2003).

Natural disturbance type – an area characterized by a natural disturbance regime. The provincial government has established five natural disturbance types for managing biological diversity according to the *Forest Practices Code of British Columbia Act* (BCF and BCE 1995a; BCF and MELP 1999a).

Objective – a broad statement describing an ideal future state or condition for a value of social, economic, or environmental interest (MSRM 2004).

Old growth/old seral – forests greater than a specified age (generally >100 years) based on forest zone and dominant species (BCF and MELP 1999a).

Patch – a reasonably uniform area that differs from its surrounding landscape. Patches can occur naturally (e.g., sloughs, burns) or as the result of human disturbance (e.g., farmyards, wellsites, clearcuts).

Population – a group of interacting individuals of the same species in a defined area distinguished by a distinct gene pool or distinct physical characteristics.

Population limiting factors – processes that quantifiably affect the population rate-of-increase. Responsible for inducing year-to-year changes in animal abundance (Messier 1991).

Population regulating factors – density-dependent processes that ultimately keep populations within normal density ranges. These are a subset of limiting factors and predictably depress population growth as animal abundance increases (Messier 1991).

Pre-Tenure Plan – a plan prepared before land rights are issued that establishes general and specific management direction that rights holders will need to adhere to.

Reach – a defined watercourse channel section, tens to thousands of meters in length, with relatively consistent channel morphology, hydrology, and water chemistry.

Regional - an area more than hundreds of square kilometres that incorporates several landscapes.

Riparian - the banks and slopes next to streams, lakes and wetlands that are affected by elevated soil moisture levels for at least part of the year. These riparian areas protect water quality, stabilize banks, provide a continuous source of woody debris, nutrients, and food organisms, and regulate stream temperature (BCF and BCE 1995c; BCF and MELP 1999a).

Riparian clearings - cleared areas within 15 m of a waterbody, including linear corridors, communities and residences, industrial and commercial facilities, cutblocks, and agricultural fields.

Riparian roads - roads and trails within 100 m of a waterbody.

Seral stage – the stages of natural ecological succession of a plant community, for example from young through mature to old stage (BCF and BCE 1995a).

Significant cultural features – archaeology or palaeontology site; camping, trapping, fishing or hunting locales; cabins; burial sites; historic trails and sites; mineral licks; berry picking and medicinal plant collecting areas; areas identified as cultural landmarks or spiritual significance.

Significant environmental features – hotsprings, hoodoos, International Biological Program sites.

Social capital – the ability and willingness of residents to work together for community goals.

Specialized habitat features – mineral licks, dens, wallows, nests.

Stream crossing - a road, trail, pipeline, powerline, railway line, or cutline crossing of a watercourse.

Subpopulation - a breeding group or stock with distinct genetic or life history attributes that interact on a regular basis. May also represent a component of a metapopulation or population found in a discrete or isolated area (Hanski et al. 1996).

Subwatershed - a subset of a watershed, generally less than 1,000 km^2 in size.

Target threshold – a politically-defined goal reflecting the optimum amount of stress on the system. This threshold is more protective than the critical threshold to provide a margin of safety. A target threshold can be characterized as the level that is politically and practically achievable and provides adequate long-term protection to the environment or resource of interest.

Threshold – a point at which a resource changes to an unacceptable condition, with acceptability defined either from an ecological or social perspective.

Viable population – a self-sustaining population with a high probability of survival despite the foreseeable effects of demographic, environmental, and genetic stochasticity and of natural catastrophes (BCF and BCE 1995a).

Visual quality – the extent to which the pre-existing or natural aesthetic or scenic quality of a landscape is maintained.

Visual quality objective – a resource management objective established to reflect the desired level of visual quality based on the physical characteristics and social concerns for the area (BCF 2001).

Waterbody – a specific aquatic basins or channel (lake, pond, wetland, river, or stream).

Watercourse – a specific flowing channel (river or stream).

Watershed – a large drainage area, generally 1,000 to 10,000 km^2 in size, which flows directly into a large river such as the Mackenzie River.

ZOI – Zone of Influence; the distance to which a species is affected by an activity or disturbance.

1. INTRODUCTION

The Deh Cho Land Use Planning Committee (DCLUPC) was established in 2001 to develop a land use plan for the Deh Cho territory pursuant to the Deh Cho First Nations (DCFN) *Interim Measures Agreement*. The land use plan is intended to balance economic, social, environmental and cultural needs and interests. It will be used as a management tool to determine what type of land use activities should occur and where they should take place.

The land use planning process in the Deh Cho territory is currently at Phase II - the technical stage - where required information is being gathering and analyzed to identify opportunities and constraints. The DCLUPC initiated a Cumulative Effects (CE) study (Deh Cho CE study) in the planning region as part of Phase II. This work is intended to help integrate information produced for the planning region and identify potential social and ecological constraints and management tools. The specific objectives of the CE study are to:

- Identify cumulative effects indicators appropriate for the Deh Cho Plan area;
- Integrate available data to document the current status of cumulative impact indicators in the Deh Cho Plan area, and identify 'hot-spots' where the risk of cumulative impacts is currently elevated;
- Develop projections of future land use activities and associated changes in cumulative impact indicators; and
- Identify candidate thresholds and impact management measures for each cumulative impact indicator.

The team of Salmo Consulting Inc., Axys Environmental Consulting Ltd., Forem Technologies, and Wildlife & Company Ltd. (the CE team) was retained to undertake the Deh Cho CE study in two phases: 1) cumulative indicator and threshold literature review; and 2) land use projections and cumulative effect analyses. This report describes CE Phase 1 – the cumulative indicator and threshold literature review.

1.1 METHODS

At the request of the DCLUPC, the Deh Cho CE literature review builds on work completed by Salmo et al. (2003) to develop made-for-northeast British Columbia ecological indicators and thresholds. Subsequent feedback on the British Columbia study has demonstrated the need to incorporate human issues and values as part of cumulative impact management. This requires social indicators and associated 'limits of acceptable change' to be an integral part of regional land use plans. Accordingly, the Deh Cho CE literature review includes three components:

1. Ecological and social information prepared for the DCLUPC and readily available reports and data for the Deh Cho Plan area;
2. Social indicators and limits of acceptable change; and
3. Ecological indicators and thresholds.

1.1.1 Deh Cho Planning Region Setting

Readily available information pertinent to the Deh Cho Plan area was obtained and reviewed to ensure that subsequent work focused on regional resources, issues, and values. This information is summarized in Section 2.

1.1.2 GIS Database Evaluation

Available Geographic Information System (GIS) data for the entire Deh Cho Plan area were obtained and evaluated during Deh Cho CE phase 1 to verify the quality and accuracy of the combined dataset. Preliminary maps of current conditions were generated to help confirm the analyses and projections that can realistically be completed within the budget proposed for Phase 2 of the Deh Cho CE study. Key considerations were the satellite imagery classification scheme and accuracy, and the attributes assigned to land use features in the GIS disturbance layer.

A licensed copy of the ALCES II® model (www.foremtech.com) was obtained to populate using data from the Deh Cho planning region. Modifications required to apply the ALCES model in the Deh Cho region were then made.

Information on GIS data availability and limitations is provided in Section 3.

1.1.3 Cumulative Impact Indicators and Thresholds

Background information on how indicators can be used to measure sustainable land use is provided in Section 4.

1.1.3.1 Physical-Chemical Indicators and Thresholds

A discussion of air and water quality indicators is provided in Section 5.

1.1.3.2 Ecological Indicators and Thresholds

The habitat indicators and candidate tiered thresholds proposed for northeast British Columbia are considered to be directly relevant to the Deh Cho planning region. Additional relevant recent indicators and thresholds literature was reviewed to confirm or revise these ecological indicators and candidate thresholds. Cumulative effects literature relevant to three ecological indicators (woodland caribou, marten, and fish) was also reviewed and summarized. This information is provided in Section 6.

1.1.3.3 Land Use Indicators and Thresholds

The land use indicators and candidate tiered thresholds proposed for northeast British Columbia are considered to be directly relevant to the Deh Cho planning region. Other relevant literature is summarized in Section 7, along with candidate thresholds for the Deh Cho Plan area.

1.1.3.4 Social Indicators and Limits of Acceptable Change

Literature relevant to cumulative social, cultural, traditional uses, and economic indicators was obtained and reviewed to identify recommended social indicators for the Deh Cho planning region. Information on social indicators and limits of acceptable change is provided in Section 8.

2. DEH CHO PLAN AREA SETTING

The Deh Cho Revised Interim Measures Area (Plan area) includes almost 210,000 square kilometres (km^2) bounded by the Yukon Territory to the west, Alberta and British Columbia to the south, the Sahtu Settlement Region to the north, and the South Slave and North Slave regions to the east. The Plan area has a population of approximately 6,700 people, contains ten permanent communities, and is within the traditional territory of fourteen aboriginal organizations (DCLUPC 2003).

Land use planning and management is used to define how and where human activities can be continued while sustaining air and water quality, plants, and animals. Two fundamental concepts that affect sustainable land use – links between geographic scales, and natural environmental variability – are discussed in more detail below as background for the discussion of the Deh Cho Plan area biophysical and social setting.

2.1 LINKING SCALES

Scale is an important consideration for land use planning and cumulative impact management. A variety of classification schemes have been developed and used to describe local, sub-regional, and regional conditions. Terrestrial and aquatic habitat classification schemes relevant to the Deh Cho Plan area are summarized here.

2.1.1 Terrestrial Habitat Classification

Terrestrial classification schemes include physical, biological, human, and integrated approaches. Physical descriptions focus on climate zones, bedrock types, permafrost patterns, landforms, and soils. Biological approaches emphasize features such as general vegetation, forests, wildlife, habitat, and peatlands. Other classifications specifically address types of human activity (e.g., rural land uses or urban settlements) or cultural groupings (e.g., Deh Cho Interim Agreement Area). These thematic or single-purpose studies are reliable tools for studying component parts of ecosystems. Integrated approaches consider one or more of these thematic components and are useful for land use planning (Wiken 1986; Ecological Stratification Working Group 1995).

Several thematic classification schemes developed for the Deh Cho Plan area are included in the Deh Cho Atlas (DCLUPC 2003): RWED Land Cover Classification (LCC) based on vegetation types as interpreted from satellite imagery (RWED 2002a); the NBIOME (Northern Biosphere Observation and Modelling Experiment) LCC based on vegetation types as interpreted from AVHRR satellite sensor (Advanced Very High Resolution Radiometry; Cihlar and Beaubien 1998 *in* Deh Cho Atlas (DCLUPC 2003)); bedrock geology, earthquakes and hotsprings; surficial geology and landforms; soil landscapes; wildlife habitat suitability by species (EBA 2003); wildlife conservation ranking; archaeology sites; existing land use features; and resource potential (forestry, tourism, oil and gas, mineral, agriculture).

Two integrated classification schemes have been applied to map terrestrial habitat in the Plan area: 1) Northwest Territories (NWT) Landscape Units based on an analysis of 4 physical factors that are believed to be correlated with biological diversity (RWED 2001a; DCLUPC 2003); and 2) the ecosystem classification developed by the Canada Committee on Ecological Land Classification (Ecological Stratification Working Group 1995; DCLUPC 2003).

The following terrestrial classification hierarchy is used in this report:

- **Plan area**: all ecozones, ecoregions and smaller habitat classes found within the 210,000 km^2 Deh Cho Revised Interim Measures area.
- **Ecozone** or **ecosystem**: a large generalized unit at the top of the ecological hierarchy as defined by the Canada Committee on Ecological Land Classification.
- **Ecoregion**: part of an ecozone characterized by distinctive regional ecological factors, including climate, physiography, vegetation, soil, water, fauna and land use (Ecological Stratification Working Group 1995).
- **Region**: an area of thousands of square kilometres defined by political, social, or ecological boundaries. Regions may contain many landscapes but may not necessarily have a repeating pattern of landscapes or landscape elements. The type and spatial arrangement of landscapes affects the way that humans and animals use the region.
- **Landscape** or **sub-region**: an area of tens to hundreds of square kilometres within an ecoregion or region that includes a particular mosaic of biophysical features.
- **Habitat unit**: a defined unit within a landscape or region with consistent vegetation or forest cover.

2.1.2 Ecozones and Ecoregions

The Deh Cho Plan area includes 3 of the 15 Canadian terrestrial ecozones (Taiga Plains, Taiga Cordillera and Boreal Cordillera). These are further subdivided into 18 ecoregions (Table 1; Figure 1).

Table 1. Ecozones and ecoregions in the Deh Cho Plan area.

Ecozone	Ecoregion
Taiga Cordillera	Mackenzie Mountains Selwyn Mountains
Taiga Plains	Franklin Mountains Great Bear Lake Plain Great Slave Lake Plain Hay River Lowland Horn Plateau Keller Lake Plain Mackenzie River Plain Muskwa Plateau Nahanni Plateau Norman Range Northern Alberta Uplands Peel River Plateau Sibbeston Lake Plain
Boreal Cordillera	Hyland Highland Liard Basin Pelly Mountains

Most of the Plan area is within the **Taiga Plains Ecozone**. It is bordered on the west by cordilleran mountain ranges oriented north-south, to the east by two large lakes – Great Slave Lake and Great Bear Lake, to the north by the extensive Mackenzie Delta, and to the south by the closed forests of the Boreal Plains Ecozone. Characteristic vegetation of the Taiga Plains Ecozone is open (generally slow-growing), conifer forests dominated by black spruce (*Picea mariana*). The shrub component is often well developed and includes dwarf birch (*Betula nana*), Labrador tea (*Ledum groenlandicum*) and willow (*Salix* spp.). Bearberry (*Arctostaphylos uva-ursi*), mosses (bryophytes) and sedges (*Carex* spp.) are dominant understory species.

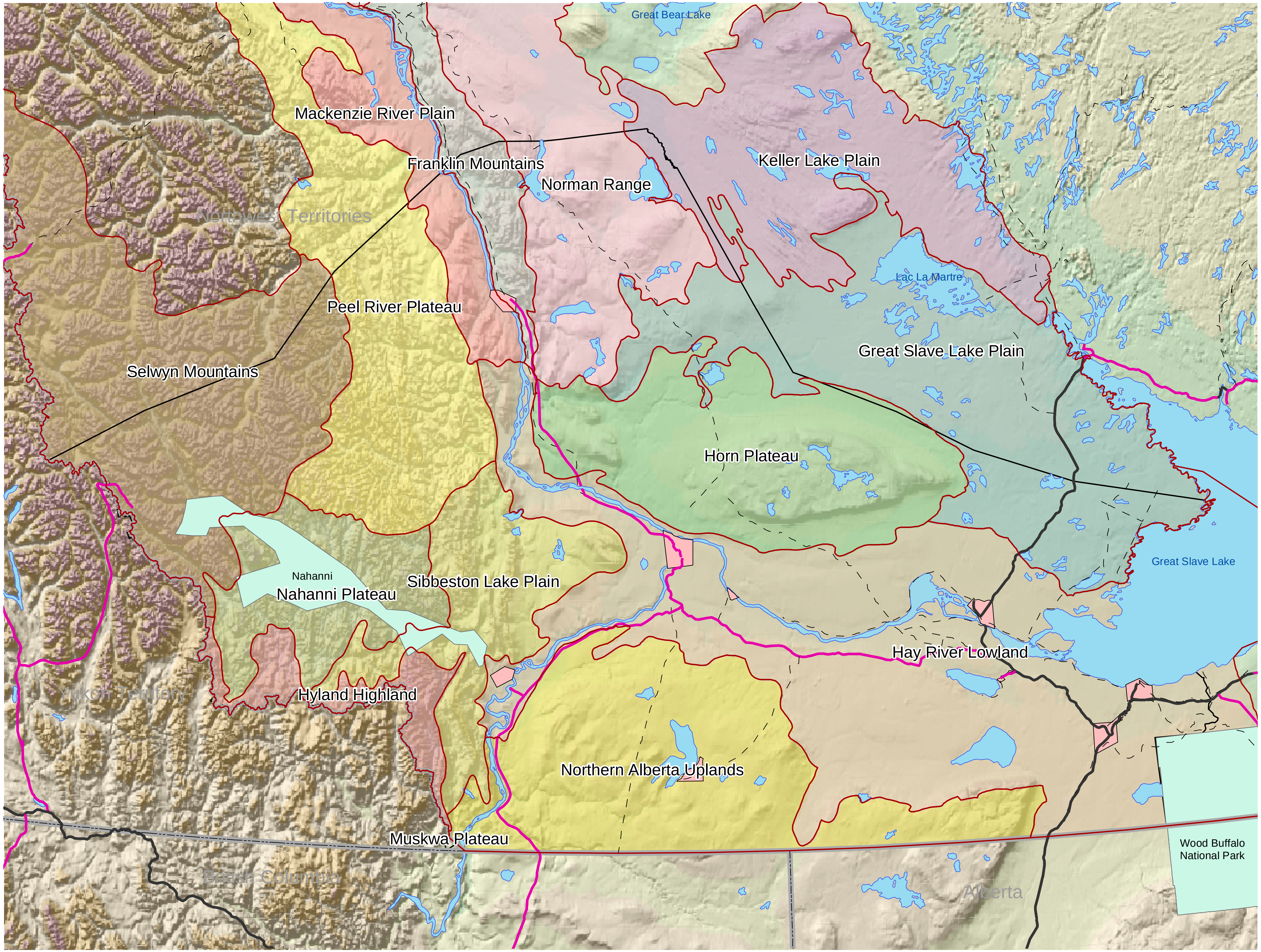
The **Taiga Cordillera Ecozone** is located along the northernmost extent of the Rocky Mountain system and covers most of the northern half of the Yukon and southwest corner of the Northwest Territories. This ecozone includes Canada's largest waterfalls, deepest canyons, and wildest rivers. Vegetation of the Taiga Cordillera Ecozone ranges from arctic tundra (dwarf or low shrubs, mosses, lichens, and cottongrass (*Eriophorum* spp.)) in the north, to alpine tundra (dwarf shrubs, lichens, saxifrages (*Saxifraga integrifolia*) and mountain avens (*Dryas* spp.)) at higher elevations and taiga or open woodland in the south (white spruce (*Picea glauca*) and white birch (*Betula papyrifera*)), mixed with medium to low shrubs (dwarf birches and willows), mosses and lichens.

Deh Cho Cumulative Effects Study

Ecoregions of the Deh Cho Plan area

Figure 1

DEH CHO LAND USE PLANNING COMMITTEE
One Land One Plan



features

Ecoregion Boundary

- Franklin Mountains
- Great Slave Lake Plain
- Hay River Lowland
- Horn Plateau
- Hyland Highland
- Keller Lake Plain
- Mackenzie River Plain
- Muskwa Plateau
- Nahanni Plateau
- Norman Range
- Northern Alberta Uplands
- Peel River Plateau
- National Parks
- Municipal Areas
- Revised Interim Plan Area Boundary
- Other Transportation Surface
- Paved Surface
- Unpaved Surface
- Provincial Border
- Selwyn Mountains
- Sibbeston Lake Plain

AXYS

NORTH

0 25 50 75 100 km

1:2,500,000

Study Area

Sources:

Deh Cho Land Use Planning Committee

Projection:

Lambert Conformal Conic
Central Meridian 122W
Reference Latitude 60N
Standard Parallel 1 60N
Standard Parallel 2 65N

Datum:

NAD 83

The **Boreal Cordillera Ecozone** is located in the midsection of the cordilleran system. It covers sections of northern British Columbia, the southern Yukon and includes a small area in the NWT. Characteristic vegetation includes closed to open boreal forest.

2.1.3 Landscape Types

The main landscape types in the Deh Cho Plan area include the boreal forest, taiga, tundra/alpine, and major waterbodies. In the **forest landscape**, there are treed patches of variable size, age, structure, and species composition. Unforested openings associated with waterbodies, bedrock, and low-growing vegetative cover is also present. Within this matrix, there are human-disturbed patches such as cabins, communities, wellsites and cutblocks, as well as disturbance corridors like roads, trails, cutlines, and powerline rights-of-way. The **taiga landscape** is similar, but is dominated by conifer forests and has large open wetland areas (Figure 2).

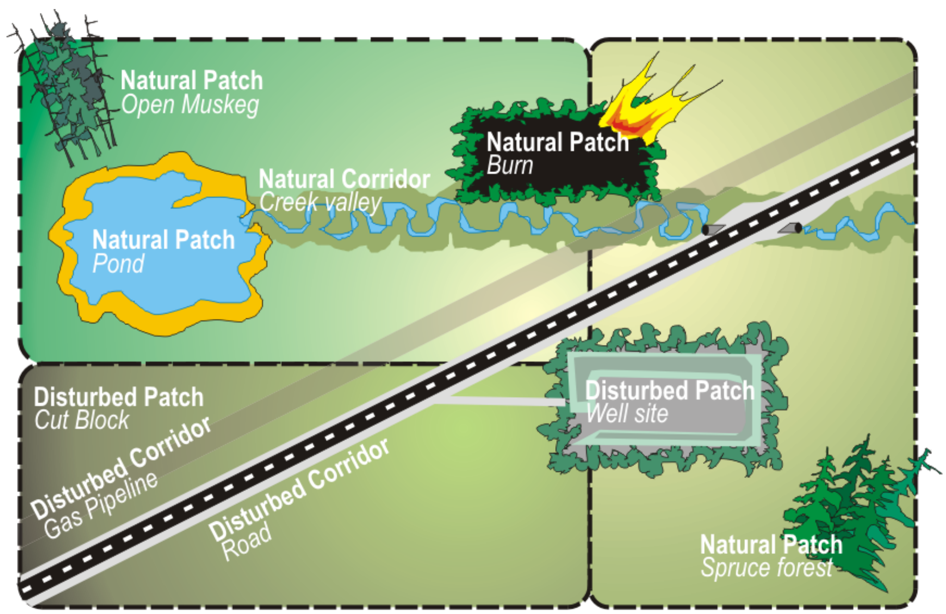


Figure 2. Elements of a taiga forest landscape.

The **tundra** or **alpine landscape** (Figure 3) is a matrix of low-growing vegetation, rock, or snow/ice with interspersed patches and corridors of trees and shrubs.

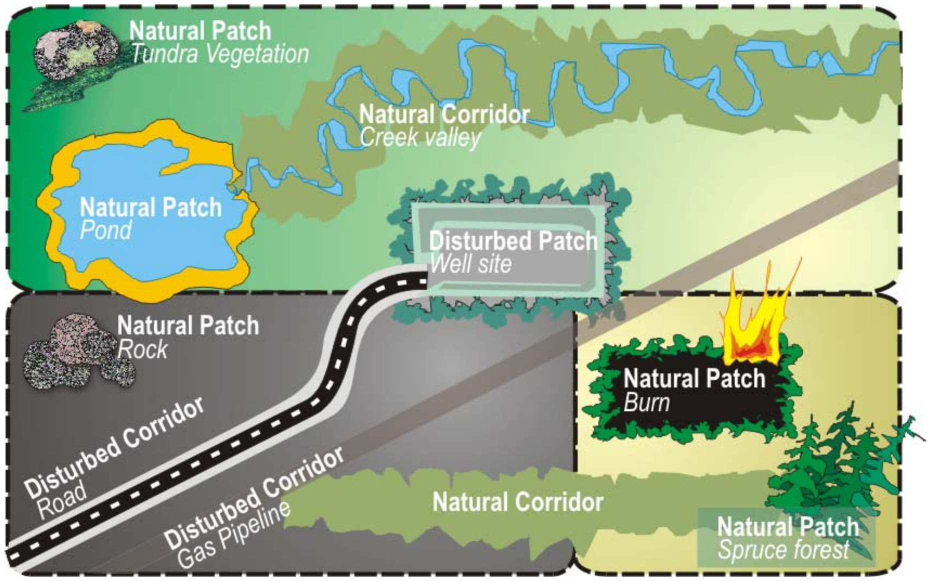


Figure 3. Elements of a tundra or alpine landscape.

2.2 AQUATIC HABITAT CLASSIFICATION

Watersheds are topographically-defined areas within which surface water runoff drains to a lake or stream. Watersheds are generally accepted to be an appropriate study and management unit for aquatic resources because the quantity and quality of water and associated habitat at a specific point reflects the aggregate physical, chemical, and biotic factors upstream of this point (Omernik and Bailey 1997).

Watersheds in the Deh Cho Plan area were mapped by the DCLUPC (Deh Cho Atlas; DCLUPC 2003) based on digital elevation model and hydrology data provided in the Natural Resources Canada National Atlas.

The following aquatic classification hierarchy is used in this report:

- **Plan area**: all watersheds and smaller aquatic habitat classes found within the 210,000 km^2 Deh Cho Revised Interim Measures area.
- **Basin**: the largest watershed unit comprising 10,000 km^2 or more.
- **Watershed**: a large drainage area, generally 1,000 to 10,000 km^2 in size that flows directly into a large river such as the Mackenzie River.
- **Subwatershed or drainage**: a subset of a watershed, generally less than 1,000 km^2 in size.
- **Waterbody**: a specific lake, pond, wetland, river, or stream.
- **Reach**: a defined channel section, tens to thousands of meters in length, with relatively consistent channel morphology, hydrology, and water chemistry.

- **Habitat unit**: a defined unit within a reach or waterbody with consistent water depth, cover, substrate, or aquatic vegetation.

Aquatic habitat can be divided into three main components: lentic, lotic, and riparian.

- **Lentic,** or standing water**,** habitat is found in wetlands, ponds and lakes. The aquatic organisms found in a particular waterbody depend on its depth, size, substrate (bottom type), water quality, and the abundance and type of littoral (shallow nearshore) habitat, among other factors (Wetzel 1975).
- **Lotic**, or running water, habitat is found in creeks, streams, and rivers. Lotic systems normally consist of a pattern of tributaries joining one another and ultimately forming the 'mainstem' channel (Hynes 1970).
- **Riparian** areas include the banks and slopes next to streams, lakes and wetlands that are affected by elevated soil moisture levels for at least part of the year. These riparian areas protect water quality, regulate stream temperature, stabilize banks, and provide a continuous source of woody debris, nutrients, and food organisms (BCF and BCE 1995c, BCF 1999; Figure 4).

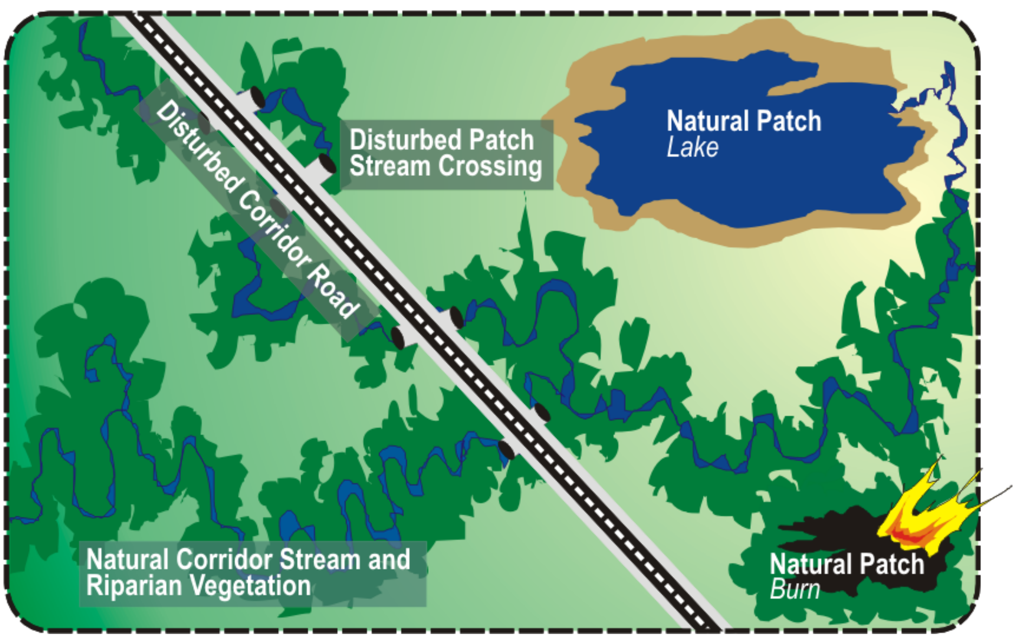


Figure 4. Elements of a watershed.

2.2.1 Watersheds

The Mackenzie River basin dominates the Plan area and gives the territory its name: Deh Cho, meaning big river. Twenty watersheds and several distinctive aquatic features are present. The largest features are Great Slave Lake and the Liard and Mackenzie rivers. Other large waterbodies include Trout, Tathlina, Buffalo, Kakisa, Willow, Bulmer, Fish, Keller, and Blackwater lakes.

2.3 NATURAL VARIABILITY

The concepts of natural range of variability and resilience to change are important for land use planning and cumulative impact management.

Environmental conditions, habitat, and populations display natural variability that result from long-term climatic trends, short-term weather fluctuations, natural succession, and random events. The **natural range of variability** is determined by these factors as well as physiographic and watershed characteristics. An underlying assumption of ecosystem management is that using natural disturbance patterns to guide management actions is one of the best possible means of achieving ecological sustainability in the absence of information on alternatives (Frissell and Bayles 1996; Andison 1999, 2000).

2.3.1 Habitat Variability

2.3.1.1 Terrestrial

The frequency and magnitude of disturbance events affect the composition, productivity, and successional state of terrestrial and riparian vegetation and stream channel characteristics (Ward 1989; Regier and Meisner 1990). Thus, the distribution, pattern, abundance, and connections between habitat units change in both time and space.

The primary natural disturbances influencing terrestrial habitat in the boreal forest are fire, insect and disease outbreaks, floods, windstorms, and beaver (*Castor canadensis*) activity. Fire is generally the most important, and natural range of variability is often related to fire regime (e.g., Weber and Flannigan 1997). Fire cycles in the boreal forest have changed at least three times in the past 300 years, probably due to climate changes. Small fires (<4 ha) have been most common, but infrequent large fires account for most of the area burned on a cumulative basis. Because fire cycles have been shorter than the lifespan of the dominant trees, old growth forest generally comprises a small percentage of the landscape in the boreal forest (Andison 1999, 2000; Johnson et al. 2001). On average, approximately 0.5-1% of forest burns each year in the NWT, although almost 40% of one detailed Deh Cho inventory area burned over the last 20 years (reviewed in PACTeam et al. 2003). Spruce budworm (*Choristoneura occidentalis*) is an increasing issue in the Deh Cho Plan area that will need to be factored into forest harvest planning (PACTeam et al. 2003). The fire history map included in the Deh Cho Atlas (DCLUPC 2003) shows that large areas have burned in the last 40 years.

Changes in long-term climatic conditions and short-term weather events can affect seasonal vegetation growth and productivity, successional patterns, and the fire regime (Weber and Flannigan 1997).

2.3.1.2 Aquatic

Disturbance events such as fires and windstorms that dramatically shape terrestrial systems may have relatively subdued long-term effects in aquatic systems (Minshall et al. 1997). Aquatic ecosystems respond more significantly to floods, acceleration of erosion, and channel barriers that have rather subtle or spatially restricted effects on terrestrial systems (Frissell and Bayles 1996). Climate and weather also affect soil moisture and evapotranspiration rates that translate into changes in basin water yield, waterbody levels, flow patterns, and surface water quality and temperature (Regier and Meisner 1990).

The frequency and magnitude of flood events affects both riparian vegetation and the characteristics of floodplain channels (Ward 1989; Regier and Meisner 1990; Meehan 1991). In the boreal forest, the spring peak flow that results from melting snow is the largest runoff event of the year in 9 years out of 10. In one year out of 10 or 15, the largest annual peak flow is produced by a summer rain event; these rain-caused peak flows are by far the largest flood events in a watershed (Alke 1995).

Beaver dams, forest fires, strong winds, and landslides, can alter water quality, channel morphology, mobilize coarse woody debris that provides cover for fish, and create barriers to movement (Meehan 1991; Young 1994; Magnan and St-Onge 2000). The location and persistence of natural barriers are particularly important for migratory species such as Arctic grayling (*Thymallus arcticus*) that undertake seasonal movements between overwintering, rearing, and spawning areas.

2.3.2 Population Variability

Northern ecosystems are characterized by large fluctuations or cycles in animal numbers. Well known examples are the decade-long cycles in snowshoe hare (*Lepus americanus*) numbers, and the large variations in lemmings (*Synaptomys* spp.), mice, and voles that occur every three to five years. There is increasing evidence that caribou (*Rangifer tarandus*) populations also cycle naturally every 75 to 90 years (Mallory and Hillis 1998). The predators of these species may also follow their prey in a cycle of high and low numbers. The cause of these fluctuations is not clearly understood, but changes in food availability, survival, and mortality rates all appear to have a role (e.g., Farnell et al. 1996; Poole and Graf 1996; Apps 1999). Populations occupying marginal or sub-optimal habitat should be expected to experience higher year-to-year fluctuations in abundance (Boulinier et al. 1998).

At any point in time, population abundance and distribution reflects habitat availability and quality, as well as biological factors such as immigration, emigration, and juvenile and adult mortality that are dictated by weather, predation rate, life history patterns, and long-term positive or negative trends in abundance (Pimm and Redfearn 1988). **Density-**

dependent factors are related to population size, while **density-independent** factors described earlier are not.

Density-dependent responses reduce population fluctuations over time. These responses include: increased reproduction and survival (generally referred to as compensation) and immigration to offset increased rates of juvenile and adult mortality; and decreased reproduction or increased dispersal to offset population increases. Density-independent factors such as environmental conditions during the winter and spring may have dramatic effects on fish and wildlife populations. Winter snow depth is critical for many resident wildlife populations (Mech et al. 1987). Weather conditions during the spring birthing period also affect newborn survival. Overwintering habitat and conditions during the spawning and emergence period may limit fish populations (Hubert et al. 1985; Ford et al. 1995; Cunjak 1996; Cattanéo et al. 2002).

2.3.3 Resilience to Change

Communities, plants, and animals differ in their inherent ability to absorb disturbance and sustain themselves over time. **Resilience** refers to the ability of a system, community, or species to absorb natural and industrial disturbance without altering its fundamental structure (Weaver et al. 1996). The resilience of selected indicators must be considered when developing thresholds or limits of acceptable change.

Although fish and wildlife species present in the Plan area have adapted to natural disturbances, individual species differ in their inherent ability to absorb disturbance and still persist as viable populations. Factors that affect animal resilience include reproductive rate, annual and seasonal home range size, population density and distribution, life expectancy, dispersal rates, ability to habituate, size, and mode of locomotion (Weaver et al. 1996). Small mammals that mature early, have high reproductive rates, and are able to exploit a wide variety of food sources have higher ecological resilience because they are more able to compensate for natural and human disturbance. In contrast, large mammals such as woodland caribou and grizzly bears (*Ursus arctos*) that range widely, have low reproductive rates, and use specialized food sources have lower ecological resilience.

At the regional scale, ecological resilience is enhanced among groups of small, extinction-prone local populations that are linked by the movement of individuals between them (Hanski and Gilpin 1991). These **metapopulations** increase resilience by spreading the risk of disturbance occurring at the local population and individual levels over time and space. Species that are spatially restricted to a single subpopulation or a few individuals have lower ecological resilience and are less likely to persist over time (Weaver et al. 1996).

At more local scales, density-dependent **population**-level responses described above minimize population fluctuations over time. Dispersal (immigration and emigration) by juveniles and adults is the mechanism by which vanishing local populations are rescued from extirpation and connectivity of metapopulations is maintained through time. In addition, local populations may exhibit a variety of life forms that increase the overall resilience of the metapopulation (Frissell and Bayles 1996; Mayhood 2001).

Finally, behavioural flexibility allows **individuals** to respond to local changes in habitat availability and quality and meet their energetic and reproductive needs (Weaver et al. 1996). This behavioural flexibility also complicates assessments of species response to both natural and human disturbance.

Communities and **social systems** also differ in their ability to absorb disturbance and sustain themselves over time. For this reason, small traditional communities may have lower resilience to external changes than large cities (Chapin and Whiteman 1998).

2.4 BIOPHYSICAL SETTING

2.4.1 Geology, Landforms, and Soils

The Deh Cho Plan area straddles two Canadian geologic provinces - the flat Interior Platform province in the east, and the mountainous Cordilleran Orogen province in the west. The Interior Platform consists of relatively flat-lying sedimentary rocks that have been deposited by sedimentary process and have remained relatively undisturbed (C.S. Lord Northern Geoscience Centre 2003). Bedrock exposures are common along lakeshores and river valleys and within the mountain ranges of the Deh Cho. Much of the area is capped in gravel, sand and till deposits of the last Wisconsin age continental glaciation, as well as glacial deposits in the Cordillera from mountain glaciers (Gal and Jones 2003).

The Interior Platform encompasses the Northern Alberta Uplands, Hay River Lowlands, Horn Plateau, Great Slave Lake Plain, Norman Range and a portion of the Sibbeston Lake Plain ecoregions. Drumlin landforms are common throughout the region. Coarse-grained glaciolacustrine deposits occupy the area near the confluence of the Liard and Mackenzie rivers (DCLUPC 2003).

Soils in this part of the Plan area are primarily organic cryosolic, gleysolic, eutric brunisolic, and Brunisolic turbic cryosolic. Areas of gray luvisolic soils can be found northeast of Great Slave Lake in the Great Slave Lake Plain and Hay River Lowland ecoregions, and in portions of the Northern Alberta Uplands ecoregion, in conjunction with Brunisolic gray luvisols (DCLUPC 2003).

The Cordilleran Orogen is comprised of folded, faulted and thrusted rocks of sedimentary, volcanic, plutonic and metamorphic origin. Although most of the rocks within the Cordilleran portion of the Deh Cho Plan area are of similar age as the Interior Platform rocks (248-65 million years), there is a significant component of much older rocks. Examples include the sedimentary Pre-Cambrian rocks that were thrust to the surface 1600-1000 million years ago at Cap Mountain, and the Mid-Cretaceous (130-87 million years old), Selwyn plutonic suite of volcanic rocks along the Yukon border in the western Deh Cho Plan area (C.S. Lord Northern Geoscience Centre 2003). Geological faults are widespread across the Cordilleran Orogen, and an active earthquake zone exists in the Peel River Plateau ecoregion (DCLUPC 2003).

Karst formations are common along the western side of the Sibbeston Lake Plain ecoregion. To the north, in the Franklin Mountains, Mackenzie River Plain and Peel River Plateau ecoregions, the surficial glaciofluvial material is interspersed with till and northwest trending drumlin landforms. The western portion of the Peel River Plateau and eastern portions of the Selwyn Mountains, Nahanni Plateau and Hyland Highland ecoregions are underlain by alluvial deposits. The western edge of the Plan area consists of alpine and glaciofluvial complexes, with several glaciers (DCLUPC 2003).

Soils of the Mackenzie River Plain and the Peel River Plateau ecoregions are primarily eutric brunisols. Soils of the Selwyn Mountains ecoregion range from gleysolic static crysolics in the east to gleysolic turbic crysolics in the west. Most of the Nahanni Plateau and Hyland Highland consist of dystric brunisolic soils (DCLUPC 2003).

The two geological provinces in the Deh Cho territory strongly influence the local and regional ecology, human settlement patterns and interaction with the land. In spite of the more rugged terrain, the Cordilleran is ‘more interesting’ from a mineral potential point of view. The geological setting in both geological provinces offer potential for a variety of mineral deposits (C.S. Lord Northern Geoscience Centre 2003).

2.4.2 Vegetation

Much of the southeastern portion of the Deh Cho Plan area, and along the Mackenzie River basin lies within the Boreal forest region (PACTeam et al. 2003). This encompasses the Northern Alberta Uplands, Hay River Lowlands, and portions of the Horn Plateau, Franklin Mountains and Mackenzie River Plain ecoregions (DCLUPC 2003). Vegetation communities include closed to open canopies of tall and low shrub, deciduous and coniferous forests (DCLUPC 2003) over much of the plateaus and valleys. Commercially viable stands are small and non-contiguous (PAC Team et al. 2003) but offer some sawlog potential.

Remaining portions of the Horn Plateau, Franklin Mountains and Mackenzie River Plain ecoregions, and much of the Great Slave Lake Plain, Norman Range, Peel River Plateau, Sibbeston Lake Plain, Nahanni Plateau, and Hyland Highland ecoregions lie within the Taiga forest region (PACTeam et al. 2003). This region is characterised by open, generally slow-growing, black spruce-dominated forests. The shrub component is often well developed and includes dwarf birch, Labrador tea and willow. Bearberry, mosses and sedges are dominant understory species (EBA 2003).

Much of the Selwyn Mountains ecoregion, and portions of the Peel River Plateau, Nahanni Plateau and Hyland Highland consist of non-forested tundra (Taiga Cordillera ecozone). Vegetation ranges from arctic tundra (dwarf or low shrubs, mosses, lichens and cottongrass) in the north, to alpine tundra (dwarf shrubs, lichens, saxifrages and mountain avens) in higher elevations and taiga or open woodland in the south (white spruce and white birch), mixed with medium to low shrubs (dwarf birches and willows), mosses and lichens (EBA 2003).

The RWED Forest Management Division has developed a vegetation LCC based on Landsat TM 5 and 7 acquired between 1992 and 2000. The primary goal of this work was to develop a fuel type database. Secondary objectives were to provide a reconnaissance tool for forest inventory, and provide vegetation information for preliminary wildlife habitat mapping. The RWED LCC is based on the classification scheme used by the National Forest Inventory. Pixel size is 30 m X 30 m and overall accuracy is between 75-80% with the exception of the non-forested wetland classes which varies from 50-75% (RWED 2002a). The LCC scheme is depicted in (Figure 5).

Black spruce and low shrub habitats dominate the Deh Cho Plan area. Less common habitats include white spruce, jack pine (*Pinus banksiana*), deciduous, and mixed forest (Gunn et al. 2002).

2.4.3 Wildlife and Wildlife Habitat

The three ecozones and 18 ecoregions represented within the Deh Cho Plan area offer considerable diversity and complexity in wildlife habitats and species. EBA (2003) reported 308 species known to have occurred, likely to occur, and that could hypothetically occur in the area. This included 3 amphibians, 36 fish, 213 birds, and 56 mammals.

EBA (2003) selected ten wildlife species as ‘Valued Ecosystem Components’ (VEC; Beanlands and Duinker 1983). These species were selected to help focus wildlife assessment and reporting in the Deh Cho Plan area, while still representing the range of wildlife and wildlife habitat values (Table 2).

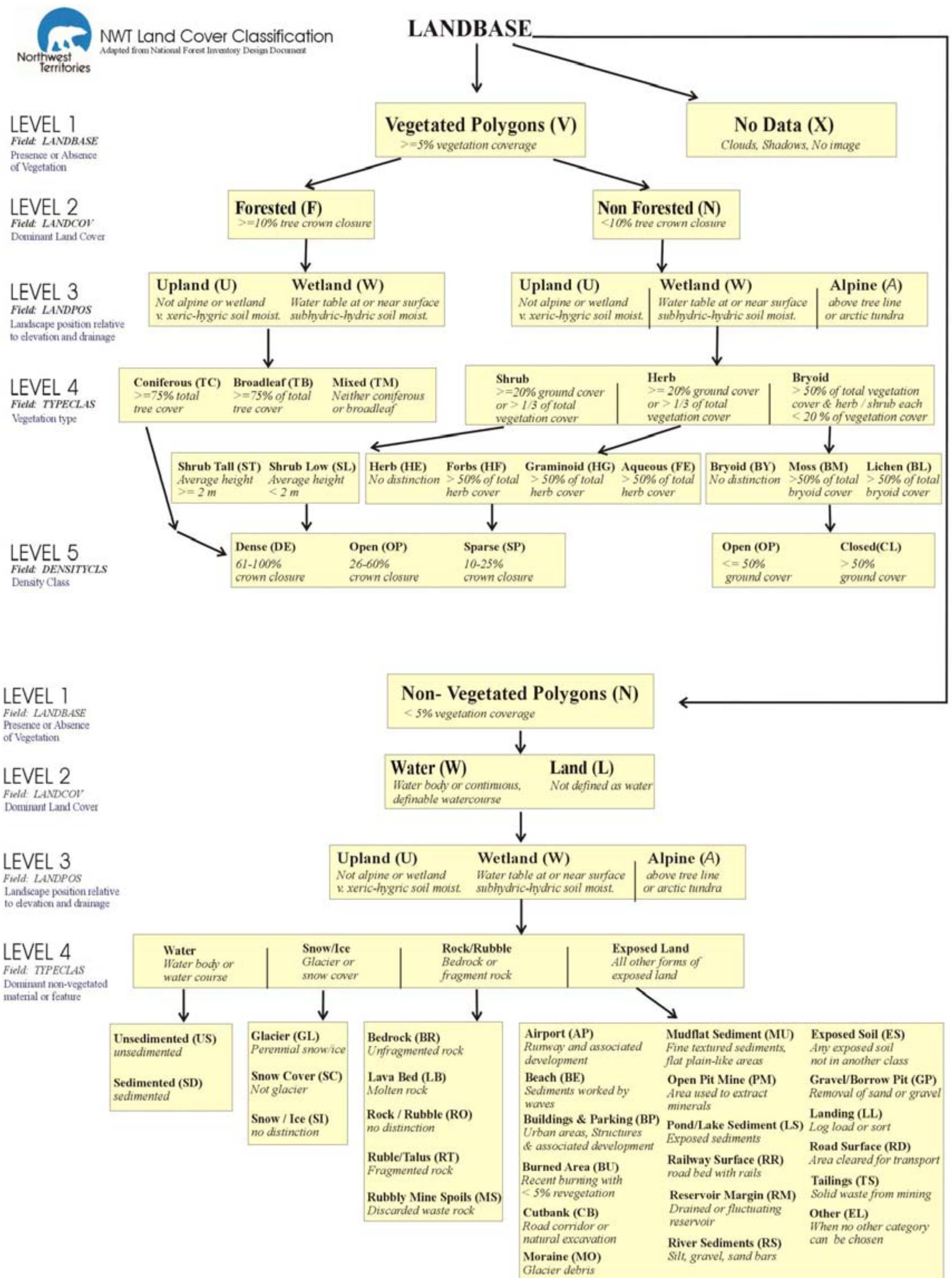


Figure 5. RWED Land Cover Classification scheme.

