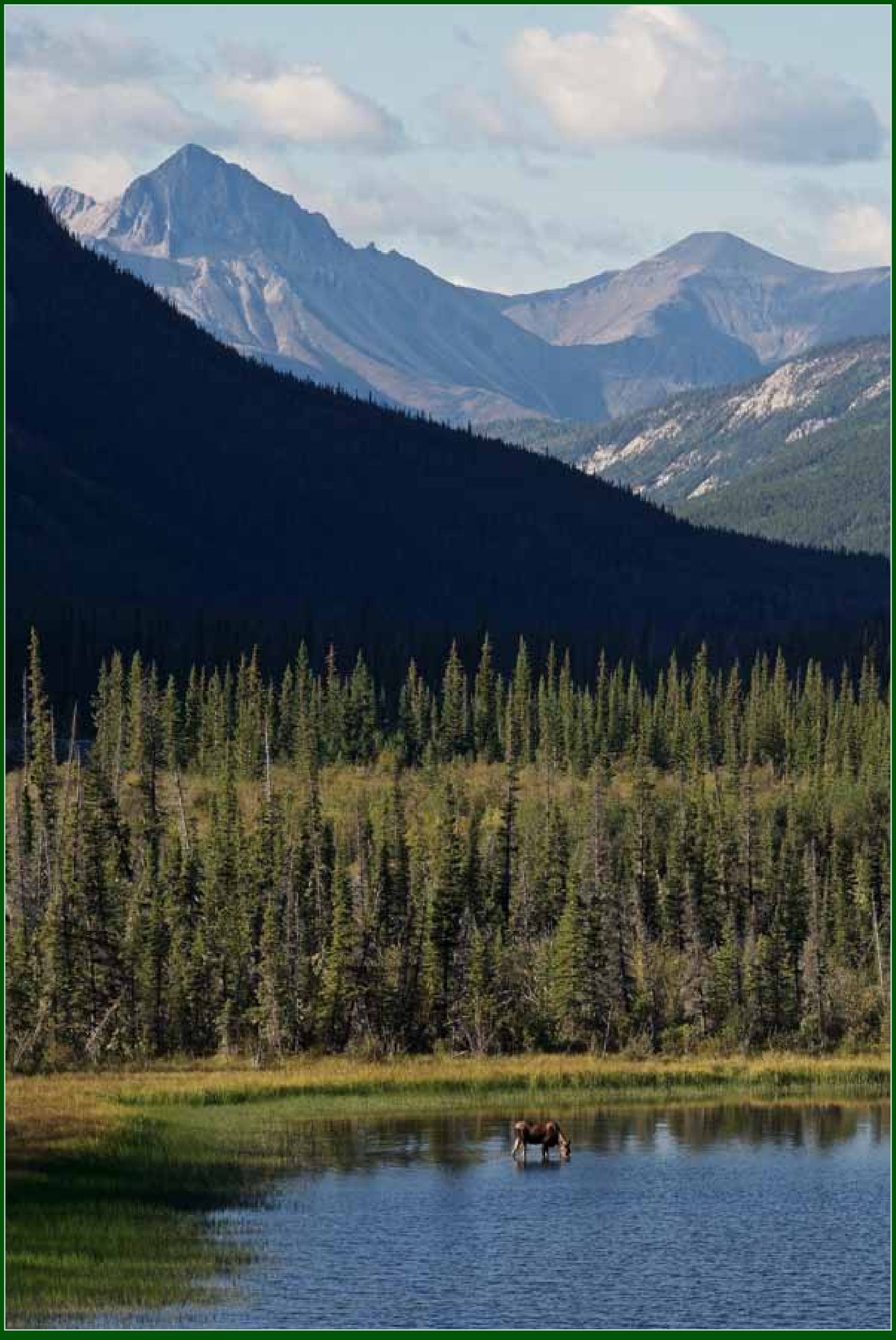
The Greater Muskwa-Kechika

Building a Better Network for Protecting Wildlife and Wildlands



WCS CANADA

JOHN WEAVER

July 2019

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THE GREATER MUSKWA-KECHIKA

BUILDING A BETTER NETWORK FOR PROTECTING WILDLIFE AND WILDLANDS

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TABLE OF CONTENTS

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Finally, I thank the Wildlife Conservation Society Canada for its continued support as we strive to conserve wildlife and wildlands.

SUMMARY

In this time of relentless march of the industrial juggernaut, there is a place in northern British Columbia that is still wild, still beautiful, still whole and healthy. Here, waves of snow-capped mountains stretch beyond the far horizon, each peak both an individual sentinel and part of a greater mountain sea. Verdant boreal forests of thick spruce and pine cover the broad valleys and lower slopes. Sapphire lakes and wetlands mirror a summer sky.