Table 2. Wildlife Valued Ecosystem Components selected by EBA (2003) for the Deh Cho Plan area.

Wildlife Group	Valued Ecosystem Component
Ungulates	Dall's Sheep
	Moose
	Wood Bison
	Woodland Caribou
	Mountain Goat
Carnivores	Bears (Grizzly and Black)
Birds	Waterfowl (treated collectively)
	Trumpeter Swan
	Whooping Crane
	Peregrine Falcon

EBA (2003) developed habitat rankings and mapped suitable and critical habitat for these VEC species in the Plan area. Assigned habitat rankings reflect a given unit's predicted ability to contribute towards the overall life history requirements of the species at a landscape scale. Rankings do not reflect actual numbers of animals but reflect the potential or expected use of an area by the species. Habitat was ranked using a four class system:

- **Low**: the habitat unit falls within the range of the species, but that the species does not necessarily occupy the habitat unit;
- **Medium**: the habitat unit provides all habitat functions or all habitat features for the species;
- **High**: the habitat unit serves a more critical role in the life history of the species (e.g., migration corridor);
- **Very High**: the habitat unit provides for the most critical life history aspects of the species (e.g., calving, nesting, staging, and denning areas).

Additional information on wildlife indicators is provided in Section 6.3.

2.4.4 Fish and Aquatic Habitat

There are potentially 36 species of fish occurring within lakes and rivers of the Deh Cho Plan area (EBA 2003). Of these species, 3 "May Be at Risk," 8 are assessed as "Sensitive," 11 species are considered "Secure," and the status of 14 species are

"Undetermined" (RWED 2001b). COSEWIC (2002) has only assessed the status of the shortjaw cisco (*Coregonus zenithicus*), and has assigned it "Special Concern" status.

The three species that may be "at risk" include the shortjaw cisco, inconnu (*Stenodus leucichthys*), and bull trout (*Salvelinus confluentus*). The list of "sensitive" species include several that are important sport or subsistence fishing species: Dolly Varden (*Salvelinus malma*), Arctic cisco (*Coregonus autumnalis*), Arctic grayling (*Thymallus arcticus*), and walleye (*Sander vitreus*, formerly *Stizostedion vitreum*). The remaining sensitive species include least cisco (*Coregonus sardinella*), pearl dace (*Semotilus margarita*), brook stickleback (*Culaea inconstans*), and deepwater sculpin (*Myoxocephalus quadricornis*).

All waterbodies in the Deh Cho Plan area are potential fish habitat, and fish are expected to inhabit most lakes and rivers within the Plan area, at least on a seasonal basis (e.g., migration or spawning). Fish overwinter in areas that are deep enough to maintain oxygenated water, where the ice does not reach the substrate or are fed by underground springs (EBA 2003).

Known spawning and migration sites occur in every ecoregion of the Deh Cho Plan area. The tributaries to the Mackenzie River in the Mackenzie River Plain, Hay River Lowland and Franklin Mountains ecoregions hold the highest concentrations of known spawning sites. The lakes and rivers of the Northern Alberta Uplands ecoregion also contain recognized spawning sites, and the upper reaches of the South Nahanni and its tributaries, within the Nahanni Plateau and Selwyn Mountains ecoregions contain known migration routes and spawning areas.

2.5 SOCIO-ECONOMIC SETTING

2.5.1 Communities

There are 11 communities in the Deh Cho Plan area with a combined population of approximately 6,700, including: Enterprise (pop. 88), Fort Liard (pop. 524), Fort Providence (pop. 837), Fort Simpson (pop. 1,273), Hay River (pop. 3,835), Hay River Reserve (pop. 268), Jean Marie River (pop. 50), Kakisa (pop. n/a), Nahanni Butte (pop. 82), Trout Lake (pop. n/a) and Wrigley (pop. 183; PACTeam 2003; GNWT 2000; GNWT HSS 2002a,b).

The Deh Cho is a relatively young region with 43% of the population younger than 24 years old and 35% between 25 and 44 years old. The communities of Jean Marie River and Trout Lake have comparatively older and younger residents respectively, than other communities. The regional population has grown by 35% over the last 30 years, but this trend has been accompanied by dramatic and unpredictable fluctuations. The majority of regional residents have a trade or non-university degree, but in smaller communities, education levels are relatively low. The unemployment rate in the Plan area is high relative to the rest of the NWT and Canada as a whole. Most residents are employed in the government, education and health sector, and in some communities, this sector provides the only wage opportunities (PACTeam 2003).

2.5.2 Culture

The Deh Cho First Nation Interim Measures Area is the negotiated boundary for a treaty agreement between the governments of Canada and the NWT, and the Deh Cho First Nations. The DCFN includes all the aboriginal peoples of the Deh Cho. Aboriginal peoples are descendants of Dene and may think of themselves today as Dene, Metis, Status or non-status. The member communities of the DCFN include the: Acho Dene Koe (Fort Liard), Deh Gah Gotie First Nation (Fort Providence), K'a'agee Tu First Nation (Kakisa), Katl'Odeeche First Nation (Hay River Reserve), Liidlii Kue First Nation (Fort Simpson), N'ah adehe First Nation (Nahanni Butte), Pehdzeh Ki First Nation (Wrigley), Sambaa K'e First Nation (Trout Lake), Ts'uehda First Nation (West Point), Tthe'K'ehdeli First Nation (Jean Marie River), Fort Liard Metis Nation, Fort Providence Metis Nation, and Fort Simpson Metis Nation.

Dene are people of several cultures. The primary Dene social and economic unit was variable groups, often comprised of related family members. Group size and location varied in response to changes in spatial and temporal shifts in food resources including major fisheries and caribou migration. Primary methods of travel were by canoe during open water and overland trail during summer and winter. Long-distance travel was restricted during freeze-up and break-up (Helm 2000).

In the summer or when ample food was available, local groups gathered together at a central campground – gatherings could grow as large as 200 to 250 people. These gatherings allowed elders to share their knowledge of the lands their families had travelled, and plan the best ways to continue using the lands to support their families. The Deh Cho Assembly held today – a summer gathering of the DCFN Leadership and community member representatives – continues this tradition. Every three years, the Deh Cho Assembly also selects a Grand Chief to represent community members.

Today, Deh Cho Elders encourage Dene descendants to learn and follow the ways of the ancestors when using the lands of the peoples. People now refer to this as making sustainable use of the environment. Dene continue to think of their lands in the way that other people have just begun to think of as ‘the environment’. For Deh Cho Dene descendants, the word "land" means everything natural in the Deh Cho territory: waters and air, trees, plants, berries, animals, birds, fish, and insects; what is on and what is below the surface of the land.

Important traditional harvesting and gathering areas generally have good access by foot or boat, or productive habitat for fish and wildlife. Approximately 10.1 million ha of the Plan area has been included in a network of key cultural and protected areas. These represent lands that are: used for harvesting food or for medicinal purposes; culturally and spiritually significant areas; ecologically sensitive; or important for watershed protection.

The Prince of Wales Northern Heritage Centre maintains records of all known archaeological and heritage sites. The Deh Cho Atlas (DCLUPC 2003) includes a map displaying the density of known archaeological sites. Most are located near rivers and lakes.

2.5.3 Infrastructure

The Deh Cho Plan area is accessible year-round via two highways from northern Alberta and one from northern British Columbia. The communities of Enterprise and Hay River are accessible via either the Fort Smith (paved with gravel sections) / Hay River (paved) highways from Fort Smith or by the Mackenzie Highway (paved) from High Level, Alberta. The Mackenzie Highway continues through to Kakisa and Fort Providence. Highway 3, the paved Yellowknife Highway continues northeast towards Edzo and Yellowknife, and the gravel Mackenzie Highway continues towards Jean Marie River and Fort Simpson. Trout Lake is accessible via winter road only. Near the confluence of the Liard and Mackenzie rivers, the paved Mackenzie Highway turns north toward Fort Simpson (paved) and continues north to Wrigley. A winter road continues to Norman Wells. Turning west-southwest at Fort Simpson, travellers join the gravel Liard Highway that accesses Nahanni Butte and Fort Liard (GNWT Dept. of Transportation 2003). The Liard Highway continues into northeastern British Columbia.

Scheduled Airline service is available to the asphalt runways at Fort Simpson and Hay River. The communities of Fort Liard, Fort Providence, Jean Marie River, Nahanni Butte, Trout Lake, and Wrigley have gravel airstrips, but no scheduled service.

All the communities of the Deh Cho Plan area, with the exception of Enterprise, offer education from the Kindergarten (K) level to at least Grade 6 (Kakisa Lake). Wrigley offers K-8, while Jean Marie River provides K-9 primary education. Trout Lake, Nahanni Butte and Hay River Reserve provide K-10 education. The rest offer K-12 (GNWT 2000).

Fort Liard, Fort Providence, Fort Simpson and Hay River offer adult education through Aurora College, which is physically located in Hay River. These communities also have a Health Centre and Royal Canadian Mounted Police (RCMP) detachments. A 50-bed hospital is located in Hay River. The Fort Liard detachment provides service to Nahanni Butte and Trout Lake; the Fort Providence detachment also serves Kakisa Lake. The Fort Simpson detachment covers a wider area, and covers both Jean Marie River and Wrigley. Hay River, the largest RCMP detachment also provides service to Hay River Reserve.

Many of the smaller communities have a dispensary and/or scheduled visits by nurses or doctors. Several have a clinic staffed by a Community Health Worker or a Community Health Representative.

2.5.4 Renewable Resources

2.5.4.1 Tourism

The Deh Cho Plan area offers both pristine wilderness and thriving aboriginal cultures and communities. Tourism market share in the Deh Cho is relatively small, however there are widely recognized and well-visited tourism products in the Deh Cho Plan area including the South Nahanni River, Nahanni National Park Reserve, and the Mackenzie River (Deh Cho Environmental 2003).

Tourism in the Deh Cho appeals to “rubber tire” visitors, who tend to follow established corridors such as the Mackenzie and Liard highways, Mackenzie and Liard rivers, and the South and North Nahanni rivers. The area radiating out from the larger communities of Fort Simpson, Hay River and Fort Liard offer more tourism opportunities than the regions outside the more remote communities, e.g., Wrigley and Tulita.

2.5.4.2 Forestry

Forest resource and timber potential in the Deh Cho Plan area is discussed in PACTeam et al. (2003). Detailed forest inventories are not available for the entire region, so they used coarse data to identify areas with sawlog potential. Productive forest is distributed throughout the Plan area (Deh Cho Atlas; DCLUPC 2003), but commercially viable timber stands are largely restricted to the southwest corner of the Plan area in the Liard River watershed. White spruce is the most important sawlog species in the area, but pine and aspen poplar may also be utilized.

Timber harvesting in the NWT is marginally economic and extremely sensitive to market conditions and past harvest levels have fluctuated dramatically. Evaluations suggest that the ACC in the NWT can be increased from past levels. Most of this would come from the Deh Cho region.

2.5.5 Non-renewable Resources

Increasing oil and gas exploration coupled with the proposed pipeline from the Mackenzie Delta through the Mackenzie Valley to northwest Alberta (the Mackenzie Gas Project) suggest that oil and gas activity will be a continuing land use in the Deh Cho Plan area. The following summary of petroleum resource potential is taken from PACTeam (2003) except where noted.

The National Energy Board (NEB) estimates that the Deh Cho Plan area contains over six trillion cubic feet of undiscovered natural gas (Oil and Gas Human Resource Development Committee 2000). The Fort Liard and Cameron Hills areas are seeing increasing activity that is estimated to almost double from 14 applications requiring regulatory approval in 2001/2002 to 24 applications in 2003/2004. Annual investment in the Fort Liard area alone has already surpassed $10 million dollars and this activity is expected to remain steady through to 2011 (RWED 2001c; Ad Hoc Committee on

Common Assumptions RWED 2002c). "Although exploration activity is influenced by external factors such as the price of natural gas and oil and the availability of transportation systems, if the Deh Cho region were fully open for business, there could be renewed exploration activity similar to northern Alberta and British Columbia" (Oil and Gas Human Resource Development Committee 2000).

The proposed Mackenzie Valley pipeline would travel south through the Deh Cho Plan area in closest proximity to Wrigley, Fort Simpson, Trout Lake, and Jean Marie River. This project would have direct and indirect effects on all communities in the Deh Cho. The development of this pipeline has already contributed to job creation and economic development to the area. According to the Mackenzie Gas Project newsletter "Focus on Jobs" (November/December 2002), people and companies based in the Deh Cho are involved in all aspects of pipeline preparation including the collection of environmental, socioeconomic and traditional knowledge, engineering and air transportation. As the Mackenzie Valley Project moves into the construction and then operational phases, business and employment opportunities will emerge. Thousands of person hours will be created in a variety of positions during the two year construction phase (Imperial et al. 2003).

2.5.5.1 Mining

In addition to oil and gas resources, minerals including diamonds, gold, lead-zinc, and tungsten are contributing to the growth of the NWT economy. In the Deh Cho Plan area, tungsten and lead-zinc are more important mineral resources than diamonds or gold. The Cantung Mine, a post-producer of tungsten trioxide is located near the western extremity of the Deh Cho Plan area. Operations closed in 1986 due to the flooding of western markets with low-priced Chinese and Russian tungsten, but the mine reopened in 2002 to extract the remaining three years of production (approx. 900,000 tonnes; NNSL 2003). The mine employs 130 people directly, as well as private contractors. Most of the mine's employees live in the Yukon (NNSL 2003).

Some significant zinc-lead-silver-copper deposits are also located in the Deh Cho. It is estimated that the mine in the Prairie Creek area (eastern end of the Nahanni National Park Reserve) has mineral resource of 11.8 million tonnes grading 10.1% lead, 12.5% zinc, 0.4% copper and 161 g/tonne silver (CZC 2001). Mineral resource development in the Deh Cho opens the opportunity to create jobs and secondary businesses for Deh Cho residents.

3. GIS DATABASE EVALUATION

The following GIS data from the Deh Cho Plan area were provided by the DCLUPC:

1. Spatial data used in creation of the "Deh Cho Atlas Version 2b", July 2003 (DCLUPC 2003).
2. Recently collected spatial data layers which do not appear to be part of the Deh Cho Atlas (DCLUPC 2003).
3. Northwest Territories LCC derived from Landsat TM 5 and 7 images acquired between 1992 and 2000 (mainly 1996-1999). Images selected were from the 'green-up' phase between early June and late August (RWED 2002a).
4. Forest Management Main Vegetation Types (Vegetation Types) classification derived from the LCC for wildlife habitat mapping and fire fuel interpretations (RWED 2002a).
5. Anthropogenic Features (Land Use Features) classification derived from Colt Geomatics Ltd. interpretation of Indian Resource Satellite (IRS) satellite imagery at 5 m resolution. This interpretation was commissioned by the DCLUPC.
6. Wildlife Survey and Caribou probability of occurrence (Wildlife) data layers generated by RWED (Gunn et al. 2002) and wildlife distribution maps generated by EBA (2003).
7. Sawlog Potential and Merchantable Timber (Timber) data layers generated by PACTeam et al. (2003) for some parts of the Plan area.

These data were evaluated to verify the quality and accuracy of the combined dataset. Key considerations were the satellite imagery classification scheme and accuracy, the attributes assigned to land use features in the GIS land use features layer, and the suitability of these data for use in the ALCES II® model.

3.1 SPATIALLY-EXPLICIT DATA

3.1.1 Deh Cho Atlas

From a purely spatial data perspective, the suite of layers provided by the DCLUPC appear to be of good quality and are well documented. Much of the data was obtained from various sources outside of the direct influence from the DCLUPC. The providers include: the National Atlas of Canada, Environment Canada, World Wildlife Fund and other government agencies. The scales of data capture lend themselves well for mapping, but less so for cumulative effects analyses. However, the datasets provided in the Deh Cho Atlas will be of assistance as a supplementary source of information when generating and interpreting landscape summaries.

3.1.2 Land Cover Classification

The DCLUPC have provided a spatial dataset that can be used to represent the vegetated landscape for almost all of the area of interest. The actual dataset is considered to be 'work in progress', but in light of the available alternatives, this will be the best dataset to work with at this time. The dataset was generated from satellite imagery by RWED and reported to be accurate 75-80% of the time with the exception of the non-forested wetland classes which varies from 50-75%. Supporting documentation indicates that the forested wetlands class (Level 3) should be interpreted with caution (RWED 2002a).

The current spatial resolution of the land cover is 900 m^2 (30 m X 30 m pixels). For comparison, previous ALCES implementations have occurred with spatial data resolution of approximately 2000 m^2 for the land cover. The spatial resolution of this dataset is considered to be sufficient to generate landscape level summaries of broad vegetation types which are required by the ALCES model. The resolution of the data is not sufficient to directly identify many vegetated or non-vegetated anthropogenic features. This type of information will have to be obtained from alternative data sources. This is especially true for wellsites, seismic lines, and other industrial related features which are present on the landscape, but are not captured at the resolution of the data.

No stand age data are available for the LCC. Forest age class information is critical for wildlife habitat mapping and simulations of cumulative effects resulting from combined natural and human disturbance. Representative forest age class distributions for the Deh Cho Plan area will need to be generated from alternative data sources.

A low resolution image of LCC coverage for the Deh Cho Plan area provided in Figure 6 demonstrates that several issues must be considered prior to generation of regional vegetation unit summaries:

- There appears to be a fair amount of 'speckle' with the dataset (isolated cells which differ from surrounding cells). This is very evident in the water polygons. The data should be filtered to become suitable for a workable and representative landscape summary.
- The base classification leaves apparent and consistent blocks which are not consistently classified. This may be related to the dates in which air truthing was completed. Nonetheless, there appears to be a systematic inclusion, or exclusion, of the classification schema. Note, the image depicted is the top level of the hierarchy and sub classes would be inherited from this class.
- There appear to be large areas in which there was insufficient data for classification. In these areas, significant filtering should occur to alleviate the lack of a contiguous land classification.
- The LCC is a very large dataset. For more efficient analysis, it should be filtered to reduce the speckles and to generalize large cover types. Various filters will need to be applied to determine which one will best represent the land base and retain the level of detail necessary for analysis.

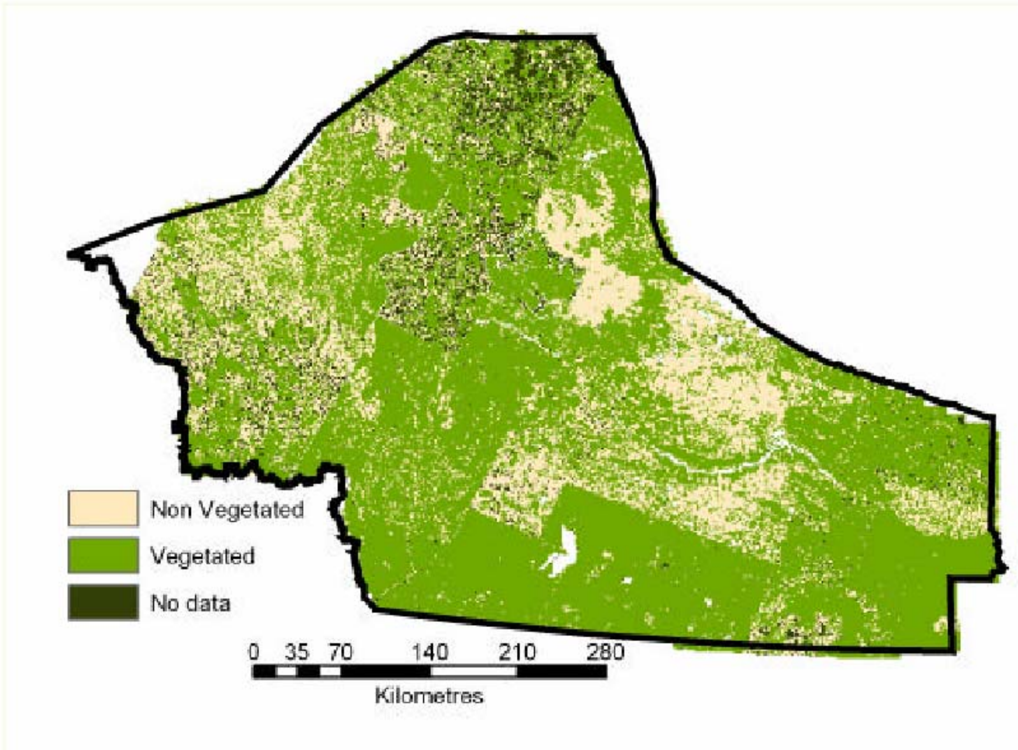


Figure 6. Land Cover Classification coverage for the Deh Cho Plan area (note the linear changes between non vegetated and vegetated land, also, the large sections of 'no data' in the North).

3.1.3 Vegetation Types

PACTeam et al. (2003) reviewed existing forest inventories for the Deh Cho Plan area and generated sawlog potential maps. They developed vector-based polygons for white spruce, jack pine, and aspen stands. Forest inventory data cover only 25% of the region, so LCC coverage was used outside these areas. Forest inventory data could be used to complement the existing LCC in some areas of the Plan area. Ideally, any spatially-explicit habitat mapping should be completed in these areas.

RWED has completed an alternate classification of the LCC data that breaks the classification into major vegetation types (the Forest Management Main Vegetation Types), comparable to Level 4 in the LCC (Figure 5; Section 2.4.2). The breakdown is not directly supported by the LCC classification structure, but supporting documentation claims that the breakdown is 80% accurate for the dominant vegetation type in the Deh Cho Plan area. This classification scheme identifies 16 different vegetation classes for the Plan area. The Vegetation Types classification was designed to be used for fire hazard analyses and preliminary wildlife habitat mapping.

Gunn et al. (2002) used the Vegetation Types dataset to predict probability of woodland caribou occurrence in the region. This vegetation classification scheme should be used for the Deh Cho CE study to be consistent with their ongoing work.

3.1.4 Land Use Features

IRS imagery has been used to delineate anthropogenic features for the DCLUPC. This provides an important and frequently unavailable data source because the resolution of Landsat TM data is not sufficiently fine to correctly map or classify all land use features. Land use information is presented as both lines (linear features) and polygons (point features).

The CE team was provided with Phase 1 IRS imagery that covers approximately 64% of the Plan area. IRS imagery for the remainder of the Plan area will be available for CE Phase 2. Supporting documentation on how the IRS was interpreted was not provided (i.e., no details on how the different features were identified). This is not of paramount importance as reasonable assumptions on feature types and attributes can be made from other sources (such as National Energy Board data; Cizek et al. 2002; Cizek 2003) if required. For example, it is likely that many of the polygons classified as 'clearing' in the Fort Liard and Cameron Hills areas were once, or currently are, 'wellsites'.

Unfortunately, no width estimates were generated for linear features. Although this would be nice to have, estimated width of features will have to be assumed. If a further accuracy and consistency is desired, feature widths could be determined from random IRS images as part of CE Phase 2 work.

3.1.5 Wildlife Habitat

Gunn et al. (2002) developed caribou probability of occurrence data for 100 km^2 cells (10 km X 10 km). These ratings are based on logistic regression equations, survey results, and traditional knowledge.

3.2 ALCES® MODEL

A licensed copy of the A Landscape Cumulative Effects Simulator (ALCES®, Version II) program registered to the DCLUPC was obtained. This model, developed by Forem Technologies Ltd. (www.foremtech.com), is a spatially proportional landscape simulator that integrates four sub-models (terrestrial and aquatic habitat availability, animal and human population, land use, natural disturbance). ALCES uses spatial information on existing **Landscape** and **Land use** patterns to simulate past, current, and future conditions. It considers all land use activities likely to occur in the Deh Cho Plan area, including traditional aboriginal uses, and is able to incorporate stochasticity (e.g., random fire and climate events). Its greatest strength is its ability to rapidly incorporate user-defined changes so that the effect of various development scenarios and management options on future ecological and social indicators can be visualized (Salmo et al. 2001).

The ALCES model was selected for the Deh Cho CE study because it allows numerous exploratory land use scenarios to be completed quickly so that trade-offs and potential cumulative ecological and social effects can be explicitly evaluated. This will provide information on optimum (as defined by residents and managers) land and resource management plans and strategies.

3.2.1 Landscape Types

The ALCES base model provided to the DCLUPC categorizes landscape patterns based on the Alberta Vegetation Inventory (AVI, Version 2.2) hierarchical classification system. This classification system is not used in the NWT, so the ALCES model was modified to accept the RWED Vegetation Types system (see Section 2.1.1). Land use information for the ALCES model was derived from the Land Use Features data layer provided by the DCLUPC as described in Section 3.1.4). The NWT Vegetation Types and LCC data do not include information on forest age.

Landscape types incorporated into the Deh Cho ALCES model are summarized in Table 3. ALCES can model up to 24 landscape types so the 16 classes identified in the RWED Vegetation Types system can all be used. An additional class was included for watercourses (moving water) to incorporate data from the 'watershed' layer.

Table 3. Landscape classes included in the Deh Cho ALCES model.

NWT Forest Management Main Vegetation Type Class	ALCES Class
Deciduous	Dec
Jackpine	JPine
Mixed forest	Mix
Spruce-lichen boreal forest	SprLic
White spruce	Wspruce
Herbaceous	Herbaceous
Lichen dominant	Lichen_Dominant
Low shrubland	Low_Shrub
Tall shrubland/open/immature deciduous and/or immature conifers open	Tall_Shrub
Sphagnum moss with scattered spruce	Sphag_Moss
Fire regeneration/low shrubland open	Low_Shrub_Open
Fire regeneration sparsely vegetated)	Sparsely_Veg
Wetland	Wetland
Moving water	Moving_Water
Standing water	Standing_Water
Rock; bedrock	Rock_Bedrock
Snow/Ice	Snow_Ice
No data; shadow; Clouds or smoke or ice; Cloud or rock shadow;	No_Data
Exposed soil	Exposed_Soil

Representative forest age class structure is needed for wildlife habitat simulations. A reasonable fire regime also needs to be identified to evaluate the effects of natural disturbance. The following options are available:

- Apply age class data available from part of the study area (e.g., age class data generated by Canadian Wildlife Service for the Fort Liard area and fire data generated by RWED).
- Generate representative age class data using Monte Carlo simulations and selected fire regime.
- Apply fire regime data generated by Parks Canada for Wood Buffalo National Park.
- Assume constant fire cycle of 125 year cycle for coniferous forest (coniferous or coniferous-dominated) and 100 year cycle for hardwood (deciduous or deciduous-dominated) forest as recommended for boreal forests in the nearby Fort Nelson region (BCF and MELP 1999a).

3.2.2 Land Use Features

Land use information for the Deh Cho Plan area was taken from the features interpretation generated from IRS satellite images. ALCES is limited to 17 land use types, so the IRS feature classification was modified into 17 cover types for the Deh Cho ALCES model (Table 4).

Table 4. Land use categories included in the Deh Cho ALCES model.

IRS Feature Class	ALCES Class
Transportation	
Primary Road	Prim_Road
Secondary Road	Second_Road
Trail, Winter Road	Trail_Winter_Road
Airport	Airport
Railway	Rail
Community	
Community	Community
Clearing (assigned)	Cabin_Clear
Energy	
Seismic	Seismic_Line
Well Site	Wellsite
Gas Pipeline, Oil Pipeline	Trans_Pipe
Gas Feeder Pipeline, Oil Feeder Pipeline	Gath_Pipe
Gas Plant; Clearing (assigned)	Facil_Clear
Forestry	
Clearing (assigned)	Cutblock
Recreation	
Campground, Golf Course, Clearing (assigned)	Recreational

cont'd

Table 4. Land use categories included in the Deh Cho ALCES model (cont'd).

IRS Feature Class	ALCES Class
Mining	
Quarry, Pull Out	Quarry
Mine	Mine
Assorted	
Lumber Mill, Radio Tower, Dump, Junk Yard, Sewage	Assorted_Ind

3.2.3 Simulations

Developing scenarios of likely future development activities in the Deh Cho Plan area presents significant challenges – evidence from elsewhere demonstrates that there is considerable uncertainty associated with development projections in comparatively undeveloped areas. The Deh Cho ALCES model will be configured so that simulations of future indicator conditions can be run using land use scenarios to be generated by the DCLUPC. This will allow the impact of changes in development rates or management objectives to be more easily visualized at the regional and sub-regional scale.

3.2.3.1 Social Indicators

ALCES can track the following social, cultural, and economic indicators:

- Size and growth of the human population and communities.
- Expansion of human communities into surrounding landscape types (e.g., forests).
- Production and treatment of human waste.
- Water requirements and availability for human population.
- Electricity requirements.
- Revenue and jobs generated by the energy and forest sectors.
- Traditional trap lines, trails, hunting areas, camps, and spiritual and cultural sites.
- Effects of buffering traditional use areas to explore consequences to other human land uses (forestry, energy, recreation).

3.2.3.2 Land Use Indicators

ALCES can track the following land use indicators:

- Growth in footprints associated with tourism industry.
- Length and area of motorized and non-motorized trail networks, railways, airstrips, flight paths.
- Vehicle use rates of road network.

- Number, age, and construction costs of bridges and culverts built as the transportation network is constructed over the stream network on the landscape
- Forest harvest levels (Annual Allowable Cut [AAC] and Long-Run Sustainable Yield [LRSY]).
- Logging and fire disturbance rates.
- Economic profile of various forest harvest scenarios.
- Forest patch size metrics.
- Historic, current, and future footprint associated with petroleum activities.
- Area, edge, and age class structure of energy sector footprints including seismic lines, wellsites, pipelines, surface mines, and processing plants.
- Quantity of hydrocarbons extracted from reserves.
- Remaining hydrocarbon reserve size.
- Revegetation rates of seismic lines, wellsites, and pipelines.
- Landscape fragmentation associated with the energy and forest sector.
- Roads and stream crossings.
- Frequency of fish barriers associated with stream crossings (calculated).

3.2.3.3 Wildlife Indicators

ALCES can simulate changes in habitat suitability for up to four wildlife species. Resource selection function-based analyses can be completed for one of these species. The Deh Cho ALCES model was modified to track habitat suitability for the four focal species discussed in Section 6.3: woodland caribou, moose, marten, and grizzly bear.

The following wildlife attributes can be tracked for these four species:

- Changes in habitat quantity and quality through time.
- Changes in size and composition of populations.
- Harvest and mortality rates for populations including sport harvest, aboriginal harvest, poaching, vehicular mortality, translocations, natural predation, and density-independent mortality.
- Effects of complete or partial land use feature buffering (roads, seismic, cutblocks, wellsites) on quantity and quality of habitat.

3.2.3.4 Aquatic Indicators

ALCES can track the following aquatic indicators:

- Area and edge of standing water (ponds, lakes).

- Flow and volume of water in aquatic systems (both surface and subsurface).
- Discontinuities of moving water (streams) caused by hanging culverts associated with the road network.
- Annual variation in water levels associated with variation in annual precipitation and changes in water absorption of a working landscape.
- Changes in water temperature associated with forest clearing.
- Changes in sediment and nutrient input into aquatic systems.
- Water volumes removed from standing and moving water.

4. MANAGEMENT INDICATORS AND THRESHOLDS

This section describes key concepts on using indicators and thresholds for land and resource management. This includes discussions on indicators (Section 4.1), thresholds (Section 4.2), and several comprehensive indicator frameworks that have been adopted elsewhere in Canada (Section 4.3).

4.1 WHY INDICATORS?

> An **indicator** is defined as a characteristic of the social or ecological setting that is used to describe, measure, manage, and report on factors that are of value to the public. In other words, they can be used to quickly provide a good idea of what's happening in the Deh Cho Plan area.

Limited time and resources make it impractical for a land use plan to consider all biophysical and social factors in equal detail. In addition, land management guidelines need to be flexible to apply to diverse land use situations and proposals. Ecological and social indicators are commonly used to summarize information and help focus land and resource management activities (Kelly and Harwell 1990; Noss 1990; Cairns et al. 1993; ELI 2003).

Selection of appropriate indicators is a critical step that has received extensive discussion in guidance documents and scientific literature. A suite of complementary indicators is generally believed to be more appropriate for both project and resource management purposes because a single indicator is not capable of tracking all pertinent factors. Each indicator measures a particular facet or facets of the ecological or social setting (Beanlands and Duinker 1983; Kelly and Harwell 1990; Noss 1990; Cocklin and others 1992a,b; Cairns and others 1993; FEARO 1994; Shoemaker 1994; Smit and Spaling 1995; Griffith 1998; Hegmann and others 1999; GRI 2002; Macleod 2002; Schiller et al. 2001).

According to SRUNA (2000), a good community indicator is one where:

- The standard is known;
- The means of measurement has been clarified and can be measured by all;
- Baseline information exists; and
- There is widespread acceptance of the action to be taken if measurement shows that the limit has been exceeded.

Ideal attributes of cumulative ecological indicators (Noss 1990; Husseini et al. 1996; Macleod 2002; NRTEE 2003; Schiller et al. 2001) are:

- Clear and understandable by non-scientists;
- Easy and cost-effective to collect, measure, or calculate;
- Informative on desired ecological or social conditions and values (i.e., outcomes);

- Sufficiently sensitive to provide an early warning of change;
- Applicable to a broad geographic area and long time frames;
- Capable of providing a continuous assessment from low through intensive land use;
- Predictable and accurate with low variability;
- Able to differentiate between natural and human-induced changes; and
- Taken as a suite, indicative of overall ecological conditions.

Suites of indicators have been developed elsewhere in Canada for sustainable forest harvest (CCFM 1995, 1997, 2003; CSA 1996; FMF 2003) and sustainable development (NRTEE 2003). Indicators have also been developed to monitor social conditions in the NWT (WKSS 2001; GNWT 2000, 2002). No simple, widely accepted suite of social and ecological indicators exists however because of the inherent complexity of these systems, and the influence of local conditions. Nevertheless, we do not have the resources to deal with all problems in all places as if they were completely new (Kelly and Harwell 1990). Existing suites of indicators therefore must be explicitly considered in the context of the Deh Cho Plan area setting described earlier.

Indicators have been classified into four types for this report: physical and chemical; ecological; land and resource use, and social. Descriptions and examples of each type are included in Table 5.

4.2 THRESHOLDS AND LIMITS OF ACCEPTABLE CHANGE

> A **threshold** is defined as a point at which an indicator changes to an unacceptable condition, with acceptability defined either from an ecological or social perspective. In other words, they can be used to quickly provide a good idea of whether combined land use in the Deh Cho Plan area is acceptable or unacceptable.

Thresholds should be based on measurable, attainable, and applicable attributes of ecosystems, communities, assemblages, or species (Merigliano et al. 1997; Hughes et al. 1998; Axys 2000). Thresholds are assumed to provide an objective, science-based standard to evaluate the acceptability of project-specific and cumulative effects (Ziemer 1994; Figure 7).

Table 5. Types of land and resource management indicators.

Indicator Type	Description	Examples
Physical and Chemical **(air and water quality; body burden)**	Based on measurements or predictions of air, water, soil conditions or tissue samples. These indicators, and associated management criteria or thresholds, have been extensively used in the NWT and elsewhere.	• Ambient ground level sulphur dioxide concentration. • Drinking water mercury concentration. • Contaminant exposure (e.g., annual sulphate deposition). • Body burden (e.g., tissue mercury content).
Ecological **(habitat; population; biodiversity; risk-based)**	Consider ecosystem measures such as biodiversity, habitat conditions, and abundance or distribution of species, communities or guilds. These indicators are widely used for regulatory review and State of the Environment reporting. Unlike physical and chemical indicators, established ecological thresholds have been applied only rarely.	• Amount of suitable habitat within a specified geographic area or watershed (e.g., greater than 60% moderate and high suitability habitat). • Number of animals in a specific geographic area or waterbody (e.g., 1,800 moose in a specified Wildlife Management Unit).
Land and Resource Use **(disturbance footprint and intensity)**	Measure the footprint of human disturbance or the intensity of human activities. These indicators are widely used for regulatory review and State of the Environment reporting, but established land use thresholds are uncommon.	• Human disturbance rate (e.g., backcountry trail use in persons/month). • Length of roads and trails per square kilometre. • Area disturbed for infrastructure and industrial activity.
Social **(community health and well being; economic; resource use)**	Describe attributes of communities, economies, or cultures and have been more widely used than ecological and land use indicators.	• Average household income. • Country food consumption rate. • Overall landscape change as subjectively expressed by residents and recreational land users (e.g., viewshed integrity). • Education level.

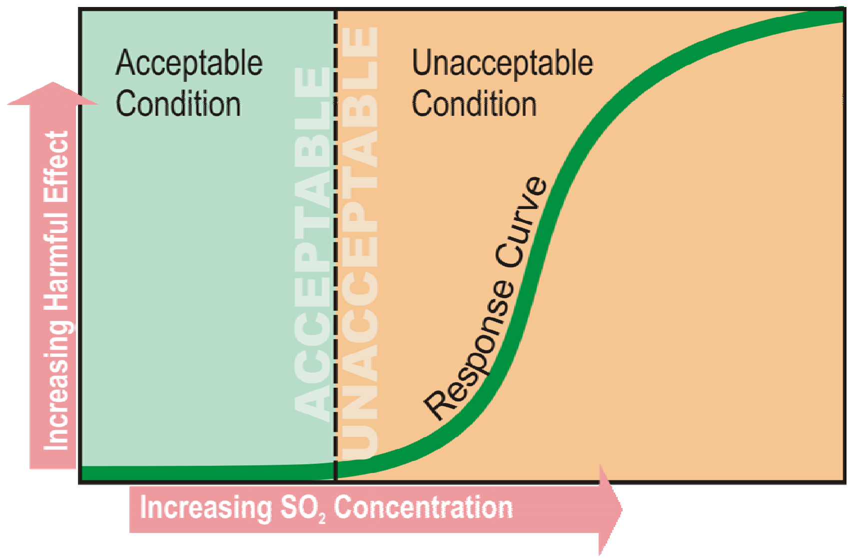


Figure 7. Theoretical dose-response curve showing an effect threshold.

Thresholds may be based on outcomes (e.g., desired conditions) or inputs (e.g., amount of disturbance). Outcome-based thresholds are preferred because outcomes can be influenced by more than one input and it is the outcome that is important from a management perspective. Nevertheless, thresholds based on acceptable inputs are required when desired outcomes cannot be practically defined (Merigliano et al. 1997).

A perceived regulatory advantage of thresholds is that they allow development activities to proceed without detailed review until the defined threshold is reached. In other words, if the incremental effects of a proposed activity do not cause the defined threshold to be exceeded, then effects are concluded to be insignificant and the proposed activity is typically viewed as acceptable. However, once the threshold range is reached, additional review, impact management, or regulation becomes necessary (Ziemer 1994; Axys 2000).

The social and ecological indicators selected for the Deh Cho Plan area should be directly linked to management priorities established in the land use plan. Because Deh Cho priorities are not yet available, the candidate indicators identified in this report are those considered to be most appropriate for this region. These will need to be reviewed and confirmed once Deh Cho land use planning priorities are established.

> **Limits of Acceptable Change** (LAC) are socially defined endpoints or thresholds that reflect the desired balance between human activities and ecological and social sustainability.

The LAC concept acknowledges that human activities will continue to occur and sets boundaries on the extent of change that will be permitted. Macleod (2002) reviews the

LAC approach in detail and discusses its applicability to the NWT. The terms 'thresholds' and 'limits of acceptable change' will be used interchangeably in this report.

4.3 INDICATOR FRAMEWORKS

> "Given the inherent complexity of ecological systems, scientists are understandably reticent about providing exact prescriptions for land use planning and design because the answers vary depending upon the species, ecosystem, or scale in question. Nevertheless, by not promoting the use of even partial knowledge about species or ecosystem responses to human disturbance and fragmentation, the result is that land use decisions – even the most well-intentioned – are being made completely uninformed by science." (ELI 2003).

Identification of social and ecological thresholds is one of the most challenging aspects of land and resource management because clear and predictable relationships between use and impact are lacking and the science and information used to quantify thresholds is imprecise and subjective (Stankey et al. 1984; MSRM 2004). Because objective science-based distinctions between acceptable and unacceptable conditions do not exist for most ecological and social indicators, other factors must be considered.

Several indicator frameworks adopted for land and resource management elsewhere in Canada could be applied to the DCLUPC. Each of these frameworks was designed to address the absence of specific, achievable management objectives for resources of interest: the LAC system, Tiered Thresholds framework, Sustainable Forest Management Indicators, and the Oil and Gas Pre-tenure Plan Results-based framework.

4.3.1 Limits of Acceptable Change System

The LAC system originally developed for wilderness management (Clark and Stankey 1979; Stankey et al. 1985) has begun to be applied to non-recreational issues (McCool and Cole 1997; Cole and Stankey 1998). This approach assumes that outcome-based thresholds are preferred because it is the outcome that is important and because outcomes can be influenced by more than one input. The following summary is derived from Stankey et al. (1984, 1985) and Cole and Stankey (1998), except where noted.

The LAC system attempts to identify "How much use is too much?" by turning the question around and asking "**How much change is acceptable?**" A critical component of the LAC system is that limits be defined in a collaborative process in which decisions reflect the input of affected stakeholders. Judgments of acceptability require not only the viewpoints of managers and scientists but of residents and land users as well. LAC treats scientific information as an aid in answering what is acceptable, not as the sole factor (Stankey et al. 1984).

One challenge is that individuals often value and desire different things, and the relationship between land use and perceived quality varies accordingly. LAC frameworks address this by defining perceived quality across a spectrum of uses such as protected areas through to industrial zones (Stankey et al. 1984; Cole and Stankey 1998). Limits are established as follows:

- Identify what special features or qualities are important in the area;
- Describe land use classes where different resource, social, and managerial conditions will be maintained;
- Select indicators that allow resource and social conditions to be described and measured;
- Inventory existing resource and social conditions; and
- Specify standards for resource and social conditions in each land use class.

LAC will not work for issues where desirable or acceptable conditions are a chaotic moving target. This is a critical limitation where impacts are pervasive, leaving no undisturbed reference areas (Cole and Stankey 1998).

The LAC system is considered to be directly relevant to land and resource planning in the Deh Cho Plan area.

4.3.2 Tiered Thresholds

Tiered thresholds are a series of progressive thresholds that reflect increasing degrees of concern or risk. Tiered thresholds were originally developed to manage deposition of acidic air pollutants (Bull 1991, 1992). This approach provides an integrated framework that relates two or more quantitative thresholds to appropriate management and regulatory responses. Figure 8 illustrates a three-tiered model defined by the Clean Air Strategic Alliance (CASA) for management of potential acidification input.

Candidate tiered ecological and land use thresholds have been developed for cumulative impact management in northeastern British Columbia (Salmo et al. 2003). Tiered thresholds have also been recommended for fisheries management (Auster 2001), and resource management in the NWT (Macleod 2002), oil sands area of Alberta (AENV 1999, 2001), and the west-central Alberta airshed (AENV and CASA 1999).

The tiered thresholds described more fully below are considered to be directly relevant to land and resource planning in the Deh Cho Plan area.

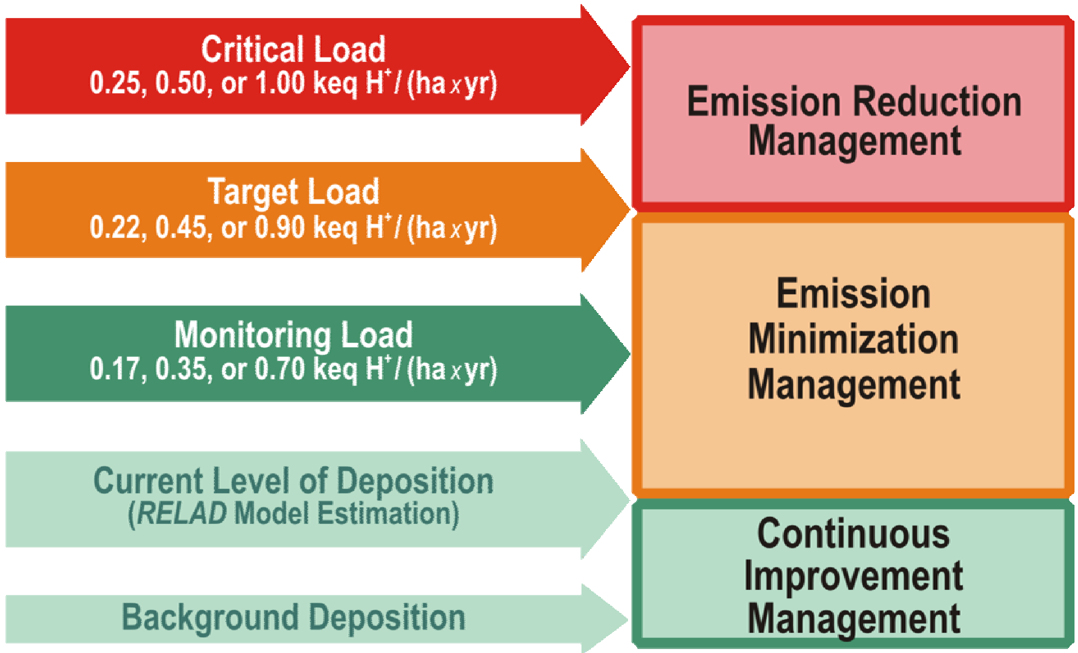


Figure 8. Application of tiered thresholds to management actions.