This place is called the ***Muskwa-Kechika*** after two of the rivers that run unfettered through the valleys. It lies within the ancestral territories of the indigenous Kaska Dena, Treaty 8 and Carrier-Sekani people. At the heart of this vast boreal-mountain landscape lies the Muskwa-Kechika Management Area (MKMA), established by provincial order-in-council in 1998 following years of public discussions. The MKMA is 63,845 km^2 in size – twice the size of Vancouver Island. The vision statement for the MKMA recognizes its world-class wilderness, wildlife, and cultures:

> "The Muskwa-Kechika Management Area in northern B.C.is a globally significant area of wilderness, wildlife and cultures, to be maintained in perpetuity, where world class integrated resource management decision-making is practiced ensuring that resource development and other human activities take place in harmony with wilderness quality, wildlife and dynamic ecosystems on which they depend."

The larger *Greater* Muskwa-Kechika (GMK) area (see map on page 23), covering 119,371 km^2, remains a key stronghold for iconic wildlife (caribou, grizzly bear) that have suffered significant declines elsewhere in British Columbia. It includes the unprotected headwaters of the mighty Liard and Peace Rivers, which flow through the MKMA. The GMK is one of the last large, intact landscapes (>98% roadless) in temperate North America, but existing Protected Areas comprise only about 17.5% (20,883 km^2) of its total, leaving vast areas unprotected by adequate safeguards. In the GMK, we have a time-limited opportunity to avoid the piecemeal planning mistakes of the past and to plan proactively for resiliency – an opportunity to conserve wild watersheds of remarkable scale and intactness.

The Greater Muskwa-Kechika is one of the last large, intact landscapes (>98% roadless) in temperate North America, but existing Protected Areas comprise only about 17.5% (20,883 km^2) of its total, leaving vast areas unprotected.

Thinking about resilient landscapes, one of the key principles is that complex terrains with high diversity provide a greater array of options. The mountains and boreal plains of the Greater Muskwa-Kechika have exactly these characteristics.

In this report, we present a scientific assessment of what it would take to ensure a resilient future for the GMK and its wildlife in the face a rapidly changing climate. In particular, we provide specific recommendations for how to develop a more representative, better connected and more resilient network of protected areas.

The global climate is getting hotter. Over the past 70 years, the level of CO_2 in the Earth's atmosphere has risen exponentially from 300 ppm to 408 ppm in 2019. The last time the atmospheric CO_2 level was this high was more than 3 million years ago. To characterize climate change patterns in the Greater Muskwa-Kechika study area, we used the ClimateBC tool developed by climatologists at the University of B.C. Since the 1950-1980 period, average annual temperature has risen by nearly 1° Celsius and is projected to increase by another 3-4° C by the 2040-2070 period. The environmental consequences will be decreasing snowpack (especially at lower elevations, which will see a switch to rain), spread of insects and invasive plants, severe fires across a wider landscape, and shifts in distribution of plants and animals.

Instead of 'business-as-usual', an alternative response to climate heating is "**think resiliency**" – resiliency being the qualitative capacity to withstand disturbance. One of the key messages of resilience thinking is to keep future options open through an emphasis on ecological diversity across space and time. Two principal strategies are to: (1) 'Save Nature's Stage,' meaning to conserve the diversity of enduring features of the lands and waters and ecoregions, and (2) protect key habitats for vulnerable fish and wildlife species, especially those areas that may serve as refugia in the future.

In thinking about resilient landscapes, one of the key principles is that *complex terrains* with high diversity in topographic and geomorphic features, elevation, variety of landforms, lakes and wetlands provide a greater array of local options for plants and animals in the face of a changing climate. This physical complexity at local or regional scale facilitates short-distance movements and greater likelihood of successful tracking of changing conditions.

The mountains and boreal plains of the Greater Muskwa-Kechika have exactly these characteristics. Here we see diverse geology (east←→west), range-of-elevation from <300m along the Liard River to 2100m peaks, and considerable topographic complexity. A remarkable rift in the earth's surface called the Rocky Mountain Trench is so prominent that it's visible to astronauts in space and extends for 1000 km across most of British Columbia. The northern 300-km section in the Muskwa-Kechika is the only remaining wild section of the entire trench. Lakes of various sizes are scattered across the area, and dense concentration of wetlands occur in the lower Liard Basin.in the northern part of the GMK.

Several major rivers thread their way through long, broad valleys. These river valleys are hotspots for biodiversity of aquatic and terrestrial species. Moreover, they offer natural corridors or 'ramps' for adaptive movements to climate heating because they span temperature gradients from lowlands up to headwaters. The higher elevations of the Rocky Mountains and along the Continental Divide on the western side of the Greater Muskwa-Kechika will offer cooler refugia in a hotter future.

The juxtaposition of the Rocky Mountains and lower foothills, the Rocky Mountain Trench, the Cassiar Mountains, and the Liard Plain provides tremendous diversity of ecoregions. Even so, a hotter climate will affect the current distribution of vegetation types; Projections indicate significant shrinking of the alpine tundra and subalpine zones by encroachment of shrubs and spruce trees over time.

To develop a plan for how to build on the MKMA in order to prepare for a hotter and more challenging future, I focused on a group of 'landscape species' that use large, ecologically diverse areas and thus can serve as useful 'umbrellas' for conservation of other species: bull trout (*Salvelinus confluentus*), moose (*Alces alces*), Stone's sheep (*Ovis dalli stonei)*, and woodland caribou (*Rangifer tarandus*). As a group, these species represent both aquatic and terrestrial habitats, a full range of elevation from river valley to mountain peak, prey species for predators such as wolves and grizzly bears, and importance for cultural and economic activities. I synthesized the latest scientific literature to develop profiles of *vulnerability* or lack of resiliency for each species using five factors: (1) niche flexibility, (2) resistance to hybridization (fish) or reproductive capacity and mortality risk (mammals), (3) dispersal and connectivity, (4) sensitivity to human disturbance, and (5) response to climate change.

I focused on a group of 'landscape species' that use large, ecologically diverse areas and thus can serve as useful 'umbrellas' for conservation of other species: bull trout, moose, Stone's sheep, and woodland caribou.

I developed a scoring system to quantify the conservation value of habitats for each species. The scoring system comprised three relative ranks: High Importance = 3, Moderate Importance = 2; and Low Importance = 1. I customized the scoring criteria for each species to reflect attributes that are important to the long-term persistence of that species – with particular consideration of changes in future conditions due to warming climate.

Bull trout have high vulnerability due to stringent requirements for cold water, susceptibility to hybridization /displacement by brook trout, connectivity of streams, and low productivity, which renders them susceptible to overfishing. Mapping of thermal suitability suggests that about 83% of waterways across the Greater Muskwa-Kechika currently have suitable temperatures for spawning/rearing, but this is projected to shrink to 53% in the future due to warming temperatures, particularly at lower elevations. Under current thermal conditions, existing protected areas include about 17% of spawning/rearing habitat and 21% of areas used for foraging/migrating/over-wintering.

Moose have low vulnerability due to their broad ecological niche, high reproduction, and good dispersal capabilities. They appear susceptible physiologically to a hot climate, however, which also may increase abundance of debilitating winter ticks. Moose are a cultural keystone species for Indigenous peoples across Canada – vital for subsistence, culture and local economic values in many northern communities. Suitable habitat for the critical winter season comprised about 55% of the Greater Muskwa-Kechika study area, mostly in the low-mid elevation areas of the Boreal white and black spruce zone and wetlands in the northern sector and mid-elevation slopes and valleys along the Rocky Mountain foothills. Only about 16% of critical winter habitat for moose is found within existing protected areas.

All 14 caribou herds in the Greater Muskwa-Kechika area belong to the Northern Mountain population of caribou assessed as "SPECIAL CONCERN" by the Committee on the Status of Endangered Wildlife in Canada (2014).

Vulnerability of Stone's sheep is rated as moderate due to their narrow foraging niche on grasses and dependence on rocky terrain for escape from predators, and low likelihood for dispersal away from these patches of preferred habitat. Stone's sheep are a distinct sub-species of thinhorn sheep, and recent genetic studies indicate that nearly all of the world's population of Stone's sheep (~15,000) occur exclusively within British Columbia. The rams are highly prized by hunters.

We assigned highest scores of conservation importance to places where sheep are plentiful at moderate to high elevation where the likelihood of long-term persistence is greater. These high-priority areas comprise about 15% of the Greater Muskwa-Kechika, including much of the Rocky Mountains from Muncho Lake south through the Northern Rocky Mountain Provincial Park and southeast to the Halfway River on the Eastern Slopes. It extends across the Northern Rocky Mountain Trench and on westward through the Cassiar Mountains to the headwaters of the Turnagain River. Areas with smaller patches of suitable habitat occur further west across the Cassiar Mountains from the Cry Lake-Horeseranch Range areas and across the Cassiar Highway (south of Good Hope Lake) and along the Continental Divide to the Yukon border.

About 38% of the high priority areas for Stone's sheep are found in existing protected areas, but important areas that are not protected include: (1) Prophet River south through the Rocky Mountains and Foothills to the Halfway River, (2) Sentinel Range east of Muncho Lake Provincial Park and eastward to the Stone Range north of Summit Pass along the Alaska Highway, and (3) mountain blocks in the Cassiar Range in the middle sections of the Turnagain River watershed.

Caribou have high vulnerability due to narrow feeding niche for lichens (and loss of lichen habitat to fire), low reproductive capacity, and susceptibility to predation where humans have increased access (roads, seismic lines). Providing caribou with large blocks of land where they can (1) separate themselves from other prey and predators, and (2) shift their range use in response to various natural processes (e.g. fire, snow conditions) and human disturbances is the key to their long-term resilience and conservation.

All 14 caribou herds in the Greater Muskwa-Kechika area belong to the Northern Mountain population of caribou assessed as "**SPECIAL CONCERN**" by the Committee on the Status of Endangered Wildlife in Canada (2014). The most recent (2018) estimate of caribou population in these herds is about 5,000 – much lower than estimates form aerial surveys undertaken in the late 1970s. Nonetheless, these herds are considered more secure than those in the Southern Mountains of B.C.