4.3.2.1 Critical Thresholds

A **Critical Threshold** is the continuous maximum amount of stress that an ecological or social system can support without sustaining long-term harm (Bull 1992). To establish a critical threshold, a level of acceptable change protection must be defined. This definition should account for local and regional public values on environmental quality and natural resource protection, which is difficult since there are many viewpoints on what constitutes an unacceptable 'adverse' effect. Once the acceptable protection level is defined, a science-based threshold is calculated from the best available information. This calculation is based on known cause and effect relationships like that depicted in Figure 7 (Bull 1991, 1992).

Acceptable change is based on desired social outcomes – but is science-based – and has been defined in a variety of ways. For example, the critical threshold may be based on predicted risk of population extinction (Lande 1987), predicted probability of population survival (Lamberson et al. 1992), or the probability and severity of an undesirable effect (Francis and Shotton 1997). CASA defined threshold loads using 'levels of protection', where a 100% level of protection meant protection for all ecosystems, while a 90% level of protection meant that 10% of ecosystems or species might experience stress above their critical load (AENV and CASA 1999). CASA defined Critical Thresholds as providing a 95% level of protection for sensitive, moderately sensitive, and low sensitivity soils.

When the Critical Threshold load is reached or approached, restrictive management practices are formally adopted. These can include pre-defined protection and recovery measures mandated through the review and approvals process. Examples include implementation of economic instruments that discourage emissions use, retrofitting of 'Best Available Technology', and use of predefined recovery responses like activity restrictions (AENV and CASA 1999).

4.3.2.2 Target Thresholds

A **Target Threshold** reflects a politically defined goal for the amount of stress on a system. It incorporates economic, social, and technological considerations; it should ideally be below the critical threshold to provide a margin of safety. A Target Threshold can be characterized as the level that is politically and practically achievable and provides adequate long-term protection to the environment or resource of interest.

The Target Threshold may reflect a precautionary management philosophy or uncertainty associated with scientific predictions of the Critical Threshold. In Alberta, CASA defined the target acid deposition threshold loads at approximately 90% of the critical load (AENV and CASA 1999; Figure 8).

When this threshold is reached, enhanced management practices are formally adopted. These can include expanded environmental monitoring and applied research, voluntary use of 'Best Available Demonstrated Technology', and implementation of enhanced protection or recovery methods like 'No Net Habitat Loss' or restrictive harvest regulations (AENV and CASA 1999). Where existing disturbance levels exceed the critical threshold, the target threshold may be set at or above the critical threshold load, or a series of diminishing target threshold loads may be applied over time to progressively reduce stress to levels below the critical threshold (AENV and CASA 1999).

4.3.2.3 Cautionary Thresholds

A **Cautionary Threshold** is established to indicate when additional or more intensive monitoring is required. This concept was established by CASA (AENV and CASA 1999) to ensure that sufficient local data existed to confirm scientific predictions of both target and critical thresholds.

When this threshold is reached, issue-specific monitoring is initiated to document environmental conditions or responses. No other management or mitigation actions are required, but activities must comply with established regulatory guidelines and best industry management practices. Routine environmental and activity monitoring is also conducted to confirm that best management practices are being applied (AENV and CASA 1999).

Where there is not enough information to determine how much stress a social or ecological system can sustain, a decision can be made to define an interim threshold between the cautionary and target thresholds. Final thresholds would then be established only after further monitoring, research, and stakeholder consultation.

4.3.3 Sustainable Forest Management

In 1993 the Canadian Council of Forest Ministers (CCFM) began an initiative to define, measure and report on the forest values that Canadians want to sustain and enhance. Following extensive consultation, the CCFM released a report that presented a suite of criteria and indicators that could be used to describe and measure the state of forests and forest management in Canada (CCFM 1995, 1997). The original CCFM framework includes 6 **criteria**, 22 critical **elements**, and 83 **indicators.** All Canadian jurisdictions are incorporating the CCFM framework into their forest policies and legislation, and a Canadian Standards Association (CSA) standard for a sustainable forest management system has been issued (CSA-Z808-96; CSA 1996).

This framework was subsequently revised to 6 criteria and 46 indicators designed for reporting at a national level. Criteria were not changed but were reworded slightly to improve clarity. The number of indicators was reduced to focus on those that are most relevant to Canadian values, can be measured with available data, and are understandable to policy makers, forest managers, and an informed public. Links between criteria have been more explicitly defined, and in some cases, indicators address multiple values under different criteria. Thirty-six of the indicators have been identified as **core indicators**. The remaining ten are considered **supporting indicators** (Table 6; CCFM 2003).

Table 6. Sustainable forest management criteria and indicators framework (from CCFM 2003).

Criterion	Element	Indicators
Biological Diversity	Ecosystem Diversity	2 Core indicators
	Species Diversity	2 Core indicators, 2 Supporting indicators
	Genetic Diversity	2 Core indicators
Ecosystem Condition and Productivity	none	5 Core indicators
Soil and Water	none	2 Core indicators, 1 Supporting indicator
Role in Global Ecological Cycles	Carbon Cycle	3 Core indicators, 1 Supporting indicator
Economic and Social Benefits	Economic Benefits	2 Core indicators, 3 Supporting indicators
	Distribution of Benefits	2 Core indicators
	Sustainability of Benefits	3 Core indicators, 3 Supporting indicators
Society's Responsibility	Aboriginal and Treaty Rights	2 Core indicators
	Aboriginal Traditional Land Use and Forest-based Ecological Knowledge	1 Core indicator
	Forest Community Well Being and Resilience	4 Core indicators
	Fair and Effective Decision-making	2 Core indicators
	Informed Decision-making	4 Core indicators

The six sustainable forest management criteria include social, environmental and aboriginal values to supplement the conventional economic focus. The criteria and indicators must be considered together, and no single criterion or indicator is a direct reflection of sustainability (CCFM 2003).

Although the sustainable forest management system is widely applied, it is more complex than other indicator frameworks and is most applicable where timber harvest is a dominant land use. Because merchantable timber resources in the Deh Cho Plan area are limited, adoption of this framework is not recommended.

4.3.4 Results-Based Framework

The British Columbia Ministry of Sustainable Resource Management (MSRM) has adopted a results-based framework for oil and gas pre-tenure planning in the Muskwa-Kechika Management Area (M-KMA) of northeast British Columbia. The purpose of a pre-tenure plan is to guide environmentally responsible development by defining expectations before any oil and gas rights are issued. These management directions then become binding conditions on any petroleum tenures that are sold. The goal of this approach is to provide greater certainty to the oil and gas industry on where and how oil and gas operations are conducted. The following discussion is based on MSRM (2004), except where noted. Additional information, including approved and draft plans is available online at: http://srmwww.gov.bc.ca/rmd/ecdev/mog/ptp/index.htm.

The pre-tenure plans emphasize the results that are to be achieved by a proponent in terms of **outputs** or products that must be delivered, and the required results defined by key **indicators**. These elements are consistent with a sustainable forest management framework that states desired outcomes in terms of **objectives**, **indicators**, and **targets** (Figure 9).

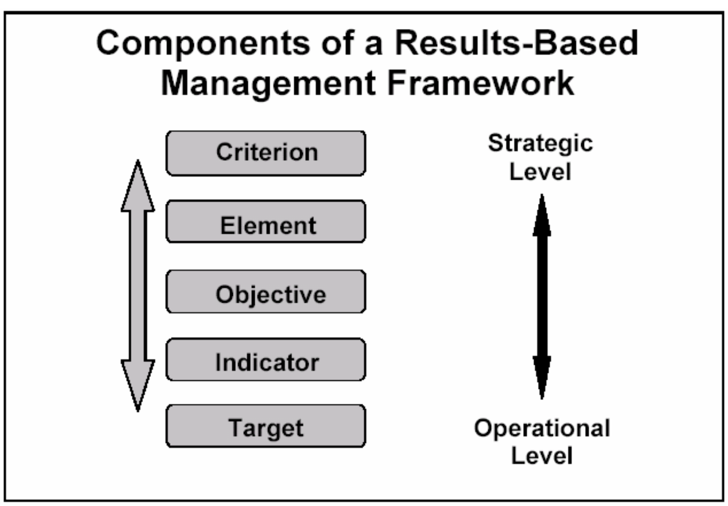


Figure 9. Oil and gas pre-tenure plan results based management framework (from MSRM 2004).

- **Criterion**: A fundamental standard against which a sustainable management framework can be assessed. In the context of pre-tenure planning, a Criterion represents a strategic resource value of the plan area.
- **Element**: A key constituent of the Criterion. Elements represent major features of the Criterion with which they are associated; they define the scope of a given Criterion.
- **Objective**: A broad statement describing an ideal future state or condition for a value.
- **Indicator**: A variable that measures or describes the state or condition of a value. Indicators identify local-level, measurable factors to assess the state of the resource values and the effectiveness of management practices. Indicators enable measurement of progress towards achieving an Objective over time. An indicator is selected to represent a larger set of conditions or values.
- **Target**: A specific statement describing a desired future state or condition of an Indicator. Targets are intended to be clearly defined, time-limited, and quantifiable.

4.3.4.1 Objectives

The M-KMA Oil and Gas Pre-Tenure Plan (Pre-Tenure Plan) includes objectives that apply to the entire region as well as objectives that apply to specific plan areas. Government and proponent requirements for monitoring various activities and outcomes are also specified. The six general planning and management objectives identified in the pre-tenure plan that are directly applicable to the Deh Cho Plan area include:

1. **Well planned activities**. Requiring activities to be well planned from inception, through operation, to closure and reclamation, will avoid or minimize effects on other users and the environment.
2. **Consultation with First Nations**. Consultation is required to identify aboriginal interests in the area and plan to avoid or minimize impacts on these interests.
3. **Consultation with other stakeholders**. Consultation is required to identify other interests in the area and plan to avoid or minimize impacts on these interests.
4. **Worker orientation**. Workers who understand land and resource management objectives will be much better informed in carrying out their daily tasks in a way that achieves objectives and targets.
5. **Monitoring and reporting**. Oil and gas proponents will be required to monitor and report on their activities to document compliance with permit conditions.
6. **Adaptive management**. This provides the opportunity to continually learn from innovative approaches and results.

4.3.4.2 Indicators and Targets

Targets represent the socially acceptable, economically feasible, and environmentally sustainable conditions that define how management activities are to occur. In most cases, the proponent has the flexibility in using professional judgement to determine how to best achieve the result.

Numerical targets were provided for the M-KMA whenever possible as a means of quantifying the acceptable future state of the indicators. These numerical targets were acknowledged to represent an initial attempt to find the balance that optimizes resource values in the M-KMA. New information and research and monitoring results will be used to amend the targets as required. Pre-tenure targets are summarized in Table 7.

Table 7. M-KMA Oil and Gas Pre-tenure plan management indicators and targets (MSRM 2004).

Indicator	Target
Disturbance (ha) to site series and associated structural stage within the project area(s).	Site series remains intact after development and restoration. (Measured as hectares of disturbance)
For each focal species, the amount (% and ha) of disturbance by habitat capability class.	For: **plains bison, moose, and elk** 97% of the winter habitat remains undisturbed in moderately high and high capability habitat. For: **Stones sheep and mountain goat** 98% of the winter habitat remains undisturbed in moderately high and high capability habitat. For: **each focal species** 95% of winter habitat remains undisturbed in moderate to nil capability habitat.
Areas of special biological significance are conserved physically and functionally.	100% of identified site-specific features remain physically undisturbed. Activities conducted within Wildlife Habitat Areas (WHA) are consistent with the requirements of the WHA and the Identified Wildlife Management Strategy (IWMS).
Abundance (% cover) and distribution of non-native species. **Proportion and amount (% and ha) of disturbed area restored.**	No increase in abundance and no change in distribution of non-**native species** with the exception of the use of short-lived non-native species to stabilize soils and facilitate native species growth where necessary. Over time, 99% of the disturbed area is restored to simulate pre-development conditions in high and moderately high capability habitat (Classes 1 and 2) for each focal species. Over time, 95% of the disturbed area is restored to simulate pre-development conditions in moderate to nil capability habitat (Classes 3 to 6) for each focal species.

cont'd

Table 7. M-KMA Oil and Gas Pre-tenure plan management indicators and targets (MSRM 2004) cont'd.

Indicator	Target
Disturbance to habitat capability (used here as a surrogate for area disturbed [% and ha] by risk class). **Introduction of deleterious substances into soils.**	The amount of permitted disturbance cannot exceed Targets specified in Element 1.2, Conservation of Species Diversity. Zero spills / seeps of deleterious substances entering soils.
Introduction of deleterious substances into waterbodies. **Changes in natural drainage patterns and flow rates.**	Zero spills / seeps of deleterious substances (human-made fluids or solids) entering waterbodies. Turbidity downstream from activities remains within the normal range. Maintain natural drainage patterns and quantity of flow.
Known traditional resource uses (including hunting, fishing and trapping) and heritage sites.	Incorporation of First Nations' and aboriginal knowledge in all phases of planning and associated activities.
Meetings with First Nations. **Discussions with First Nations regarding economic and training opportunities in a variety of occupations.** **Discussions with First Nations regarding employment or contracting opportunities in a variety of occupations.**	Ongoing information exchange with First Nations, and the proponent regarding economic opportunities. Seasonal and/or ongoing training opportunities for First Nations in a variety of occupations. Seasonal and/or ongoing employment opportunities for First Nations in a variety of occupations.
Volume of oil and gas produced from each well. **Royalty generated from project.**	Energy resources developed in a manner consistent with the British Columbia Oil and Gas Commission (OGC) requirements for oil and gas resource conservation.
Development plans incorporate measures to resolve potential conflicts. **Number and nature of unresolved conflicts referred to the OGC for resolution.** **Access development and use that is coordinated with other users.**	Compliance with all measures included in development plans. Unresolved issues submitted to the OGC are minimized as much as possible. All unresolved issues are fully documented. Coordinated development and use of access, where opportunities exist. Access use is controlled consistent with the M-KMA Access Management Area requirements.

cont'd

Table 7. M-KMA Oil and Gas Pre-tenure plan management indicators and targets (MSRM 2004) cont'd.

Indicator	Target
Location and amount of area disturbed.	Proponents are required to submit: • a digital map showing the location of activities; • the total number of hectares disturbed by activities, and • the total number of kilometres of linear disturbance.
Area disturbed (% and ha) in Visual Sensitivity Classes.	Visual Sensitivity Classes are not yet available. The information provided above will be used to monitor impacts.
Natural appearing environments.	Use of landscape design in development plans to mimic natural environments.
Maintaining Ecological Integrity.	Meeting the Targets for Ecosystem Restoration will address this issue in the longer term.
Measures included in the development plan to reduce long range visibility of facilities.	Compliance with all measures included in development plans.
Noise levels at 1.5 km (or equivalent distance) from project area.	<40 dBA Leq at 1.5 km from project area (ambient + industrial noise).

4.4 RECOMMENDED DEH CHO INDICATOR FRAMEWORK

The DCLUPC mission statement is to: "… develop a land use plan as a management tool to determine what type of land use activities should occur and where they should take place. This plan will balance economic, social, environmental and cultural needs and interests." A results-based framework (Figure 10) consisting of land management **objectives**, **indicators**, and **limits of acceptable change** is recommended for the Plan area.

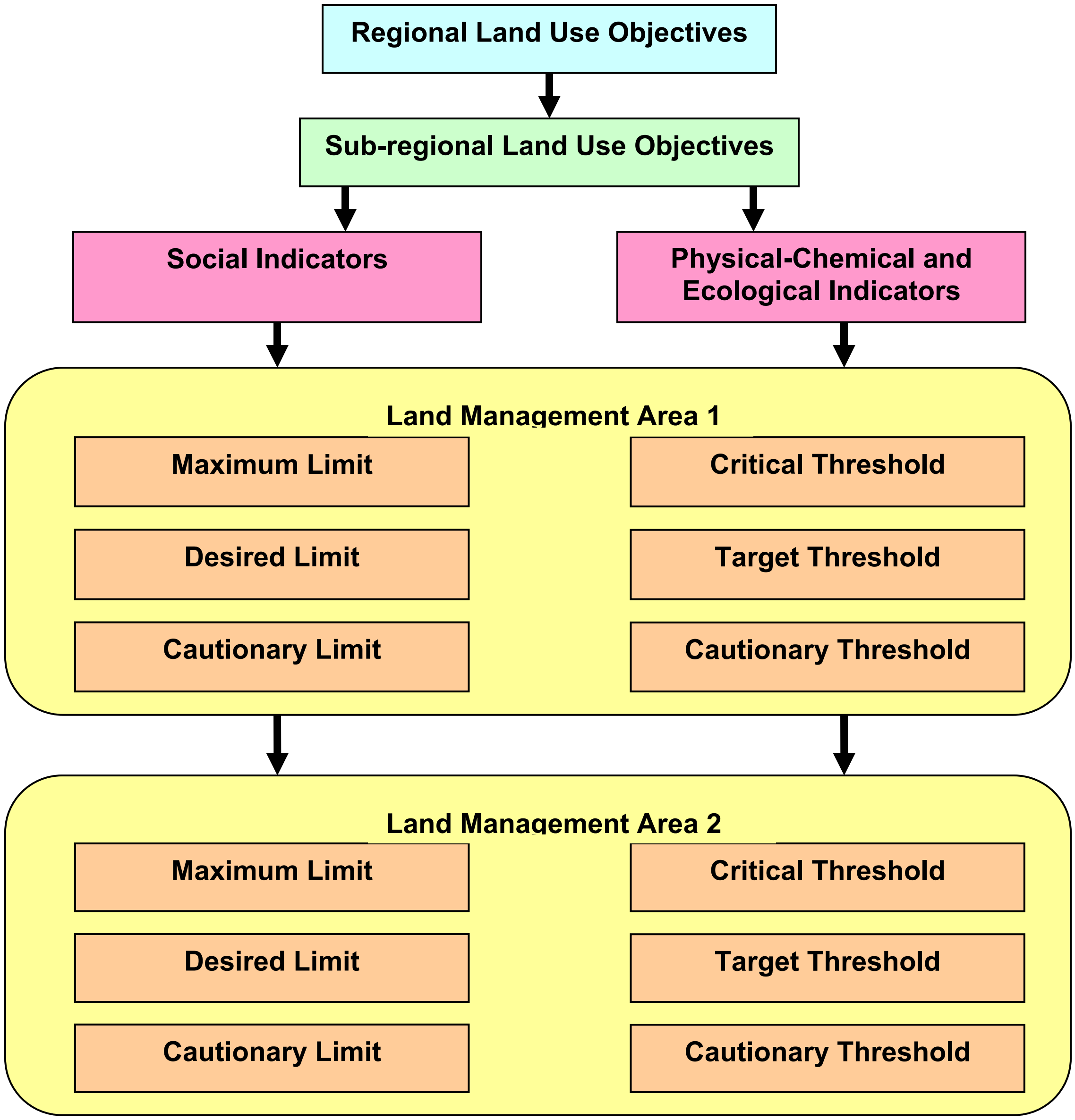


Figure 10. Recommended Deh Cho Plan area indicator and threshold framework.

4.4.1 Management Objectives

Overall and sub-regional land and resource management objectives should be defined for the Deh Cho Plan area by the DCLUPC in consultation with key stakeholders. These objectives should be achievable and describe desired conditions rather than management actions wherever possible. The results-based approach adopted for M-KMA oil and gas pre-tenure planning (Section 4.3.4) is considered to provide the best model because it considers both ecological and social values, is applicable to the energy, tourism, and forestry sectors, and provides flexibility on how to best achieve the stated objective.

4.4.2 Social and Ecological Indicators

A reasonable suite of complementary social and ecological indicators should be identified to describe, measure, manage, and report on these management objectives. These indicators should be: clear and understandable by non-scientists; easy and cost-effective to collect, measure, or calculate; and able to provide information on the desired ecological and social conditions.

4.4.3 Tiered Limits of Acceptable Change

A series of two to three tiered limits of acceptable change is recommended for each indicator. The primary strength of a tiered framework is the formal link between the limits and impact management. This provides a mechanism to gather data on actual responses and modify management actions as appropriate. A secondary benefit is that tiered limits directly recognize the uncertainty around our understanding of complex social and ecological relationships. Finally, tiered thresholds provide the flexibility for different land management zones and settings, for a full range of development proposals, and for both project-specific and cumulative effects. As shown in Figure 10, progressive thresholds can be used to reflect different land management zones or designations within the Deh Cho Plan area (e.g., most conservative in Protected Areas and most liberal in areas zoned for resource development).

The discussion of social, physical-chemical, ecological, and land use indicators provided in Sections 5 through 8 reflects this recommended framework.

5. PHYSICAL-CHEMICAL INDICATORS AND THRESHOLDS

Historically, environmental policy and management goals have centered on reducing the contaminants that enter the environment (Cairns et al. 1993), and physical-chemical indicators and thresholds are well established. NRTEE (2003) identified air and freshwater quality as national indicators for monitoring sustainable development.

An overview of air quality and water quality/quantity indicators is provided below along with recommended indicators and thresholds for the Deh Cho Plan area.

5.1 AIR QUALITY

Air quality affects human, plant, and animal physiology and health. Human actions can change air quality by releasing pollutants into the atmosphere. **Transitory** symptoms are caused by low pollutant levels over relatively short intervals. Vegetation, animals, and humans can normally recover fully from transitory injury. **Acute**, or short-term effects occur as a result of brief exposure (hours or less) to relatively high concentrations of pollutants. Responses to acute events can range from severe but short-lived reactions, to death. **Chronic**, or long-term damage results from constant or periodic exposure to pollutants (Linzon 1978; Malholtra and Blauel 1980).

The territorial Department of Resources, Wildlife and Economic Development (RWED) has established ambient air quality standards that apply to the Deh Cho Plan area (RWED 2002b). Both short- and long-term standards have been developed to provide adequate protection for acute and chronic exposure. The standards for sulphur dioxide, ground level ozone, total suspended particulates, and fine particulate matter are used to assess the acceptability of emissions from existing and proposed developments, and to report on the state of air quality in the territory (e.g., RWED 2000, 2001d, 2002e; available online at: http://www.gov.nt.ca/RWED/eps/environ.htm).

Air quality modelling tools and methods are well developed. A draft Air Quality Code of Practice for the Upstream Oil and Gas Industry has been issued by RWED (2002d). This document discusses design considerations and modelling requirements.

5.1.1 Candidate Thresholds

Air quality should be included as a land and resource management indicator for the Deh Cho Plan area because of its social and ecological importance. The approved NWT ambient air quality standards represent an appropriate Critical Threshold applicable to the entire Plan area. Project design and regulatory approvals should be designed to maintain ambient air quality below these values. Adoption of a Cautionary Threshold is also recommended to ensure that monitoring is conducted to document actual environmental conditions. The recommended Cautionary Threshold is an approved emission source (i.e., an appropriate monitoring program should be required for all approved emission sources to document actual ambient air quality and confirm impact predictions over several years).

The DCLUPC should also consider the need for intermediate Target Thresholds in areas where pristine air quality is defined as a management objective. Target Thresholds could also be used where defined standards do not exist for a particular pollutant.

A list of air quality standards currently being applied in the Northwest Territories is provided in Table 8.

Table 8. Air quality standards utilized in the Northwest Territories.

Parameter	Standard	Comments
Total Suspended Particulate (TSP): - 24-hour - annual average	 120 µg/m^3 60 µg/m^3	General protection against effects to human and environmental health
Fine Particulate Matter (PM) 2.5: (2.5 microns or less) - 24-hour average	 30 µg/m^3	
PM 10: (10 microns or less) - 24-hour average		
Sulphur dioxide (SO_2): - hourly - 24-hour (daily) - annual	 450 µg/m^3 150 µg/m^3 30 µg/m^3	
Ground-level ozone (O_3): - 8-hour running average	 127 µg/m^3	
Acid Precipitation:	7 kg/ha/yr	Protects sensitive ecosystems in the NWT.

5.1.2 Future Scenarios

Established air quality models can be readily used or modified to consider future land development scenarios for pollutants of interest (e.g., Paramount 2003).

5.2 WATER QUALITY AND QUANTITY

Clean water is a valuable ecological and social resource, and maintaining acceptable water quality is frequently identified as a land management objective (e.g., Fort Nelson Land and Resource Management Plan (1997)). Water quality and quantity have been used as federal environmental indicators (CCFM 1997; NRTEE 2003) and water quality is important to residents of the Deh Cho Plan area.

Clearings, road and trail networks, muskeg drainage, and waste discharge are known to cause both direct and indirect effects on water quality and flow. Changes can result from the combined effects of small routine activities as well as large industrial and residential disturbances (Furniss et al. 1991; Newcombe and MacDonald 1991; McGurk and Fong 1995; Waters 1995; Anderson et al. 1996; Trombulak and Frissell 2000). However, natural fluctuations in the quality and quantity of water occur as a result of annual and seasonal variations in precipitation and temperature as well as disturbance events such as fires and insect damage (CCFM 1997; Minshall et al. 1997; Carignan et al. 2000). To be useful, aquatic indicators must be able to differentiate natural variability from changes caused by human activities.

5.2.1 Indicators

An overview of watershed assessment models and indicators is provided in Appendix 1, Section 5.5 of Salmo et al. (2003). The most common water quality indicators are the concentration of one or more parameters of interest such as turbidity (CCFM 1997), dissolved organic carbon (Schindler et al. 1992), or nutrients (Hession et al. 1996; Cooke and Prepas 1998; Olson+Olson et al. 2002). Direct measurements of hydrology (water level, trends and timing in stream flow) are frequently used indicators of water quantity (Bosch and Hewlett 1982; Reid and Dunne 1984; CCFM 1997; Hudon 1997; Olson+Olson et al. 2002). Other indirect land use indicators are discussed later in Section 7 of this report.

A direct water quantity index is not recommended at this time because the level of existing and likely future activity in the Deh Cho Plan area is unlikely to cause a detectable cumulative effects risk at the regional scale. However, waterbody level would be an appropriate indicator to manage water withdrawals at sub-regional scales where concerns warrant.

5.2.1.1 Candidate Water Quality Thresholds

The federal government has established Water Quality Guidelines (CCME 1996). These contain recommendations for chemical, physical, radiological and biological parameters necessary to protect and enhance designated end uses: drinking water; recreation; protection of aquatic life; and industry. Impairment to guideline concentrations should not be acceptable for waters of superior quality.

Unfortunately, water chemistry and hydrology data are limited in the Deh Cho Plan area, and unlike air quality, widely accepted models and assumptions are not available because of the influence of local variability. In recognition of these challenges, CCFM (2003) recently revised its water quality and water level indicators from measured values to rate of compliance with construction and management standards (CCFM 2003).

A water quality indicator should be included as a land and resource management indicator for the Deh Cho Plan area because of its social and ecological importance. The recommended Canadian water quality guidelines for the protection of aquatic life represent an appropriate Critical Threshold applicable to the entire Plan area. Project design and regulatory approvals should be designed to maintain water quality below these values. Adoption of a Cautionary Threshold is also recommended to ensure that monitoring is conducted to document actual environmental conditions. The recommended Cautionary Threshold is an approved discharge (i.e., an appropriate monitoring program should be required for all approved discharges into lakes and streams). Monitoring will document actual water quality and confirm impact predictions. Because some water quality parameters naturally exceed the recommended Canadian water quality standards, site-specific monitoring will also provide the data required to allow guidelines to be modified to reflect local conditions.

The DCLUPC should also consider the need for intermediate Target Thresholds in areas where pristine water quality is defined as a management objective. Target Thresholds could also be used where defined guidelines for do not exist for a particular water quality parameter. Table 9 summarizes the Canadian water quality guidelines for protection of freshwater aquatic life (CCME 1996).

Table 9. Canadian water quality guidelines for protection of freshwater aquatic life.

Parameter	Guideline	Comments
Aluminum:	0.005 mg/L 0.1 mg/L	pH ≤6.5 pH >6.5
Arsenic:	0.05 mg/L	
Cadmium:	0.2 µg//L 0.8 µg/L 1.3 µg//L 1.8 µg//L	Hardness 0-60 mg/L ($CaCO_3$) Hardness 60-120 mg/L ($CaCO_3$) Hardness 120-180 mg/L ($CaCO_3$) Hardness >180 mg/L ($CaCO_3$)
Chromium:	0.02 mg/L 2.0 µg//L	To protect fish To protect aquatic life, including zooplankton and phytoplankton
Copper:	2.0 µg//L 2.0 µg//L 3.0 µg//L 4.0 µg//L	Hardness 0-60 mg/L ($CaCO_3$) Hardness 60-120 mg/L ($CaCO_3$) Hardness 120-180 mg/L ($CaCO_3$) Hardness >180 mg/L ($CaCO_3$)
Cyanide:	5.0 µg//L	Free cyanide as CN
Dissolved Oxygen:	6.0 mg/L 5.0 mg/L 9.5 mg/L 6.5 mg/L	warm-water biota – early life stages – other life stages cold-water biota – early life stages – other life stages
Iron:	0.3 mg/L	
Lead:	1.0 µg//L 2.0 µg//L 4.0 µg//L 7.0 µg//L	Hardness 0-60 mg/L ($CaCO_3$) Hardness 60-120 mg/L ($CaCO_3$) Hardness 120-180 mg/L ($CaCO_3$) Hardness >180 mg/L ($CaCO_3$)
Mercury:	0.1 µg//L	
Nickel:	25 µg//L 65 µg//L 110 µg//L 150 µg//L	Hardness 0-60 mg/L ($CaCO_3$) Hardness 60-120 mg/L ($CaCO_3$) Hardness 120-180 mg/L ($CaCO_3$) Hardness >180 mg/L ($CaCO_3$)
Nitrogen: **- ammonia (total)** **- nitrite** **- nitrate**	 2.2 mg/L 1.37 mg/L 0.06 mg/L	 pH 6.5; temp. 10°C pH 8.0; temp. 10°C Avoid concentrations that stimulate prolific weed growth

cont'd

Table 9. Canadian water quality guidelines for protection of freshwater aquatic life (cont'd).

Parameter	Guideline	Comments
pH:	6.5 to 9.0 (units)	
Phosphorous	No criterion available	
Selenium:	1 µg//L	
Silver:	0.1 µg//L	
Total Suspended Solids:	Increase of 10 mg/L Increase of 10%	Background suspended solids ≤100 mg/L Background suspended solids >100 mg/L
Zinc:	0.03 mg/L	

Future Scenarios

ALCES II® provides the user with the opportunity to evaluate changes in water quality over time using various land use features such as road density, percent of landscape disturbed, and runoff loads of sediments and nutrients (nitrogen and phosphorus). A water quality index was incorporated into the ALCES model to evaluate the potential effects of future land use scenarios. This 'Relative Water Quality Index' does not predict whether water quality is adequate for a particular use, but allows relative effects on nutrient and total suspended sediment levels to be tracked over time, or under different development and management scenarios.

A summary of published runoff coefficients for nitrogen, phosphorus, and sediment from various landscape and land use features was completed and included in the ALCES model. These coefficients allow for the calculation of total annual load. Although these numerical relationships have not yet been validated in the Deh Cho Plan area, they provide a science-based approach to evaluate cumulative effects risk in the Plan area over the foreseeable future.

A relative change of 20% is proposed as Critical Threshold applicable to the entire Plan area. A 20% reduction in measured physical or chemical parameters has been proposed as a significance standard for ecological risk assessment by Suter et al. (1995). Their rationale was that effects less than 20% cannot be reliably confirmed by field measurements, and that conventional statistical significance levels almost always correspond to effects levels greater than 20%. This value is also consistent with the way that the United States Environmental Protection Agency regulates effluents. Land use planning should be designed to restrict future water quality changes within this range.

A relative change of 10% is proposed as a Target Threshold for the Relative Water Quality Index. A 10% change in total suspended sediment concentration (turbidity) relative to natural conditions has been identified as a water quality criterion in a number of North American jurisdictions (Singleton 1985).

5.3 CANDIDATE PHYSICAL-CHEMICAL INDICATORS AND THRESHOLDS

The suite of three physical-chemical cumulative effects indicators and associated thresholds recommended for the Deh Cho Plan area is summarized in Table 10.

Table 10. Candidate physical-chemical indicators and thresholds for the Deh Cho Plan area.

Type	Indicator	Thresholds
Physical and Chemical	Air quality	• **Critical**: NWT Ambient Air Quality Standard. Management designed to maintain ambient air quality below this threshold. • **Cautionary**: Emissions subject to regulatory approval. Management designed to ensure that appropriate level of monitoring is conducted to document actual conditions. • **Target**: Consider for areas where pristine air quality is identified as management objective, or where standards do not exist for the pollutant of interest.
	Water quality	• **Critical**: CCME Water Quality Guideline for the Protection of Aquatic Life. Management designed to maintain water quality below this threshold. • **Cautionary**: Discharges subject to regulatory approval. Management designed to ensure that appropriate level of monitoring is conducted to document actual conditions. • **Target**: Consider for areas where pristine water quality is identified as management objective, or where guidelines do not exist for the parameter of interest.
Future Scenarios	Relative water quality index	• **Critical:** 20% change from baseline conditions. • **Target:** 10% change from baseline conditions.

6. ECOLOGICAL INDICATORS AND THRESHOLDS

Indicators of ecological conditions are increasingly focusing on biological parameters other than physical and chemical measurements (Griffith 1998). Several recent reviews of ecological indicators and thresholds are relevant to the Deh Cho Plan area. Axys (2000, 2001a, 2002) and Anderson et al. (2002) reviewed indicators and thresholds for selected wildlife species in the Yukon. A review of ecological indicators and thresholds applicable to the NWT is provided in Macleod (2002). Olson+Olson et al. (2002) reviewed terrestrial and watershed indicators applicable to the oil sands area of Alberta. Salmo et al. (2003) reviewed ecological indicators and thresholds for management of wildlife resources in the boreal forest and foothills of northeast British Columbia. A literature review and meta-analysis of ecological indicators and thresholds applicable to land use planning is provided in ELI (2003).

Ecological thresholds should strive to keep indicators within the natural range of variability and socially-derived limits should strive to keep indicators within the range of desirable conditions.

6.1 SPECIES-SPECIFIC VS. GENERALIZED INDICATORS

A wide variety of species-specific and generalized indicators and thresholds have been identified or proposed in the scientific literature. There has been considerable debate in the literature about the relative merits and disadvantages of both approaches (e.g., Cash 1995; Griffith 1998; Gustafson 1998; Olson+Olson et al. 2002).

Species-specific approaches are commonly used by resource managers such as RWED who are responsible for maintaining sustainable populations of economically important species in defined sub-regional management areas. Species have also been used as indicators of environmental conditions (e.g., air and water quality). Species-specific ecological indicators will continue to be an integral part of land use planning and resource management frameworks (Griffith 1998).

Generalized indicators track multiple species, communities, landscapes, and suites of metrics (e.g., biotic integrity indices) and generally focus on ecological status and trends over large geographic areas (Griffith 1998). These indicators are very useful for land management purposes. For example, a composite habitat map that collectively represents a range of biophysical values was prepared for the M-KMA Pre-Tenure Plan (MSRM 2004). This is intended to convey overview information to oil and gas proponents when they are planning activities in the area. Generalized indicators do not adequately address the conservation of species or habitat types that are rare or localized (ELI 2003). The Pre-Tenure Plan recognizes this by requiring site-specific survey of localized or sensitive habitat features.

Both species-specific and generalized indicators will ultimately be needed for cumulative impact management in the Deh Cho Plan area. Generalized habitat indicators and thresholds are discussed in Section 6.2. A summary of relevant literature for the four most frequently used wildlife indicators in the Deh Cho Plan area is provided in Section 6.3.

6.2 HABITAT

Animal distribution and abundance is the result of both local habitat conditions and larger-scale environmental and human factors (Rich et al. 2003). Animal response to habitat and disturbance features such as roads can be considered at two scales of analysis. At the regional scale, individuals or groups select home ranges or territories that meet all their life history need (2^{nd} order selection). Within this home range or territory, individuals and groups select or avoid areas based on site-specific features (3^{rd} order selection; Johnson 1980; Rettie and Messier 2000; Apps et al. 2001; Szkorupa 2002).

Continuity of forest habitat is lost through natural disturbance or conversion of lands for human use (e.g., cutting forest for buildings or facilities). This causes both **habitat loss** and **habitat fragmentation**. The loss and fragmentation of habitat are normally assumed to be the most significant threats to the long-term persistence of species and communities (Collinge 1996; Jalkotzy et al. 1998; Fahrig 2001, 2002; Schmiegelow and Mönkkönen 2002; ELI 2003). Three general effects result from habitat loss and fragmentation (Figure 11):

- original habitat is lost,
- remaining habitat patches decrease in size, and
- patches become increasingly isolated from one another.

Figure 11. Representation of the habitat fragmentation process (adapted from Collinge 1996).

Natural and human disturbances introduce changes into forest landscape patterns that affect the availability, distribution and juxtaposition of specific habitat types (Section 2.3.1). Studies in temperate and tropical areas have shown a positive relationship between the number of species and the area of contiguous suitable habitat, and habitat destruction is assumed to be the major cause of species extinctions (e.g., Forman and Godron 1986; Seagle 1986; Tilman et al. 1994; Flather and Sauer 1996). However, moderate levels of forest fragmentation may benefit habitat generalists with good mobility (Enns et al. 1993; Bayne and Hobson 2000).

Theoretical and field investigations have identified critical thresholds in the process of habitat fragmentation where rapid changes in the size and isolation of patches occur (Andrén 1994; With and Crist 1995; Mönkkönen and Reunanen 1999; Fahrig 2001, 2002). As habitat becomes increasingly fragmented, the number of local extinctions increases. In remnant patches, even moderate habitat loss increases the extinction risk of abundant species, although there is a 50 to 400 year lag before this is predicted to occur (Tilman et al. 1994).

Indirect cumulative effects occur where areas immediately adjacent to human features are used differently from nearby areas of identical habitat by individuals or species. This change in **'habitat effectiveness'** can accumulate over time and lead to reduced biodiversity and species abundance. In general, impacts are inversely related to the level and predictability of human disturbance. Unpredictable high-intensity activities (e.g., motorized snow machines, powerboats, gun shots) cause greater response than low intensity continuous activities (e.g., generator motor noise). Response of hunted animal populations is normally greatest. Animals may habituate to repeated or predictable disturbance that is perceived to be non-threatening. However, specific responses vary, and are complicated by many factors (reviewed in Appendix 1, Salmo et al. 2003).

Habitat indicators and thresholds are often the most practical option for cumulative impact management because they can be readily quantified and are assumed to be biologically meaningful (Hill et al. 1997; Axys 2000). Habitat indicators can refer to the availability of specific habitat units (e.g., disturbance of each habitat quality class; MSRM 2004) or to measures of larger scale habitat patterns (e.g., area in forest cover and area in wetlands; NRTEE 2003).

Larger-scale landscape indicators are used based on the assumption that landscape composition and spatial patterns affect habitat quality and ultimately, animal population dynamics (Franklin and Forman 1987; Andrén 1994; Dooley and Bowers 1998; Mönkkönen and Reunanen 1999; Fahrig 2001, 2002). General conservation guidelines reflect ecological principles such as the size of habitat patches that species require to survive, or the amount of habitat necessary for long-term persistence of native species (ELI 2003).

6.2.1 Terrestrial Habitat Availability

Habitat suitability or quality is commonly used as an environmental impact assessment indicator in the Deh Cho, NWT, and Canada (e.g., Hegmann et al. 1999; Paramount 2003). Habitat suitability models provide a relative numerical value of importance rating to a mapped habitat unit. These values reflect the ability of the habitat unit to support and maintain individuals of an identified wildlife or fish species and frequently consider specific season and life requisites (Salmo et al. 2001, but see Van Horne 1983).

The most commonly used predictive models of species-habitat relationships are the Habitat Evaluation Procedures (HEP) and Instream Flow Incremental Methodology (IFIM) developed by the United States Fish and Wildlife Service (USFWS 1980; Stalnaker et al. 1995). These were developed for use in environmental assessments and provide a common measure of available habitat (Habitat Units) that allows potential losses and gains to be quantified (Salmo et al. 2001).

More recently, resource selection functions (RSF) have used statistical analyses of animal location data to predict the probability of occurrence of a species as a function of the availability of mapped variables in a study area (Manly et al. 2002). This approach was used by Gunn et al. (2002) to predict the probability of occurrence of woodland caribou in the Deh Cho Plan area.

Habitat effectiveness models predict the value and amount of habitat available to an animal after taking into account the disturbance effects of human developments and activities (Trombulak and Frissell 2000; Hamilton and Wilson 2001). This approach has been recommended for development of woodland caribou thresholds in the Yukon and Alberta (Anderson et al. 2002; BCC 2003).

Habitat thresholds are generally outcome-based. Figure 12 provides a theoretical example of how habitat-based ecological thresholds can be developed and applied using a road density-habitat effectiveness response. The green line displays the observed or predicted effect on habitat availability or effectiveness as disturbance intensity increases. No single point represents a transition from an acceptable to unacceptable state. An outcome-based target threshold may be established at points where rapid changes in the size and isolation of habitat patches occur (e.g., change at 69% habitat indicator in Figure 12). In this example, 30% habitat availability/effectiveness was selected as the transition point from acceptable to unacceptable habitat condition. This threshold may be established arbitrarily or based on a calculated degree of risk. Finally, generalized habitat availability thresholds (e.g., >40% habitat availability) have been applied for landscape-level cumulative effects evaluations.

Species-specific evaluations normally also consider the quality of available habitat. Where the habitat requirements of a species are reasonably well understood, minimum levels of suitable habitat can be identified for regulatory or management purposes (Axys 2000).

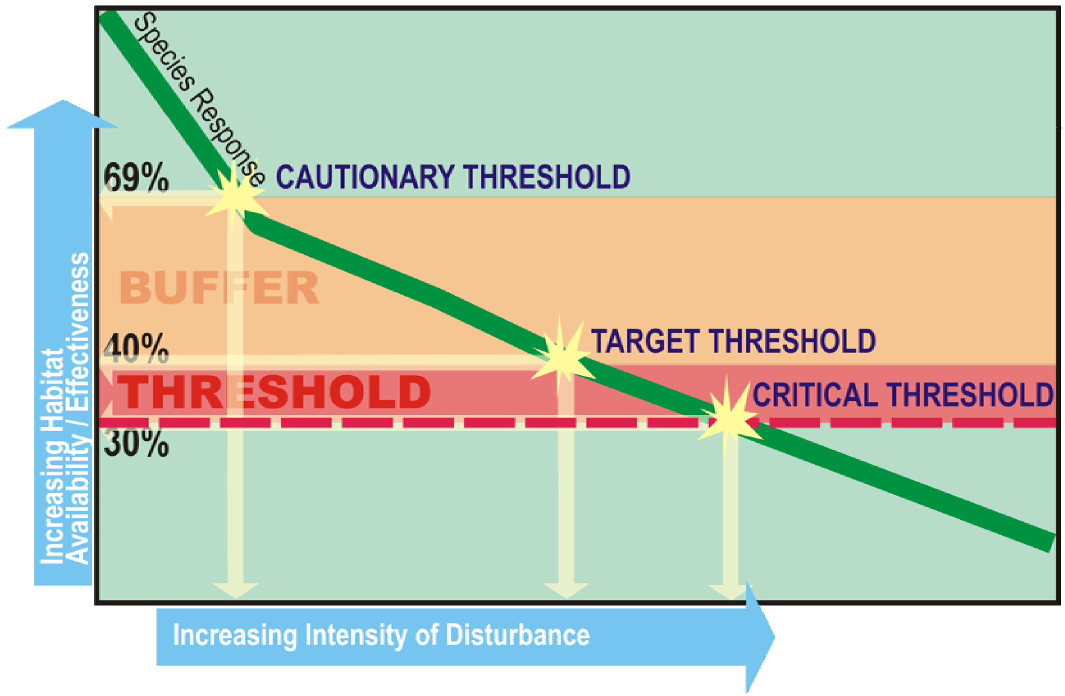


Figure 12. Ecological response curve and tiered habitat thresholds.

Habitat loss appears to be an important limiting factor for wetland and boreal forest wildlife. However, recent research and meta-analyses suggest that additive effects from habitat fragmentation (e.g., patch isolation and edge effects) have likely been overstated for boreal forest species (Findlay and Houlahan 1997; Fahrig 2001, 2002; Schmiegelow and Mönkkönen 2002). For most species, habitat fragmentation effects do not appear to occur when less than 10% of available regional habitat is lost. The risk of these additive or multiplicative effects increases at intermediate levels of habitat loss (10% to 40%), and cumulative effects risk increases dramatically when 70% to 90% of functional habitat in a region is lost (Andrén 1994; Rich et al. 1994; Fahrig 1997; Forman and Collinge 1997; Hannon 2000; Schmiegelow and Mönkkönen 2002). However, some species appear to be more sensitive. These include habitat specialists associated with localized or uncommon habitat units or features (e.g., old growth cavity nesters), and species with large area requirements (Schmiegelow and Mönkkönen 2002). Habitat availability guidelines and thresholds are reviewed in Appendix 1 of Salmo et al. (2003).