Noted caribou researchers (Palm and Hebblewhite) developed a model of habitat selection for our assessment using location data from 217 radio-collared caribou from eight different herds throughout the Greater Muskwa-Kechika area. Caribou selected temperate needleleaf forests in both seasons, moved to higher elevations during spring-fall, and avoided steep slopes. The top five classes (of 10) accounted for 81% of winter locations and 91% of spring-fall locations. These classes comprised 54% of the GMK. Most of the important habitat occurs in subalpine-alpine areas, while boreal conifer forests with more open canopy furnished critical wintering sites. Only 18% of the important habitat and 6% (variable between herds) of the winter locations occur in existing protected areas. We identified numerous key wintering areas that are not in protected areas.

There are two stretches along the Alaska Highway that are important crossings for caribou and Stone's sheep. One is about a 22-km stretch covering both sides of Summit Pass, while the other is a 12-15 km stretch west of the community of Toad River.

The plan for the Muskwa-Kechika Management Area set a very high and bold conservation standard that embodied values of wildness, ecological integrity and resiliency for the long term. The plan was visionary for its time, but we can now see its limitations: protected areas that are not large enough for wide-ranging animals like caribou and grizzly bear and not well enough connected to facilitate seasonal movements by wildlife now or in response to climate heating, while also not adequately representing all of the ecological diversity across the area; and 'special management' areas do not have strong enough safeguards against industrial development.

Our percent-area recommendations for protection emerge from the bottom-up, based upon scientific evidence about the biological needs of species and representation of diverse land and water features.

Contemporary efforts by national governments to protect areas have often relied upon largely politically based targets, such as the current Aichi 2020 Target 11 of 17%. Our percent-area recommendations for protection emerge from the bottom-up, based upon scientific evidence about the biological needs of species and representation of diverse land and water features. We incorporated **several** contemporary principles of conservation planning to guide our recommendations for a new network of protected areas for the Greater Muskwa-Kechika area:

- **Represent the full range of environmental variation across the region – including diversity of ecoregions, enduring features, and freshwaters (lakes, rivers, and wetlands).**
- **Conserve high-value habitat for populations of vulnerable fish and wildlife species.**
- **Provide for gradients of landscape diversity and cooler refugia for greater resiliency in a hotter future.**
- **Embed hydrologic and terrestrial connectivity *within* core areas (or otherwise provide it between core areas) to facilitate fish and wildlife movements for population and genetic diversity**
- **Identify areas large enough to accommodate scale of natural disturbances (e.g., fire) and at least average size of individual home ranges for caribou in the region (>3,500 km²).**
- **Safeguard intact watersheds – especially in the headwaters – as the gold standard in conservation planning (and a natural mapping unit).**

These recommendations will secure greater representation of lands and waters, larger core areas and better connectivity for vulnerable fish and wildlife, and stronger future resiliency.

In terms of conflict with economic activities, oil-and-gas basins occur extensively across northeast B.C. and have been developed intensively. The salient geologic formation extends into the northeast corner of the Greater Muskwa-Kechika west of Ft. Nelson, north of the Alaska Highway. This area has lower conservation value and already has some existing wells and roads, and timber clearcuts. Although timber potential appears extensive across the GMK, only some areas with road accessibility and proximity to mills and markets are economically viable (closer to Fort Nelson, Watson Lake, and Kwadacha). High potential for wind power is restricted to a few sites along the eastern foothills. Mines have the most potential for conservation impacts for several reasons: (1) their location at headwaters and risk of catastrophic consequences should dams/reservoirs of tailings collapse, (2) often require new area-opening access into remote regions, and (3) overlap with important areas for vulnerable fish and wildlife.

Areas with high and moderate composite scores for species and enduring features covered 83% of the Greater Muskwa-Kechika. Various scenarios pointed to a need to protect between 64% and 76% of the GMK. The majority of important areas occur within the MKMA; nonetheless, others are found outside as well.

To build a more representative, better connected, and more resilient network of protected areas commensurate with the vision for the Greater Muskwa-Kechika, I recommend protection of several new areas. These would add 31,149 km^2 within the MKMA, raising the extent of Protected Areas in the original area from 27% up to 76%. Outside the MKMA, I recommend establishing protected areas covering 11,905 km^2 (see map on page 131). This would raise the coverage of Protected Areas for the Greater Muskwa-Kechika from 17% to 54%. **These recommendations will secure greater representation of lands and waters, larger core areas and better connectivity for vulnerable fish and wildlife, and stronger future resiliency.** They will also ensure that the bold vision in the original MKMA plan for one of the last large, intact landscapes in temperate North America can be realized.

Among the key areas:

(1) The **Kechika River watershed** can be considered the showpiece at the heart of the Greater Muskwa-Kechika area. It contains the wildest section of the Rocky Mountain Trench and encompasses several boreal ecoregions and notable concentration of diverse enduring features. The lower section has high primary productivity and myriad wetlands. It includes key habitat for two caribou herds, Stone's sheep, and bull trout. The Kechika River valley provides a long 'ramp' from boreal forests in lower sections to cool refugia in the headwaters for resiliency in a hotter world. This would connect and enhance existing protected areas: Northern Rockies and Dune Za Keyih Provincial Parks and Ne'āh' Conservancy.