6.2.1.1 Candidate Thresholds

We recommend that the DCLUPC adopt a **habitat availability** threshold using the results-based approach included in the M-KMA Pre-Tenure Plan (MSRM 2004). Habitat availability should be considered for the four wildlife indicator species discussed in Section 6.3 (woodland caribou, moose, marten, grizzly bear). Other focal species identified in Table 2 (EBA 2003) should be considered in any zones where they are the primary management objective.

Candidate thresholds are based on the hectares of direct disturbance or alteration for species found within the planning or analysis unit. The candidate Critical Threshold applicable to the entire Plan area is 10% habitat loss, based on the apparent boreal fragmentation effects threshold described above. A candidate Target Threshold of 5% habitat loss is proposed. Adoption of Cautionary Thresholds and more restrictive Critical and Target Thresholds should be considered in areas where wildlife values are the primary management objective (e.g., key migratory bird habitat, wildlife areas of special interest such as the Mackenzie Wood Buffalo Sanctuary, and calving and nursing areas).

Specialized habitat features (mineral licks, dens, wallows, nests), is recommended as another terrestrial habitat indicator. The candidate Target Threshold for these features is no disturbance. However, recognizing that site avoidance may not always be possible, the Critical Threshold is no net loss, defined as no disturbance without mitigation or compensation. Cautionary Thresholds and more restrictive Critical Thresholds should be considered in areas (e.g., Candidate Protected Areas) where environmental or biodiversity values are the primary management objective.

6.2.2 Aquatic Habitat Availability

The federal Department of Fisheries and Oceans (DFO) has developed tools to promote the protection of fish and fish habitat, including the guiding ‘No Net Loss’ principle (DFO 1995). Under this principle, DFO strives to balance unavoidable losses of the ‘productive capacity of fish habitat’ with habitat replacement on a project-by-project basis. This approach is designed to avoid direct loss and alteration of waterbody banks and substrate.

6.2.2.1 Candidate Threshold

Fish habitat should be used as an aquatic indicator in the Deh Cho Plan area. The candidate Critical Threshold is no net loss of the productive capacity of fish habitat.

6.2.3 Core Area

Remaining **core area** is a widely used habitat index that quantifies the availability and location of areas with minimal human impacts. Core areas are relatively undisturbed, ‘wilderness’ areas and are often source areas for plant and animal populations or metapopulations. Core areas can be critical for population persistence in fragmented landscapes; conservation of these areas can be required to protect certain species (e.g., grizzly bear). Salmo et al. (2003) provides a review of literature relevant to the core area indicator; Figure 13 presents a graphical summary of core area guidelines and thresholds identified in this review.

In Canada, core areas have normally been defined to include those areas greater than a specified distance (often 500 m) from high use features (e.g., primary and secondary roads, truck trails, wellsites, petroleum and industrial facilities). A common approach is

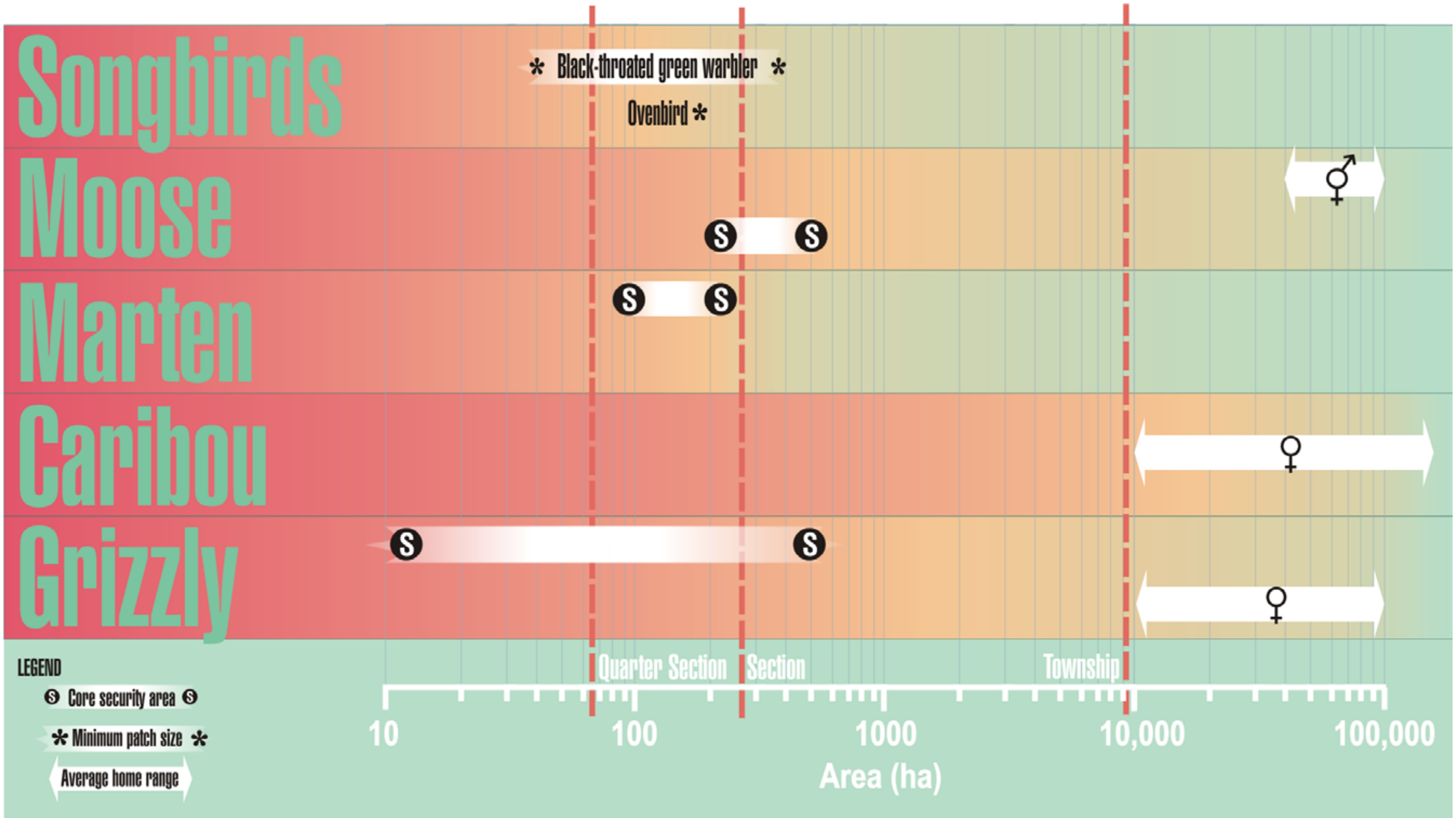


Figure 13. Documented core area, minimum patch size, and home range areas for selected wildlife species.

to include a 500 m zone of influence around all potential high use features (roads, trails, wellsites, facilities, communities, and recreational sites). This is a conservative choice, since avoidance is generally related to activity levels rather than the features themselves (Mattson 1993; Dyer 1999; Gibeau 2000; ELI 2003). To be most effective, core areas should be larger than the minimum home range or territories of target species (Wilcove et al. 1986), or at minimum, meet minimum width and size criteria that reflect the desired level of protection for target management species.

The candidate core area thresholds developed for northeast British Columbia are also proposed for the Deh Cho Plan area, as no additional information was located that would necessitate changes. The rationale for these thresholds is provided below. Figure 14 shows core areas remaining in the Plan area. Core area was defined as the area more than 500 m from assumed high use features including: primary roads, secondary roads, airports, communities, unspecified clearings, wellsites, gas plants, campgrounds, golf courses, quarries, mines, lumber mills, dumps, and junk yards (Table 4).

6.2.3.1 Candidate Thresholds

A conservative suite of candidate core area thresholds was identified for areas where maintenance of wildlife values is the primary management objective. The candidate Critical Threshold for these ecological management areas (>65% large core areas [greater than 1,000 ha and 500 m wide]) was set above the 60% threshold calculated for boreal-ecotype woodland caribou and proposed for grizzly bear. This conservative threshold is intended to represent the current level of uncertainty associated with this indicator, and the variable habitat suitability present in core areas. The Target Threshold for special resource management areas (>75% large core areas) was set between proposed thresholds for grizzly bear recovery and the Critical Threshold. The Cautionary Threshold for special resource management areas (>85% core areas) was set above thresholds for grizzly bear recovery.

At present, almost 99% of the Deh Cho Plan area with IRS coverage is classified as large core areas. (Figure 14)

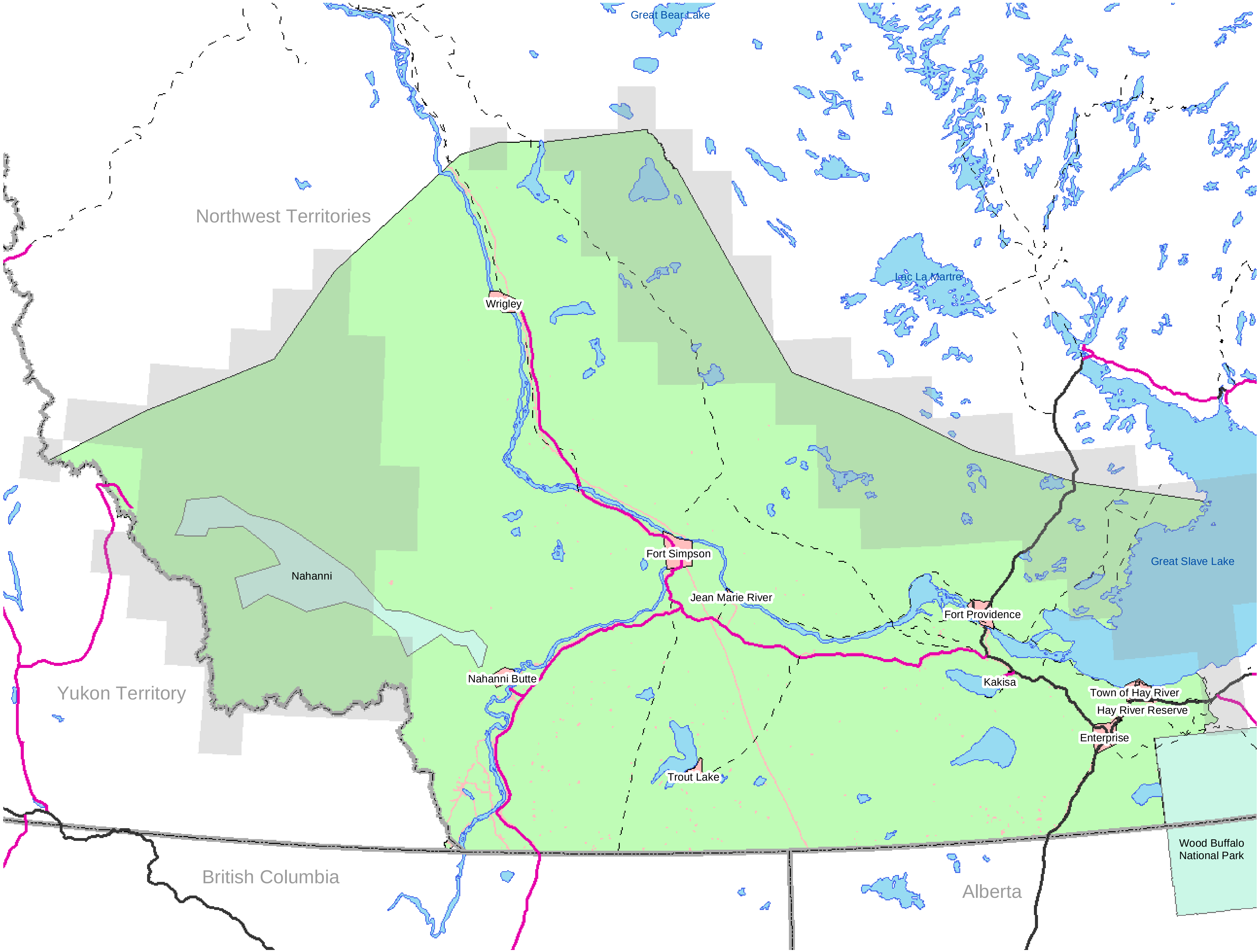
A less conservative suite of candidate core area thresholds was also identified for areas where resource development is a defined management objective. The Critical Threshold for these resource development areas (>40% medium core areas [>200 ha and 350 m wide]) was set at the threshold calculated for interior habitat specialists. The Target Threshold for resource development areas (>50% medium core areas) was set at the observed 50% caribou threshold. The Cautionary Threshold for resource development areas (>65% medium core areas) was set to be consistent with the Critical Threshold for ecological management areas; this would initiate monitoring to determine whether this threshold can be relaxed while still providing adequate long-term protection.

At present, almost 99% of the Deh Cho Plan area with IRS coverage is classified as medium or larger core areas. (Figure 14).

Deh Cho Cumulative Effects Study

Figure 14. Core area remaining in the Deh Cho Plan area

DEH CHO LAND USE PLANNING COMMITTEE
One Land One Plan
Ndéh Łué - Mek'éé Ats'et'į Łué
Dehcho Ndéhé T'áhagot'į gha Sáahniogįoąh-ké



status

Core

Non core

Disturbance from IRS imagery not recorded

features

National Parks

Municipal Areas

Revised Interim Plan Area Boundary

Other Transportation Surface

Paved Surface

Unpaved Surface

Provincial Border

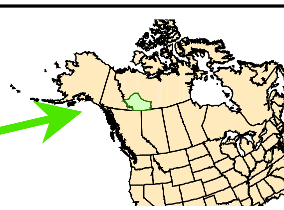
AXYS

NORTH

0 25 50 75 100 km

1:2,500,000

Study Area



Sources:

Deh Cho Land Use Planning Committee

Projection:

Lambert Conformal Conic
Central Meridian 122W
Reference Latitude 60N
Standard Parallel 1 60N
Standard Parallel 2 65N

Datum:

NAD 83

6.2.4 Patch and Corridor Size

Patches and corridors are reasonably uniform areas and linear features that differ from their surroundings (Figure 15). The shape of patches and corridors determines the amount of core habitat vulnerable to edge effects. Long, thin rectangles, like roads and cutlines, create more edge per unit area than other man-made features. As a result, they can have dramatic impacts on habitat effectiveness.

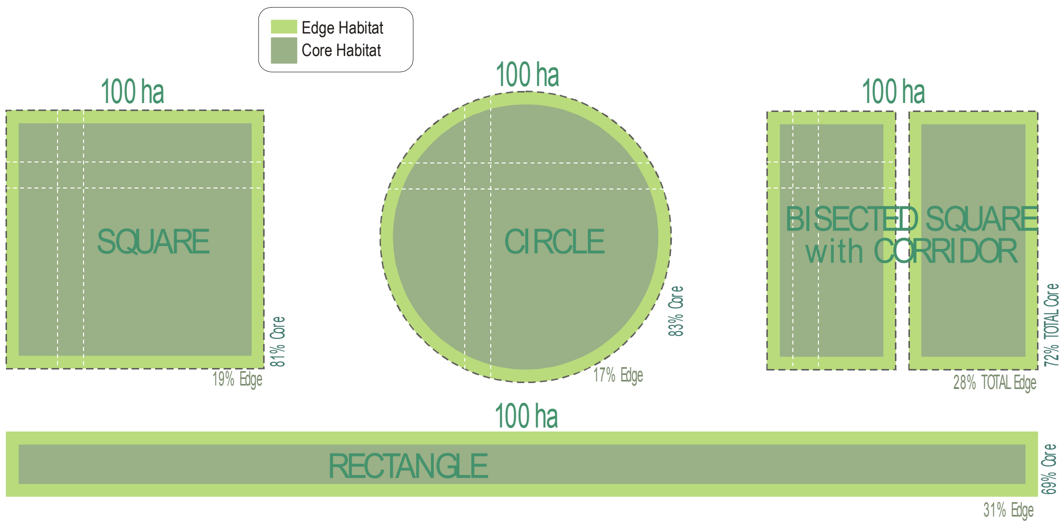


Figure 15. Relationship between patch geometry and edge area assuming 50 m edge width (adapted from Collinge 1996).

Patch and corridor criteria can help define suitable habitat in fragmented landscapes. In the habitat fragmentation process, there appear to be 'critical thresholds' where rapid changes in patch size and isolation occur; criteria should reflect these critical thresholds. Salmo et al. (2003) provides a review of literature relevant to patch and corridor size indicators.

Candidate patch and corridor size thresholds for the Deh Cho Plan area are incorporated into the core area thresholds described above.

6.3 SPECIES-SPECIFIC INDICATORS AND GUIDELINES

Appropriate species or guilds used for cumulative effects assessment and management are generally selected by considering the following criteria (adapted from Noss 1990):

- economic importance (e.g., **featured** species important for hunting, fishing, traditional land use, or recreation),

- sensitivity to potential development activities or early indicator of environmental stress or incremental demand on facilities and services (e.g., **ecological** and **sensitive** indicators: species that signal the effects of perturbations on a number of species with similar habitat requirements),
- importance in the food chain or ecosystem function (e.g., **keystones**: pivotal species upon which the diversity of a large part of a community depends),
- social importance (e.g., **flagships**: popular, charismatic species that serve as symbols and rallying points for conservation initiatives),
- special conservation status (e.g., **vulnerables**: species that are rare, genetically impoverished, of low fecundity, dependent on patchy or unpredictable resources, extremely variable in population density, persecuted, or otherwise vulnerable to extinction in human-dominated landscapes),
- ecological or economic significance for more than one discipline and disturbance type (e.g., **umbrellas**: species with large area requirements that incorporate many other species),
- ability to be quickly and cost-effectively calculated, estimated or assessed from existing data sources, and
- ability to be efficiently and cost-effectively monitored.

The following species have been consistently used as ecological indicators in the NWT (e.g., GeoNorth and Axys 1997; DIAND 2002; Paramount 2003). These species were among the ten defined to be Valued Ecosystem Components in the Deh Cho wildlife report (EBA 2003) and are considered to be appropriate cumulative effects indicators. Summaries of indicator and threshold literature relevant to these species are provided below:

- **woodland caribou** (*Rangifer tarandus*): species of concern; occasional traditional harvest species; associated with treed muskeg, lichen forest, and alpine areas; intolerant of human disturbance; very sensitive to overharvest and increased predation.
- **moose** (*Alces alces*): important subsistence and sport harvest species; associated with young to intermediate-aged boreal forest and subalpine habitat; relatively tolerant of human disturbance; moderately sensitive to overharvest.
- **American marten** (*Martes americana*): important trapping species; associated with old boreal forest; relatively tolerant of human disturbance; sensitive to overharvest.
- **grizzly bear** (*Ursus arctos*): widely used umbrella species for regional assessment; associated with foothills and subalpine habitat; intolerant of human disturbance; very sensitive to overharvest.

6.3.1 Woodland Caribou

Caribou are widely distributed across the Deh Cho Plan area, and three caribou ecotypes are present in the Deh Cho Territory: 'boreal', 'northern mountain' (mountain), and 'barren-ground' (Heard and Vagt 1998). Woodland caribou have low ecological resilience; they are a habitat specialist, intolerant of human disturbance, and have low reproductive productivity (Bergerud 1974). Gunn et al. (2002) evaluated caribou abundance and distribution in the Deh Cho and developed a draft map predicting probability of occurrence on a 3 class scale (low, medium, high).

Barren-ground caribou recently wintered in northeastern Deh Cho Territory for the first time in approximately 20 years (T. Lennie pers. comm. *in* Gunn et al. 2002). This ecotype is not considered further because their use of the Deh Cho Plan area is not continuous.

COSEWIC lists **boreal caribou** in Canada as 'Threatened', and the NWT lists them as 'Sensitive'. Boreal-ecotype caribou reside in low elevation coniferous forests year-round; treed fens and bogs appear to be important (Bradshaw et al. 1995; Stuart-Smith et al. 1997; Brown and Hobson 1998; Anderson et al. 2000, Rettie and Messier 2000). Boreal caribou are widespread across the Deh Cho Plan area. The factors that best predicted probability of boreal caribou occurrence were black spruce-lichen habitat, fire regeneration habitat, sphagnum habitat, herb and tall shrub habitat, mixed forest habitat, elevation, moose presence, and harvest locations. The best predictor was presence of black spruce-lichen habitat. These coniferous-lichen forests are relatively productive in the Deh Cho Plan area and may support a large proportion of the NWT's boreal caribou (Gunn et al. 2002).

Northern **mountain-ecotype** caribou are found primarily in mountainous terrain in the west half of the Deh Cho Plan area from the Nahanni National Park reserve in the south to the Richardson Mountains to the north. Mountain caribou in the Deh Cho are classified into five herds shared with the Yukon: the Redstone, South Nahanni, Finlayson, Coal River, and La Biche (Anderson et al. 2002; EBA 2003). These herds undertake seasonal movements from low elevation winter habitat to plateaus and upland sites in spring. Post-calving areas include moist alpine tundra and open meadows. Calving has been documented in the northwest corner of the Plan area. Known wintering areas are present both east and west of the Mackenzie River (EBA 2003). Cow:calf ratios of mountain ecotype caribou in the Deh Cho Plan area appear to be low; this is indicative of a declining population (EBA 2003). COSEWIC lists northern mountain caribou in Canada as 'Special Concern', and the NWT lists them as 'Sensitive'.

Farnell and McDonald (1987) provide results of a demography study on the Finlayson mountain caribou herd. The Finlayson herd undertakes seasonal movements from low elevation winter range within the Pelly River – Ross River watersheds to mountainous calving sites and summer ranges in three relatively distinct regions (Upper Ross, Logan Range, and St. Cyr Range). Rut takes place during early October along alpine plateaus near summer and winter range. Seasonal movements to winter range usually occur between November and January, but the timing varies with weather conditions. Herd size was estimated to be 3,067 ±413 in March 1986. Predators were implicated in all known mortalities, and fall calf survival increased following a reduction in wolf numbers.

More intensive radio-telemetry studies have been completed for mountain (northern-ecotype) caribou in northeast British Columbia and west-central Alberta. Mountain caribou there used a combination of windswept alpine and low- to high-elevation mature to old coniferous forests where lichens are most abundant and available. Deciduous and mixedwood forests appeared to be avoided. Considerable individual and between-year variability in habitat use was observed. Some individuals remained in low elevation coniferous lichen-spruce forests year-round (Edmonds and Bloomfield 1984; Sopuck 1985; Murray 1992; Backmeyer 1994; Brown and Hobson 1998; Apps et al. 2001, Culling and Culling 2001).

6.3.1.1 Resilience

Caribou have a relatively low productive rate. Females are generally 2.5 years old before first breeding, and rarely produce more than one calf per year. The most important source of adult caribou mortality is predation by wolves (*Canis lupus*), followed by predation by bears, and legal and illegal hunting (Bergerud and Elliot 1998; Dyer 1999; reviewed in Culling and Culling 2001). The main limiting factors for caribou populations are assumed to be predation, forage availability, snow conditions, and insects.

Predation appears to be the proximate limiting factor for woodland caribou (Farnell and McDonald 1987; Seip and Cichowski 1996; Dzus 2001; Anderson et al. 2002; McLoughlin et al. 2003). Relative safety from predators is assumed to be a key feature of habitat used by caribou. Most calf mortality occurs within 10 days of birth, and a cow's ability to avoid predators during this period has the greatest effect on calf survival. By placing themselves at high elevations or in isolated wetlands, females are thought to increase the distance between themselves and predators that are using uplands and valley bottoms (Bergerud and Page 1987; Rettie and Messier 2001; Dunford et al. 2003).

Woodland caribou generally occur in low densities over large ranges. This distribution is assumed to reduce the risk of predation by reducing encounter rate (Bergerud and Page 1987; Stuart-Smith et al. 1997). It also allows caribou to persist in areas with a continually changing mosaic of the older habitat types that they rely on.

Fire can play an important role in forage availability, and recently burned areas are usually avoided because lichen cover is low (Klein 1982; Schaefer and Pruitt 1991; Webb 1998). Winter habitat quality appears to be directly related to the abundance and accessibility of terrestrial and arboreal lichens (Schaefer 1996; EBA 2003).

Deep or hard snow can make foraging difficult for caribou (Carruthers and Sopuck 1982; Farnell and McDonald 1987; Brown and Theberge 1990) and insect harassment alters caribou behaviour (Klein 1991; Noel et al. 1998).

6.3.1.2 Response to Land Use and Human Activity

Woodland caribou numbers in southern populations have declined precipitously since 1960 (Bloomfield 1979; Harper 1988; Edmonds 1991; Harding and McCullum 1994; Dzus 2001). In all areas, this decline occurred concurrently with an increase in road access and logging. These factors are believed to have resulted in a significant increase in mortality from wolves and hunters (Bergerud et al. 1984; Seip 1992; Harding and McCullum 1994). This is considered to be a good example of the cumulative effects of habitat loss, fragmentation, and human development (Harding and McCullum 1994). Calf and adult mortality has recently been identified as the proximate cause of boreal caribou population declines in Alberta (McLoughlin et al. 2003).

Caribou have been shown to avoid human developments and activity, but response appears to vary by sex, season, and population. Reduced use has been documented near roads (Dau and Cameron 1986; Nelleman and Cameron 1998; Dyer 1999; James and Stuart-Smith 2000), seismic lines (Dyer 1999; James and Stuart-Smith 2000), wellsites (Dyer 1999), pipelines (James and Stuart-Smith 2000), powerlines (Nelleman et al. 2001), cutblocks (Cumming and Beange 1993; Smith et al. 2000), recreational facilities (Nelleman et al. 2001), snowmobiles (Reimers et al. 2003), and skiers (Reimers et al. 2003). Documented zones of reduced use by boreal caribou in north-central Alberta are summarized in Table 11. This reduced use is presumed to reduce the risk of predation (Dyer 1999; James and Stuart-Smith 2000).

Table 11. Boreal caribou reduced-use buffers in north-central Alberta (Dyer 1999).

SEASON	FEATURE				
	ROADS		WELLSITES		Seismic Lines
	Open Coniferous Wetland	Closed Coniferous Wetland	New - <15.5 months old (drilling completion date)	Old - ≥15.5 months old (drilling completion date)	
Early Winter Nov 16 – Feb 21	*	*	250 m	0 m	100 m
Late Winter Feb 22 – Apr 30	250 m	250 m	250 m	500 m	250 m
Calving May 1 – Jun 30	100-250 m	0 m	1000 m	500 m	100 m
Summer July 1 – Sep 15	250 m	100 m	0 m	250 m	100 m
Rut Sep 16 – Nov 15	250 m	0 m	250 m	0 m	100 m
Weighted Annual Average	215-250 m	93 m	326 m	238 m	129 m

* Insufficient caribou had roads within their home ranges to perform analysis to examine avoidance of roads during this time period.

Available information suggests that the probability of adverse effects is inversely related to corridor width, activity intensity, and presence of right-of-way vegetation that is dramatically different from adjacent areas (reviewed in Jalkotzy et al. 1998). Roads are believed to have the greatest cumulative effect because they represent corridors where vehicle traffic is likely to occur, revegetation of the right-of-way is prevented, and hunting and vehicle mortality is concentrated. Utility corridors (pipelines, powerlines, railway lines) represent features where off road vehicle access may occur and revegetation of the right-of-way is usually discouraged. Motorized access along seismic lines occurs least frequently and unlike roads and utility corridors, revegetation of the corridor is not actively discouraged. Research will be required to determine actual response of boreal- and mountain-ecotype caribou in the Deh Cho Plan area.

Mountain-ecotype caribou in the Redrock/Prairie Creek range of the west-central Alberta foothills used areas within 500 m of active roads and 250 m of inactive roads and streams less frequently than expected during winter, but use of areas within 100 m of cutlines did not differ from that expected (Oberg 2001). Caribou in this range also used areas within 540 m of old cutblocks and 1.2 km of newly harvested cutblocks less frequently than expected (Smith et al. 2000).

Access creation can increase hunting and predation rates by providing travel corridors that allow humans and wolves to increase their encounter rate and hunting efficiency (Bergerud et al. 1984; Cumming and Beange 1993; James 1999). In north-central Alberta, predation rates for caribou were higher in proximity to linear corridors (Stuart-Smith et al. 1997; James and Stuart-Smith 2000). In the west-central Alberta foothills, however, non-forested clearings and linear corridors were least preferred by wolves (Kuzyk 2002). Clearing and access creation may alter caribou movements and distribution and also lead to increased predation and hunting pressure (Whitten et al. 1992; James and Stuart-Smith 2000; Dzus 2001).

Dzus (2001) concluded that the challenge for caribou conservation is to maintain sufficient quantities of suitable habitat through time in each caribou range and not unduly increase predation pressure. He recommended that cumulative effects thresholds be developed and incorporated into range management plans. A primary habitat management technique for this species is identification and protection of primary use areas.

Analyses conducted for the Alberta Boreal Caribou Committee (BCC 2003) found that two home range attributes: 1) industrial footprint, expressed as area within 250 m of corridors; and 2) forest age, expressed as area burned within the last 50 years; were excellent predictors of population trends. Caribou population growth rate was inversely related to industrial footprint and young forest.

No specific relationships have been developed to relate linear corridor density to woodland caribou habitat effectiveness. Nellemann and Cameron (1998) found that the density of calving barren-ground caribou was inversely related to road density although non-maternal individuals did not display the same relationship (Dau and Cameron 1986). Vehicle traffic influenced barren-ground caribou crossing success more than the presence of elevated pipelines and roads (Murphy 1984). The most easily disturbed group is cows and calves during the calving season (Wolfe et al. 2000). Preliminary modelling conducted for the BCC suggests that wolf encounters with abundant prey such as moose substantially increase when linear corridor densities approach 3-4 km/km^2; this same relationship is not predicted for scarce prey such as caribou. Further work is ongoing to refine and test the models (Dunford et al. 2003).

Current average corridor densities in the winter range of the rapidly declining Little Smoky boreal-ecotype herd are 0.23 km/km^2 for roads, 0.77 km/km^2 for truck trails, 0.15 km/km^2 for pipelines, and 2.90 km/km^2 for cutlines. Existing road and truck trail corridor densities are calculated to be Very Low or Low (<1.1 km/km^2) on about 35% of the Little Smoky caribou winter range and Moderate (1.1 to 2.9 km/km^2) on approximately 28% of the area. High to Extremely High road and truck trail densities (>2.9 km/km^2) are present on approximately 37% of the caribou winter range (Salmo unpub. data).

Based on information provided in Brown and Hobson (1998) and Smith et al. (2000), the main wintering areas of the mountain-ecotype Redrock/Prairie Creek northern-ecotype caribou herd are located in subwatersheds with road and trail densities between 0.35 and 0.6 km/km^2, and this herd appears to have at least temporarily moved away from areas with road and trail densities that exceed 0.6 km/km^2 (Salmo unpub. data). On this basis, an average road and trail density threshold of 0.6 km/km^2 was derived for northern- and mountain-ecotype caribou in west-central Alberta (Salmo unpub. data). Dyer et al. (2002) found that road density in boreal-ecotype caribou seasonal home ranges was less than 0.3 km/km^2.

Seismic lines are the dominant land use feature in the Deh Cho Plan area and much of the Western Canada Sedimentary Basin. A key uncertainty is how line width and age influences caribou and predator response. Limited research has specifically examined caribou response to varying seismic line widths. As noted previously, Dyer (1999) found that boreal-ecotype caribou used areas adjacent to conventional width seismic lines (5-9 m) less than expected in all seasons. Dyer et al. (2002) found that these seismic lines were not barriers to movement, as boreal caribou crossed as often as expected during all seasons. In contrast, moderate to high-use roads were crossed significantly less frequently than expected during all time periods except calving. Oberg (2001) found that mountain-ecotype caribou used areas near seismic lines as frequently as expected. This contrast with Dyer's conclusions was attributed to: greater topographic relief and reduced line of sight; lower overall seismic line density; recent use of meandering Low Impact Seismic (LIS) lines; dominance of older conventional seismic lines (80% >23 years old); and low sample size. A recent study in northeast Alberta found that LIS lines (3-5 m wide or less) are structurally different from conventional seismic lines (5-10 m wide). LIS lines had more barriers and shorter line-of-sight than conventional seismic lines which is likely to reduce predator efficiency (Dunford et al. 2003). Available information suggests that adverse effects of seismic lines is directly related to width and line-of-sight and inversely related to age. Meandering LIS lines less than 3 m wide are assumed to create low cumulative effects risk for woodland caribou.

No specific thresholds for core area were located for woodland caribou, however this concept was originally applied to grizzly bears and work on that species is applicable. Like caribou, female grizzly bears appear to require a portion of their home range that is secure from disturbance and mortality associated with high use human features. These core security areas are considered to be that portion of home range that corresponds to a

24- to 48-hour feeding bout of an adult female grizzly bear (Mattson 1993; Mace et al. 1996). Daily winter movement rates of woodland caribou in Alberta average 0.64 km/day (Stuart-Smith et al. 1997; Smith et al. 2000), which translates to a 24- to 48-hour range area of 130 to 515 ha.

Recommended and established land use guidelines for woodland caribou are summarized in Table 12. Reviews of habitat availability and population thresholds applicable to woodland caribou in the Yukon are provided in Axys (2000) and Anderson et al. (2002).

Table 12. Management indicators and guidelines for woodland caribou.

Indicator	Guideline or Threshold	Comments
Edge Use	• Boreal-ecotype woodland caribou under-used areas <500 m of old wells during late winter and calving, <250 m of these same features during summer; they also under-used areas <250 m of roads and cutlines during late winter (Dyer 1999). • Mountain-ecotype woodland caribou under-used areas adjacent to roads and streams but not cutlines (Oberg 2001). • Predation rates for caribou may be higher <500 m of linear corridors (Stuart-Smith et al. 1997; James and Stuart-Smith 2000). • On average, mountain-ecotype woodland caribou were 540 m farther from cutblocks and 1.2 km from newly harvested cutblocks than random (Smith et al. 2000).	• Based on studies in north-central Alberta. • Based on studies in west-central Alberta foothills. • Based on studies in north-central Alberta. • Based on studies in west-central Alberta foothills.
Habitat Availability	• Combined cleared area <5% within the Pedigree caribou management area; all subsequent activities to be restricted to existing corridors (Pedigree Caribou Standing Committee and Delta 1991). • A regression equation has been developed to predict boreal caribou population trends; the equation is based on % of habitat within 250 m of an industrial feature and % of habitat that is of fire origin and less than 50 years old (BCC 2003).	• Management guideline for Pedigree area in northwest Alberta. • Range planning target under development for Alberta.
Core Area	• Boreal-ecotype woodland caribou populations declined when core area <50%; threshold identified at <60% core area; 250 m zone of influence used (Anderson et al. 2002). • Timber harvesting should avoid presently defined core use areas (Smith et al. 2000).	• Threshold based on review of Alberta population data; used 250 m buffer from all linear features. • Management recommendation based on studies in west-central Alberta foothills.

cont'd

Table 12. Management indicators and guidelines for woodland caribou (cont'd).

Indicator	Guideline or Threshold	Comments
Road Density	• Density of calving barren-ground caribou highest at road density of 0 km/km^2 and declined by 86% at road densities >0.6 km/km^2; male and yearling density highest at 0.3-0.6 km/km^2 (Nellemann and Cameron 1998). • Road densities <0.6 km/km^2 in winter range used by mountain-ecotype caribou (Salmo unpub. data). • Road density in boreal-ecotype woodland caribou seasonal home ranges was 0.1 to 0.3 km/km^2 (Dyer et al. 2002).	• Based on studies in Alaska petroleum development areas. • Based on studies in west-central Alberta foothills. • Based on studies in north central Alberta.
Corridor Density	• Boreal-ecotype woodland caribou populations declined when total corridors >1.8 km/km^2 (Francis et al. 2002). • Average seismic line density in mountain-ecotype home range was 0.67 km/km^2 (Oberg 2001). • Seismic line density in boreal-ecotype woodland caribou seasonal home ranges was 1.0 to 1.3 km/km^2 (Dyer et al. 2002). • Boreal-ecotype woodland caribou populations do not persist when total corridors >3 km/km^2 (B. Stelfox pers. comm.).	• Threshold based on review of Alberta population data. • Based on studies in west-central Alberta foothills. • Based on studies in north-central Alberta. • Threshold identified by caribou biologists in Delphi process.
Activity	• Roads with moderate vehicle traffic were semi-permeable barriers to boreal-ecotype caribou (Dyer et al. 2002). • Boreal-ecotype caribou avoided active logging roads through traditional wintering area (Cumming and Hyer 1998). • Boreal-ecotype caribou could suffer abnormal weight loss after 23 disturbances during one winter (Bradshaw 1994). • Maximum 300 km new seismic line per township in a single winter in caribou management area (Pedigree Caribou Standing Committee and Delta 1991). • Maximum 30 km active seismic line per township at any point in time from December 1 to April 30 in caribou management area (Pedigree Caribou Standing Committee and Delta 1991).	• Based on studies in north-central Alberta. • Based on experiment in northern Ontario. • Based on predictive energetics modelling. • Management guideline for Pedigree area in northwest Alberta. • Management guideline for Pedigree area in northwest Alberta.

The Alberta BCC has been working to develop a habitat planning target for boreal-ecotype herds. Their goal was to describe the amount of effective habitat that must be present in caribou range in order for caribou populations to be stable. Habitat effectiveness targets were identified as the preferred approach by caribou specialists. However, habitat effectiveness (as defined by the working group), was found to be a very poor predictor of population trends. A statistical equation was subsequently found to be an excellent predictor of population trends. The multiple regression equation includes two factors: percent of range within 250 m of an industrial feature; and percent of range that is of fire-origin and less than 50 years old (BCC 2003). This regression equation integrates multiple sources of disturbance and mortality and does not define cause-effect relationships.

6.3.1.3 Candidate Indicators and Thresholds

Three indicators appear to be the most practical choices for woodland caribou in the Deh Cho Plan area: the total corridor density indicator recommended for northeast British Columbia; herd population trend, as predicted by the BCC habitat regression equation, and habitat availability (see Section 6.2.1.1). The regression equation is more defensible because it is based on actual data from Alberta, but requires information on vegetation age structure that is not currently available for the Deh Cho.

The total corridor density indicator and candidate thresholds previously developed for northeast British Columbia appears to be the most practical approach in the Deh Cho at this time. Candidate thresholds are intended to be protective and are set at or below the lowest detected effect level identified for this species (Table 12). The candidate woodland caribou indicator includes all linear rights-of-way greater than 3 m in width, although there is scientific uncertainty associated with this assumption. Passable features >3 m wide could increase winter predation and harassment risk from wolves and snow machines. Figure 16 displays current total corridor density in the Deh Cho Plan area, calculated for 5 km square cells with IRS coverage. 'Total corridors' was defined to include all primary and secondary roads, trails and winter roads, pipelines, and seismic lines (seismic lines less than 3 m wide are not visible on the IRS coverage).

A conservative suite of candidate total corridor thresholds is proposed for designated caribou management areas. The Critical Threshold for special resource management areas (median <1.5 km/km^2) was set below the 1.8 km/km^2 threshold identified for boreal-ecotype caribou (Table 12). The Target and Cautionary Thresholds for special resource management areas (respectively median <1.2 km/km^2 and <1 km/km^2) were arbitrarily set below this threshold to ensure that monitoring and restrictive measures are implemented at early stages of development in designated caribou management areas. At present, 97% of the Deh Cho Plan area is below the 1.0 km/km^2 candidate Cautionary Threshold, 98% is below the 1.2 km/km^2 candidate Target Threshold, and 99% is below the 1.5 km/km^2 candidate Critical Threshold (Figure 16).

A less conservative suite of candidate core area thresholds was also identified for areas where resource development is a defined management objective. The Critical Threshold for these multiple use areas (median <1.8 km/km^2) was set at the persistence threshold identified for boreal-ecotype caribou (Table 12). The Target and Cautionary Thresholds for special resource management areas (respectively median <1.5 km/km^2 and <1.2 km/km^2) were arbitrarily set to be protective and consistent with special resource management area thresholds. At present, 98% of the Deh Cho Plan area is below the 1.2 km/km^2 candidate Cautionary Threshold, 99% is below the 1.5 km/km^2 candidate Target Threshold, and 99.5% is below the 1.8 km/km^2 candidate Critical Threshold (Figure 16).

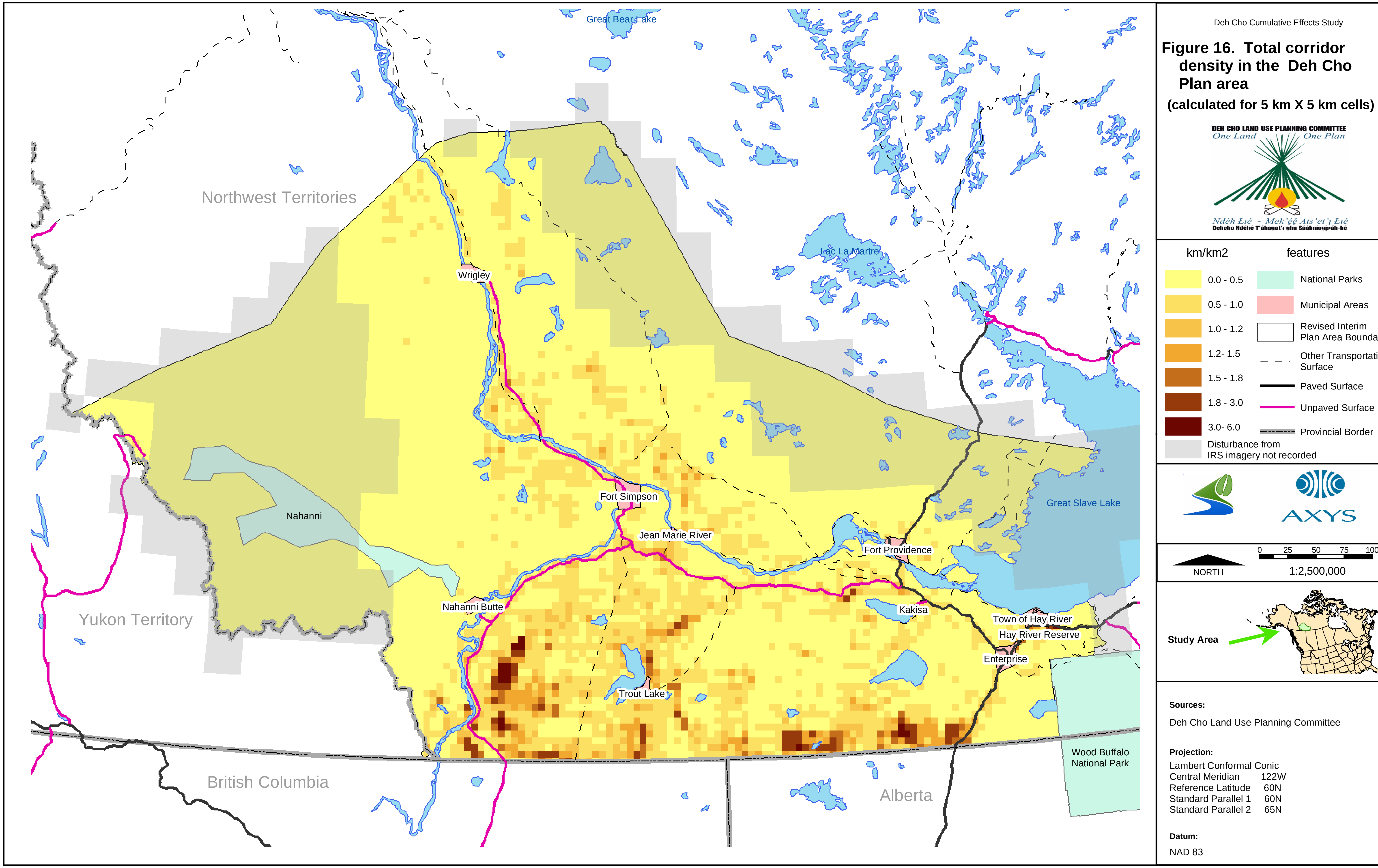


Figure 16. Total corridor density in the Deh Cho Plan area (calculated for 5 km X 5 km cells)

6.3.2 Moose

Moose are highly sought after by subsistence and recreational hunters, and are the most abundant large mammal in the Deh Cho Plan area. Moose occupy the entire Deh Cho Plan area but are infrequently observed on tundra landscapes. Densities are relatively low, ranging from 3 to 17 animals per 100 km^2 (Graf 1992 *in* EBA 2003).

Moose are primarily browsers and are most abundant where food supplies are available adjacent to security and thermal cover. High quality browse consists of young shrubs and deciduous trees, so conifer-dominated forests are rated as lower quality. Riparian willow habitat is important, particularly during winter, and the availability of this habitat appears to determine moose distribution in the Deh Cho Plan area. Moose occurring in mountainous regions rely heavily on birch-moss tundra habitat during spring, summer, and fall. Use of aquatic habitats is highest during summer. Early seral stages such as areas disturbed by fire or flooding provide the highest quality habitat (EBA 2003).