(2) **Rocky Mountains and Foothills**: Called the "Serengeti of the North", the diverse ecosystems along the Eastern Slopes support a notable diversity of predators and prey (caribou, Stone's sheep, moose, elk, and even bison). This is a rare opportunity to protect a spectacular landscape at lower elevations and would connect and enhance existing Provincial Parks: Northern Rockies, Redfearn-Keily, and Graham-Laurier.

(3) **Muncho Lake Connection and Headwaters of the Peace**: This would provide a vital connection across the Alaska Highway for caribou and Stone's sheep between Northern Rockies and Muncho Lake Provincial Parks. It would protect key habitat for caribou at the head of Rabbit River and headwaters of the Peace River. This would connect Finlay-Russel Provincial Park with Northern Rockies and Dune Za Keyih Provincial Parks.

(4) **Beyond the MKMA**: Protecting the lower Dease River north of the Ne'āh' Conservancy would enhance representation of boreal forests (carbon storage) and wetlands in the Liard Basin ecoregion and some winter range for the Horseranch caribou herd. Adding the area south of Ne'āh' towards Cry Lake would protect summer range of the Horseranch caribou herd, and for Stone's sheep as well.

Conservation is about human relationships threaded with the rest of Earth's beautiful tapestry, finding a sense of our place in a universal vascular system while affirming our own nature as part of the larger Nature. A clear-eyed assessment of the accelerating impacts of industrial resource development indicates that the dominant viewpoint and narrative has already incurred significant costs to our natural systems and likely is not sustainable. Is there a better pathway? Indigenous viewpoints on relationships with Nature have much to offer.

The pathway to Canada's target for protected areas in support of biodiversity is more than just a minimalist number – it may be the beginning of a new path to something much deeper and more meaningful. As originally envisioned 20 years ago, the Greater Muskwa-Kechika can continue to be the crucible for fresh viewpoints from diverse cultures, deeper relationships, and a richer story of the lands, waters and people.

The Greater Muskwa-Kechika can continue to be the crucible for fresh viewpoints from diverse cultures, deeper relationships, and a richer story of the lands, waters and people.

RÉSUMÉ

Dans ces temps de marche implacable du mastodonte industriel, il existe au nord de la Colombie Britannique un lieu qui reste encore sauvage, beau, entier et sain. Là, des vagues de montagnes enneigées s'étendent au-delà de l'horizon lointain, chaque pic à la fois sentinelle individuelle et membre d'une chaîne montagneuse. De denses forêts boréales verdoyantes d'épicéas et de pins couvrent les vastes vallées et les pentes inférieures. Les lacs couleur saphir et les zones humides reflètent le ciel d'été.

Ce lieu se nomme le Muskaw-Kechika, d'après deux rivières qui courent sans entrave au fond des vallées. Il se trouve au sein des territoires ancestraux des peuples indigènes Kaska Dena, Treaty 8 et Carrier-Sekani. Au cœur de ce vaste paysage de montagnes boréales se situe la Zone de Gestion Muskwa-Kechika (Muskwa-Kechika Management Area, MKMA), établie en 1998 par ordre du conseil provincial après des années de discussions publiques. La MKMA couvre 63.845 km^2 – le double de la taille de l'Ile de Vancouver. La déclaration de vision pour la MKMA reconnait son caractère sauvage, sa faune et ses cultures d'importance mondiale :

> « *La Zone de Gestion Muskwa-Kechika dans la Colombie Britannique du Nord est un site d'importance globale pour son caractère sauvage, sa faune et ses cultures, devant* être *maintenue* à *perpétuité, et* où *la mise en place de décisions de classe mondiale de gestion des ressources naturelles garantie que l'utilisation de ces ressources et autres activités humaines se fasse en harmonie avec l'*état *sauvage, la faune et la dynamique des* écosystèmes *dont elle dépend* ».

La zone plus étendue du Greater Muskwa-Kechika (GMK), qui couvre 119,371 km^2, demeure une forteresse-clé pour une faune iconique (caribou, ours Grizzly) qui a subi des déclins significatifs ailleurs en Colombie Britannique. Elle comprend les eaux d'amont non protégées des puissantes rivières Liard et Peace qui traversent la MKMA. Le GMK est l'un des derniers grands paysages intacts (>98% sans route) de l'Amérique du Nord tempérée, mais les sites protégés existants en couvrent seulement 17.5% (20.883 km^2), laissant de vastes zones sans protection adéquate. Avec le GMK, nous disposons d'une opportunité limitée dans le temps pour éviter les erreurs de gestion au coup-par-coup du passé et pour planifier proactivement pour la résilience – l'opportunité de conserver des bassins versants sauvages à une échelle et avec un degré d'inaltération remarquables.

Dans ce rapport, nous présentons une évaluation scientifique de ce qu'il faudrait mettre en œuvre pour assurer un future résilient pour le GMK et sa faune face à un climat qui change rapidement. Nous fournissons en particulier des recommandations spécifiques pour le développement d'un réseau de zones protégées plus représentatif, mieux connecté et plus résilient.