6.3.2.1 Resilience

Moose are a habitat generalist with moderate reproductive potential and are relatively tolerant of human disturbance. Key factors limiting moose populations are:

- human-caused direct and indirect mortality (sport, subsistence and illegal harvest, increased predation risk, vehicle collisions),
- natural environmental and biotic factors (predation, tick infestations and disease, snow depth, natural succession), and
- habitat loss and alteration (clearing, fire suppression).

Local and regional abundance of moose is naturally variable due to factors such as fire history and environmental conditions (EBA 2003; Salmo et al. 2003; Ursus and Salmo 2003). Winter is the critical period in the Deh Cho Plan area and snow depth is a critical factor affecting moose populations. Limiting snow depths are assumed to be 65 cm for moose (Nietfeld et al. 1985).

6.3.2.2 Response to Land Use and Human Activity

Moose have been shown to avoid human developments and activity, but response appears to vary by sex, season, and population. Reduced use has been documented near roads (Rolley and Keith 1980; Knight and Temple 1995), industrial activity (Penner and Duncan 1983; Morgantini 1984), residences (Rolley and Keith 1980), and skiers (Ferguson and Keith 1982). Moose in hunted populations appear to display greater behavioural and physiological response to human activity than to vehicles or aircraft (Andersen et al. 1996). However, moose will move closer to sources of disturbance if alternate undisturbed habitat is not available (Rolley and Keith 1980).

Moose densities were found to be highest in settled areas of northern Alberta and densities decreased with increasing latitude and increasing distance from settled areas (Schneider and Wasel 2000). It is likely that the agricultural landscape in settled areas provides an abundant food supply coupled with protection from predators. In addition, private land ownership restricts hunting access and local licensed hunting is focused on males, allowing the majority of the females to escape harvest and reproduce (Osko 2001). In contrast, the lowest reported moose density occurred near the community of Fort Providence and the moose population is assumed to be declining in this area (RWED 2001b *in* EBA 2003).

A review of habitat availability and population thresholds applicable to moose in the Yukon is provided in Axys (2000). Cumulative effects indicators and thresholds have been infrequently applied to this species even though they have been intensively studied (Table 13). This likely reflects the fact that moose populations are more sensitive to overharvest and other sources of mortality than to habitat loss and fragmentation.

Table 13. Management indicators and guidelines for moose.

Indicator	Guideline or Threshold	Comments
Habitat Availability	• Maintain >97% high capability and moderately high capability winter moose habitat and >95% moderate to nil capability habitat undisturbed in special management areas (MSRM 2004).	• Oil and Gas Pre-tenure Plan management target for M-KMA in northeast British Columbia.
Edge Use	• Moose sightings lower than expected <300 m from Denali road (Yost and Wright 2001). • Moose may avoid linear features and ground-based disturbance by 100 m to 500 m (Penner and Duncan 1983; Ferguson and Keith 1982).	• Based on study in Denali National Park, Alaska. • Based on studies in Alberta.
Core Area	• Moose population estimates unchanged as core area declined from 40% to 15% over 30 years (Salmo et al. 2003).	• Based on study in moderate to high quality boreal forest habitat of northeast British Columbia.
Road Density	• Moose population estimates unchanged as road and trail density increased from 0.62 to 1.61 km/km^2 over 30 years (Salmo et al. 2003). • Regional moose population density was directly related to road density (Schneider and Wasel 2000). • Moose population density remained stable as road density associated with timber harvest increased over 16 years; density increased where hunter access did not occur (Rempel et al. 1997).	• Based on study in moderate to high quality boreal forest habitat of northeast British Columbia. • Based on surveys in settled and forested areas of northern Alberta. • Based on study in Ontario.
Patch Size	• Patches >3 to 5 ha in size within moose management areas (DIAND 1998).	• Yukon Timber Harvesting and Planning Ground Rules.

cont'd

Table 13. Management indicators and guidelines for moose (cont'd).

Indicator	Guideline or Threshold	Comments
Corridor Width	• All point within cutblocks <200 m from thermal/ hiding cover within moose management areas (DIAND 1998).	• Yukon Timber Harvesting and Planning Ground Rules.
Human Activity	• Allowable annual moose harvest rate <5%, except for high density or rapidly growing populations (YRRMMT 1996 *in* Axys 2000). • Moose sightings from highway decreased by 72% as traffic rate increased by 50% over 9 year period (Singer and Beattie 1986).	• Yukon Territory moose management objective. • Based on study in Denali National Park, Alaska.

6.3.2.3 Candidate Indicators and Thresholds

Available information including the case studies conducted in the boreal forest and foothills of northeast British Columbia (Salmo et al. 2003), indicates that moose in the Deh Cho Plan area can be adequately protected by generalized habitat, core area, patch and corridor size, and woodland caribou indicators and candidate thresholds.

6.3.3 American Marten

American, or pine, marten are a small, commercially important furbearer found in boreal and subalpine forests throughout the Deh Cho Plan area. Marten are considered 'Secure' in the NWT (EBA 2003).

The marten was selected as a wildlife indicator because it is an important furbearer in the Deh Cho and because its requirement for mature forest cover (ecological) and its avoidance of open areas such as multiple rights-of-way (vulnerable) make it a valuable indicator of environmental change and how humans manage forested landscapes. In addition, the species ecology has been studied throughout its range and field techniques have been refined to allow marten to be efficiently and cost-effectively monitored (Zielinski and Kucera 1996). The marten has been considered one of the most habitat-specialized mammal in North America (Buskirk and Powell 1994) and is absent from small patches (Chapin et al. 1998).

Marten are closely associated with mature coniferous and mixedwood forests, but the presence of complex structure in the overstory and near the ground (dead and downed woods, shrubs, and understory) may be more important than tree species composition (Koehler and Hornocker 1977; Taylor and Abrey 1982; Buskirk 1984; Chapin et al. 1997). These structural components provide habitat for prey species as well as resting and birthing sites. Coniferous forests of highest market value tend to support the greatest number of marten (Edwards 1950 *in* Hagmeier 1956; Thompson et al. 1989). Marten, however, can be found in managed habitat such as cutovers and second growth forests (Koehler and Hornocker 1977; Soutiere 1979; Steventon and Major 1982; Snyder and Bissonette 1987; Thompson and Curran 1995).

6.3.3.1 Resilience

Marten are a habitat specialist with moderate reproductive potential and are relatively tolerant of human disturbance. Marten are vulnerable to overharvest because they are easily trapped and have late sexual maturity and small litters. Populations are based on territorial home ranges of resident adults, which though variable in size, are relatively large for a small carnivore. Dispersing individuals, often juveniles, overlap with adults of the same or opposite sex (Buskirk 1994; Powell 1996). Unharvested populations undergo large fluctuations, sometimes greater than an order of magnitude, in response to prey population changes (Powell 1996). Marten have a varied diet and prey primarily on voles and mice, but the snowshoe hare population cycle has a significant impact on marten populations in the northern boreal forest (Poole and Graf 1996).

6.3.3.2 Response to Land Use and Human Activity

There has been considerable distribution loss at the southern limit of marten range due to human land-use practices and habitat loss (Strickland et al. 1992; Gibilisco 1994). Marten are tolerant of human development and activity when habitat loss, hunting, and trapping are not limiting (Holyan et al. 1998).

Logging has been implicated as an important factor in the reduction of the species abundance and range (Thompson and Harestad 1994). Research on marten use of working forests has been conducted in a wide range of habitat types from Maine to Newfoundland, to western Quebec to Utah and California. Marten can tolerate clearcutting within their home range, but various limits of habitat conversion have been observed, as summarized in Table 12. The abundance and availability of food may affect marten habitat use and productivity in both natural and disturbed landscapes (Lensink et al. 1955; Koehler and Hornocker 1977).

Marten densities are highest in uncut forest (Soutiere 1979) and marten abundance may be significantly reduced when the landscape is comprised of more than 25% open cover, The range of clearcut forest within marten home ranges varies up to 50%; more generally in the range of 25-40%. Recommendations for the configuration of timber harvests in marten habitat range from leaving residual stands 20-25 m^2/ha basal area, residual stands >25 ha, or clusters of trees ≤50 m apart with logs and slash left on the ground. In western Quebec, it was suggested that ≥50% of uncut forest be retained inside 9-10 km^2 blocks with <30% clearcut over a period of 30 years. In Maine and in Utah, it was suggested that fragmentation of marten habitat could be reduced by consolidating clearcuts and retaining large residual patches. It was also noted that progressive harvesting from a single patch would retain the largest amount of interior habitat.

Marten are also known to use regenerating clearcuts, but there is an indication that these habitats are mostly frequented by juveniles and in heavily trapped areas can function as populations ‘sinks’. These habitats need to be carefully managed to ensure population sustainability in source habitats.

The juxtaposition of edge and meadow habitat within old growth forest stands has been shown to be important for marten foraging activity. Marten, however, are also known to be averse to travelling across wide treeless openings. The range of travel in open areas has been variously reported but is generally less than 200 m wide. Dispersal is primarily a juvenile trait, and marten have been shown to disperse over distances of about 60 km. Presumably, significant forest patches must remain in landscapes traversed during these long distance dispersal events. One researcher noted that a continuous distance of >5 km of unforested habitat was a barrier to dispersal. Structurally complex riparian areas may provide important movement corridors in fragmented landscapes (Jones and Raphael 1990).

Logging or clearcutting extensive areas will reduce marten habitat and possibly, prey availability. Marten tend to avoid small cutovers in the first year, and clearcuts up to 15 years old are poor habitat (Snyder and Bissonette 1987). Females avoid openings more than males (Thompson 1991). Low use of logged forests is due to deep snow in openings, lack of coarse woody debris and reduced cover resulting in predation on marten, particularly by raptors (Hargis and McCullough 1984; Thompson and Colgan 1994). In clearcuts, home range size increases, probably to ensure adequate resources in winter. Thompson (1994) found that marten density indices were 90% greater in uncut forests than in logged forests. Resident marten in uncut forests had higher mean ages, were more productive, and had lower natural and trapping mortality.

6.3.3.3 Candidate Indicators and Thresholds

Available information indicates that marten in the Deh Cho Plan area can be adequately protected by generalized habitat, core area, patch and corridor size, and woodland caribou indicators and candidate thresholds. Recommended and established land use guidelines for marten are summarized in Table 14.

Table 14. Management indicators and guidelines for marten.

Indicator	Guideline or Threshold	Comments
Critical Habitat Elements	• Most resting sites were located in old growth spruce and spruce-birch with canopy cover >60%, optimal conditions for red squirrels.	• Based on Buskirk (1984) working in southcentral Alaska.
	• Winter resting sites were cavities in large decayed stumps or logs; marten rested in conifer crowns during summer.	• Work by Soutiere (1979) in Maine.
	• Most maternal dens in large hollow logs or over-mature trees (40-70 cm dbh; males rested in tree canopies).	• Summer home range studies by Wynne and Sherburne (1984) in northwestern Maine.
	• During winter, marten rested primarily in subnivean sites in logs and stumps.	• Work in the Central Rocky Mtns. (Buskirk et al. 1989).
Habitat Availability	• A female home range in largely uncut forest was 25% clearcut.	• Based on Steventon and Major (1982) in northern Maine.
	• Males occupied home ranges with 16-50% clearcut forest.	• Steventon and Major (1982) working in northern Maine.
	• Harvesting that maintains residual stands 20-25 m^2/ha basal area in pole and larger trees provides adequate habitat for marten.	• From Soutiere (1979) working in spruce-fir hardwood forests in Maine.
	• Marten would be least affected by keeping clearcuts small and scattering cutting units.	• From Soutiere (1979) working in Maine.
	• Marten captures reached zero when openings occupied >25% of the landscape.	• Hargis and Bissonette (1997), Uinta Mountains, Utah.
	• Maximum observed regenerating clearcuts in male and female home ranges were 40% and 31%, respectively.	• Chapin et al. (1998) working in Maine.
	• Winter home ranges usually contained <30-35% open or closed regenerating stands and >40-50% uncut forest.	• Based on Potvin et al. (2000) working in boreal landscapes of western Quebec.
	• Impacts of logging can be reduced by leaving clusters of trees ≤50 m apart with logs and slash left on the ground.	• From Hargis and McCullough (1984), Yosemite, California.
	• Fragmentation can be reduced in logged landscapes by consolidating clearcuts and retaining large residual patches.	• Chapin et al. (1998) from Maine.
	• Marten rarely used 0-15 year-old clearcuts.	• Based on work by Soutiere (1979) in Maine.
	• Marten seldom used clearcuts and used residual stands >25 ha and undisturbed forest; presence of residual stands can enable marten to survive despite clearcutting.	• Based on work by Snyder and Bissonette (1987) in Newfoundland.
	• Density of adult resident marten in commercially clearcut forest = 0.4/km^2.	• Soutiere (1979) from Maine.
	• To maintain marten at local scale in black spruce forests, suggest ≥50% uncut forest be preserved inside 10 km^2 units and <30% of forest clearcut over a 30-year period.	• Potvin et al. (2000) working in boreal landscape of western Quebec.
	• Progressive cutting from a single patch would retain the largest amount of interior forest habitat.	• Hargis et al. (1999) from Uinta Mountains, Utah.
	• Recommend that timber harvest and natural openings comprise <25% of landscape ≥9 km^2 in size.	• Hargis et al. (1999) from Uinta Mountains, Utah.

cont'd

Table 14. Management indicators and guidelines for marten (cont'd).

Indicator	Guideline or Threshold	Comments
Edge Use	• Preferred edge areas within 60 m of a meadow; rarely used sites >400 m from meadows. • Passed through but did not hunt in opening <100 m wide. • Occasionally crossed clearcuts 200 m wide and hunted in the windfall and slash. • The quality of habitat is related to availability of meadows and other non-forested habitat that provide abundant food. • Marten crossed treeless areas ≤60 m wide. • The largest open distance crossed was 135 m. • Open meadows and burns avoided during winter, but may be used during summer and fall if adequate cover and food such as high densities of fruits, insects and ground squirrels is available.	• Based on Spencer et al. (1983) in Pacific Northwest. • Based on Koehler and Hornocker (1977) in Idaho. • Based Soutiere (1979) working in Maine. • Based on Buskirk and MacDonald (1984) in south-central Alaska. • Based on work in western Newfoundland by Bateman (1986). • Hargis and McCullough (1984), Yosemite National Park, California. • Based on an evaluation of the effects of fire on marten in Idaho by Koehler and Hornocker (1977).
Core Area	• Maximum foraging area = 3,530 ha.	• Taylor and Abrey (1982) in Algonquin Park, Ontario.
Patch Size	• >100-200 ha of suitable habitat in a patch for marten. • Maximum foraging area = 3,530 ha. • Marten require >200 ha of suitable habitat. • Capture rates were greatest in residual stands 25 – 35 ha (4.6 captures/100 trap nights).	• Based on literature review (Buskirk and Ruggiero 1994). • Taylor and Abrey (1982) in Algonquin Park, Ontario. • Review in Nietfeld et al. (1985). • Snyder and Bissonette (1987) working in Newfoundland.
Corridor Width	• Marten sometimes hunted in moderately open black spruce-tamarack bogs ≤200 m wide.	• Observed by Raine (1987) working in southeastern Manitoba.

6.3.4 Grizzly Bear

The grizzly bear is widely used as an umbrella species for the assessment and management of cumulative effects at regional scales (Banci 1991; Noss et al. 1996; Kansas 2002). Grizzly bear in the NWT are divided into two groups: mountain and barren-ground. Mountain grizzlies are found in boreal forest, subalpine, and alpine habitats west of the Mackenzie River. This species is classed as Special Concern by COSEWIC (2003), and Sensitive in the NWT (RWED 2001b), where population numbers are thought to be stable (EBA 2003).

Grizzly bears occur primarily in open alpine and subalpine habitats in the western half of the Deh Cho Plan area. Dens are normally constructed on steep, warm-aspect slopes. Habitat requirements outside the denning season are complex and this species has very large home ranges. Bears in mountainous areas undertake seasonal movements between valleys and alpine areas in response to plant phenology (Hamer and Herrero 1987a,b). Willow and spruce riparian habitat is assumed to be high quality. Grizzly bears are also opportunistic predators and will kill caribou, moose, and sheep, particularly neonates (Reynolds and Garner 1987; EBA 2003). Grizzly bears require a diverse mosaic of habitat types because of the seasonal and annual changes in food abundance and availability; this generally translates to large home ranges (Banci 1991).

6.3.4.1 Resilience

Grizzly bears are considered to have low ecological resilience and display variable life history and home range sizes. Distinct seasonal habitat use periods occur during spring, summer and fall. Female home ranges are usually smaller than males and females with young appear to select isolated habitats; this is thought to minimize disturbance and encounters with mature males that kill cubs. Reproductive rate is the lowest recorded among North American land mammals (Weaver et al. 1996). Because of their low productivity, grizzly bear populations respond slowly to impacts that produce a change in status (Mattson et al. 1996).

6.3.4.2 Response to Land Use and Human Activity

There is considerable evidence that grizzly bears avoid occupied and active human facilities (reviewed in Mattson 1993). The reported Zone of Influence (ZOI) varies by geographic setting, season and time of day, type of use (motorized or non-motorized; dispersed or point source), intensity and frequency of use, and whether the population is hunted, among others (e.g., Archibald et al. 1987; McLellan and Shackleton 1988, 1989; Kasworm and Manley 1990; Banci 1991; Manley and Mace 1992; Mace and Manley 1993; Mace et al. 1996; Gibeau 2000; McLellan and Hovey 2001; Chruszcz et al. 2003).

Development of cumulative effects assessment methods for grizzly bear began in the early 1980's and are now well established and generally accepted (Gibeau et al. 1996; Kansas 2002). The standardized Cumulative Effects Model (CEM; Weaver et al. 1986; USDA 1990) includes three components: habitat effectiveness (integrating habitat availability, quality, and disturbance); mortality; and connectivity (linkage zone prediction). Conventional Canadian grizzly bear cumulative effects assessment methods are described in Apps (1993), Gibeau et al. (1996), ESGBP (1998), and Kansas (2002) and will not be discussed further. Each component is applicable at different scales and for different cumulative effects pathways; they are most frequently used as a suite (Axys 2001b). Reviews of habitat availability and population thresholds applicable to grizzly bear in the Yukon and British Columbia are provided respectively in Axys (2000) and Salmo et al. (2003). Recommended and established management indicators and guidelines for grizzly bear are summarized in Table 15.

Table 15. Management indicators and guidelines for grizzly bear.

Indicator	Guideline or Threshold	Comments
Habitat Availability	• <10% of each Forest Operating Unit should be affected by logging (Horejsi 1996).	• Recommendation to protect grizzly bear in Yukon Territory.
Habitat Effectiveness	• No net loss of habitat effectiveness for grizzly bear (BCF and MELP 1999b). • Resident female range use appears to be severely restricted in areas with <50% habitat effectiveness (Kansas et al. 1997; Gibeau et al. 1996; ESGBP 1998; Kansas 2002). • Most areas with resident female grizzly bears have habitat effectiveness >70% (Parks Canada 1997). • >80% of all Bear Management Units with 80% or greater habitat effectiveness for grizzly bear (Parks Canada 1997). • >80% habitat effectiveness for grizzly bear (Horejsi 1996).	• Recommended British Columbia threshold. • Based on studies in Banff Park and Kananaskis Country west of Calgary, Alberta. • Based on study in Jasper National Park, Alberta. • Threshold adopted by Banff National Park, Alberta. • Recommendation calculated based on road density, assuming that 1 km/km^2 equates to 80% habitat effectiveness.
Core Area	• Minimize loss of core habitat (NCGBRT 2001). • No Net Loss of Core Area for grizzly bear (NCGBRT 2001). • >60% of available habitat as core area (Gibeau 2000). • >58 to 68% of land area as core area (NCGBRT 2001). • >60% of Forest Planning Area as roadless core wildlife habitat (Horejsi 1996).	• Recommendation for recovery of grizzly bear in the North Cascades of British Columbia. • Grizzly bear management goal in the North Cascades of Washington. • Grizzly bear management threshold for Banff National Park, Alberta. • Management goal for grizzly bear in Montana and Idaho National Forests. • Grizzly bear management recommendation for Yukon Territory.
Suitable Core Area	• Minimum viable core area of 450 to 1,000 ha (Gibeau et al. 1996). • Core area >10 ha in size, ideally >1,000 ha (NCGBRT 2001). • No vegetation change within established grizzly bear core areas for at least 11 years (USFS 1993). • Total weighted road density should be 0 km/km^2 in grizzly bear core areas (USFS 1993).	• Grizzly bear core area used in western Canadian analyses based on 24 to 48 hr. feeding bout of an adult female grizzly. • Recommendation for recovery of grizzly bear in the North Cascades of British Columbia. • Management goal for Idaho National Forest. • Management goal for Idaho Nat'l Forest; Total Weighted Road density considers hiding cover, use intensity, and closure status to provide a common standard.

cont'd

Table 15. Management indicators and guidelines for grizzly bear (cont'd).

Indicator	Guideline or Threshold	Comments
Total Road Density	• Road density <0.6 km/km^2 to protect high quality grizzly bear habitat (BCF and MELP 1999b). • Areas selected by grizzly bears had average road densities of 0.6 to 0.68 km/km^2 (Mace et al. 1996; McLellan and Hovey 2001). • Areas with road densities greater than 6 km/km^2 do not support grizzly bears (Mace et al. 1996). • Forest Operating Area with road density >1.25 km/km^2 on <10% of area and additional 10% up to 0.6 km/km^2 (Horejsi 1996). • <30% of Forest Operating Area with road density <0.3 km/km^2 (Horejsi 1996).	• Recommended British Columbia threshold. • Based on studies in northern Montana and southeast British Columbia. • Based on study in northern Montana. • Management recommendation for grizzly bear in Yukon Territory. • Management recommendation for grizzly bear in Yukon Territory.
Open Road Density	• Average open road density <0.45, <0.48, or <0.6 km/km^2 (Servheen 1993).	• Management objectives in Yellowstone Grizzly Bear Recovery Zone National Forests.
Mortality	• <4% grizzly bear harvest rate from all sources; females should be <33% of total kills, including estimated natural mortality, accidental kills, and illegal kills (MELP 1995).	• Sustainable harvest rate for British Columbia.

Grizzly bear cumulative effects assessments in western Canada have adopted a standardized 500 m ZOI (Axys 2001b), or the ZOI originally developed for the Yellowstone Ecosystem: 800 m ZOI for motorized access roads, and 400 m for non-motorized trails and corridors (e.g., Gibeau et al. 1996; ESGBP 1998).

Habitat effectiveness evaluations appear to be useful for comparing the relative amounts of effective habitat loss between subregional planning units, but the relationship between these numerical values and actual grizzly bear use or density is more tenuous (e.g., Kansas 2002). The core security area evaluation technique was discussed in Section 6.2.3; this technique was originally developed for grizzly bears. Road density standards have become an important component of grizzly bear management (Mattson 1993; Dugas and Stenhouse 2000). Road density thresholds have also been proposed for British Columbia (BCF and MELP 1999b).

Available information on management indicators and guidelines must also be put into regional context.

Direct and indirect human-caused mortality appears to be the most significant factor affecting grizzly bear populations in western North America. Human-caused grizzly bear mortality is determined by the rate of encounter between humans and bears and by the probability that such an encounter will result in a bear's death. Encounter and mortality rates are affected by human population density and access patterns, human and bear behaviour during and following an encounter, grizzly bear population density and social structure, and the distribution of bear foods (reviewed in Mattson et al. 1996). Most grizzly bear mortality occurs within 500 m of roads and facilities and 200 m of backcountry facilities and trails (Mattson 1993; Gibeau et al. 1996; Mace et al. 1996; ESGBP 1998; McLellan et al. 1999).

Linkage zone prediction considers the degree of landscape fragmentation caused by human disturbance and identifies areas where grizzly bear movements are not adversely impacted. This is used to identify and protect critical movement corridors between important seasonal habitats, or to identify barriers to movement (Servheen and Sandstrom 1993; Gibeau et al. 1996). There is ample evidence that highways can limit bear movements. In Banff National Park, grizzly bears were closer to low-volume than to high-volume roads regardless of sex or season. Habituated bears tended to be closer to low-volume roads than wary bears. Traffic volume was the most important predictor of road crossing behaviour: road crossing of low-volume roads was influenced by sex and season but both sexes were more likely to cross low-volume than high-volume roads (Chruszcz et al. 2003). Connectivity models are most applicable in highly fragmented landscapes or narrow valleys where movements are restricted by topographic features. They have not been tested for validity (Salmo et al. 2001).

Most quantitative studies of grizzly bear response to human features and activities have been conducted in areas where grizzly bears must coexist with large numbers of people (Servheen 1993; Culling and Culling 2001). Differences in response of grizzly bears may reflect the amount of use that roads receive. In southeast British Columbia, high grizzly bear densities occurred in areas with higher open road densities than observed in American studies (McLellan 1990; Servheen 1993). However, these roads receive very little use except during hunting season, while use is much higher in most areas of the United States with comparable road densities. Proximity to human population centres, ease of access, and actual road use intensity are therefore important factors (Servheen 1993). In the Deh Cho Plan area, human use and pressure is currently much lower, so actual effects on grizzly bears will likely differ.

Ideally, grizzly bear management indicators and thresholds should vary as a function of bear home range and human dimensions (e.g., population density and attitudes towards bears). They should reflect mortality risk more than habitat alienation, and allow the effects of vegetation cover, topography, and road restrictions and rehabilitation to be considered (Mattson 1993).

6.3.4.3 Candidate Indicators and Thresholds

Available information including the case studies conducted in the boreal forest and foothills of northeast British Columbia (Salmo et al. 2003), indicates that grizzly bear in the Deh Cho Plan area can be adequately protected by generalized habitat, core area, patch and corridor size, and woodland caribou indicators and candidate thresholds.

6.4 CANDIDATE ECOLOGICAL INDICATORS AND THRESHOLDS

A suite of three generalized terrestrial habitat indicators, one aquatic habitat indicator, and one species-specific cumulative effects indicator is recommended for consideration by the DCLUPC (Table 16).

The Deh Cho Plan area is currently lightly developed relative to the generalized ecological indicators and candidate thresholds. Approximately 99% of the Plan area is classified as medium to large core areas (Table 16). Total corridor density over more than 97% of the area is less than the most restrictive candidate Cautionary Threshold (Figure 16). Most development has occurred along the highways and in the Cameron Hills and Fort Liard areas.

Table 16. Candidate ecological indicators and thresholds for the Deh Cho Plan area.

Type	Description	Thresholds
Generalized Terrestrial Habitat	**Habitat Availability**	• **Critical**: <10% of available habitat for focal species disturbed. • **Target**: <5% of available habitat for focal species disturbed. • **Cautionary/Restrictive Critical**: Consider for management units where wildlife values are the primary objective.
	Specialized Habitat Features (mineral licks, dens, wallows, nests)	• **Target**: No disturbance. • **Critical**: No net loss (taking into account mitigation or compensation). • **Cautionary/Restrictive Critical**: Consider for management units where wildlife values are the primary objective.
	Minimum Core Area	• **Critical**: >65% large core areas (>1000 ha and 500 m wide) in wildlife management areas. • **Target**: >75% large core areas (>1000 ha and 500 m wide) in wildlife management areas. • **Cautionary**: >85% large core areas (>1000 ha and 500 m wide) in wildlife management areas. • **Critical**: >40% medium core areas (>200 ha and 350 m wide) in resource development areas. • **Target**: >50% medium core areas (>200 ha and 350 m wide) in resource development areas. • **Cautionary**: >65% medium core areas (>200 ha and 350 m wide) in resource development areas.

cont'd

Table 16. Candidate ecological indicators and thresholds for the Deh Cho Plan area (cont'd).

Type	Description	Thresholds
Aquatic Habitat	**Fish Habitat**	• **Critical**: No net loss of bed and bank habitat.
Species-specific	**Woodland Caribou**	• **Critical**: Total corridor density (all corridors >3 m wide) <1.5 km/km^2 in designated caribou management areas. • **Target**: Total corridor density all corridors >3 m wide) <1.2 km/km^2 in designated caribou management areas. • **Cautionary**: Total corridor density all corridors >3 m wide) <1.0 km/km^2 in designated caribou management areas. • **Critical**: Total corridor density all corridors >3 m wide) <1.8 km/km^2 in resource development areas. • **Target**: Total corridor density all corridors >3 m wide) <1.5 km/km^2 in resource development areas. • **Cautionary**: Total corridor density all corridors >3 m wide) <1.0 km/km^2 in resource development areas.

7. LAND AND RESOURCE USE INDICATORS AND THRESHOLDS

Over the last 30 years, and particularly during the last decade, a wide array of **land use indicators** have been developed and applied to environmental management. Land and resource use indicators are generally input-based and measure the footprint of human disturbance or the intensity of human activities. These indicators are widely used for regulatory review and State of the Environment reporting (e.g., NRTEE 2003). Five types of land and resource use indicators were reviewed by Salmo et al. (2003):

- Human activity.
- Human-caused mortality.
- Cleared/disturbed area.
- Access density.
- Watershed assessment.

One class of resource use indicators – harvest limits and mortality thresholds – has been commonly used by fish and wildlife management agencies to keep mortality at sustainable levels (Auster 2001). Land-use thresholds have been applied in the northwest United States for management of species at risk such as grizzly bear and spotted owl (e.g., Lamberson et al. 1992; Mattson 1993; Bart 1995). In Canada, similar thresholds have been applied within national parks; research is underway to establish disturbance-based thresholds for grizzly bear and boreal-ecotype caribou in Alberta (Dugas and Stenhouse 2000; BCC 2001).

7.1 HUMAN ACTIVITY

Repeated intrusions by recreational users and other groups has been shown to alter bird behaviour, habitat use, reproduction, and survival (Skagen et al. 1991; Riffell et al. 1996; Richardson and Miller 1997; Rodgers and Smith 1997; Gutzwiller et al. 1998). A recreational trail may have a ZOI up to 100 m into adjacent habitat (Miller et al. 1998 *in* Hamilton and Wilson 2001), although responses vary considerably within and between species (Owens 1977; Tuite et al. 1984; Bélanger and Bédard 1989; Skagen et al. 1991; Holmes et al. 1993; Hill et al. 1997; Rodgers and Smith 1997; Gutzwiller et al. 1998; Jalkotzy et al. 1998). Additive and synergistic effects from multiple disturbance sources may affect population dynamics, even when individual disturbance types have no impact (Holmes et al. 1993; Riffell et al. 1996).

Wildlife species are most sensitive to disturbance at their nesting or birthing sites. Flushing or flight responses are common at these sites, and management buffers are commonly used to reduce the risk of these behavioural responses and related predation of eggs or young.

Human residences appear to reduce habitat suitability for some raptor and songbird species. As the number of houses within 100 m of a forest edge increased, the diversity and abundance of neotropical migrant songbirds decreased, regardless of forest size (Friesen et al. 1995). They found that a 25-ha urban woodlot had a poorer, less abundant neotropical community than did a 4-ha woodlot without residences nearby. Both species diversity and individual abundance sharply declined with an increase from 8 to 15 residences to ≥25 residences adjacent to the forest studied (Friesen et al. 1995). Raptor nests are normally >250 m from houses (reviewed in Jalkotzy et al. 1998*).* As noted previously, tolerant species such as moose may habituate to repeated, non-threatening disturbance.

Human activity guidelines and thresholds and flushing distances are reviewed in Salmo et al. (2003). No activity indicators are recommended for the Deh Cho Plan area, although activity buffers will likely be applied to site-specific industrial and recreational activities.

7.2 HUMAN-CAUSED MORTALITY

Human-caused mortality results from legal and illegal harvest, trapping, management actions (e.g., problem wildlife control, defence of life and property), and vehicle collisions. Human activities and structures may also indirectly increase mortality, but detection and assessment of this mortality is difficult. For example, road construction causes limited or no direct mortality, but the road can increase mortality rates by increasing harvest effort and success. Increased mortality is a concern for species with low reproductive rates and limited ability to rebound from population declines (Ursus and Salmo 2002).

Vehicle collisions can be a significant mortality source for some species. In general, mortality increases with traffic volume (Trombulak and Frissell 2000). Often, high mortality road-kill locations are associated with substantially higher quality feeding opportunities available along the roadside (Gibeau and Heuer 1996; Lehnert et al. 1996; Chruszcz et al. 2003). Road-kill mortality is a serious concern for low-density populations (e.g., woodland caribou) particularly because it is additive with natural mortality, management removal, and hunting mortality (Gibeau and Heuer 1996; Brown and Hobson 1998). Road-kill can have substantial demographic effects, particularly because it kills regardless of age, sex, or condition of the animal (Trombulak and Frissell 2000).

Mortality guidelines are reviewed in Salmo et al. (2003). No mortality indicators are recommended for the Deh Cho Plan area at this time.

7.3 CLEARED/DISTURBED AREA

Total cleared or **disturbed area** is frequently used as a numerical index of forest habitat availability and fragmentation. This index is the inverse of the available habitat indicator discussed in Section 6.2.1. Cleared or disturbed area can also be used as an indicator of cumulative effects risk for physical landscape elements, vegetation communities and age classes, biodiversity, and water quality and quantity (reviewed in Salmo et al. 2003).

7.3.1 Candidate Indicators and Thresholds

Cleared/disturbed area (reported in ha) is recommended as an indicator to evaluate cumulative effects risk to rare and unique physical and vegetation features found within the Deh Cho Plan area.

The candidate Critical Threshold applicable to the entire Plan area is 10% feature loss, based on the apparent boreal fragmentation effects threshold (described in Section 6.2.1). A candidate Target Threshold of 5% habitat loss is proposed. Adoption of Cautionary Thresholds and more restrictive Critical and Target Thresholds should be considered in areas where biodiversity values are the primary management objective (e.g., Candidate Protected Areas).

Significant environmental features (International Biological Program sites, hotsprings, hoodoos), should be used as another physical indicator. The proposed Target Threshold for these features is no disturbance. The candidate Target Threshold for these features is no disturbance. However, recognizing that site avoidance may not always be possible, the Critical Threshold is no net loss, defined as no disturbance without mitigation or compensation. Cautionary Thresholds and more restrictive Critical Thresholds should be considered in areas where environmental or biodiversity values are the primary management objective.

7.4 ACCESS DENSITY

Road density is the best known and most widely applied land-use and access density indicator. This index represents the total length of roads, utility corridors (pipelines, powerlines, railways) or other human linear features present in a defined land area or watershed, and is usually expressed as km/km^2. It is a useful summary index because it integrates the many ecological effects of roads and vehicles (Forman and Hersperger 1996).

Roads are a very specific type of corridor. As long, narrow linear features, they create a very high edge per unit area. Thus, they can have dramatic impacts on the effectiveness of adjacent habitat. As well, the habitat occupied by the roads is temporarily or permanently lost. If the road is eventually reclaimed and allowed to revegetate, the habitat loss is temporary; permanent habitat loss may occur with public roads like highways. In addition, roads are of increasing concern for terrestrial and aquatic communities because research indicates that some animals under-use areas adjacent to active roads. As an example, Figure 17 depicts road-habitat effectiveness models developed for a hunted elk (*Cervus elaphus*) population; habitat effectiveness is inversely related to road density.

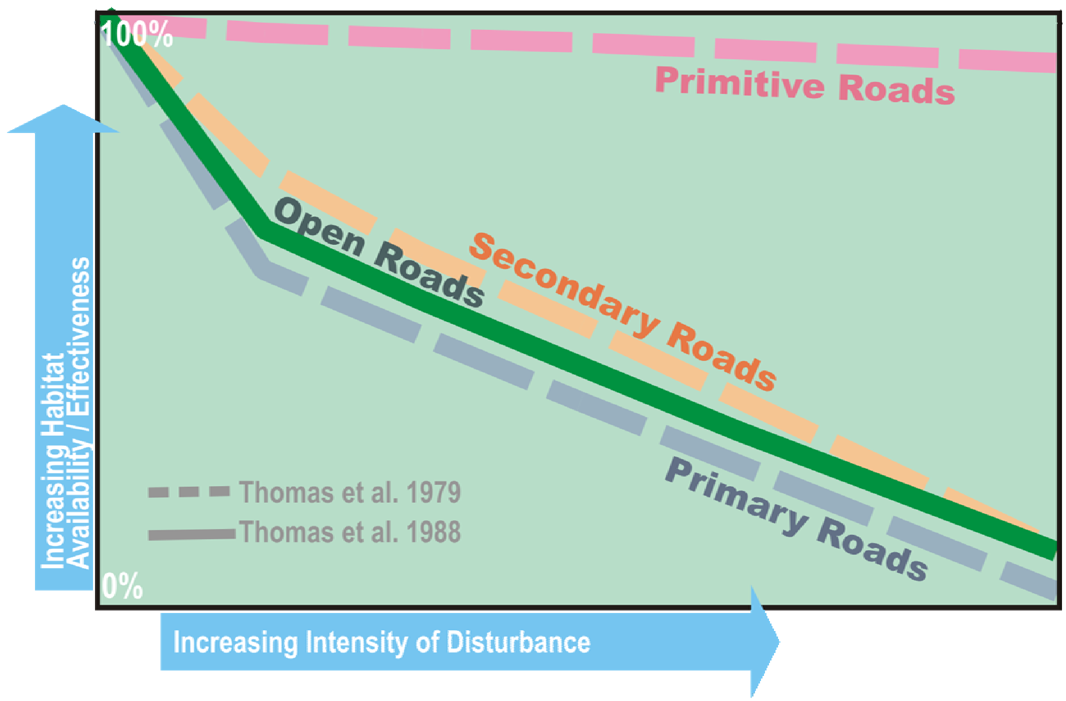


Figure 17. Impact of roads on predicted habitat effectiveness for elk (adapted from Thomas et al. 1979, 1988).

Figure 17 also illustrates the effect of disturbance intensity on habitat effectiveness. ‘Open roads’ is a summary class that includes all road types and is assumed to represent the average effect. Infrequently used access features like ‘Primitive Roads’ (truck trails) affect elk habitat use considerably less than more regularly used Primary and Secondary Roads. This suggests that activity levels, rather than the roads themselves, are affecting wildlife response. The impact of cutlines and utility corridors (pipeline and powerline rights-of-way) may be lower since these features receive less human use, especially in lightly populated regions like the Deh Cho Plan area. However, all types of linear corridors may increase predation rates by providing travel routes for wolves, thereby increasing their search range and efficiency (Bergerud et al. 1984; Stuart-Smith et al. 1997; James and Stuart-Smith 2000). There is currently substantial debate on other effects (e.g., habitat fragmentation) associated with cutlines and utility corridors.

Access corridors can contribute to cumulative effects by increasing direct and indirect mortality rates. Primary and secondary roads can substantially increase vehicle collisions and direct mortality rates. All types of linear corridors can provide access for hunters and anglers, leading to increased harvest effort and success. These indirect mortality effects are difficult to manage (Mychasiw and Hoefs 1988; Trombulak and Frissell 2000). In addition, there is a tendency for roads and trails to be extended beyond their original destination, ultimately creating a permanent access network.

Increased road and trail density is related to increased sediment transport and peak flows in streams, and has been correlated with declines in trout and salmon species, including bull trout (USDA 1996; Rieman et al. 1997). Fish populations in areas accessible by roads may be more vulnerable to introductions of non-native species that can displace or replace native species (Baxter et al. 1999; BCF 1999). Road and corridor density guidelines and thresholds were reviewed in Salmo et al. (2003).

7.4.1 Candidate Indicators and Thresholds

Road and trail density is considered to be a useful generalized indicator of cumulative effects risk for both terrestrial and aquatic systems. However, all-season access is limited in much of the Deh Cho Plan region by the presence of extensive muskeg and open black spruce forest areas. This suggests that most trails and winter roads are unlikely to receive high use. For this reason, the total corridor density is the recommended access indicator for the Deh Cho Plan area.

Total corridor density and associated thresholds were based on available cause-effect relationships for woodland caribou, the most sensitive ecological receptor in the region. Candidate thresholds were previously described in Section 6.3.1.3.

7.5 WATERSHED ASSESSMENT

Cumulative effects on watersheds can result from the accumulation of the seemingly insignificant effects of small routine activities, or from changes in dominant watershed processes (Collins and Pess 1997). Studies in western North America have shown that clearings and road and trail networks created for timber harvest and resource extraction can create direct and indirect effects on flow rates, patterns, sediment yield, stream habitat, invertebrates, and fisheries (Furniss et al. 1991; McGurk and Fong 1995; Trombulak and Frissell 2000). Several models and indices have been developed to describe these effects (reviewed in Salmo et al. 2003).

Investigators in Alberta, British Columbia, and the northwest United States have developed watershed assessment techniques that use watershed indices to evaluate the potential for cumulative aquatic effects from combined land uses in a watershed. Most cumulative effects techniques consider disturbed area, potential for sediment yield, water quality, or changes in probable peak flow and channel characteristics (Klock 1985; Reid 1993; Lowrence and Vellidis 1995; Lull et al. 1995; McGurk and Fong 1995; Collins and Pess 1997; Carver 2001).

Several watershed assessment models are based on total area harvested, cleared, or burned in a watershed. In some cases, factors applied to account for hydrological recovery due to forest regrowth, regeneration, or harvest method. Total cleared area was found to be inversely related to bull trout presence in west-central Alberta, and effects occurred at low forest harvest levels (Scrimgeour et al. 2003). Arctic grayling also appear to be very sensitive to sedimentation and increased water temperature resulting from forest harvest (reviewed in Ursus and Salmo 2003).

The number of road crossings of streams has been used as an indicator of land use activity for aquatic evaluations (Baxter et al. 1999; BCF 1999). This index is an easily calculated measure of sediment and mortality sources and stream habitat fragmentation in a watershed. It is expressed as the number of access corridor (road, trail, utility corridor, or cutline) crossings per kilometre of stream or watershed area.

Active stream crossings are often a chronic source of sediments and in-stream and riparian habitat changes. This can be either directly from the crossing construction, or indirectly from delivery of sediments along the right-of-way (Reid and Dunne 1984; BCF and BCE 1995b; Anderson 1996; Haskins and Mayhood 1997; Anderson et al. 1996, 1998; Brown 1999; Reid and Anderson 1999). Road stream crossing density has been found to be positively correlated with fine substrate and embeddedness and negatively correlated with trout presence, abundance, and redd densities (Eaglin and Hubert 1993; Baxter et al. 1999; Scrimgeour et al. 2003). Stream crossings also represent points of access for subsistence users and anglers as well as potential barriers to movement (Marshall 1996; Harper and Quigley 2000; Scrimgeour et al. 2003). As with terrestrial habitat fragmentation, actual effects depend on the extent and nature of the disturbance, watershed geology and topography, and species present, among others.

7.5.1 Candidate Indicator and Thresholds

The **stream crossing index** is recommended as the most practical aquatic cumulative effects indicator for the Deh Cho Plan area. This index is readily calculated, and provides the most direct indicator of cumulative effects erosion and mortality risk because it includes features that intersect watercourses directly. A watercourse that is repeatedly crossed is more likely to suffer increased erosion and water temperature, have higher angling pressure, and have temporary or permanent barriers to fish passage.

Current stream crossing density in that portion of the Deh Cho Plan area with IRS coverage is depicted in Figure 18. Density was calculated for 25 km^2 cells (5 km X 5 km) using digital 1:1,000,000 watershed data and included primary roads, secondary roads, trails and winter roads, pipelines, and railways.

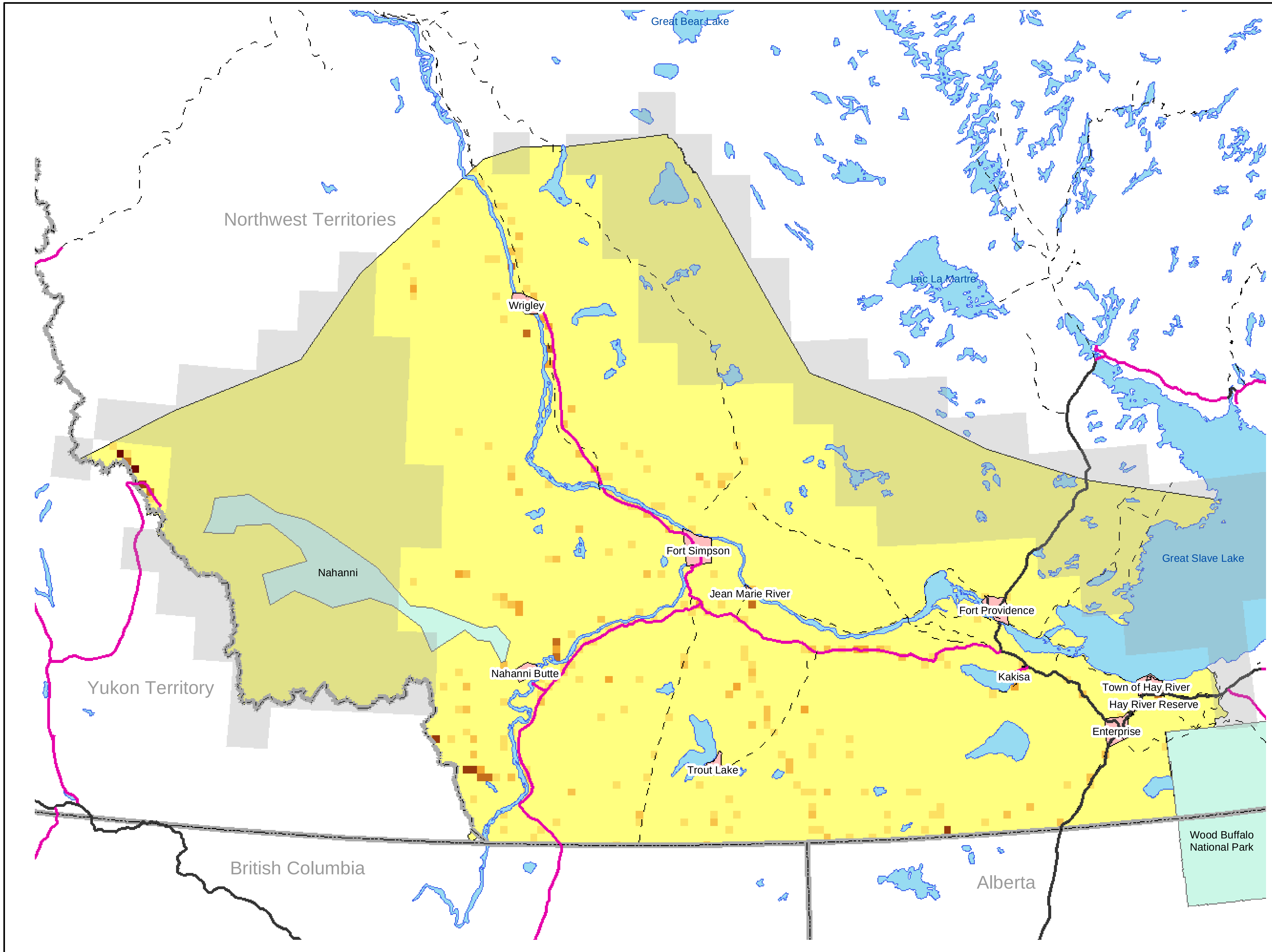
The candidate stream crossing density Critical Threshold for the Deh Cho Plan area (median $<0.5/km^2$) was set at the 0.6 hazard index level defined in the Interior Watershed Assessment Process; (IWAP; BCF and BCE 1995b). This is considered to represent low risk of peak flow and surface erosion effects over the long-term. The Target Threshold (median <0.32 km/km^2) was set at the 0.3 hazard index level defined in the IWAP (BCF and BCE 1995b) to represent very low risk of long-term watershed effects. Adoption of Cautionary Thresholds and more restrictive Critical and Target Thresholds should be considered in areas where fisheries or watershed values are the primary management objective (e.g., known spawning areas).

Current stream crossing density in the Deh Cho Plan area with IRS coverage is low. The candidate Critical Threshold was not exceeded and the candidate Target Threshold was exceeded on less than 0.01% of the region (Figure 18).

Deh Cho Cumulative Effects Study

Figure 18. Stream crossing density in the Deh Cho Plan area (calculated for 5 km X 5 km cells)

DEH CHO LAND USE PLANNING COMMITTEE
One Land One Plan
Ndéh Łıé - Mek'éé Ats'et'ı Łıé



crosses/km2	features
0.00	National Parks
0.00 - 0.04	Municipal Areas
0.04 - 0.08	Revised Interim Plan Area Boundary
0.08 - 0.12	Other Transportation Surface
0.12 - 0.16	Paved Surface
0.16 - 0.24	Unpaved Surface
0.24 - 0.40	Provincial Border
Disturbance from IRS imagery not recorded	

AXYS

NORTH

0 25 50 75 100 km

1:2,500,000

Study Area

Sources:

Deh Cho Land Use Planning Committee

Projection:

Lambert Conformal Conic
Central Meridian 122W
Reference Latitude 60N
Standard Parallel 1 60N
Standard Parallel 2 65N

Datum:

NAD 83

7.6 CANDIDATE LAND USE INDICATORS AND THRESHOLDS

Four land use indicators are recommended for consideration by the DCLUPC (Table 17).

Table 17. Candidate land use indicators and thresholds for the Deh Cho Plan area.

Type	Description	Thresholds
Land Use	**Total Cleared/Disturbed Area**	• **Critical**: <10% of available focal feature area disturbed. • **Target**: <5% of available focal feature area disturbed. • **Cautionary/Restrictive Target**: Consider for management units (e.g., Candidate Protected Areas) where biodiversity values are the primary objective.
	Significant Environmental Features (hotsprings, hoodoos, International Biological Program sites)	• **Target**: No disturbance. • **Critical**: No net loss (taking into account mitigation or compensation). • **Cautionary/Restrictive Critical**: Consider for management units (e.g., Candidate Protected Areas) where biodiversity values are the primary objective.
	Total Corridor Density (all linear corridors >3 m width)	• **Critical**: Total corridor density (all corridors >3 m wide) <1.5 km/km^2 in designated caribou management areas. • **Target**: Total corridor density all corridors >3 m wide) <1.2 km/km^2 in designated caribou management areas. • **Cautionary**: Total corridor density all corridors >3 m wide) <1.0 km/km^2 in designated caribou management areas. • **Critical**: Total corridor density all corridors >3 m wide) <1.8 km/km^2 in resource development areas. • **Target**: Total corridor density all corridors >3 m wide) <1.5 km/km^2 in resource development areas. • **Cautionary**: Total corridor density all corridors >3 m wide) <1.0 km/km^2 in resource development areas.
	Stream Crossing Density (roads, trails, pipelines, railways)	• **Critical**: median <0.5/km^2 calculated for subwatershed. • **Target**: <0.32/km^2 calculated for subwatershed. • **Cautionary/Restrictive Target**: Consider for management units (e.g., spawning sites) where fisheries or watershed values are the primary objective.

8. SOCIAL INDICATORS AND LIMITS OF ACCEPTABLE CHANGE

Social indicators are widely used, and there is extensive literature concerning their selection. The best known social indicators are economic metrics such as Gross Domestic Product (GDP) used to track and support national-level decision making on economic development (NRTEE 2003). Other social indicators are commonly used to track community health and well being, resource use, and cultural values (Table 18).

Table 18. Types of social indicators.

Indicator Type	Description	Examples
Community Health and Well Being	Describe community and cultural characteristics including: quality of life (poverty, employment, physical and mental health, crime, education, civic participation); infrastructure (health services, local government services, social services); and culture (language retention, aboriginal interests, heritage resources).	• Life expectancy. • Number of property crimes. • Population changes. • Country food consumption rate. • Education level. • Employment and unemployment. • Traditional use sites. • Heritage sites.
Economic	Measure local, regional, territorial, and federal economic variables including: income, prices, expenditures, employment, revenue-generation, supply-demand.	• Average household income. • Consumer price index. • Economic diversity index. • Net profitability. • Contribution to territorial revenues. • Contribution to GDP.
Resource Use	Measure renewable and non-renewable resource use and supply, including sustainability.	• Net present value. • Natural gas production. • Timber harvest relative to allowable cut. • Hunting and trapping statistics. • Visual aesthetics.

There are two general types of social indicators: objective and subjective. **Objective** metrics are generally drawn from secondary datasets (most commonly census data) that document social structural variables; **subjective** metrics generally involve some form of community involvement (e.g., surveys). Both types of indicators have associated strengths and weaknesses. For instance, objective metrics can be poorly correlated with the results of self-assessments of community wellness – communities with a high number of negative metrics can view the situation as 'perfectly normal', while communities with a reasonably average metrics can view the situation as 'huge room for improvement' (Murdie et al. 1992; Beckley and Burkosky 1999). When choosing a suite of indicators, one must consider how best to assess the goals of the project and balance the issues of audience, data availability, validity, reliability and comparability.

Objective, quantifiable indicators are very useful for describing and monitoring economic and social conditions. If chosen correctly, the data can be robust and defensible, and the metrics can be comparable across jurisdictions. However, they will never completely describe or allow understanding of the local context that gave rise to these specific socio-economic conditions. Parkins and Beckley (2001) synthesize their statistical reporting on indicators in the Foothills Model Forest (FMF) communities with a detailed qualitative reporting of local residents' perceptions of the social and economic conditions in question. Similarly, the GNWT (2000) has committed to incorporate attitudinal survey information into their annual reporting on community health and well being for point-of-hire communities for BHP Billiton Diamonds Inc.

Only objective social indicators were considered for the Deh Cho CE study because community involvement was beyond the terms of reference. The need for subjective metrics should be evaluated by the DCLUPC as part of the ongoing land use planning process.

Social indicators reflect a wide range of interests and objectives. No simple, widely accepted suite of social indicators exists because of the inherent complexity of social systems, and the influence of local values and interests. For this project, discussion is restricted to those indicators that can be practically applied to land use planning and cumulative effects management. This includes those that help understand how people, communities, and local economies could be affected by land and resource management decisions (BCIRPC 1993). Emphasis was placed on work done for the Sustainable Forest Management Criteria and Indicators initiative discussed in Section 4.3.3., sustainable development, and regional cumulative impact studies, rather than literature from the fields of sociology and anthropology.

Several discussions of social indicators are particularly relevant to the social issues and values anticipated for the Deh Cho Plan area. Beckley (2000) discusses social sustainable forest indicators using nine Canadian communities including two, Fort Liard and Fort Providence, located in the Plan area. A suite of indicators is being used to monitor social conditions in communities affected by diamond mining in the NWT (e.g., WKSS 2001; GNWT 2000, 2002). Beckley and Burkosky (1999) review 22 initiatives that take an indicator approach to social sustainability and identify a suite of 'consensus indicators'. Parkins and Beckley (2001) discuss indicators adopted for the FMF in west-central Alberta.

8.1 COMMUNITY HEALTH AND WELL BEING

Community health and well being indicators describe community and cultural characteristics including: quality of life (poverty, employment, physical and mental health, crime, education, civic participation); infrastructure (health services, local government services, social services); and culture (traditional use and language retention). Human health and community wellness has been identified as a valued component in the Northwest Territories Cumulative Impact Monitoring Program; this is to be one of twelve focus points for data collection and reporting (DIAND 2003). Kennett (2000) reviews issues that must be addressed to build economically viable aboriginal communities in the NWT while protecting environmental integrity and preserving social structure and culture. This NRTEE State of the Debate report also discusses cumulative effects indicators applicable to aboriginal communities.

The selection of a few, representative indicators for monitoring community health and well being is difficult because communities respond and adapt to change. In fact, sustainability of communities is integrally related to their ability to accommodate outside change (Beckley 2000).

8.1.1 Culture

The Dene occupy and use the land, waters, trees, plants, berries, animals, birds, and fish of the Deh Cho Plan area. Key areas have been traditionally used for harvesting food and for medicinal, cultural, and spiritual purposes. These traditional subsistence activities may remain important culturally, even where participation rate is low.

Culturally significant features include three major groups: traditional sites that continue to be culturally important to the Dene (e.g., hunting areas, burial sites), archaeology sites that are no longer used (e.g., artifacts and palaeontological resources), and heritage resources (e.g., historic sites, historical and cultural records).

8.1.1.1 Traditional Sites

Traditional sites must be identified by the community. Typically researchers or proponents work with designated community representatives to identify culturally important sites through a Traditional Knowledge or Traditional Land Use study.

8.1.1.2 Heritage Resource Potential

Heritage resource potential is an indicator that has been used in impact assessments in the Deh Cho Plan area to predict the probability of finding archaeology and heritage resources. This evaluation considers topography, hydrology, and vegetation, recognized land use patterns, and locations of known resources. For example, well drained areas within 100 m to 200 m of large lakes or rivers where a slope break provides a overlook would be rated as high potential (Paramount 2003).

8.1.2 Quality of Life

Murdie et al. (1992) reviewed the 'quality of life' literature to identify indicators that could be practically applied to Canadian communities. They identify a basic framework built on three interrelated components: social well being, economic vitality, and environmental integrity. The recommended indicators reflect housing, land use, infrastructure and public services that are mainly applicable to large urban centres.

Small subsistence communities have several unique attributes that must be considered when selecting social and cultural indicators. These communities have traditionally had high unemployment rates and low average education and income levels because many residents participate in the non-wage economy. Subsistence activities can also function as a local social safety net by allowing those without work to return to traditional land uses, either seasonally or continually. This means that conventional social indicators based on the wage economy may not accurately reflect the health and well being of these communities (Beckley and Hirsch 1997 *in* Beckley 2000; Beckley 2000).

In addition, there are many challenges to be faced when measuring human health and community wellness, particularly in the NWT for reasons including the following:

- lack of consistency in data collection and analysis between agencies;
- lack of baseline data, particularly on community wellness;
- rapid social, economic and cultural changes resulting from fast-paced economic development;
- the region's cultural diversity, which brings different values and perceptions of health and wellness; and,
- small community sizes, which affect both the collection of confidential personal data and lead to substantial variability in the dataset (DIAND 2003; PACTeam 2003).

Fourteen health and wellness indicators have been chosen to monitor and assess the impacts of the Ekati Diamond Mine development (GNWT 2000). Currently, individual human health data is collected for over 60 measures by a variety of agencies and monitoring programs in the NWT (DIAND 2003). The government collects the majority of this information, which is used to analyze population and social trends. By contrast, community wellness data collection and analysis has only recently been initiated.

8.1.2.1 Population Change

One of the most obvious indicators of community health and well being is population change. Rapid growth, rapid decline, and high turnover can lead to stress on a community's infrastructure and adaptive capacity. Most community developers agree that well being is highest where communities are stable or where new families and individuals stay for a long time rather cycling through. Between 1991 and 1996, Fort Providence experienced a 14% increase in population, compared to roughly 2% in Fort Liard. Ten to fifteen percent of these communities migrated in or out during this same period (Beckley 2000).

Population data for the Deh Cho Plan area are summarized in PACTeam (2003). This report also summarizes projected growth rates for six of the region's communities to the year 2019.

8.1.2.2 Education Level

'Human capital' refers to the combined skills, education, training, experience, and general abilities of residents or a community. Measures of education level are used as a human capital indicator in the West Kitikmeot-Slave Study (WKSS Macleod 2002), national sustainable development monitoring (Kennett 2000; NRTEE 2003), and sustainable forest management (Parkins and Beckley 2001; CCFM 2003). Education attainment data for the Deh Cho Plan area summarized in PACTeam (2003) confirm that a resident's chance of wage employment increases with their education level. This report also includes future education level projections to the year 2019.

Unfortunately, this indicator does not factor in informal on-the-job training, bush skills that may be critical for a subsistence lifestyle, or entrepreneurial skills that are common in the tourism industry. In traditional subsistence communities there is often a trade-off between acquiring bush skills and attending school (Beckley 2000). In theory therefore, increased average education level should reflect decreased reliance on non-wage subsistence activities.

8.1.2.3 Employment Rate

The employment or unemployment rate is another common indicator of both community well being and economic performance and is used in the Sustainable Forest Management system (CCFM 2003). Parkins and Beckley (2001) review the theoretical basis, benefits, and disadvantages of this indicator. Stakeholders are likely to identify jobs as one aspect of acceptable conditions associated with industrial development. Indicators such as local employment participation rates can be used to track the quality of employment and to monitor the geographic distribution of economic benefits of industrial development (Macleod 2002).

Although unemployment rates were high in both Fort Liard and Fort Providence in 1996, the unemployment rate in Fort Liard dropped dramatically in 2000 when nearby oil and gas exploration and development activity created business and employment opportunities for everyone who wanted to pursue them. This was accompanied by reduced reliance on traditional subsistence activities, although there was near consensus that economic diversification was healthy (Beckley 2000). It appears that employment rate may also be used as an indirect indicator of community reliance on traditional subsistence activities.

Employment data and future labour force participation rates for the Deh Cho Plan area are summarized in PACTeam (2003). Projections suggest that additional jobs will be required in the region to balance increased population and education levels.

8.1.2.4 Income and Poverty Measures

Annual income and poverty rates are related indicators used as indirect measures of quality of life and direct measures of economic performance. These indicators are likely poor choices for subsistence communities because they do not reflect the cultural value of non-wage subsistence activities (Beckley 2000).

8.1.3 Candidate Indicators

Significant cultural features including traditional sites, archaeology sites, and heritage resources is a recommended cultural indicator. This includes palaeontology and archaeology sites; camping, trapping, fishing or hunting locales; cabins; burial sites; historic sites and trails; mineral licks; berry picking and medicinal plant collecting areas; or areas identified as cultural landmarks or of spiritual significance by community representatives. The candidate Target Limit for these features is no disturbance. However, recognizing that site avoidance may not always be possible, the Critical Limit is no net loss, defined as no disturbance without mitigation or compensation (e.g., archaeology/palaeontology site excavation and interpretation, or feature relocation). Cautionary Thresholds and more restrictive Critical Thresholds should be considered in areas (e.g., Candidate Protected Areas) where cultural values are the primary management objective.

Two indicators, community **population change**, and **wage-based employment**, are recommended as candidate community health and well being measures for the Deh Cho Plan area. These indicators can be estimated or measured at both regional and community levels. Both can be related to the current and future activities of each development sector (i.e., forestry, oil and gas, tourism) in ALCES II® and economic models to evaluate trade-offs between different land use scenarios. For example, estimates of jobs per 1,000 m^3 of spruce harvested are available for the NWT (PACTeam et al. 2003). Population and employment can also be predicted by project proponents, compared to desired conditions, and monitored to track achievement relative to desired conditions. Candidate Target and Critical limits have not been identified, because these must be developed with community and stakeholder input.

Ideally, subsistence activity participation rate would be a more appropriate indicator than wage employment in the Deh Cho Plan area because it reflects current conditions and values. However, it is more difficult to measure and predict. Wage-based employment can be used as an indirect measure of traditional activity participation rate because it is likely to be inversely related to the subsistence participation rate over long periods.

8.2 ECONOMIC

Economic indicators measure local, regional, territorial, and federal economic variables including: income, prices, expenditures, employment, revenue-generation, supply-demand. For instance, the Consumer Price Index (CPI) is an indicator used to track the rate at which prices change for all goods and services bought by Canadian consumers (Macleod 2002).

Economic indicators such as GDP and total capital expenditures are commonly used to measure or predict the societal benefits of land and resource use. However, most of these indicators focus on current production, rather than 'wealth' – a concept that considers both current and future production, and which reflects both human and social capital. Although GDP was not designed to act as a summary indicator of overall society progress, it is often used that way (NRTEE 2003).

The Sustainable Forest Management criteria and indicators system described in Section 4.3.3 includes measures to quantify the magnitude, distribution, and sustainability of economic benefits (CCFM 2003). Metrics include:

- economic benefits (contribution of timber products, non-timber products, and forest-based services to GDP).
- distribution of financial benefits.
- sustainability of benefits (return on capital employed; direct, indirect, and induced employment; average income; economic diversity index).

8.2.1 Candidate Indicator

Regional revenue created by each economic sector is the candidate economic indicator for the Deh Cho Plan area. This indicator can be estimated or measured at both regional and community levels. Revenue can be related to the current and future activities of each development sector (i.e., forestry, oil and gas, tourism) in ALCES and economic models to evaluate trade-offs between different land use scenarios. Incremental revenue can also be predicted by project proponents, compared to desired conditions, and monitored to track achievement relative to desired conditions. While it is assumed that revenue growth by the forestry, oil and gas, and tourism sectors is desired, Candidate Target and Critical limits are not identified here, because these must be developed with community and stakeholder input.

8.3 RESOURCE USE

Resource use indicators measure renewable and non-renewable resource supply and use, including sustainability. Three classes of resource use indicators can be identified:

1. Activity- or supply-based.
2. Experience-based.
3. Benefits-based.

8.3.1 Activity-Based

Activity-based criteria focus on opportunities to participate in a specified activity (e.g., subsistence harvest, forest harvest, mining, wilderness recreation). This approach is supply oriented and does not specifically consider the environmental setting required to support the activity, or the perceived quality of the activity. The activity-based approach has been most commonly applied to recreational opportunities, one of the probable economic growth sectors in the Deh Cho region.

8.3.1.1 Availability of Recreational Opportunities

Indicators of the benefits of recreational opportunities must be selected to incorporate both the importance of the recreational opportunity (i.e., worth per individual) and the intensity of use (i.e., total participation levels; CCFM 1997). Recreational opportunity indicators include: number of days spent hunting, fishing, skiing, or engaging in some other outdoor recreational pursuit; numbers of visits to national or provincial parks or historic sites; and, trends in expenditures on related goods and services.

The availability of recreational opportunities is also valuable in and of itself; some people just want to know that natural areas continue to exist and will be available for future generations, even though they choose to never actually visit or use them. This is termed a ‘passive use’ value. Indicators of passive use include: total land area protected from economic development; and participation in wildlife, conservation or environmental groups (e.g., donations, memberships; CCFM 1997).

Recreational use of the Deh Cho Plan area is currently low. The dominant form of tourism is rubber-tire traffic that comprise over 70% of visitors. Hard adventure trips also take place, particularly in Nahanni National Park Reserve and backcountry hunting lodges and camps. Hard data on recreational use in the Deh Cho Plan area are limited but recreational opportunities currently appear to be constrained more by lack of infrastructure and marketing than by land use conflicts (Deh Cho Environmental 2003).

8.3.1.2 Resource Availability

Resource availability and potential of the Deh Cho Plan area has been defined and mapped in the Deh Cho Atlas (DCLUPC 2003). Changes in the amount and distribution of renewable and non-renewable resources provide information on opportunities for, and constraints to, current and future resource use. In some cases, different land uses are compatible and can co-exist. In others, a decision to develop one resource (e.g., mining) may permanently or temporarily foreclose opportunities for another (e.g., wilderness recreation; Deh Cho Environmental 2003).

One easily understood measure of resource availability is the total area where resource development can be pursued. For the forest sector, this represents productive forest area less any areas where harvest is prohibited, uneconomic, or where other land uses have affected the forest land base (FMF 2003). The inverse measure – area not available for development – has also been used (CCFM 2003; FMF 2003).

8.3.2 Experience-Based

Experience-based criteria focus on the behavioural response of participants or the desired environmental setting and perceived quality of the activity (e.g., wilderness or primitive recreation). Examples of this approach include the LAC approach previously discussed in Section 4.3.1, and the associated Recreation Opportunities Spectrum described below.

8.3.2.1 Recreation Opportunities Spectrum

When considering opportunities for outdoor recreation, people must make choices about activities in which to engage, settings in which to recreate, and kinds of recreation experiences to seek. The Recreation Opportunities Spectrum classification was developed by academic researchers to evaluate the recreational opportunities offered by any defined area (Stankey et al. 1985). The opportunities range from primitive on one end of the spectrum to developed on the other. This classification system is widely used by recreation specialists.

The Recreation Opportunities Spectrum provides a link between activity- and experience-based objectives (Table 19). This classification considers remoteness, size, evidence of humans, social interaction, and management control. This links physical, biological, and social conditions in a way that allows it to be applied by managers to provide a variety of recreational opportunities. It is also scalable and can be applied at regional, landscape, and local scales. This approach can also be applied to ecosystem management although it must be supplemented by complementary models that consider ecological requirements and values.

Inventories of recreational opportunities are normally prepared within a GIS by developing a road, trail, and facilities layer, and then classifying the human use frequency (social setting) of each feature. The area within each Recreational Opportunity class is then quantified and compared to established management thresholds (e.g., landscape with more than 5% Primitive and 15% Semi-primitive).

Table 19. Recreational Opportunities Spectrum classes.

Class	Description
Primitive	Unmodified natural environment; high probability of experiencing solitude; greater than 5 to 8 km from a 4-wheel drive road; non-motorized access only; greater than 2,000 ha in size; usually less than 6 parties per day encountered on trails and less than 3 parties visible at camp site; no encounters with domestic livestock; management on-site regimentation is low with controls (e.g., barriers and permits) primarily off-site.
Semi-Primitive: Non-motorized	Natural or natural-appearing environment; high probability of experiencing solitude; greater than 0.8 to 1 km but not further than 5 km from a 4-wheel drive road; non-motorized access only; limited facilities; greater than 1,000 ha in size; usually 6 to 15 parties per day encountered on trails and 6 or less parties visible at camp site; management on-site regimentation and controls present but subtle.
Semi-Primitive: Motorized	Natural or natural-appearing environment; moderate opportunity for solitude; greater than 1 km from a 4-wheel drive road; motorized access and travel; limited facilities; greater than 1,000 ha; low to moderate human contact frequency; management on-site regimentation and controls present but subtle.
Roaded Resource Land	Natural environment may be substantially modified; opportunities for both privacy and social interaction; often within 1 km of a 2-wheel drive road with gravel or dirt surface; motorized access and travel; natural; rustic facilities; low to moderate human contact frequency on trails and moderate to high human contact frequency on roads; management on-site regimentation and controls noticeable but harmonize with the natural environment.
Rural	Natural environment is culturally modified; opportunities for social interaction and convenient facilities; obvious on-the-ground evidence of other people; access and travel by conventional motorized vehicle; complex and numerous facilities; moderate to high human contact frequency; management regimentation and controls noticeable but harmonize with the man-made environment.
Urban	Substantially urbanized environment; vegetation cover is often exotic and manicured; facilities for highly intensified motorized use and parking available; high human contact frequency; management regimentation and controls obvious and numerous.

8.3.2.2 Visual Quality

Scenic landscapes are a source of everday enjoyment for residents, as well as a tourism resource. Visual quality is the extent to which the aesthetic or scenic value of a landscape is maintained or altered compared to pre-existing or natural conditions. Land use plans may designate 'scenic areas' or 'visually sensitive areas' – normally adjacent to important tourist routes or features – where visual quality is to be managed (e.g., Fort Nelson Land and Resource Management Plan 1997). In some cases, specific 'Visual Quality Objectives' have been established to identify the desired level of visual quality based on the physical conditions and social concerns for the area (BCF 2001).

Visual values will likely be identified as important management objectives in highway corridors and 'icon' tourist sites (Deh Cho Environmental 2003) in the Deh Cho Plan area.

8.3.3 Benefits-Based

Benefits-based management focuses on the local and regional benefits to users, communities, and businesses. Management criteria and thresholds define explicit employment and expenditure targets. The candidate wage-based employment and regional revenue indicators discussed above are examples of benefits-based measures.

8.3.4 Candidate Indicators

Total area available for each resource use is an appropriate candidate indicator for the Deh Cho Plan area. This indicator can be considered at multiple scales with existing GIS data. Resource uses to be considered include: traditional use, oil and gas, forestry, mining, primitive recreation opportunity, and roaded resource recreation opportunity. Area available can be modelled for each resource use sector in ALCES to evaluate trade-offs between different land use scenarios. This can be done by including buffers and decision rules to restrict overlap of incompatible uses (e.g., roads and primitive recreation opportunity). While it is assumed that revenue growth by the forestry, oil and gas, and tourism sectors is desired, Candidate Target and Critical limits are not identified here, because these must be developed with community and stakeholder input.

Visual quality is another candidate resource use indicator to be applied in recreational and tourism areas where visual values are a management objective. Candidate Target and Critical limits are not identified here, because these must be developed with community and stakeholder input.

8.4 CANDIDATE SOCIAL INDICATORS

The suite of candidate social indicators recommended for consideration by the DCLUPC is provided in Table 20.

Table 20. Candidate social indicators for the Deh Cho Plan area.

<table>
<tr><th>Type</th><th>Description</th><th>Limits of Acceptable Change</th></tr>
<tr><td rowspan="3">Community Health and Well Being</td><td>Significant Cultural Features
(archaeology or palaeontology site; camping, trapping, fishing or hunting locales; cabins; burial sites; historic trails and sites; mineral licks; berry picking and medicinal plant collecting areas; areas identified as cultural landmarks or spiritual significance)</td><td>• Target: no disturbance.
• Critical: no net loss (taking into account mitigation or compensation).
• Cautionary/Restrictive Critical: Consider for management units (e.g., Candidate Protected Areas) where cultural values are the primary objective.</td></tr>
<tr><td>Community Population</td><td>• Target and Critical limits to be defined based on land use plan objectives.</td></tr>
<tr><td>Wage Employment Participation Rate</td><td>• Target and Critical limits to be defined based on land use plan objectives.</td></tr>
<tr><td>Economic</td><td>Regional Revenue by Sector
(tourism, forestry, energy, mining, other)</td><td>• Target and Critical limits to be defined for each sector based on land use plan objectives.</td></tr>
<tr><td rowspan="2">Resource Use</td><td>Area Available by Sector
(traditional use, primitive recreation opportunity; roaded resource recreation opportunity, forestry, energy, mining, other)</td><td>• Target and Critical limits to be defined for each sector based on land use plan objectives.</td></tr>
<tr><td>Visual Quality</td><td>• Target and Critical limits to be defined for management units (e.g., highway corridors) where visual values are the primary objective.</td></tr>
</table>

9. CONCLUSIONS AND RECOMMENDATIONS

Land and resource use planning is undertaken to provide guidance on whether, where, and how human activities should be located, encouraged, or restricted to provide an appropriate balance between social, economic, and ecological factors. The purpose of the Deh Cho Land Use Plan is defined in the DCFN *Interim Measures Agreement*: "... to promote the social, cultural, and economic well being of residents and communities in the [Plan area], having regard to the interests of all Canadians. … the Plan shall provide for the conservation, development and utilization of the land, waters, and other resources in the Deh Cho [Plan area]."

Limited time and resources make it impractical for a land use plan to consider all social and ecological factors in equal detail. This Cumulative Effects (CE) Phase 1 study was undertaken to identify cumulative effects indicators appropriate to the Deh Cho Plan area and where possible, to recommend science-based candidate thresholds or limits for these indicators. The CE indicators and thresholds study also evaluated and integrated available data to document the current status of land use indicators in the Plan area. This section summarizes CE Phase 1 research and discusses work that should be undertaken in CE Phase 2 to develop projections of future land use activities and associated changes in cumulative impact indicators, and to refine the candidate indicators and thresholds.

9.1 MANAGEMENT INDICATOR FRAMEWORK

The Deh Cho Land Use Plan will establish the 'vision' and 'rules' for future development and utilization of land and resources in this region. To be most effective, residents and developers should be able to relate their on-the-ground actions and activities directly to the overall management 'visions'. Regulators should be able to translate these same visions into rules and decision-making processes. This requires a framework that builds links between regional, sub-regional (management unit), and local plans and decisions.

Several existing land and resource management frameworks were reviewed in Section 4.3 to consider their suitability for cumulative effects management. These included: the Limits of Acceptable Change (LAC) system originally developed for wilderness recreation; the Tiered Thresholds approach developed for air quality; criteria and indicators developed for Sustainable Forest Management; and a results-based framework developed for oil and gas activities in a wilderness/wildlife management area of northeast British Columbia.

A results-based framework including elements of all four approaches is recommended for the Deh Cho Plan area (Figure 19). The critical component of a results-based framework is explicit land and resource management **objectives** set for the Deh Cho Plan area and smaller zones (landscapes, watersheds, sub-regions). These objectives describe the ideal future condition of these areas. Specific **indicators** are then used to measure progress in achieving these objectives. Wherever possible, **limits of acceptable change** or **thresholds** are established for the Plan area and smaller zones to describe acceptable, unacceptable, and desired future conditions of each indicator.

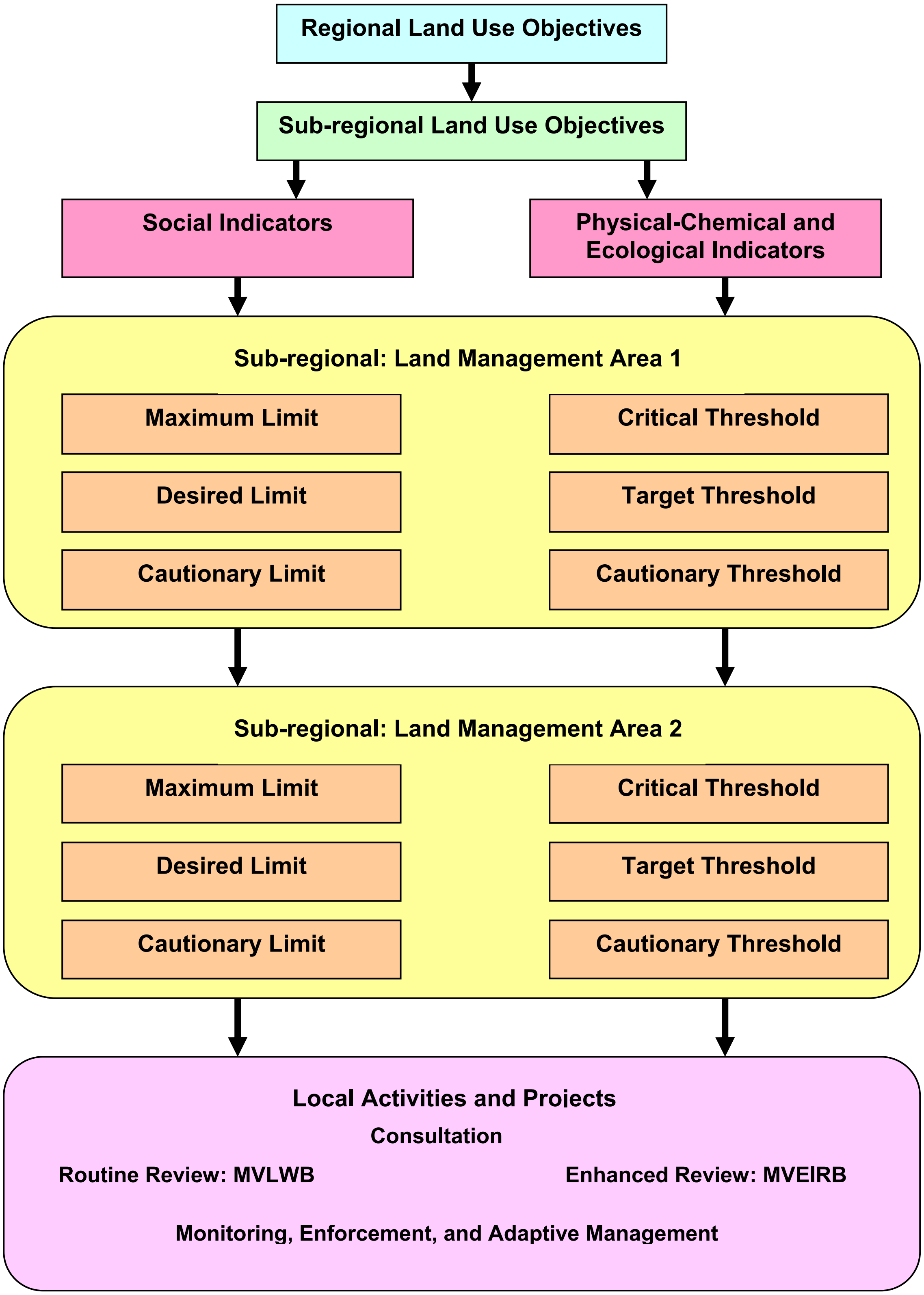


Figure 19. Recommended Deh Cho Plan area indicator and threshold framework.

Limits of acceptable change and thresholds provide clear socially-based rules for design and decision-making by communities, project proponents, and regulators. Without these limits, land use decisions will continue to be made in isolation and with no consideration of how local activities are contributing to broader cumulative effects.

9.2 MANAGEMENT OBJECTIVES

Management objectives for the Deh Cho Plan area have not yet been developed. Science-based indicators and thresholds cannot identify these objectives, but they can help inform the stakeholders who must define them.

Clear regional management objectives should be identified for each resource by Deh Cho region residents and stakeholders. The following examples of general land use objectives are adapted from the Fort Nelson Land and Resource Management Plan (1997):

- Recognize and maintain traditional uses and values.
- Maintain rare ecosystems, habitat types, plant, and animal species.
- Manage wildlife habitats and populations to meet both consumptive and non-consumptive demands.
- Maintain acceptable air quality.
- Maintain acceptable water quality.
- Minimize loss of soil productivity.
- Provide opportunities for new transportation routes, utility corridors, communication sites, and airstrips.
- Provide opportunities for growth of the tourism sector.
- Maintain (or provide opportunities for growth) of the mining sector.
- Maintain (or provide opportunities for growth) of the forestry sector.
- Maintain (or provide opportunities for growth) of the oil and gas sector.

Specific measures to protect and conserve resource values are often applied at the management unit or watershed scale (tens to thousands of square kilometres). For this reason, management objectives will also be needed for sub-regional management areas. As well, smaller areas may have unique features or resources that warrant more restrictive or liberal objectives, for example:

- Identify and conserve Significant Cultural Sites.
- Identify and protect Specialized Habitat Features.
- Manage for visual quality in Visually Sensitive Areas.
- Manage for oil and gas, mineral, and timber resources.

This finer scale management is necessary to accommodate variation in natural conditions and human development patterns in a manner that links regional objectives and local activities (Figure 19).

9.3 CANDIDATE INDICATORS AND THRESHOLDS

9.3.1 Indicators

A reasonable suite of complementary social and ecological indicators is needed to describe, measure, manage, and report on management objectives established for the Deh Cho Plan area. These indicators should be: clear and understandable by non-scientists; easy and cost-effective to collect, measure, or calculate; able to provide information on the desired ecological and social conditions; and flexible enough to apply to diverse land use situations and project proposals. If possible, indicators should provide information that can be related to more than one objective.

Eighteen candidate physical-chemical, ecological, land use, and social indicators have been identified to summarize information and help focus land and resource management activities in the Deh Cho Plan area (Table 21). This suite of indicators must be considered together; as no single indicator is capable of describing current or desired conditions on its own.

This suite of indicators has the following attributes:

- All key resources are reflected (landscapes and physical features, air quality, water quality, biodiversity, fish and wildlife habitat, traditional use, community well being, heritage resources, economic benefits, renewable and non-renewable resources, recreation and tourism).
- Both common and rare resources are reflected.
- Existing and potential future land uses can be considered.
- Indicators can be applied at regional, sub-regional, and local scales.
- Indicators can be practically measured or estimated with existing data or accepted modelling tools (specialized habitat features and significant cultural features will likely require site-specific field investigations, but these data are normally required for project approvals).
- Community consultation is encouraged.
- Indicators can be adapted to local conditions (e.g., different wildlife focal species and water quality parameters).
- Well-planned activities are encouraged.
- Indicators support adaptive management by helping to focus data gathering, monitoring, and mitigation on key resources and unknowns.

Table 21. Candidate management indicators and thresholds for the Deh Cho Plan area.

Indicator Type	Description	Examples
Physical and Chemical		
Air Quality	**Air quality**	• **Critical**: NWT Ambient Air Quality Standard. Management designed to maintain ambient air quality below this threshold. • **Cautionary**: Emissions subject to regulatory approval. Management designed to ensure that appropriate level of monitoring is conducted to document actual conditions. • **Target**: Consider for areas where pristine air quality is identified as management objective, or where standards do not exist for the pollutant of interest.
Water Quality	**Water quality**	• **Critical**: CCME Water Quality Guidelines for the Protection of Aquatic Life. Management designed to maintain water quality below this threshold. • **Cautionary**: Discharges subject to regulatory approval. Management designed to ensure that appropriate level of monitoring is conducted to document actual conditions. • **Target**: Consider for areas where pristine water quality is identified as management objective, or where guidelines do not exist for the parameter of interest.
Future Scenarios	**Relative water quality index**	• **Critical**: 20% change from baseline conditions. • **Target**: 10% change from baseline conditions.
Ecological		
Generalized Terrestrial Habitat	**Habitat Availability**	• **Critical**: <10% of available habitat for focal species disturbed. • **Target**: <5% of available habitat for focal species disturbed. • **Cautionary/Restrictive Target**: Consider for management units where wildlife values are the primary objective.
	Specialized Habitat Features (mineral licks, dens, wallows, nests)	• **Target**: No disturbance. • **Critical**: No net loss (taking into account mitigation or compensation). • **Cautionary/Restrictive Critical**: Consider for management units (e.g., Candidate Protected Areas) where wildlife values are the primary objective.

cont'd

Table 21. Candidate management indicators and thresholds for the Deh Cho Plan area (cont'd).

Indicator Type	Description	Examples
Generalized Terrestrial Habitat (cont'd)	**Minimum Core Area**	• **Critical**: >65% large core areas (>1000 ha and 500 m wide) in wildlife management areas. • **Target**: >75% large core areas (>1000 ha and 500 m wide) in wildlife management areas. • **Cautionary**: >85% large core areas (>1000 ha and 500 m wide) in wildlife management areas. • **Critical**: >40% medium core areas (>200 ha and 350 m wide) in resource development areas. • **Target**: >50% medium core areas (>200 ha and 350 m wide) in resource development areas. • **Cautionary**: >65% medium core areas (>200 ha and 350 m wide) in resource development areas.
Aquatic Habitat	**Fish Habitat**	• **Critical**: No net loss of bed and bank habitat.
Species-specific	**Woodland Caribou**	• **Critical**: Total corridor density <1.5 km/km^2 in designated caribou management areas. • **Target**: Total corridor density <1.2 km/km^2 in designated caribou management areas. • **Cautionary**: Total corridor density <1.0 km/km^2 in designated caribou management areas. • **Critical**: Total corridor density <1.8 km/km^2 in resource development areas. • **Target**: Total corridor density <1.5 km/km^2 in resource development areas. • **Cautionary**: Total corridor density <1.0 km/km^2 in resource development areas.
Land Use		
Land Use	**Total Cleared/Disturbed Area**	• **Critical**: <10% of available focal feature area disturbed. • **Target**: <5% of available focal feature area disturbed. • **Cautionary/Restrictive Target**: Consider for management units (e.g., Candidate Protected Areas) where biodiversity values are the primary objective.
	Significant Environmental Features (hotsprings, hoodoos, International Biological Program sites)	• **Target**: No disturbance. • **Critical**: No net loss (taking into account mitigation or compensation). • **Cautionary/Restrictive Critical**: Consider for management units (e.g., Candidate Protected Areas) where biodiversity values are the primary objective.

cont'd

Table 21. Candidate management indicators and thresholds for the Deh Cho Plan area (cont'd).

Indicator Type	Description	Examples
Land Use (cont'd)	**Total Corridor Density** (all linear corridors >3 m width)	• **Critical**: Total corridor density <1.5 km/km^2 in designated caribou management areas. • **Target**: Total corridor density <1.2 km/km^2 in designated caribou management areas. • **Cautionary**: Total corridor density <1.0 km/km^2 in designated caribou management areas. • **Critical**: Total corridor density <1.8 km/km^2 in resource development areas. • **Target**: Total corridor density <1.5 km/km^2 in resource development areas. • **Cautionary**: Total corridor density <1.0 km/km^2 in resource development areas.
	Stream Crossing Density (roads, pipelines, railways)	• **Critical**: median <0.5/km^2 calculated for subwatershed. • **Target**: <0.32/km^2 calculated for subwatershed. • **Cautionary/Restrictive Target**: Consider for management units (e.g., spawning sites) where fisheries or watershed values are the primary objective.
Social		
Community Health and Well Being	**Significant Cultural Features** (archaeology or palaeontology site; camping, trapping, fishing or hunting locales; cabins; burial sites; historic trails and sites; mineral licks; berry picking and medicinal plant collecting areas; areas identified as cultural landmarks or spiritual significance)	• **Target**: No disturbance. • **Critical**: No net loss (taking into account mitigation or compensation). • **Cautionary/Restrictive Critical**: Consider for management units (e.g., Candidate Protected Areas) where cultural values are the primary objective.
	Community Population	• Target and Critical limits to be defined based on land use plan objectives.
	Wage Employment Participation Rate	• Target and Critical limits to be defined based on land use plan objectives.
Economic	**Regional Revenue by Sector** (tourism, forestry, energy, mining, other)	• Target and Critical limits to be defined for each sector based on land use plan objectives.
Resource Use	**Area Available by Sector** (traditional use, primitive recreation opportunity; roaded resource recreation opportunity, forestry, energy, mining, other)	• Target and Critical limits to be defined for each sector based on land use plan objectives.
	Visual Quality	• Target and Critical limits to be defined for management units (e.g., highway corridors) where visual values are the primary objective.

9.3.2 Thresholds and Limits of Acceptable Change

Setting limits or thresholds is one of the most challenging aspects of land and resource management because science cannot provide decision makers with a single threshold value that represents the difference between acceptable and unacceptable conditions. For these and other reasons, land use planners should generally err on the side of caution and adopt conservative limits or thresholds (ELI 2003).

A series of two to three tiered limits or thresholds was considered for each indicator. The primary strength of a tiered framework is the formal link between the limits and impact management. This provides a mechanism to gather data on actual responses and modify management actions as appropriate. A secondary benefit is that tiered limits directly recognize the uncertainty around our understanding of complex social and ecological relationships. Finally, tiered thresholds provide the flexibility for different land management zones and settings, for a full range of development proposals, and for both project-specific and cumulative effects.

- **Critical thresholds** or limits reflect the minimum acceptable resource values or maximum acceptable change.
- **Target thresholds** or limits reflect the desired value or range of resource values.
- **Cautionary thresholds** reflect the point at which monitoring or enhanced protection measures would be implemented to slow the rate of change and determine actual response. Monitoring helps ensure that sufficient local data exist to confirm predictions or estimates, along with the benefits of management actions.

The hybrid threshold scheme proposed for the Deh Cho Plan area was designed to guide decision-making at both the individual project and regional landscape level. Candidate thresholds are summarized in Table 21. Generalized thresholds were proposed for indicators such as habitat availability that will be applied to regional evaluations, multiple use areas, or very small projects. More restrictive or liberal thresholds were also proposed to allow site- or resource-specific values to be addressed. As shown in Figure 19 for example, progressive thresholds can be used to reflect different land management zones or designations within the Deh Cho Plan area (e.g., most restrictive in Protected Areas and most liberal in areas zoned for resource development).