Le climat global se réchauffe. Au cours des 70 dernières années, le niveau de CO_2 dans l'atmosphère terrestre a augmenté exponentiellement, de 300 ppm à 408 ppm en 2019. Un tel niveau de CO_2 n'a pas été atteint depuis au moins 3 millions d'années. Afin de caractériser le changement climatique dans la zone d'étude du Greater Muskwa-Kechika, nous avons utilisé l'outil ClimateBC développé par les climatologistes de l'Université de Colombie Britannique. Depuis la période 1950-1980, la température annuelle moyenne a augmenté de près d'1° Celsius et est projetée de continuer à augmenter d'encore 3-4° C d'ici la période 2040-2070. Les conséquences environnementales en seront la réduction du manteau neigeux (particulièrement aux altitudes inferieures, qui verront une transition a la pluie), l'étendue des insectes et des plantes invasives, des incendies sévères à travers un paysage plus large, et des décalages de la distribution d'espèces faunistiques et floristiques.

Plutôt que le « business comme d'habitude », une réponse alternative au réchauffement climatique est de « **penser résilience** » – la résilience étant la capacité qualitative à supporter une perturbation. L'un des messages-clé de la pensée résiliente est de garder ouvertes des options futures en mettant l'emphase sur la diversité écologique à travers espace et temps. Deux stratégies principales sont : (1) « Sauver l'état naturel », soit conserver la diversité des traits durables des terres, des eaux et des écorégions, et (2) protéger des habitats clés pour la faune vulnérable, particulièrement dans les lieux pouvant servir de refuge dans le futur.

L'un des principes-clé des paysages résilients est que les *terrains complexes* qui comprennent une grande diversité de traits topographiques et géomorphiques, d'altitude, de variété de relief, de lacs et de zones humides fournissent un spectre plus large d'options pour les plantes et les animaux face au changement climatique. Cette complexité physique à l'échelle locale ou régionale facilite les petits déplacements et augmente la probabilité de suivre avec succès les conditions changeantes.

Les montagnes et les plaines boréales du Greater Muskwa-Kechika présentent précisément ces caractéristiques. Nous y voyons une géologie diverse (est ←ouest), une altitude qui va de <300m le long de la Rivière Liard jusqu'à des pics de 2100m, et une diversité topographique considérable. Un rift remarquable dans la surface terrestre, appelé le Sillon des Montagnes Rocheuses, est si imposant qu'il est visible aux astronautes dans l'espace et s'étend sur 1000km à travers presque toute la Colombie Britannique. La section de 300km la plus au nord dans le Muskwa-Kechika est la seule partie du sillon à rester sauvage. Des lacs de taille variée y sont éparpillés, et l'on trouve une dense concentration de zones humides dans le Basin Liard inférieur dans la zone nord du GMK.

Plusieurs rivières majeures serpentent au fond de longues et larges vallées qui constituent des points chauds de biodiversité aquatique et terrestre. De plus, elles offrent des corridors naturels, des « rampes » pour les déplacements adaptifs au réchauffement climatique car elles couvrent un gradient de température allant des basses terres jusqu'aux eaux d'amont. Les altitudes supérieures des Montagnes Rocheuses et le long de la ligne de partage des eaux a l'ouest du Greater Muskwa-Kechika offriront un refuge plus frais dans un futur plus chaud.

La juxtaposition des Montagnes Rocheuses et de leurs contreforts, du Sillon des Montagnes Rocheuses, des Monts Cassiar et de la Plaine du Liard fournit une énorme diversité d'écorégions. Malgré tout, un climat plus chaud affectera la distribution actuelle de la végétation ; les projections indiquent une réduction significative de la toundra alpine et des zones subalpines via l'empiètement progressif par des buissons et des épicéas.

Afin de développer un plan s'appuyant sur la MKMA pour se préparer à un futur plus chaud et difficile, je me suis concentré sur un groupe d'espèces « du paysage » qui utilisent des zones larges et écologiquement diverses et peuvent ainsi servir de « parapluies » utiles à la conservation d'autres espèces : l'omble a tête plate (*Salvelinus confluentus*), l'*élan* (*Alces alces*), le mouflon de Stone (*Ovis dalli stonei*), et le caribou des bois (*Rangifer tarandus*). Ce groupe d'espèces couvre des habitats aquatiques et terrestres, l'amplitude complète d'altitude de la vallée au pic montagnard, des proies pour des prédateurs tels que le loup ou l'ours Grizzly, et est d'une grande importance aux activités culturelles et *économiques locales*. J'ai synthétisé la littérature scientifique la plus récente afin de développer des profils de *vulnérabilité* ou de <u>manque de résilience</u> pour chaque espèce en utilisant cinq facteurs : (1) la flexibilité de la niche, (2) la résistance *à* l'hybridation (poisson) ou la capacité *à* se reproduire et le risque de mortalité (mammifères), (3) la dispersion et la connectivité, (4) la sensibilité au dérangement humain, et (5) la réponse au changement climatique.