Candidate thresholds or limits of acceptable change were not proposed for most social indicators because these must reflect community and stakeholder values and interests, and must therefore be developed with their input.

9.3.3 Current Conditions

9.3.3.1 GIS Data

Available Geographic Information System (GIS) datasets were obtained and evaluated to verify the quality and accuracy of the combined dataset (see Section 3.1). From a purely spatial data perspective, the suite of layers provided by the DCLUPC appear to be of good quality and are well documented.

The RWED Land Cover Classification (LCC) and Forest Management Main Vegetation Types (Vegetation Types) GIS spatial datasets can be used to represent the current landscape conditions for almost all of the Deh Cho Plan area. The spatial resolution of these data is 900 m^2 (30 m X 30 m pixels), which is sufficient for regional and landscape-level summaries of broad vegetation types. The resolution of the data is not sufficient to directly identify many vegetated or non-vegetated anthropogenic features. Most required land use information can be obtained from the spatial dataset generated from interpretation of Indian Resource Satellite (IRS) imagery. No width estimates were generated for linear features, so estimated width of features will have to be assumed.

No stand age data are available for the LCC or Vegetation Types datasets. Forest age class information is critical for wildlife habitat mapping and simulations of cumulative effects resulting from combined natural and human disturbance.

Several issues must be considered before the RWED LCC or Vegetation Types datasets are used to generate regional vegetation unit summaries. First, there appear to be large areas in which there was insufficient data for classification. Second, there appears to be a fair amount of ‘speckle’ with the dataset (isolated cells which differ from surrounding cells), and the base classification leaves apparent and consistent blocks which are not consistently classified. Finally, the land cover classification is a very large dataset. For more efficient analysis, it should be filtered to: alleviate areas with insufficient data; reduce the speckles; deal with systematic inclusion or exclusion between blocks; and generalize large cover types. Various filters will need to be applied to determine which one will best represent the land base and retain the level of detail which is necessary for analysis.

9.3.3.2 Cumulative Effects ‘Hot Spots’

Land use data were consolidated to generate estimates for the generalized ecological and land use indicators described in Sections 6 and 7. Mapping confirms that the development footprint in the Deh Cho Plan area is small relative to most other areas of Canada. Approximately 99% of the Plan area is classified as medium to large core areas (Figure 14). Total corridor density over more than 97% of the area is less than the most restrictive candidate Cautionary Threshold (Figure 16). Fortunately this means that few land use planning options have been foreclosed in the region.

Most development has occurred along the Mackenzie, Yellowknife, and Liard highways and in the Cameron Hills, Trout Lake south, and Fort Liard-Nahanni Butte areas where most oil and gas and forestry activity has occurred. In these areas, which represent approximately 1% of the Deh Cho Plan area, the candidate Critical total corridor density threshold for woodland caribou is exceeded. These areas are likely to be 'sinks' for caribou, i.e., the probability of caribou persistence is reduced. Although this is not likely to be a significant issue at the regional scale because relatively undisturbed source areas are present nearby, it may warrant further investigation at a sub-regional scale. Sufficient habitat and age class data exist to complete spatially-explicit cumulative effects analyses for woodland caribou and other focal wildlife species in the Fort Liard area.

9.3.4 ALCES Model

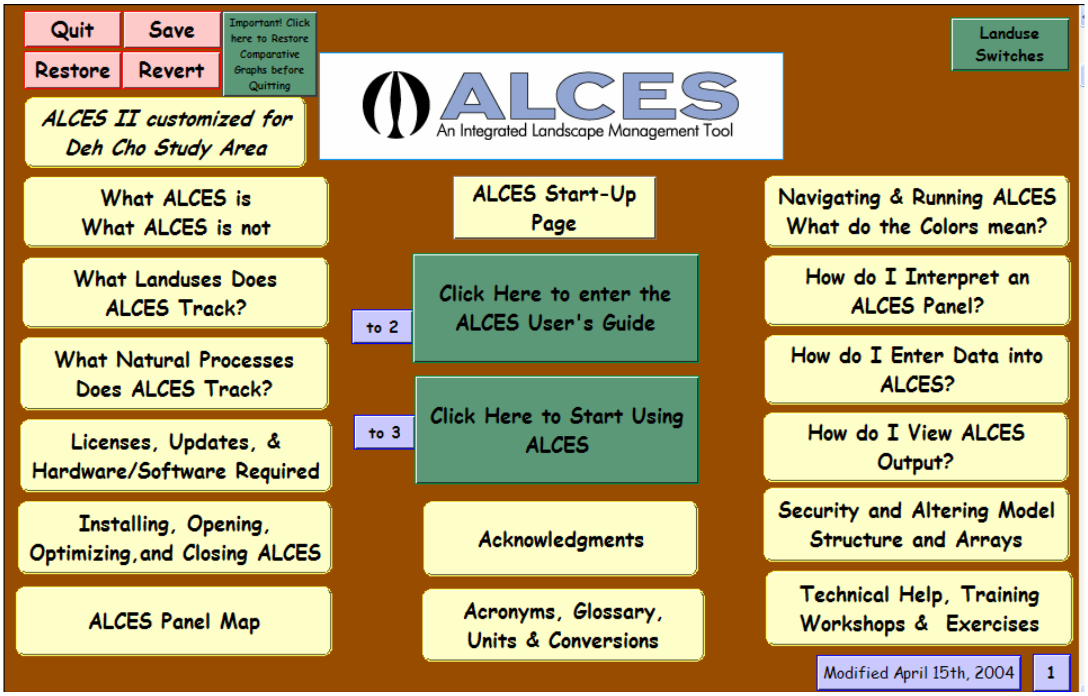
A licensed copy of A Landscape Cumulative Effects Simulator (ALCES®, Version II) program registered to the DCLUPC was obtained. This model uses spatial information on existing **Landscape** and **Land Use** patterns to simulate past, current, and future conditions. It considers all land use activities likely to occur in the Deh Cho Plan area, including traditional aboriginal uses, and is able to incorporate stochasticity (e.g., random fire and climate events). Its greatest strength is its ability to rapidly incorporate user-defined changes so that the effect of various development scenarios and management options on future ecological and social indicators can be visualized. Additional information on ALCES model outputs is provided in Section 3.2.3.

Based on the review of available information for the Deh Cho Plan area, ALCES is still considered to be the most appropriate choice for evaluating potential cumulative effects from current and potential future land and resource use.

The ALCES base model provided to the DCLUPC categorizes landscape patterns based on the Alberta Vegetation Inventory (AVI) classification system. This classification system is not used in the NWT, so the ALCES model was modified to accept 16 landscape types identified in the RWED Vegetation Types system (Figure 20; also see Table 3). The Vegetation Types dataset was selected because Gunn et al. (2002) had previously used this, rather than the LCC dataset, to predict probability of woodland caribou occurrence in the region.

As noted above, a key constraint to use of the ALCES model is the lack of vegetation age class data for the Deh Cho Plan area. Representative forest age class distributions for the Deh Cho Plan area will need to be generated from alternative data sources before the ALCES model can be used.

ALCES is limited to 17 land use types, so the IRS feature classification was modified into 17 classes for the Deh Cho ALCES model (Figure 20; also see Table 4).



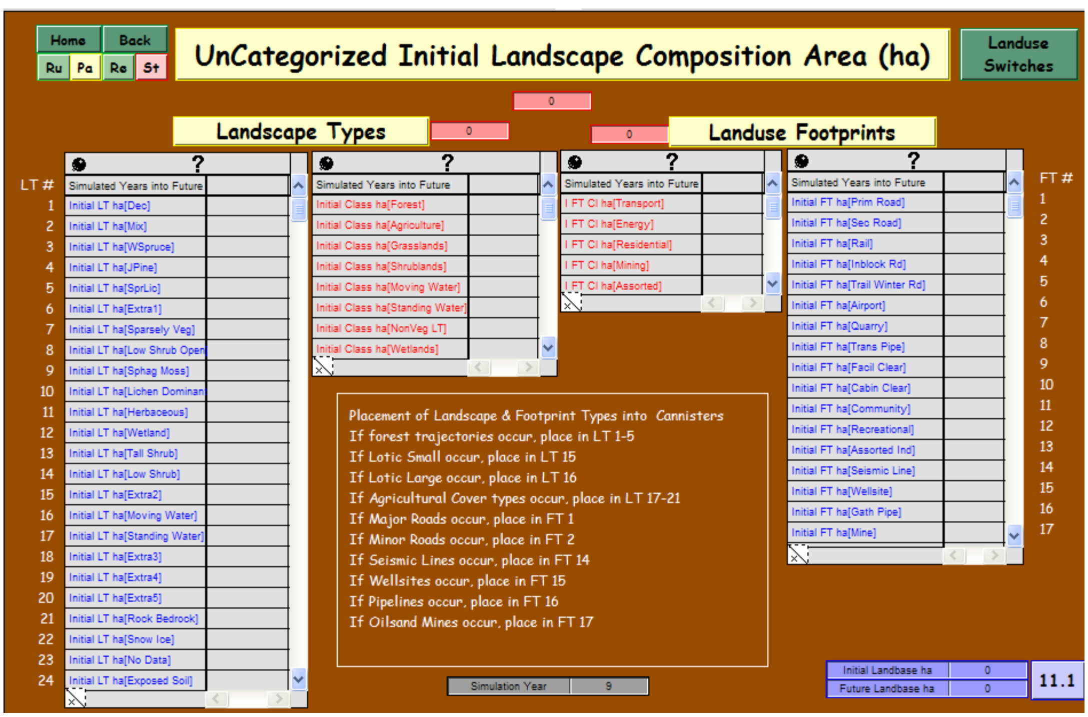


Figure 20. Deh Cho ALCES® Version II Model Startup and Initial Landscape Composition screens.

9.4 REFINING INDICATORS AND THRESHOLDS

The suite of candidate indicators, thresholds, and limits is an important first step towards cumulative effects management in the Deh Cho Plan area. Only objective social indicators were considered for the Phase 1 CE study because community involvement was beyond the terms of reference. However, the suite of candidate social indicators will need to be reviewed with residents to ensure that they reflect local interests and values. The need for subjective metrics should be considered as part of this review.

A critical step, as experience in other jurisdictions clearly demonstrates, is to give all affected groups and individuals the opportunity to help define limits of acceptable change. Implementation is a shared responsibility that will be most effective when indicators and limits are accepted as both reasonable and based upon accepted science and traditional knowledge. The adaptive management approach also suggests that proposed management actions should be rigorously tested before they are widely applied.

The following steps are recommended for Phase 2 of the Deh Cho Cumulative Effects study.

9.4.1 Confirm Indicators and Analyses

A meeting should be convened with DCLUPC representatives to review the conclusions and recommendations from the first phase, confirm the cumulative impact indicators for subsequent work, identify up to three land use scenarios to be used, and confirm the GIS datasets to be used and analyses to be undertaken.

9.4.2 GIS Data Preparation

The next step will be to finalize the GIS resource and land use dataset initiated during the first phase. The Vegetation Types or LCC data should be filtered as appropriate and prepared for use in ALCES.

If further accuracy and consistency in interpretation of linear feature widths is required, random IRS images should be obtained for direct measurement of widths. These estimates can then be extrapolated to the remainder of the Deh Cho Plan area.

Spatial forest inventory data for the Fort Liard area will be integrated for spatially-explicit cumulative effects analyses for woodland caribou and other focal wildlife species areas.

9.4.3 Land Use Scenarios

Developing scenarios of likely future development activities in the Deh Cho Plan area presents a significant challenge – evidence from elsewhere demonstrates that there is considerable uncertainty associated with development projections in comparatively undeveloped areas. Projections of likely future land use activities should be developed by reviewing information on historical development trends in the area, reviewing the cumulative impact sections of project applications, and interviewing knowledgeable land and resource managers and industry representatives. This information should be used to translate the land use scenarios generated by the DCLUPC into up to three explicit 50-year future land use projections. This will allow the impact of changes in development rates or management objectives to be more easily visualized at the regional and sub-regional scale.

Industry members will have particular interest in ensuring that development scenarios accurately reflect their perceptions of likely activity levels. The DCLUPC may wish to convene a workshop with representatives of industry and other appropriate stakeholder groups to validate the development scenarios and thereby build consensus around this critical component.

9.4.4 Cumulative Effects Analyses

Many stakeholders believe that spatially-explicit models are required to adequately assess and manage cumulative effects. However, because spatially-explicit modelling is data-intensive and expensive, indicators and thresholds that rely on spatially-explicit models may not be the most effective option for land use planning and decision-making in the Deh Cho Plan area. Instead, ‘aspatial’ models, or ‘spatially-stratified’ models such as ALCES may provide more appropriate planning and management tools. To address this technical uncertainty, spatially-stratified projections from ALCES can be compared to spatially-explicit modelling projections developed for the Fort Liard area.

Projections of land use-related changes on cumulative impact indicators should be generated for the Deh Cho Plan area and each of the three future land use scenarios using the ALCES model. Simulations can then be compared to candidate thresholds and limits to confirm that they provide the desired balance between environmental protection and economic development. These formal evaluations are recommended to allow government, industry, and other regional groups to understand the implications of indicator and threshold implementation as part of the Deh Cho Land Use Plan.

9.4.5 Local and Regional Management Tools

Indicators, thresholds, and limits are a critical component, but if cumulative effects management in the Deh Cho Plan area is to be effective, they must be supplemented with other land and resource management tools. A suite of appropriate impact management measures should be identified and incorporated into the land use planning framework. Impact management includes any measures needed to minimize or eliminate effects from human activities. These may be the responsibility of a single project proponent, of multiple project proponents, or of government. As such, impact management may be regional or project-specific in nature.

Land and resource managers working in the region should be consulted to ensure that recommended tools reflect social, cultural, and economic values and interests and support defined management objectives, responsibilities, and mandates to be defined in the Deh Cho Land Use Plan.

9.4.6 Stakeholder Involvement

The preferred approach to Phase 2 of the CE study would be to conduct it as part of an iterative process where the CE team interacts with a wider set of stakeholders during several workshops. This process could include the following steps:

1. Workshop #1: Deh Cho stakeholders and CE team meet in a workshop setting to establish management objectives, validate development scenarios, and confirm the candidate indicators. Key assumptions are discussed. The ALCES model is used to show how changes in management objectives, development scenarios, and assumptions would change future indicator conditions.
2. CE team completes preliminary cumulative effects analyses for the defined development scenarios to simulate changes for each indicator. Candidate limits and thresholds are compared to simulated changes to identify incompatible or unachievable objectives.
3. Workshop #2: Deh Cho stakeholders and CE team meet to review results of preliminary cumulative effects analyses. The key assumptions and sensitive aspects of land use - resource management relationships are discussed. Traditional knowledge is discussed relative to assumptions and findings. Social, economic, and ecological implications of candidate thresholds are discussed. Management options are identified for each indicator where objectives cannot be met. The group identifies areas of major agreement or uncertainty for further evaluation by the CE team. Development scenarios, assumptions, and candidate limits and thresholds are revised where appropriate.
4. CE team refines cumulative effects analyses based on input from Workshop #2.
5. Workshop #3: Deh Cho stakeholders and CE team meet to review revised results and candidate limits and thresholds. Traditional knowledge is discussed relative to assumptions and findings. Social, economic, and ecological implications of candidate thresholds are discussed and final revisions to development scenarios, assumptions, and candidate limits and thresholds are made.
6. CE team refines cumulative effects analyses based on input from Workshop #3 and prepares draft final report.
7. Deh Cho stakeholders review draft final report and forward comments to DCLUPC. DCLUPC consolidates comments for final revision.

10. REFERENCES

10.1 LITERATURE CITED

AENV and CASA (Alberta Environment and the Clean Air Strategic Alliance). 1999. Application of critical, target, and monitoring loads for the evaluation and management of acid deposition. Prepared by Clean Air Strategic Alliance, Target Loading Subgroup. Publication No.: T/472. 67 pages. www.gov.ab.ca/env/protenf/standards.

AENV (Alberta Environment). 1999. Regional Sustainable Development Strategy for the Athabasca Oil Sands area. Available online at: http://www3.gov.ab.ca/env/regions/neb/rsds/rsds_final.pdf

AENV (Alberta Environment). 2001. Regional Sustainable Development Strategy for the Athabasca Oil Sands area, Progress Report July 2001. Available online at: http://www3.gov.ab.ca/env/regions/neb/rsds/RSDS_Progress_report_2001_10.pdf.

Alke, E. 1995. Executive summary of a workshop on the impacts of land clearing on the hydrologic and aquatic resources of boreal forests in Alberta. Edmonton, AB. Northern River Basins Study. Northern River Basins Study Project Report No. 63. vi+82 pages.

Andersen, R., J.D.C. Linnell, and R. Langvatn. 1996. Short term behavioural and physiological response of moose *Alces alces* to military disturbance in Norway. Biological Conservation. (77):169-176.

Anderson, P.G. 1996. Sediment generation from forestry operations and associated effects on aquatic ecosystems. Proceedings of the Forest-Fish Conference: Land Management Practices Affecting Aquatic Ecosystems; Calgary, Alberta. Calgary, Alberta: Trout Unlimited Canada.

Anderson, P.G., B.R. Taylor, and G.C. Balch. 1996. Quantifying the effects of sediment release on fish and their habitats. Vancouver, British Columbia and Winnipeg, Manitoba. Fisheries and Oceans Canada, Eastern B.C. Habitat Unit and Alberta Area Habitat Management Division. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2346. 110 pages + 3 Append.

Anderson, P.G., C.G.J. Fraikin, and T.J. Chandler. 1998. Impacts and recovery in a coldwater stream following a Natural gas pipeline crossing installation. In. Proceedings of the 6th International Symposium, Environmental Concerns in Rights-of-way Management; New Orleans, LA. ASME 1013-1022.

Anderson, R.B., E. Dzus, and S. Boutin. 2000. Using selection to define crucial caribou habitat: a case for caution. In: Darling, L., ed. Proceeding of a Conference on the Biology and Management of species and habitats at risk; University College of the Caribou, Kamloops, BC. Victoria, BC: British Columbia Ministry of Environment 207-208. 490 pages.

Anderson, R.B., S.J. Dyer, S.R. Francis, and E.M. Anderson. 2002. Development of a threshold approach for assessing industrial impacts on woodland caribou in Yukon. Draft ver. 2.1 ed. Whitehorse, YK. Prepared for Environment Directorate, Northern Affairs Program. 60 pages.

Andison, D.W. 1999. Assessing forest age data in foothills and mountain landscapes in Alberta. Alberta Foothills Disturbance Ecology Research Series, Report No. 1. December, 1999. Foothills Model Forest, Hinton, Alberta.

Andison, D.W. 2000. Landscape-Level Fire Activity on Foothills and Mountain Landscapes of Alberta. Belcarra, B.C. 42 pages. (Alberta Foothills Disturbance Ecology Research Series (Report No. 2)).

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos. 71:355-366.

Apps, C.D. 1993. Cumulative Effects Assessment for Large Carnivores: A Literature Review and Development Strategy for the Canadian Rockies. Calgary, AB. Canadian Parks Service, Western Region. 68 pages.

Apps, C.D. 1999. Chapter 12. Space-use, diet, demographics, and topographic associations of lynx in the southern Canadian Rocky Mountains: a study. In: Ruggiero, L.F., K.B. Aubry, S.W. Buskirk, G.M. Koehler, C.J. Krebs, K.S. McKelvey, and J.R. Squires. Ecology and conservation of lynx in the United States. University Press of Colorado and the USDA, Rocky Mountain Research Station. General Technical Report RMRS-GTR 30WWW.

Apps, C.D., B.N. McLellan, T.A. Kinley, and J.P. Flaa. 2001. Scale-dependent habitat selection by mountain caribou, Columbia Mountains, British Columbia. Journal of Wildlife Management. 65(1):65-77.

Archibald, W.R., R. Ellis, and A.N. Hamilton. 1987. Responses of grizzly bears to logging truck traffic in the Kimsquit Valley, British Columbia. In: Zager, P.E., (ed). Int. Conf. Bear Res. and Manage.; Williamsburg, VA; Yugoslavia. International Association for Bear Research and Management 251-257.

Auster, P.J. 2001. Defining thresholds for precautionary habitat management actions in a fisheries context. North American Journal of Fisheries Management. 21:1-9.

Axys Environmental Consulting Ltd. 2000. Regional Approaches to Managing Cumulative Effects in Canada's North. Calgary, Alberta. Department of the Environment, Government of Canada. 72 pages + appendices.

Axys Environmental Consulting Ltd. 2001a. Thresholds for addressing cumulative effects on terrestrial and avian wildlife in the Yukon. Calgary, AB. Department of Indian and Northern Affairs, Environmental Directorate and Environment Canada, Whitehorse, Yukon. 92 pages. + appendices.

Axys Environmental Consulting Ltd. 2001b. Wildlife CEA Thresholds: Phase II Workshop Summary. Calgary, AB. DIAND, Environmental Directorate, Whitehorse, Yukon. 14 pages. + appendices.

Axys Environmental Consulting Ltd. 2002. Options for implementation of a Yukon wildlife thresholds pilot program: a scoping level review. Prepared for Environment Directorate, Northern Affairs Program, DIAND. 22 pages. + Appendix.

Backmeyer, R. 1994. Peace/Williston Wildlife Compensation Program: Graham River Caribou Study. Draft ed. Fort St. John, B.C. Prepared for Mari Wood Peace/Williston Wildlife Compensation Program B.C. Environment/B.C. Hydro.

Banci, V. 1991. The status of the grizzly bear in Canada in 1990. A COSEWIC status report commissioned by B.C. Ministry of Environment Wildlife Branch, Alberta Forestry, Lands and Wildlife Fish and Wildlife Division and Yukon Government, Department of Renewable Resources. 171 pages.

Bart, J. 1995. Amount of suitable habitat and viability of northern spotted owls. Conservation Biology. 9(4):943-946.

Bateman, M.C. 1986. Winter habitat use, food habits and home range size of the marten, *Martes americana*, in western Newfoundland. Canadian Field-Naturalist 100(1):58-62.

Baxter, C.V., C.A. Frissell, and F.R. Hauer. 1999. Geomorphology, logging roads, and the distribution of bull trout spawning in a forested river basin: Implications for management and conservation. Transactions of the American Fisheries Society. 128:854-867.

Bayne, E.M. and K.A. Hobson. 2000. Relative use of contiguous and fragmented boreal forest by red squirrels (*Tamiasciurus hudsonicus*). Canadian Journal of Zoology. 78:359-365.

BCC (Alberta Boreal Caribou Committee). 2001. Strategic Plan and Industrial Guidelines for Boreal Caribou Ranges in Northern Alberta. 35 pages.

BCC (Alberta Boreal Caribou Committee). 2003. Boreal Caribou Committee Quicknote: Developing a habitat planning target for range planning, August 22, 2003.

BCF (British Columbia Forest Service). 1999. Coastal (CWAP) and Interior Watershed Assessment Procedures (IWAP) Guidebook. Second ed. British Columbia. BC Environment. 41 pages. (Forest Practices Code of British Columbia).

BCF (British Columbia Forest Service). 2001. Visual Impact Assessment Guidebook. Second ed. (Forest Practices Code of British Columbia). Available online at: http://www.for.gov.bc.ca/TASB/LEGSREGS/FPC/FPCGUIDE/visual/VIA-01.pdf

BCF (British Columbia Forest Service) and BCE (British Columbia Environment). 1995a. Biodiversity guidebook. ix+99 pages. (Forest Practices Code of British Columbia).

BCF (British Columbia Forest Service) and BCE (British Columbia Environment). 1995b. Interior Watershed Assessment Procedures Guidebook (IWAP) Level 1 Analysis. Vi+82 pages. (Forest Practices Code of British Columbia).

BCF (British Columbia Forest Service) and BCE (British Columbia Environment). 1995c. Riparian Management Area Guidebook. British Columbia. BC Environment. (BC Forest Practices Code of British Columbia).

BCF (British Columbia Ministry of Forests) and MELP (British Columbia Ministry of Environment, Lands and Parks). 1999a. Landscape Unit Planning Guide. Victoria, B.C.: British Columbia Ministry of Environment, Lands and Parks. 101 pages. (Forest Practices Code of British Columbia).

BCF (British Columbia Ministry of Forests) and MELP (British Columbia Ministry of Environment, Lands and Parks). 1999b. Managing Identified Wildlife: Procedures and Measures Volume 1 Management Strategy. Available online at http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/other/wild/index.htm

BCIRPC (British Columbia Integrated Resource Planning Committee). 1993. Social and Economic Impact Assessment for Land and Resource Management Planning in British Columbia. Available online at: http://srmwww.gov.bc.ca/rmd/lrmp/socioec/se-toc.htm

Beanlands, G.E. and P.N. Duinker. 1983. An ecological framework for environmental impact assessment in Canada. Halifax, NS. Institute for Resource and Environmental Studies, Dalhousie University and Federal Environmental Assessment Review Office. 132 pages.

Beckley, T.M. 2000. Sustainability for Whom? Social Indicators for Forest-dependant Communities in Canada. Edmonton, AB. University of Alberta. 2000-34. 34 pages.

Beckley, T.M. and T. Burkosky. 1999. Social Indicator Approaches to Assessing and Monitoring Forest Community Sustainability. Northern Forestry Centre. Edmonton, Alberta. 29 pages.

Beckley, T.M., and B. Hirsch. 1997. Subsistence and non-industrial forest use in the Lower Liard Valley. Information Report Series of the Northern Forestry Centre, Canadian Forest Service, Edmonton, Alberta. NOR-X-352.

Bélanger, L. and J. Bédard. 1989. Responses of staging greater snow geese to human disturbance. Journal of Wildlife Management. 53(3):713-719.

Bergerud, A.T. 1974. Decline of caribou in North America following settlement. Journal of Wildlife Management. 38(4):757-770.

Bergerud, A.T. and R.E. Page. 1987. Displacement and dispersion of parturient caribou at calving as antipredator tactics. Canadian Journal of Zoology. 65:1597-1606.

Bergerud, A.T. and J.P. Elliott. 1998. Wolf predation in a multiple-ungulate system in northern British Columbia. Canadian Journal of Zoology. 76:1551-1569.

Bergerud, A.T., R.D. Jakimchuk, and D.R. Carruthers. 1984. The buffalo of the North: caribou (*Rangifer tarandus*) and human developments. Arctic. 37(1):7-22.

Bloomfield, M. 1979. The ecology and status of mountain caribou and caribou range in central British Columbia. M.Sc. 318 pages.

Bosch, J.M. and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology. 55:3-23.

Boulinier, T., J.D. Nichols, J.E. Hines, J.R. Sauer, C.H. Flather, and K.H. Pollock. 1998. Higher temporal variability of forest breeding bird communities in fragmented landscapes. Proceedings National Academy of Sciences. 95(13):7497-7501.

Bradshaw, C.J.A. 1994. An assessment of the effects of petroleum exploration on woodland caribou (*Rangifer tarandus caribou*) in northeastern Alberta. Edmonton, AB: University of Alberta.; c1994. 121 pages.

Bradshaw, C.J.A., D.M. Hebert, B.A. Rippin, and S. Boutin. 1995. Winter peatland habitat selection by woodland caribou in northeastern Alberta. Canadian Journal of Zoology. 73:1567-1574.

Brown, C.M. 1999. Evaluating the effects of pipeline watercourse crossings on fish habitat in streams and recommendations to prevent or mitigate effects. Calgary, AB: University of Calgary.; c1999. 127 pages.

Brown, W.K. and D.P. Hobson. 1998. Caribou in west-central Alberta - information review and synthesis. Revised edition ed. Prepared for The Research Subcommittee of the West-central Alberta Caribou Standing Committee. 74 pages + appendices.

Brown, W.K. and J.B. Theberge. 1990. The effect of extreme snowcover on feeding-site selection by woodland caribou. Journal of Wildlife Management. 54(1):161-168.

Bull, K.R. 1991. The critical loads/levels approach to gaseous pollutant emission control. Environmental Pollution. 69:105-123.

Bull, K.R. 1992. An introduction to critical loads. Environmental Pollution. 77:173-176.

Buskirk, S.W. 1984. Seasonal use of resting sites by marten in south-central Alaska. J. Wildl. Manage. 48(3):950-953.

Buskirk, S.W. 1994. Introduction to the genus Martes. Pp. 1-10. In Buskirk, S.W., A.S. Harestad, M.G. Raphael, R.A. Powell (eds.). Martens, sables and fishers. Cornel University Press, Ithaca and London. 484 pages.

Buskirk, S.W. and S.O. MacDonald. 1984. Seasonal food habits of marten in south-central Alaska. Can. J. Zool. 62(5):944-950.

Buskirk, S.W. and R.A. Powell. 1994. Habitat ecology of fishers and martens. Pp. 283-296. In Buskirk, S.W., A.S. Harestad, M.G. Raphael, R.A. Powell (eds.). Martens, sables and fishers. Cornel University Press, Ithaca and London. 484 pages.

Buskirk, S.W. and L.F. Ruggiero. 1994. American marten. Pp. 7–37 *In* American marten, fisher, lynx, and wolverine in the western United States. Ruggiero et al. (eds.), USDA Forest Service, General Technical Report RM-254.

Buskirk, S. W., S. C. Forrest, M. G. Raphael, and J. J. Harlow. 1989. Winter resting site ecology of marten in the central Rocky Mountains. J. Wildl. Manage. 53:191-196.

Cairns, Jr., John, P.V. McCormick, and B.R. Niederlehner. 1993. A proposed framework for developing indicators of ecosystem health. Hydrobiologia. 263:1-44.

Carignan, R., P. D'Arcy, and S. Lamontagne. 2000. Comparative impacts of fire and forest harvesting on water quality in Boreal Shield lakes. Edmonton, AB. Sustainable Forest Management Network. Final Project Report 2000-32. 24 pages.

Carruthers, D.R. and L.G. Sopuck. 1982. Caribou distribution on forested winter range northwest of Great Bear Lake in relation to snow, habitat and seismic activities.

Carver, M. 2001. Using indicators to assess hydrologic risk. In: Toews, D.A.A. and S. Chatwin, eds. Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings; Penticton, B.C. Victoria, B.C.: British Columbia Ministry of Forests 26-43.

Cash, K. 1995. Assessing and monitoring aquatic ecosystem health: approaches using individual, population and community/ecosystem measurements. Edmonton, Alberta. Northern River Basins Study. Northern River Basins Study Project Report No. 45. 66 pages.

Cattanéo, F., N. Lamouroux, P. Breil, and H. Capra. 2002. The influence of hydrological and biotic processes on brown trout (*Salmo trutta*) population dynamics. Canadian Journal of Fisheries and Aquatic Sciences. 59:12-22.

CCFM (Canadian Council of Forest Ministers). 1995. Defining sustainable forest management: A Canadian approach to criteria and indicators. Available online at: http://www.ccfm.org/ci/framain_e.html.

CCFM (Canadian Council of Forest Ministers). 1997. Criteria and indicators of sustainable forest management in Canada, Technical Report. Available online at: http://www.ccfm.org/ci/pdf/tech/ci_e.pdf.

CCFM (Canadian Council of Forest Ministers). 2003. Defining sustainable forest management in Canada, Criteria and indicators 2003. Available online at: http://www.ccfm.org/2000pdf/CI_Booklet_e.pdf.

CCME (Canadian Council of Ministers of the Environment). 1996. Canadian Water Quality Guidelines. Ottawa, ON.

CEQ (Council on Environmental Quality). 1993. Incorporating Biodiversity Considerations into Environmental Impact Analysis under the *National Environmental Policy Act*. Washington, DC. 29 pages.

Chapin, F.S. and G. Whiteman. 1998. Sustainable development of the boreal forest: interaction of ecological, social, and business feedbacks. Conservation Ecology [Online]. 2(2): 12.

Chapin, T.G., D.J. Harrison, and D.M. Phillips. 1997. Seasonal habitat selection by marten in an untrapped forest preserve. Journal of Wildlife Management. 61(3):707-717.

Chapin, T.G., D.J. Harrison, and D.D. Katnik. 1998. Influence of landscape pattern on habitat use by American marten in an industrial forest. Conservation Biology. 12(6):1327-1337.

Cihlar, J. and J. Beaubien. 1998. Land cover of Canada Version 1.1. Special publication, NBIOME Project. Produced by the Canada Centre for Remote Sensing and the Canadian Forest Service, Natural Resources Canada.

Chruszcz, B., A.P. Clevenger, K.E. Gunson, and M.L. Gibeau. 2003. Relationships among grizzly bears, highways, and habitat in the Banff-Bow Valley, Alberta, Canada. Canadian Journal of Zoology. 81:1378-1391.

Cizek, P. 2003. Estimated physical footprint of human activities in the Bathurst Inlet port and road study area of the Slave Geological Province. Prepared for Canadian Arctic Resources Committee by Cizek Environmental Services, Yellowknife.

Cizek, P., J. McCullum, and A. Booth. 2002. Fort Liard area cumulative impacts mapping project, Technical Report. Prepared for Canadian Arctic Resources Committee by Cizek Environmental Services and McCullum Environmental Services, Yellowknife. Available online at: http://www.indelta.com/cgi-bin2/carcpub.cgi?http://www.carc.org/2002/Final_Fort_Liard_Technical_Report_May_17_2002.pdf

Clark, R.N. and G.H. Stankey. 1979. The Recreation Opportunity Spectrum: A Framework for Planning, Management, and Research. U.S. Department of Agriculture. 32 pages.

Cocklin, C., S. Parker, and J. Hay. 1992a. Notes on cumulative environmental change I: concepts and issues. Journal of Environmental Management. 35:31-49.

Cocklin, C., S. Parker, and J. Hay. 1992b. Notes on cumulative environmental change II: a contribution to methodology. Journal of Environmental Management. 35:51-67.

Cole, D.N. and G.H. Stankey. 1998. Historical development of Limits of Acceptable Change: conceptual clarifications and possible extensions. In: McCool, S.F. and D.N. Cole, comps. Limits of Acceptable Change and related planning processes: progress and future directions; Missoula MT. Ogden, UT: Department of Agriculture, Forest Service, Rocky Mountain Research Station 5-9.

Collinge, S.K. 1996. Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. Landscape and Urban Planning. 36:59-77.

Collins, B.D. and G.R. Pess. 1997. Critique of Washington's watershed analysis program. Journal of the American Water Resources Association. 33(5):9997-1010.

Cooke, S.E. and E.E. Prepas. 1998. Stream phosphorus and nitrogen export from agricultural and forested watersheds on the Boreal Plain. Canadian Journal of Fisheries and Aquatic Sciences. 55(10):2292-2299.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2002. Canadian Species at Risk. Ottawa, ON. 44 pages. Available on-line at: http://www.cosewic.gc.ca

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003. Canadian Species at Risk. Ottawa, ON. 44 pages. Available on-line at: http://www.cosewic.gc.ca

C.S. Lord Northern Geoscience Centre. 2003. Mineral Potential Mapping Deh Cho Territory, NWT. Final Report. Prepared for Deh Cho Land Use Planning Committee

CSA (Canadian Standards Association). 1996. A sustainable forest management system: guidance document. Etobicoke, ON. CAN/CSA-Z808-96. 49 pages.

Culling, D.E. and B.A. Culling. 2001. A literature review of the ecology and habitat requirements of wildlife species in the Graham River watershed Volume III: large mammals. Fort St. John, B.C. Prepared for Canadian Forest Products Ltd. Fort St. John/Taylor Division. 35 pages.

Cumming, H.G. and D.B. Beange. 1993. Survival of woodland caribou in commercial forests of northern Ontario. The Forestry Chronicle. 69(5):579-588.

Cumming, H.G. and B.T. Hyer. 1998. Experimental log hauling through a traditional caribou wintering area. In: Lankester, M., G.D. Racey, and T. Timmermann, eds. Proceedings of the 7th North American Caribou Workshop; Thunder Bay, ON. Tromsø, Norway: Nordic Council for Reindeer Research 241-258. 264 pages. Rangifer. v. 18 Special Issue No. 10.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences. 53(Suppl.1)(1):267-282.

CZC (Canadian Zinc Corporation). 2001. Environmental Assessment Report, Mineral Exploration Drilling Program, Prairie Creek Mine. Vancouver, BC. 45 pages.

Dau, J.R. and R.D. Cameron. 1986. Effects of a road system on caribou distribution during calving. In: Gunn, A., F.L. Miller, and S. Skenneberg, eds. Proceedings of the Fourth International Reindeer/Caribou Symposium; Whitehorse, Yukon. Harstad, Norway: Nordic Council for Reindeer Research (NOR) 95-101. 374 pages.

Deh Cho Environmental. 2003. Tourism potential in the Deh Cho, NWT: A literature review and spatial analysis. Prepared for the Deh Cho Land Use Planning Commission. 86 pages.

DCLUPC (Deh Cho Land Use Planning Commission). 2003. Deh Cho Atlas. Cartographer: Chris Turner. Version 2.b. Fort Providence, NT: 45 pages.

DFO (Department of Fisheries and Oceans). 1995. Fish habitat Conservation and Protection: Guidelines for Attaining No Net Loss. Available on-line at: http://www.dfo-mpo.gc.ca/canwaters-eauxcan/infocentre/guidelines-conseils/guides

DIAND (Department of Indian Affairs and Northern Development). 1998. Timber Harvest Planning and Operating Ground Rules: Incorporating Environmental and Human Values into Timber Harvest Planning. DIAND, Whitehorse, Yukon.

DIAND (Department of Indian Affairs and Northern Development). 2002. A preliminary state of knowledge of valued components for the NWT Cumulative Impact Monitoring Program (NWT CIMP) and Audit - Final Draft. Prepared for NWT CIMP and Audit Working Group. 94 pages. Available online at http://www.nwtcimp.ca/documents/cimp%20vc%20report%20sept23.pdf.

DIAND (Department of Indian and Northern Affairs and Northern Development). 2003. A preliminary state of knowledge of valued components for the NWT Cumulative Impact Monitoring Program (NWT CIMP) and audit. Edited September 24, 2003. Prepared for the NWT CIMP and Audit Working Group. Available online at: http://www.nwtcimp.ca/documents/cimp%20vc%20report%20sept23.pdf.

Dooley, J.L. and M.A. Bowers. 1998. Demographic responses to habitat fragmentation: experimental tests at the landscape and patch scale. Ecology. 79(3):969-980.

Dugas, J. and G.B. Stenhouse. 2000. Grizzly Bear Management: Validating Existing Cumulative Effects Models, Proceedings of the thirteenth annual symposium on Geographic Information Systems 1999, Vancouver. 157-161

Dunford, J., J.W. Nolan, and P.D. McLoughlin. (eds). 2003. Boreal Caribou Research Program 2003 Research Summary. 57 pages.

Dunham, J.B. and B.E. Rieman. 1999. Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics. Ecological Applications. 9(2):642-655.

Dyer, S.J. 1999. Movement and distribution of woodland caribou (*Rangifer tarandus caribou*) in response to industrial development in northeastern Alberta. Edmonton, Alberta: University of Alberta.

Dyer, S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology. 80:839-845.

Dzus, E. 2001. Status of the Woodland Caribou (*Rangifer tarandus caribou*) in Alberta. Edmonton, AB. Alberta Environment, Fisheries and Wildlife Management Division, and Alberta Conservation Association. Wildlife Status Report No. 30. 47 pages.

EBA Engineering Consultants Ltd. 2003. A Spatial Analysis and Literature Review of Wildlife and Wildlife Habitat in the Deh Cho Territory, NWT. Prepared for the Deh Cho Land Use Planning Committee. 184 pages.

Eaglin, G.S. and W.A. Hubert. 1993. Effects of logging and roads on substrate and trout in streams of the Medicine Bow National Forest, Wyoming. 199313, (4): 844-846.

Ecological Stratification Working Group. 1995. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull. 125 p report and national map at 1:7 500 000 scale.

Edmonds, E.J. 1991. Status of woodland caribou in western North America. In: Heard, D.C. and M. Williams, Eds. Proceedings of the Fifth North American Caribou Workshop; Yellowknife, NT. Harstad, Norway: Nordic Council for Reindeer Research 91-107. 170 pages. Rangifer. v. 11 Special Issue No. 7.

Edmonds, E.J. and M. Bloomfield. 1984. A study of woodland caribou (*Rangifer tarandus caribou*) in West Central Alberta, 1979 to 1983. Edmonton, Alberta. Alberta Energy and Natural Resources, Fish and Wildlife Division.

Edwards, R.Y. 1950. Variations in the fur productivity of northern British Columbia. Unpublished M.A. thesis, University B.C. 126 pages.

ELI (Environmental Law Institute). 2003. Conservation thresholds for land use planners. Environmental Law Institute, Washington, D.D. Available online at: http://www.elistore.org/reports_detail.asp?ID=10839&topic=Land_Use.

Enns, K.A., E.B. Peterson, and D. McLennan. 1993. Impacts of hardwood management on British Columbia wildlife: problem analysis. Forestry Canada and British Columbia Ministry of Forests. Forest Resource Development Agreement Report 208. 78 pages.

East Slopes Grizzly Bear Project. 1998. Grizzly bear population and habitat status in Kananaskis Country, Alberta: A report to the Department of Environmental Protection, Natural Resources Service, Alberta. Calgary, AB. Alberta Environmental Protection, Natural Resources Service.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management. 61(3):603-610.

Fahrig, L. 2001. How much habitat is enough? Biological Conservation 100: 65-74.

Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecological Applications 12: 346-353.

Farnell, R. and J. McDonald. 1987. The Demography of Yukon's Finlayson Caribou Herd 1982-1987. Yukon Renewable Resources. 54 pages.

Farnell, R., N. Barichello, K. Egli, and G.W. Kuzyk. 1996. Population ecology of two woodland caribou hers in the southern Yukon. Rangifer, Special Issue. 9:63-72.

FEARO (Federal Environmental Assessment Review Office). 1994. A reference guide for the *Canadian Environmental Assessment Act* Determining whether a project is likely to cause significant adverse environmental effects. Canadian Environmental Assessment Agency. 181-215 pages.

Ferguson, M.A.D. and L.B. Keith. 1982. Influence of nordic skiing on distribution of moose and elk in Elk Island National Park, Alberta. Canadian Field-Naturalist. 96(1):69-78.

Findlay, C.S. and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology. 11(4):1000-1009.

Flather, C.H. and J.R. Sauer. 1996. Using landscape ecology to test hypotheses about large-scale abundance patterns in migratory birds. Ecology. 77(1):28-35.

FMF (Foothills Model Forest). 2003. Local level indicators of sustainable forest management for the Foothills Model Forest - initial status report. 54 pages.

Ford, B.S., P.S. Higgins, A.F. Lewis, K.L. Cooper, T.A. Watson, C.M. Gee, G.L. Ennis, and R.L. Sweeting. 1995. Literature reviews of the life history, habitat requirements and mitigation/compensation strategies for thirteen sport fish species in the Peace, Liard and Columbia river drainages of British Columbia. Vancouver, B.C. Department of Fisheries and Oceans Habitat and Enhancement Branch. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2321. xxiv + 342 pages.

Forman, R.T.T. and S.K. Collinge. 1997. Nature conserved in changing landscapes with and without spatial planning. Landscape and Urban Planning. 37:129-135.

Forman, R. T. T. and M. Godron. 1986. Landscape Ecology. John Wiley, New York. 619 pages.

Forman, R.T.T. and A.M. Hersperger. 1996. Road ecology and road density in different landscapes, with international planning and mitigation solutions. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trends in addressing transportation related wildlife mortality. Tallahassee, FL: State of Florida Department of Transportation.

Fort Nelson Land and Resource Management Plan. 1997. Recommended Fort Nelson Land and Resource Management Plan. 184 pages.

Francis, R.I.C.C. and R. Shotton. 1997. 'Risk' in fisheries management: a review. Canadian Journal of Fisheries and Aquatic Sciences. 54(8):1699-1715.

Francis, S., R. Anderson, and S. Dyer. 2002. Development of a threshold approach for assessing industrial impacts on woodland caribou in Yukon. Presentation provided at the Assessment and Management of Cumulative Effects Workshop, Whitehorse, Yukon, March 25-26, 2002.

Franklin, J.F. and R.T.T. Forman. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. Landscape Ecology. 1(1):5-18.

Friesen, L.E., P.F.J. Eagles, and R.J. MacKay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conservation Biology. 9(6):1408-1414.

Frissell, C.A. and D. Bayles. 1996. Ecosystem management and the conservation of aquatic biodiversity and ecological integrity. Water Resources Bulletin. 32(2):229-240.

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. Road construction and maintenance. In: Meehan, W.R., ed. Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. Bethesda, Maryland: American Fisheries Society; pages 297-323.

Gal, L.P. and A.L. Jones. 2003. Oil and Gas Potential Evaluation of the Deh Cho Territory. Prepared for Deh Cho Land Use Planning Committee. Draft. 113 pages.

Geo-North Ltd. and Axys Environmental Consulting Ltd. 1997. Identifying research priorities to refine the West Kitikmeot Slave Study Research Framework: Final Report. 40 pages. + Appendices.

Gibeau, M.L. 2000. A conservation biology approach to management of grizzly bears in Banff National Park. [Web Page]. Accessed 2000. Available at: http://www.canadianrockies.net/Grizzly/pubs_and-papers.htm.

Gibeau, M.L. and K. Heuer. 1996. Effects of transportation corridors on large carnivores in the Bow River Valley, Alberta. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trends in addressing transportation related wildlife mortality Tallahassee, FL: State of Florida Department of Transportation.