J'ai développé un système de notation pour quantifier la valeur de conservation de l'habitat pour chaque espèce. Ce système comprend trois classes relatives : Haute Importance = 3, Importance Modérée = 2, et Faible Importance = 1. J'ai personnalisé les critères de notation pour chaque espèce afin de refléter les caractéristiques importantes *à* la survie *à* long terme de cette espèce – avec une considération particulière donnée au changement des conditions futures lié au réchauffement climatique.

L'omble a tête plate présente une vulnérabilité *élevée* de par ses exigences strictes pour l'eau froide, sa susceptibilité *à* l'hybridation et au déplacement par l'omble de fontaine, la connectivité des rivières, et une faible productivité le rendant susceptible a la surpêche. La cartographie de la pertinence thermique suggère qu'environ 83% des cours d'eau du Greater Muskwa-Kechika ont pour l'instant des températures favorables au frai et *à* l'*élevage* des jeunes, mais une réduction *à* 53% est projetée dans le futur *à cause de l'augmentation des* températures, particulièrement *à* basse altitude. Dans les conditions thermiques actuelles, les zones protégées existantes couvrent environ 17% de l'habitat de frai et d'*élevage* des jeunes et 21% des zones utilisées pour l'alimentation, la migration et l'hivernage.

L'élan **présente une vulnérabilité faible** en raison de sa vaste niche écologique, de son taux de reproduction élevé, et de ses bonnes capacités de dispersion. Il est cependant sensible physiologiquement à un climat chaud, qui pourrait aussi augmenter l'abondance des tiques hivernales débilitantes. L'élan est une espèce culturelle clé pour les peuples indigènes au Canada – vital pour la subsistance et les valeurs culturelles et économiques locales de nombreuses communautés du nord. L'habitat favorable de la saison hivernale critique constitue environ 55% de la région d'étude du Greater Muskwa-Kechika, principalement à faible et moyenne altitude dans la zone boréale des épicéas blancs et noirs, dans les zones humides du secteur nord, et dans les pentes et vallées d'altitude moyenne dans les contreforts des Montagnes Rocheuses. Seulement 16% de l'habitat hivernal critique de l'élan est actuellement protégé.

La vulnérabilité du mouflon de Stone est jugée modérée en raison de sa niche alimentaire herbacée étroite, de sa dépendance au terrain rocheux pour échapper aux prédateurs, et d'une probabilité faible de dispersion loin de ces parcelles d'habitat préfère. Le mouflon de Stone est une sous-espèce distincte du mouflon de Dall, et des études génétiques récentes indiquent que pratiquement toute la population mondiale de mouflon de Stone (~15.000) se trouve exclusivement en Colombie Britannique. Les béliers sont fortement prisés des chasseurs.

Nous avons attribué les scores d'importance de conservation les plus élevés aux endroits où les mouflons sont abondants à moyenne et haute altitude où la probabilité de persistance à long terme est la plus forte. Ces zones de haute priorité comprennent environ 15% du Greater Muskwa-Kechika, y compris une grande partie des Montagnes Rocheuses, de Muncho Lake au sud à travers le Northern Rocky Mountain Provincial Park et au sud-est jusqu'à la Rivière Halfway sur les Pentes de l'Est. Elles s'étendent à travers le Sillon des Montagnes Rocheuses et à l'ouest en travers des Monts Cassiar jusqu'aux eaux d'amont de la Rivière Turnagain. Des parcelles d'habitat convenable se trouvent plus à l'ouest en face des Monts Cassiar, du Lac Cry et de la Chaine Horseranch et de l'autre côté de la Cassiar Highway (au sud du Lac Good Hope) et le long de la ligne de partage des eaux, jusqu'à la frontière avec le Yukon.

Environ 38% des sites de haute priorité pour le mouflon de Stone se trouvent en zone protégée, mais les importants sites non protégés comprennent : (1) le sud de la Rivière Prophet en travers des Montagnes Rocheuses et les contreforts jusqu'à la Riviere Halfway, (2) la chaîne Sentinel à l'est du Parc Provincial de Muncho Lake et à l'est jusqu'à la chaîne Stone au nord du col Summit le long de l'Alaska Highway, et (3) des blocs montagneux dans la chaîne Cassiar dans les sections au centre du bassin versant de la Rivière Turnagain.

Le caribou présente une vulnérabilité élevée en raison d'une niche alimentaire étroite pour les lichens (et de la perte de ce milieu suite aux incendies), d'une capacité de reproduction faible, et d'une susceptibilité à la prédation là où les hommes disposent d'un accès (routes, lignes sismiques). Fournir aux caribous de large blocs de terrain ou ils peuvent (1) être séparés d'autres proies et des prédateurs, et (2) décaler leur utilisation du milieu en réponse à divers procédés naturels (tels qu'incendies ou conditions d'enneigement) et aux dérangements humains forme la clé de leur résilience et de leur conservation à long terme.