Gibeau, M.L., S. Herrero, J.L. Kansas, and B. Benn. 1996. Grizzly bear population and habitat status in Banff National Park. Calgary, AB. A report tot he Banff Bow Valley Task Force. 62 pages.

Gibilisco, C.J. 1994. Distributional dynamics of modern Martes in North America. Pp. 59-71. In Buskirk, S.W., A.S. Harestad, M.G. Raphael, R.A. Powell (eds.). Martens, sables and fishers. Cornel University Press, Ithaca and London. 484 pages.

GWNT (Government of Northwest Territories). 2000. 1999 Annual Report on Community Health and Well Being. Prepared by Departments of Health and Social Services, Resources, Wildlife and Economic Development, and NWT Bureau of Statistics. 51 pages.

GNWT (Government of the Northwest Territories). 2002. Communities and Diamonds: Socio-economic impacts on the communities of Lutselk'e, Rae-Edzo, Rae Lakes, Wha Ti, Wekweti, Dettah, Ndilo, and Yellowknife. Prepared by the Departments of Health and Social Services, Education, Culture and Employment, NWT Housing Corporation, Resources, Wildlife and Economic Development and the NWT Bureau of Statistics under the BHP Socio-economic Agreement.

GNWT HSS (Government of the Northwest Territories Health and Social Services). Accessed 2002a. Deh Cho Region Community Programs and Services. 23 pages. Available online at http://www.hlthss.gov.nt.ca/Features/Initiatives/reports_pdf/social_agenda/dehcho.pdf

GNWT HSS (Government of the Northwest Territories Health and Social Services). Accessed 2002b. South Slave Region Community Programs and Services. 27 pages. Available online at http://www.hlthss.gov.nt.ca/Features/Initiatives/reports_pdf/social_agenda/southslave.pdf

GNWT (Government of the Northwest Territories) Department of Transportation. 2003. Northwest Territories Highway System Base Map. Accessed 2004. Available online at http://www.gov.nt.ca/Transportation/hwyinfo/hwymap.htm

GRI (Global Reporting Initiative). 2002. Sustainability reporting guidelines. Global Reporting Initiative, Boston, MA. Available online at: http://www.globalreporting.org/guidelines/2002/gri_2002_guidelines.pdf.

Gunn, A., J. Antoine, J. Boulanger, J. Bartlett, B. Croft, A. D'Hont. 2002. Draft. Boreal Caribou Habitat and Land Use Planning in the Deh Cho, Northwest Territories. Prepared for Environment Canada's Habitat Stewardship Program for Species at Risk. 47 pages.

Graf, R. 1992: Status and management of moose in the Northwest Territories, Canada. Alces Suppl.1:22-28.

Griffith, J.A. 1998. Connecting ecological monitoring and ecological indicators: a review of the literature. Journal of Environmental Systems. 26(4):325-363.

Gustafson, E.J. 1998. Quantifying landscape spatial pattern: what is the state of the art? Ecosystems. 1:143-156.

Gutzwiller, K.J., H.A. Marcum, H.B. Harvey, J.D. Roth, and S.H. Anderson. 1998. Bird tolerance to human intrusion in Wyoming montane forests. The Condor. 100:519-527.

Hagmeier, D.M. 1956. Distribution of marten and fisher in North America. Can. Field-Nat. 70(4):149-168.

Hamer, D. and S. Herrero. 1987a. Grizzly bear food and habitat in the front ranges of Banff National Park, Alberta. In: Zager, P.E., (ed). Int. Conf. Bear Res. and Manage.; Williamsburg, VA; Yugoslavia. International Association for Bear Research and Management 199-213. Bears - their biology and management.

Hamer, D. and S. Herrero. 1987b. Wildfire's influence on grizzly bear feeding ecology in Banff National Park, Alberta. In: Zager, P.E., (ed). Int. Conf. .Bear Res. and Manage.; Williamsburg, VA; Yugoslavia. International Association for Bear Research and Management 179-186. Bears - their biology and management.

Hamilton, D. and S. Wilson. 2001. Access management in British Columbia: a provincial overview. Victoria, B.C. Prepared for Ministry of Environment, Lands and Parks, Habitat Protection Branch. 29 pages.

Hannon, S.J. 2000. Avian response to stand and landscape structure in the boreal mixedwood forest in Alberta. Edmonton, AB. Sustainable Forest Management Network. Project Report 1999-37. 26 pages.

Hanski, I. and M. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. Biological Journal of the Linnean Society. 42:3-16.

Hanski, I., A. Moilanen, and M. Gyllenberg. 1996. Minimum viable metapopulation size. The American Naturalist. 147(4):527-541.

Harding, L.E. and E. McCullum, Eds. 1994. Biodiversity in British Columbia: Our changing environment. Environment Canada, Canadian Wildlife Service. 426 pages.

Hargis, C.D. and J.A. Bissonette. 1997. Effects of forest fragmentation on populations of American marten in the intermountain west. Pp. 437-451. *In* G. Proulx, H., N. Bryant and P.M. Woodard (eds.). Provincial Museum of Alberta, Edmonton, Alberta.

Hargis, C.D. and D.R. McCullough. 1984. Winter diet and habitat selection of marten in Yosemite National Park. J. Wildl. Manage. 48(1):140-146.

Hargis, C.D., J.A. Bissonette, and D.L. Turner. 1999. The influence of forest fragmentation and landscape pattern on American martens. Journal of Applied Ecology. 36:157-172.

Harper, F.E. 1988. Regional Wildlife Plan for the Peace Sub-region, Northern Region. Ministry of Environment and Parks Wildlife Branch. 212 pages.

Harper, D.J. and J.T. Quigley. 2000. No net loss of fish habitat: An audit of forest road crossings of fish-bearing streams in British Columbia, 1996-1999. Vancouver, British Columbia. Fisheries and Oceans Canada. Canadian Technical Report of Fisheries and Aquatic Sciences 2319.

Haskins, W. and D.W. Mayhood. 1997. Stream crossing density as a predictor of watershed impacts. In. Proceedings of the Seventeenth Annual ESRI User Conference Conference Paper 457. 5 pages.

Heard, D.C. and K.L. Vagt. 1998. Caribou in British Columbia: a 1996 status report. In: Lankester, M., G.D. Racey, and T. Timmermann, eds. Proceedings of the 7th North American Caribou Workshop; Thunder Bay, ON. Tromsø, Norway: Nordic Council for Reindeer Research 117-123. 264 pages. Rangifer. v. 18 Special Issue No. 10.

Hegmann, G.L., C. Cocklin, R. Creasey, S. Dupuis, A.J. Kennedy, L. Kingsley, W.A. Ross, H. Spaling, and D. Stalker. 1999. Cumulative Effects Assessment Practitioners Guide. Hull, Quebec. Prepared by AXYS Environmental Consulting Ltd. and the CEA Working Group for the Canadian Environmental Assessment Agency.

Helm, J. 2000. People of the Denendeh: Ethnohistory of the Indians of Canada's Northwest Territories. McGill-Queen’s University Press. 430 pages.

Hession, W.C., D.E. Storm, C.T. Haan, S.L. Burks, and M.D. Matlock. 1996. A watershed-level ecological risk assessment methodology. Water Resources Bulletin. 32(5):1039-1054.

Hill, D., D. Hockin, D. Price, G. Tucker, R. Morris, and J.R. Treweek. 1997. Bird disturbance: Improving the quality and utility of disturbance research. Journal of Applied Ecology. 34(2):275-288.

Holmes, T.L., R.L. Knight, L. Stegall, and G.R. Craig. 1993. Responses of wintering grassland raptors to human disturbance. Wildlife Society Bulletin. 21(4):461-468.

Holyan, J.A., L.L.C. Jones and M. G. Raphael. 1998. American marten use of cabins as resting sites in central Oregon. Northwestern Naturalist 79:68-70.

Horejsi, B.L. 1996. Guidelines enabling land use managers to eliminate or reduce the impact of their decisions on bears and bear habitat in the Yukon Territory. 24 pages.

Hubert, W.A., R.S. Helzner, L.A. Lee, and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: arctic grayling riverine populations. U.S. Department of the Interior Fish and Wildlife Service. Biological Report 82(10.110). 34 pages.

Hudon, C. 1997. Impact of water level fluctuations on St. Lawrence River aquatic vegetation. Canadian Journal of Fisheries and Aquatic Sciences. 54(12):2853-2865.

Hughes, R.M., P.R. Kaufmann, A.T. Herlihy, T.M. Kincaid, L. Reynolds, and D.P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. Canadian Journal of Fisheries and Aquatic Sciences. 55(7):1618-1631.

Husseini, A., G. Burford, A. Martin, and M. Adragna, eds. 1996. A sustainable forest management system: guidance document. Etobicoke, ON. Canadian Standards Association. 33 pages. CSA, 178 Rexdale Boulevard, Etobicoke, ON M9W 1R2.

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press. 555 pages.

Imperial Oil, Arctic Gas Project, ConocoPhillips, Shell Canada, ExxonMobil. 2003. Preliminary Information Package. Volume 1: Project Description.

Jalkotzy, M.G., P.I. Ross, and M.D. Nasserden. 1998. The Effects of Linear Development on Wildlife: A Review of Selected Scientific Literature. Calgary, Alberta. Prepared for the Canadian Association of Petroleum Producers by Arc Wildlife Services Ltd. Publication #1998-0002. 117 pages.

James, A.R.C. 1999. Effects of industrial development on the predator-prey relationship between wolves and caribou in northeastern Alberta. Edmonton, Alberta: University of Alberta. 70 pages.

James, A.R.C. and A.K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management. 64(1):154-159.

Jones, L.L.C. and M.G. Raphael. 1990. Ecology and management of marten in fragmented habitats of the Pacific Northwest. Progress Report: Fiscal Year 1990. Pacific Northwest Research Station, Olympia, Washington.

Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology. 61(1):65-71.

Johnson, E.A., K. Miyanishi, and S.R.J. Bridge. 2001. Wildfire regime in the boreal forest and the idea of suppression and fuel buildup. Conservation Biology. 15(6):1554-1557.

Kansas, J.L. 2002. Critical review of methods to evaluate grizzly bear cumulative effects. In: Kennedy, A.J., ed. Cumulative Environmental Effects Management: tools and approaches; Calgary, Alberta. Edmonton, AB: Alberta Society of Professional Biologists 247-265. 487 pages.

Kansas, J.L., R. Usher, and J. Bowen. 1997. Grizzly bear status and habitat effectiveness: Moose Mountain study area. Calgary, AB. Prepared for GAIA Consultants Inc. 56 pages. + Figs.

Kasworm, W.F. and T.L. Manley. 1990. Road and trail influences on grizzly bears and black bears in northwest Montana. In. Int. Conf. Bear Res. and Manage. 79-84.

Kelly, J.R. and M.A. Harwell. 1990. Indicators of Ecosystem Recovery. Environmental Management. 14(5):527-545.

Kennett, S.A. 2000. Aboriginal communities and non-renewable resource development: State of the Debate Report. Prepared for the National Round Table on the Environment and the Economy. Available online at: http://www.nrtee-trnee.ca/Publications/PDF/SOD_Aboriginal_E.pdf.

Klein, D.R. 1982. Fire, lichens, and caribou. Journal of Range Management. 35(3):390-395.

Klein, D.R. 1991. Limiting factors in caribou population ecology. Rangifer, Special Issue. (7):30-35.

Klock, G.O. 1985. Modeling the cumulative effects of forest practices on downstream aquatic ecosystems. Journal of Soil and Water Conservation. March-April:237-241.

Koehler, G.M. and M.G. Hornocker. 1977. Fire effects on marten habitat in the Selway-Bitterroot Wilderness. J. Wildl. Manage. 41(3):500-505.

Knight, R.L. and S.A. Temple. 1995. Origin of wildlife responses to recreationists. In: Knight, R.L. and K.J. Gutzwiller, eds. Wildlife and Recreationists - Coexistence Through Management and Research. Washington, DC: Island Press; pages. 81-91.

Kuzyk, G.W. 2002. Wolf distribution and movements on caribou ranges in west-central Alberta. Edmonton, AB: University of Alberta. 125 pages.

Lamberson, R.H., R. McKelvey, B.R. Noon, and C. Voss. 1992. A dynamic analysis of northern spotted owl viability in a fragmented forest landscape. Conservation Biology. 6(4):505-512.

Lande, R. 1987. Extinction thresholds in demographic models of terrestrial populations. The American Naturalist. 130(4):624-635.

Lehnert, M.E., L.A. Romin, and J.A. Bissonette. 1996. Mule deer-highway mortality in northeastern Utah: causes, patterns, and a new mitigative technique. In: Evink, G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trends in addressing transportation related wildlife mortalityTallahassee, FL: State of Florida Department of Transportation.

Lensink, C.J., R.O. Skoog and J.L. Buckley. 1955. Food habits of marten in interior Alaska and their significance. J. Wildl. Manage. 19(3):364-368.

Linzon, S.N. 1978. Effects of air-borne sulfur pollutants on plants. *In*: J.O. Nriagu (ed.). Sulfur in the Environment, Part II: Ecological Impacts. J. Wiley & Sons, pages 109-162.

Lowrence, R. and G. Vellidis. 1995. A conceptual model for assessing ecological risk to water quality function of bottomland hardwood forests. Environmental Management. 19(2):239-258.

Lull, K.J., J.A. Tindall, and D.F. Potts. 1995. Assessing nonpoint-source pollution risk. Journal of Forestry. 35-40.

Mace, R.D. and T.L. Manley. 1993. South Fork Flathead River grizzly bear project: progress report for 1992. 34 pages.

Mace, R.D., J.S. Waller, T.L. Manley, L.J. Lyon, and H. Zuuring. 1996. Relationships among grizzly bears, roads, and habitat in the Swan Mountains, Montana. Journal of Applied Ecology. 33:1395-1404.

Macleod (Macleod Institute). 2002. Carrying capacity and thresholds: Theory and practice in environmental management. Prepared for Canadian Arctic Resources Committee, Ottawa and Yellowknife, by Macleod Institute, Calgary. Available online at: http://www.macleodinstitute.com/publications/pdf/report_final.pdf

Magnan, P. and I. St-Onge. 2000. Impact of logging and natural fires on fish communities of Canadian Shield lakes. Edmonton, AB. Sustainable Forest Management Network. Final Project Report 2000-36. 22 pages.

Malholtra, S.S., and R.A. Blauel. 1980. Diagnosis of air pollutant and natural stress symptoms on forest vegetation in western Canada. Northern Forest Research Centre, Canadian Forestry Service, Edmonton, Alberta. Information Report NOR-X-228. 84 pages.

Mallory, F.F. and T.L. Hillis. 1998. Demographic characteristics of circumpolar caribou populations: ecotypes, ecological constraints, releases, and population dynamics. In: Lankester, M., G.D. Racey, and T. Timmermann, eds. Proceedings of the 7th North American Caribou Workshop; Thunder Bay, ON. Tromsø, Norway: Nordic Council for Reindeer Research 49-60. 264 pages. Rangifer. v. 18 Special Issue No. 10.

Manley, T.L. and R.D. Mace. 1992. Grizzly Bear Habitat Use and Disturbance Studies: South Fork of the Flathead River. Progress Report for 1991. Kalispell, MT. Montana Department of Fish, Wildlife and Parks. 41 pages.

Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource Selection by Animals. 2nd ed. The Netherlands: Kluwer Academic Publishers. 221 pages.

Marshall, T. 1996. Stream crossings on the Weldwood FMA, 1995 stream crossing inventory report. Prepared for Weldwood of Canada, Hinton Division.

Mattson, D.J. 1993. Background and Proposed Standards for Managing Grizzly Bear Habitat Security in the Yellowstone Ecosystem. U.S. Forest Service and U.S. Fish and Wildlife Service. 18 pages.

Mattson, D.J., S. Herrero, R.G. Wright, and C.M. Pease. 1996. Science and management of Rocky Mountain grizzly bears. Conservation Biology. 10(4):1013-1025.

Mayhood, D.W. 2001. Conceptual framework and an action plan for conserving Westslope cutthroat trout in Canada. In: Brewin, M.K., A.J. Paul, and M. Monita, eds. Ecology and Management Northwest Salmonids: bull trout II conference; Canmore, AB. Calgary, AB: Trout Unlimited Canada 265. 276 pages.

McCool, S.F. and D.N. Cole, eds. 1997. Proceedings - Limits of Acceptable Change and Related Planning Processes: Progress and Future Directions. Ogden, UT. United States Department of Agriculture Forest Service. INT-GTR-371. 86 pages.

McGurk, B.J. and D.R. Fong. 1995. Equivalent roaded area as a measure of cumulative effect of logging. Environmental Management. 19(4):609-621.

McLellan, B.N. 1990. Relationships between human industrial activity and grizzly bears. In. 8th International Conference on Bear Research and Management; Victoria. 57-64.

McLellan, B.N. and F.W. Hovey. 2001. Habitats selected by grizzly bears in a multiple use landscape. Journal of Wildlife Management. 65(1):92-99.

McLellan, B.N. and D.M. Shackleton. 1988. Grizzly bears and resource-extraction industries: effects of roads on behaviour habitat use and demography. Journal of Applied Ecology. 25:451-460.

McLellan, B.N. and D.M. Shackleton. 1989. Grizzly bears and resource-extraction industries: habitat displacement in response to seismic exploration, timber harvesting and road maintenance. Journal of Applied Ecology. 26:371-380.

McLellan, B.N., F.W. Hovey, R.D. Mace, J.G. Woods, D.W. Carney, M.L. Gibeau, W.L. Wakkinen, and W.F. Kasworm. 1999. Rates and causes of grizzly bear mortality in the interior mountains of British Columbia, Alberta, Montana, Washington and Idaho. Journal of Wildlife Management. 63(3):911-920.

McLoughlin, P.D., E. Dzus, B. Wynes, and S. Boutin. 2003. Declines in populations of woodland caribou. Journal of Wildlife Management. 67(4):755-761.

MELP (British Columbia Ministry of Environment, Lands and Parks). 1995. Conservation of grizzly bears in British Columbia - background report. Victoria, B.C. 70 pages.

Mech, L.D., R.E. McRoberts, R.O. Peterson, and R.E. Page. 1987. Relationship of deer and moose populations to previous winters' snow. Journal of Animal Ecology. 56: 615-627.

Meehan, W.R. 1991. Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. Bethesda, Maryland: American Fisheries Society. 751 pages.

Merigliano, L., D.N. Cole, and D.J. Parsons. 1997. Application of LAC-type processes and concepts to non-recreation management issues in protected areas. In: McCool, S.F. and D.N. Cole, comps. 1997. Proceedings - Limits of acceptable change and related planning processes: progress and future directions; 1997 May 20-22. Ogden, UT. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Gen. Tech. Rep. INT-GTE-371.

Messier, F. 1991. On the concepts of population limitation and population regulation as applied to caribou demography. In: Butler, C.E. and S.P. Mahoney, eds. Proceedings 4th North American Caribou Workshop; St. John's, Newfoundland. Newfoundland and Labrador Wildlife Division 260-277. 529 pages.

Miller, S.G., R.L. Knight, and C.K. Miller. 1998. Influence of recreational trails on breeding bird communities. Ecological Applications 8:162-169.

Minshall, G.W., C.T. Robinson, and D.E. Lawrence. 1997. Postfire responses of lotic ecosystems in Yellowstone National Park, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences. 54(11):2509-2525.

Mönkkönen, M. and P. Reunanen. 1999. On critical thresholds in landscape connectivity: a management perspective. Oikos. 84(2):302-305.

Morgantini, L.E. 1984. Pipeline and Wildlife - A wildlife monitoring study during the construction of the Hanlan and Brazeau gas pipelines. Edmonton, AB. Prepared for Canterra Energy Limited.

MSRM (British Columbia Ministry of Sustainable Resource Management). 2004. Pre-tenure plans for oil and gas development in the Muskwa-Kechika Management Area. Consultation Draft.

Murdie, R.A., D. Rhyne, and J. Bates. 1992. Modelling Quality of Life Indicators in Canada: A Feasibility Analysis. Toronto, ON. Institute for Social Research York University. 68 pages.

Murphy, S.M. 1984. Caribou use of ramps for crossing pipe/road complexes, Kuparuk oilfield, Alaska, 1984. Fairbanks, AK. Prepared for ARCO Alaska, Inc. 61 pages.

Murray, L.J. 1992. Habitat Use and Seasonal Movements of Radio-collared Caribou in the Peace Subregion, 1988-1990. Prince George, British Columbia. BC Ministry of Environment and Ministry of Forests. 61 pages.

Mychasiw, L. and M. Hoefs. 1988. Access-related impacts of backcountry roads to wildlife and management approaches to mitigate them. Whitehorse, YK. Department of Renewable Resources, Government of Yukon. 37 pages + app.

NCGBRT (North Cascades Grizzly Bear Recovery Team). 2001. Recovery plan for grizzly bears in the North Cascades of British Columbia. Consensus Recommendation Draft for Consultation.

Nellemann, C. and R.D. Cameron. 1998. Cumulative impacts of an evolving oilfield complex on the distribution of calving caribou. Canadian Journal of Zoology. 76:1425-1430.

Nellemann, C., I. Vistnes, P. Jordhøy, and O. Strand. 2001. Winter distribution of wild reindeer in relation to power lines, roads and resorts. Biological Conservation. 101:351-360.

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management. 11:72-82.

Nietfeld, M., J. Wilk, K. Woolnough, and B. Hoskin. 1985. Wildlife habitat requirement summaries for selected wildlife species in Alberta. Edmonton, AB. Alberta Energy and Natural Resources Fish and Wildlife Division. ENR Technical Report No. T/73. 259 pages.

NNSL (Northern News Services Limited). 2003. Tungsten makes a comeback. Available on-line at: http://www.nnsl.com/ops/tungsten.html.

Noel, L.E., R.H. Pollard, W.B. Ballard, and M.A. Cronin. 1998. Activity and use of active gravel pads and tundra by caribou, *Rangifer tarandus granti*, within the Prudhoe Bay oil field, Alaska. Canadian Field-Naturalist. 112(3):400-409.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology. 4(4):355-364.

Noss, R.F., H.B. Quigley, M.G. Hornocker, T. Merrill, and P.C. Paquet. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology. 10(4):949-963.

NRTEE (National Round Table on the Environment and the Economy). 2003. Environment and Sustainable Development Indicators for Canada. Ottawa, ON. Renouf Publishing Co. Ltd. 92 pages.

Oberg, P.R. 2001. Responses of mountain caribou to linear features in a west-central Alberta landscape. Edmonton, AB: University of Alberta. 126 pages.

Oil and Gas Human Resource Development Committee. 2000. Oil and Gas Human Resources Strategic Plan Final Report; Prepared for the Inuvialuit Regional Corporation Human Resources Department.

Olson+Olson Planning and Design Consultants, Watertight Solutions Ltd., Bandaloop Landscape-Ecosystem Services, K. Freemark, and D. Kirk. 2002. Landscape, Biodiversity and Watershed Indicator Review and Assessment. Prepared for CEMA Landscape & Biodiversity Subgroup. 246 pages.

Omernik, J.M. and R.G. Bailey. 1997. Distinguishing between watersheds and ecoregions. Journal of the American Water Resources Association. 33(5):935-949.

Osko, T. 2001. Industrialization in Alberta's boreal forest and its effects on wildlife. Prepared for Alberta-Pacific Forest Industries, Inc. 40 pages.

Owens, N.W. 1977. Responses of wintering Brent geese to human disturbance. Wildfowl. 28:5-14.

PACTeam Canada. 2003. Socio-demographic and job creation needs analysis for the Deh Cho Territory, NWT. Prepared for the Deh Cho Land Use Planning Committee. 97 pages.

PACTeam Canada, Victory Point FX, and The Forestry Corp. 2003. A Spatial Analysis and Literature Review of Timber Potential in the Deh Cho Territory, NWT. Prepared for the Deh Cho Land Use Planning Committee. 66 pages.

Paramount (Paramount Resources Ltd., Golder Associates, and AllNorth Consultants Limited). 2003. Developers Assessment Report for the Paramount Cameron Hills Extension. Submitted to the Mackenzie Valley Environmental Impact Review Board. Available online at: ftp://www.mveirb.nt.ca/Registry/EAParamountoil/DAR_Paramount_Oil/

Parkins, J. and T. Beckley. 2001. Monitoring Community Sustainability in the Foothills Model Forest: a Social Indicators Approach. Fredericton, NB. Canadian Forest Service. M-X-211E. 146 pages.

Parks Canada. 1997. Banff National Park Management Plan. Minister of Public Works and Government Services Canada.

Pedigree Caribou Standing Committee and Delta Environmental Management Group Ltd. 1991. Caribou Protection Plan for Oil and Gas Activity in the Pedigree Region of Northwestern Alberta. Final ed; 20 pages.

Penner, D.F. and J.A. Duncan. 1983. Monitoring of a geophysical exploration program and its effect on wildlife, particularly woodland caribou, near Manning, Alberta. Prepared for Mobil Oil Canada Ltd. 137 pages.

Pimm, S.L. and A. Redfearn. 1988. The variability of population densities. Nature. 334:613-614.

Poole, K.G. and R.P. Graf. 1996. Winter diet of marten during a snowshoe hare decline. Canadian Journal of Zoology. 74:456-466.

Potvin, F., L. Bélanger, and K. Lowell. 2000. Marten habitat selection in a clearcut boreal landscape. Conservation Biology. 14(3):844-857.

Powell, R.A. 1996. Structure and spacing of *Martes* populations. Pp. 101-121. *In* Buskirk, S.W., A.S. Harestad, M.G. Raphael, R.A. Powell (eds.). Martens, sables and fishers. Cornel University Press, Ithaca and London. 484 pages.

Raine, R.M. 1987. Winter food habits and foraging behaviour of fishers (*Martes pennanti*) and martens (*Martes Americana*) in southeastern Manitoba. Can. J. Zool. 65(3):745-747.

Regier, H.A. and J.D. Meisner. 1990. Anticipated effects of climate change on freshwater fishes and their habitat. Fisheries. 15(6):10-15.

Reid, L.M. 1993. Research and cumulative watershed effects. Albany, CA. Pacific Southwest Research Station. General Technical Report PSW-GTR-141. vii+118 pages.

Reid, L.M. and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research. 20(11):1753-1761.

Reid, S.M. and P.G. Anderson. 1999. Effects of sediment released during open-cut pipeline water crossings. Canadian Water Resources Journal. 24(3):235-251.

Reimers, E., S. Eftestøl, and J.E. Colman. 2003. Behavior responses of wild reindeer to direct provocation by a snowmobile or skier. Journal of Wildlife Management. 67(4):747-754.

Rempel, R.S., P.C. Elkie, A.R. Rodgers, and M.J. Gluck. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. Journal of Wildlife Management. 61(2):517-524.

Rettie, W.J. and F. Messier. 2000. Hierarchical habitat selection by woodland caribou: its relationship to limiting factors. Ecography. 23:466-478.

Rettie, W.J. and F. Messier. 2001. Range use and movement rates of woodland caribou in Saskatchewan. Canadian Journal of Zoology. 79:1933-1940.

Reynolds, H.V. and G.W. Garner. 1987. Patterns of grizzly bear predation on caribou in northern Alaska. *In*: Zager, P.E., (ed). Int. Conf. Bear Res. and Manage. Bears - their biology and management. Williamsburg, VA; Yugoslavia. International Association for Bear Research and Management 59-67. 9 pages.

RIC (Resources Inventory Committee). 1999. British Columbia Wildlife Habitat Rating Standards. Resources Inventory Committee. 15 pages.

Rich, A.C., D.S. Dobkin, and L.J. Niles. 1994. Defining forest fragmentation by corridor width: the influence of narrow forest-dividing corridors on forest-nesting birds in southern New Jersey. Conservation Biology. 8(4):1109-1121.

Rich, C.F., Jr., T.E. McMahon, B.E. Rieman, and W.L. Thompson. 2003. Local-habitat, watershed, and biotic features associated with bull trout occurrence in Montana streams. Transactions of the American Fisheries Society. 132:1053-1064.

Richardson, C.T. and C.K. Miller. 1997. Recommendations for protecting raptors from human disturbance: a review. Wildlife Society Bulletin. 25(3):634-638.

Rieman, B.E., D.C. Lee, and R.F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River basins. North American Journal of Fisheries Management. 17(4):1111-1125.

Riffell, S.K., K.J. Gutzwiller, and S.H. Anderson. 1996. Does repeated human intrusion cause cumulative declines in avian richness and abundance? Ecological Applications. 6(2):492-505.

Rodgers, J.A., Jr. and H.T. Smith. 1997. Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida. Wildlife Society Bulletin. 25(1):139-145.

Rolley, R.E. and L.B. Keith. 1980. Moose population dynamics and winter habitat use at Rochester, AB, 1965-1979. Can. Field Nat. 94(1): 9-18.

RWED (Resources, Wildlife & Economic Development). 2000. 1999/2000 Northwest Territories Air Quality Report. 9 pages. Available online at: http://www.gov.nt.ca/RWED/eps/environ.htm).

RWED (Resources, Wildlife and Economic Development). 2001a. NWT Landscape units map layer dated November 2001. 1:1,000,000.

RWED (Resources, Wildlife and Economic Development). 2001b. NWT species 2000. General status ranks of wild species in the Northwest Territories. Government of the Northwest Territories (GNWT), RWED, Yellowknife NT. 50pp. Also available at: http://www.nwtwildlife.rwed.gov.nt.ca/monitoring/speciesmonitoring/_Monitoring%20report%20NEW.pdf

RWED (Resources, Wildlife & Economic Development). 2001c. The Northwest Territories at a glance. 4 pages. Available online at: http://www.gov.nt.ca/RWED/iea/fact_sheets/nwteconomy2001.pdf

RWED (Resources, Wildlife & Economic Development). 2001d. 2000/2001 Northwest Territories Air Quality Report. 9 pages. Available online at: http://www.gov.nt.ca/RWED/eps/environ.htm).

RWED (GNWT Resources, Wildlife and Economic Development). 2002a. Northwest Territories Land Cover Classification for Satellite Imagery. v.1:2002. 22 pages.

RWED (Resources, Wildlife & Economic Development). 2002b. Guideline for Ambient Air Quality Standards in the Northwest Territories. Yellowknife, NWT 2 pages. Available online at http://www.gov.nt.ca/RWED/eps/pdfs/ambient_airquality.pdf

RWED (GNWT Resources, Wildlife and Economic Development). 2002c. Common Assumptions about Oil & Gas Activity in the Northwest Territories. Ad Hoc Committee on Common Assumptions. Yellowknife, NWT.

RWED (Resources, Wildlife & Economic Development). 2002d. Air Quality Code of Practice Upstream Oil and Gas Industry Consultation Draft. 98 pages. Available on-line at: http://www.gov.nt.ca/RWED/eps/pdfs/airquality_codeofpractice.pdf

RWED (Resources, Wildlife & Economic Development). 2002e. 2001/2002 Northwest Territories Air Quality Report. 12 pages. Available online at: http://www.gov.nt.ca/RWED/eps/environ.htm).

Salmo Consulting Inc., URSUS Ecosystem Management Ltd., and GAIA Consultants Inc. 2001. Review of predictive modelling tools for wildlife and fish key indicators in the Wood Buffalo Region. Ft. McMurray, AB. Prepared for: Cumulative Environmental Management Association - Wood Buffalo Region Wildlife and Fish Working Group. 55 pages + Attachment.

Salmo Consulting Inc., Diversified Environmental Services, GAIA Consultants Inc., Forem Technologies Ltd., and Axys Environmental Consulting Ltd. 2003. Volume 2 Cumulative Effects Indicators, Thresholds, and Case Studies. Calgary, AB. Prepared for British Columbia Oil and Gas Commission and Muskwa-Kechika Advisory Board. 83 pages.

Schaefer, J.A. 1996. Canopy, snow, and lichens on woodland caribou range in southeastern Manitoba. In: Brown, W.K., D.B. Cichowski, E.J. Edmonds, D.R. Seip, S.K. Stevenson, D.C. Thomas, and M.D. Wood, Eds. Proceedings of the 6th North American Caribou Workshop; Labrador City, Labrador and Prince George, B.C. Tromsø, Norway: Nordic Council for Reindeer Research 239-244. 400 pages. Rangifer. v. 16 Special Issue No. 9.

Schaefer, J.A. and W.O. Pruitt. 1991. Fire and woodland caribou in southeastern Manitoba. Wildlife Monographs. 116:1-39.

Schiller, A., C.T. Hunsaker, M.A. Kane, A.K. Wolfe, V.H. Dale, G.W. Suter, C.S. Russell, G. Pion, M.H. Jensen, and V.C. Konar. 2001. Communicating ecological indicators to decision makers and the public. Conservation Ecology 5(1): 19. [online] URL: http://www.consecol.org/vol5/iss1/art19

Schmiegelow, F.K.A. and M. Mönkkönen. 2002. Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest. Ecological Society of America. 12(2):375-389.

Schneider, R.R. and S. Wasel. 2000. The effect of human settlement on the density of moose in northern Alberta. Journal of Wildlife Management. 64(2):513-520.

Schindler, D.W., S.E. Bayley, P.J. Curtis, B.R. Parker, M.P. Stainton, and C.A. Kelly. 1992. Natural and man-caused factors affecting the abundance and cycling of dissolved organic substances in precambrian shield lakes. Hydrobiologia. 229:1-21.

Scrimgeour, G.J., P. Hvenegaard, J. Tchir, S. Kendall, and A. Wildeman. 2003. Stream fish management: cumulative effects of watershed disturbances on stream fish communities in the Kakwa and Simonette River Basins, Alberta. Alberta Conservation Association (Peace River) and the Alberta Research Council (Vegreville) for the Northern Watershed Project Stakeholder Committee. Northern Watershed Project Final Report No. 3. 126 pages.

Seagle, S.W. 1986. Generation of species-area curves by a model of animal-habitat dynamics. P. 281-285 *in*: J.E. Verner, M.L. Morrison, and C.J. Ralph (*eds*.). Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison.

Seip, D.R. 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. Canadian Journal of Zoology. 70:1494-1503.

Seip, D.R. and D.B. Cichowski. 1996. Population ecology of caribou in British Columbia. In: Brown, W.K., D.B. Cichowski, E.J. Edmonds, D.R. Seip, S.K. Stevenson, D.C. Thomas, and M.D. Wood, Eds. Proceedings of the 6th North American Caribou Workshop; Labrador City, Labrador and Prince George, B.C. Tromsø, Norway: Nordic Council for Reindeer Research 73-80. 400 pages. Rangifer. v. 16 Special Issue No. 9.

Servheen, C. 1993. Grizzly bear recovery plan. Missoula, MT. U.S. Fish and Wildlife Service. 181 pages.

Servheen, C. and P. Sandstrom. 1993. Human Activities and Linkage Zones for Grizzly Bears in the Swan-Clearwater Valleys, Montana. Missoula, MT. U.S. Fish and Wildlife Service. 28 pages.

Shoemaker, D.J. 1994. Cumulative Environmental Assessment. Waterloo, ON. University of Waterloo, Department of Geography. 129 pages. (Department of Geography Publication Series; No. 42).

Singer, F.J. and J.B. Beattie. 1986. The controlled traffic system and associated wildlife responses in Denali National Park. Arctic. 39(3):195-203.

Singleton, H.J. 1985. Water quality criteria for particulate matter - technical appendix. Victoria, B.C. British Columbia Ministry of Environment. 82 pages.

Skagen, S.K., R.L. Knight, and G.H. Orians. 1991. Human disturbance of an avian scavenging guild. Ecological Applications. 1(2):215-225.

Smit, B. and H. Spaling. 1995. Methods for cumulative effects assessment. Environ Impact Assess Rev. 15:81-106.

Smith, K.G., E.J. Ficht, D.P. Hobson, and T.C. Sorensen. 2000. Winter distribution of woodland caribou in relation to clear-cut logging in west-central Alberta. Canadian Journal of Zoology. 78:1433-1440.

Snyder, J.E. and J.A. Bissonette. 1987. Marten use of clear-cuttings and residual forest stands in western Newfoundland. Can. J. Zool. 65(1):169-174.

Sopuck, L.G. 1985. Movements and distribution of caribou in relation to the Quintette Coal Development. Prepared for Denison Mines Ltd. 56 pages.

Soutiere, E.C. 1979. Effect of timber harvesting on marten in Maine. J. Wildl. Manage. 43(4):850-860.

Spencer, W.D., R.H. Barrett and W.J. Zielinski. 1983. Marten habitat preferences in the northern Sierra Nevada. J. Wildl. Manage. 47(4):1181-1186.

SRUNA (Sustainable Recreational Use of Natural Assets). 2000. Best Practice Guidelines: Communities and Sustainability Indicators. 31 pages.

Stalnaker, C., B.L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The Instream Flow Incremental Methodology - a primer for IFIM. Washington, DC. United States Department of the Interior National Biological Service. Biological Report 29. 45 pages.

Stankey, G.H., S.F. McCool, and G.L. Stokes. 1984. Limits of Acceptable Change: a new framework for managing the Bob Marshall wilderness complex. Western Wildlands. 10(3):33-37.

Stankey, G.H., D.N. Cole, R.C. Lucas, M.E. Petersen, and S.S. Frissell. 1985. The limits of acceptable change (LAC) system for wilderness planning. Ogden, UT. U.S. Department of Agriculture, Forest Service. General Technical Report INT-176. 37 pages.

Steventon, J.D. and J.T. Major. 1982. Marten use of habitat in a commercially clear-cut forest. J. Wildl. Manage. 46(1):175-182.

Strickland, M.A., C.W. Douglas, M. Novak and N.P. Hunziger. 1992. Marten, *Martes americana*. Pp. 599-612. *In* Chapman, J.A. and G. A. Feldhamer (eds.). Wild mammals of North America: biology, management and economics. The Johns Hopkins University Press, Baltimore and London. 1147 pages.

Stuart-Smith, A.K., C.J.A. Bradshaw, S. Boutin, D.M. Hebert, and A.B. Rippin. 1997. Woodland caribou relative to landscape patterns in northeastern Alberta. Journal of Wildlife Management. 61(3):622-633.

Suter, G.W., B.E. Sample, D.S. Jones, T.L. Ashwood and J.M. Loar. 1995. Approach and strategy for performing ecological risk assessments for the U.S. Department of Energy's Oak Ridge Reservation: 1995 Revision. Prepared by the Environmental Restoration Risk Assessment Program for the U.S. Department of Energy Office of Environmental Management. ES/ER/TM-33/R2.

Szkorupa, T.D. 2002. Multi-scale habitat selection by mountain caribou in west central Alberta. Edmonton, AB: University of Alberta. 91 pages.

Taylor, M.E. and N. Abrey. 1982. Marten, *Martes americana*, movements and habitat use in Algonquin Provincial Park, Ontario. Canadian Field-Naturalist 96(4):439-447.

Thomas, J.W., H. Black, Jr., R.J. Scherzinger, and R.J. Pedersen. 1979. Deer and elk. In: Thomas, J.W., (ed.). Wildlife habitats in managed forests - the Blue Mountains of Oregon and Washington. USDA Forest Service. (Agricultural Handbook (553)).

Thomas, J.W., D.A. Leckenby, M.G. Henjum, R.J. Pedersen, and L.D. Bryant. 1988. Habitat-effectiveness index for elk on Blue Mountain winter ranges. Portland, Oregon. United States Department of Agriculture Forest Service. PNW-GTR-218. 28 pages.

Thompson, I.D. 1991. Could marten become the spotted owl of eastern Canada? The Forestry Chronicle 67(2)136-140.

Thompson, I.D. 1994. Marten populations in uncut and logged boreal forests in Ontario. Journal of Wildlife Management. 58(2):272-280.

Thompson, I.D. and P.W. Colgan. 1994. Marten activity in uncut and logged boreal forests in Ontario. Journal of Wildlife Management. 58(2):280-288.

Thompson, I.D. and A.S. Harestad. 1994. Effects of logging on American martens, and models for habitat management. *In* Buskirk, S.W., A.S. Harestad, M.G. Raphael, R.A. Powell (eds.). Martens, sables and fishers. Cornel University Press, Ithaca and London. 484 pages.

Thompson, I.D. and W.J. Curran. 1995. Habitat suitability for marten of second-growth balsam fir forests in Newfoundland. Can. J. Zool. 73(11):2059-2064.

Thompson, I.D., I.J. Davidson, S. O'Donnell and R. Brazeau. 1989. Use of track transects to measure the relative occurrence of some boreal mammals in uncut forest and regeneration stands. Can. J. Zool. 67(7):1816-1823.

Tilman, D., R.M. May, C.L. Lehman, and M.A. Nowak. 1994. Habitat destruction and the extinction debt. Nature. 371:65-66.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14(1):18-30.

Tuite, C.H., P.R. Hanson, and M. Owen. 1984. Some ecological factors affecting winter wildfowl distribution on inland waters in England and Wales, and the influence of water-based recreation. Journal of Applied Ecology. 21:41-62.

URSUS Ecosystem Management Ltd. and Salmo Consulting Inc. 2003. Review and Assessment of Environmental Effects Information for Wildlife and Fish Indicators in the Regional Sustainable Development Strategy (RSDS) Study Area within the Athabasca Oil Sands Region (AOSR). 426 pages.

USDA (United States Department of Agriculture). 1990. CEM - A model for assessing effects on grizzly bears. 24 pages.

USDA (United States Department of Agriculture, Forest Service). 1996. Status of the Interior Columbia Basin: summary of scientific findings. Portland, OR. Gen. Tech. Rep. PNW-GTR-385. 144 pages.

USFS (United States Forest Service). 1993. Grizzly bear management strategy for Westline Timber Sale and Plateau Bear Management Unit, Targhee National Forest. Unpublished manuscript report. 104 pages.

USFWS (United States Fish and Wildlife Service). 1980. Ecological Services Manual Habitat Evaluation Procedures. U.S. Department of the Interior. ESM 100.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management. 47(4):893-901.

Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. Journal of North American Benthological Society. 8(1):2-8.

Waters, T.F. 1995. Sediment in Streams: Sources, Biological Effects and Control. Bethesda, Maryland: American Fisheries Society; 251 pages.

Weaver, J.L., P.C. Paquet, and L.F. Ruggiero. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology. 10(4):964-976.

Webb, E.T. 1998. Survival, persistence, and regeneration of the reindeer lichens, *Cladina stellaris*, *C. rangiferina*, and *C. mitis* following clearcut logging and forest fire in northwestern Ontario. In: Lankester, M., G.D. Racey, and T. Timmermann, eds. Proceedings of the 7th North American Caribou Workshop; Thunder Bay, ON. Tromsø, Norway: Nordic Council for Reindeer Research 41-47. 264 pages. Rangifer. v. 18 Special Issue No. 10.

Weber, M.G. and M.D. Flannigan. 1997. Canadian boreal forest ecosystem structure and function in a changing climate: impact on fire regimes. Environmental Reviews. 5:145-166.

Wetzel, R.G. 1975. Limnology. Philadelphia, PA: W.B. Saunders Company. 743 pages.

Whitten, K.R., G.W. Garner, F.J. Mauer, and R.B. Harris. 1992. Productivity and early calf survival in the Porcupine caribou herd. Journal of Wildlife Management. 56(2):210-212.

Wiken, E.B. 1986. *Terrestrial Ecozones of Canada*. Ecological Land Classification, Series No. 19. Environment Canada. Hull, Quebec. 26 pages. + map.

Wilcove, D.S.; C.H. McLellan, and A.P. Dobson. 1986. Habitat fragmentation in the temperate zone. pages 237-257 in: Soulé, Michael E., Editor. Conservation Biology The Science of Scarcity and Diversity. Sunderland, Massachusetts: Sinauer Associates, Inc. 584 pages.

With, K.A. and T.O. Crist. 1995. Critical thresholds in species' responses to landscape structure. Ecology. 76(8):2446-2459.

WKSS (West Kitikmeot/Slave Study Society). 2001. State of knowledge report. West Kitikmeot Slave Society, Yellowknife, NWT. Available on-line at: http://www.wkss.nt.ca/HTML/08_ProjectsReports/PDF/SOK_FINAL.pdf.

Wolfe, S.A., B. Griffith, and C.A.G. Wolfe. 2000. Response of reindeer and caribou to human activities. Polar Research. 19(1):63-73.

Wynne, K.M. and J.A. Sherburne. 1984. Summer home range use by adult marten in northwestern Maine. Can. J. Zool. 62(5):941-943.

YRRMMT (Yukon Renewable Resources Moose Management Team). 1996. Moose Management Guidelines. 12 pages.

Young, M.K. 1994. Movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming. Canadian Journal of Forest Resources. 24:1933-1938.

Yost, A.C. and R.G. Wright. 2001. Moose, caribou, and grizzly bear distribution in relation to road traffic in Denali National Park, Alaska. Arctic. 54(1):41-48.

Zielinski, W.J. and T.E. Kucera. 1996. American marten, fisher, lynx, and wolverine: survey methods for their detection. USDA, Forest Service, Pacific Northwest Research Station, General Technical Report PSW-GTR-157. 163 pages.

Ziemer, R.R. 1994. Cumulative effects assessment impact thresholds: myths and realities. Pages 319-326 in: Kennedy, A.J., ed. Cumulative Effects Assessment in Canada: From Concept to Practice; Calgary, Alberta. Edmonton, Alberta: Alberta Association of Professional Biologists. 333 pages.