Les 14 hardes de caribou dans le Greater Muskwa-Kechika appartiennent toutes à la population de caribou des Montagnes du Nord, évaluée comme « **PREOCCUPATION SPECIALE** » par le Comité sur l'Etat de la Faune en

Danger au Canada (2014). L'estimation la plus récente (2018) de la population de caribou dans ces hardes est environ 5.000 – beaucoup plus faible que les estimations de levés aériens conduits en fin des années 1970. Malgré tout, ces hardes sont jugées être plus en sécurité que celles des Montagnes du Sud de la Colombie Britannique.

Des spécialistes renommés du caribou (Palm et Hebblewhite) ont développé un modèle de sélection de l'habitat pour notre évaluation en utilisant les données de 217 animaux venant de 8 hardes et équipes de colliers émetteurs dans le Greater Muskwa-Kechika. Ces caribous sélectionnent les forêts de conifères tempérées les deux saisons, se déplacent en altitude du printemps à l'automne, et évitent les pentes raides. Les 5 classes supérieures du modèle (sur 10) comprennent 81% des localisations hivernales et 91% des localisations du printemps à l'automne. Ces classes composent 54% du GMK. La plupart de l'habitat important se trouve dans les zones subalpine et alpine, tandis que les forêts de conifères boréales à canopée plus ouverte fournissent des sites d'hivernage critiques. Nous avons identifié de nombreuses zones d'hivernage clé qui ne sont pas protégées.

Deux sections le long de l'Alaska Highway constituent d'importants sites de traversée pour les caribous et les mouflons de Stone. L'une est une section d'environ 22km qui couvre les deux côtés du Col de Summit, tandis que l'autre est une section de 12 à 15km à l'ouest de la communauté de Toad River.

Le plan pour la Zone de Gestion Muskwa-Kechika a mis en place un standard de conservation très élevé et audacieux qui incarne les valeurs de « wildness », d'intégrité écologique et de résilience à long terme. Ce plan était visionnaire pour son époque, mais nous en voyons maintenant les limites : des zones protégées qui ne sont pas assez grandes pour des espèces à vaste territoire comme le caribou ou l'ours Grizzly, et pas suffisamment connectées pour faciliter les mouvements saisonniers de la faune maintenant ou en réponse au réchauffement climatique, tout en manquant de représenter toute la diversité écologique du lieu ; et les zones de « gestion spéciale » ne constituent pas une protection suffisamment forte contre le développement industriel.

Les efforts contemporains de protection par les gouvernements nationaux ont souvent compté sur des cibles largement politiques, telles que la cible 11 Aichi 2020 de 17%. Nos recommandations de pourcentage de protection émergent de la base et vont vers le haut, et se basent sur l'évidence scientifique des besoins biologiques des espèces et sur la représentation de caractéristiques terrestres et aquatiques variées. Nous incorporons plusieurs principes contemporains de gestion de conservation qui guident nos recommandations pour un réseau de zones protégées pour le Greater Muskwa-Kechika :

➢ **Représente la gamme entière des conditions environnementales de la région – y compris la diversité d'**écorégions, **de traits durables, et d'eaux douces (lacs, rivières et zones humides).**

➢ **Conserve l'habitat** à **haute valeur des populations d'espèces vulnérables de poissons et de mammifères.**

- ➢ **Prévoit des gradients de diversité du paysage et des refuges plus frais pour une plus grande résilience dans un futur plus chaud.**
- ➢ **Intègre la connectivité hydrologique et terrestre à l'intérieur des zones centrales (ou la prévoit entre les zones centrales) afin de faciliter les déplacements des poissons et des mammifères pour maintenir la diversité génétique et des populations.**
- ➢ **Identifie des zones suffisamment larges pour accommoder l'échelle des perturbations naturelles (par exemple les incendies) et au minimum la taille moyenne des domaines vitaux des caribous dans la région (>3.500km^2).**
- ➢ **Sauvegarde les bassins versants intacts – en particulier dans les eaux d'amont – comme étalon-or en planification de la conservation (et comme unité de cartographie n**

En terme de conflit avec les activités économiques, les bassins pétrolifères et de gaz naturel sont répandus à travers la Colombie Britannique nord-est et ont été développés intensivement. La formation géologique saillante s'étend dans le coin nord-est du Greater Muskwa-Kechika à l'ouest de Fort Nelson, au nord de l'Alaska Highway. Cette zone a une valeur de conservation plus faible et possède déjà des puits et des routes, ainsi que des coupes franches. Bien que le potentiel forestier soit répandu dans le GMK, seules certaines zones disposant d'un accès routier et à proximité de scieries et de marchés sont économiquement viables (plus près de Fort Nelson, Watson Lake, et Kwadacha). Le plus haut potentiel pour l'énergie éolienne est restreint à quelques sites le long des contreforts de l'est. Les mines ont le plus de potentiel d'impact en conservation pour plusieurs raisons : (1) leur localisation dans les eaux d'amont et le risque de conséquences catastrophiques en cas d'effondrement des barrages et réservoirs de résidus, (2) elles requièrent souvent l'ouverture d'un accès nouveau dans une région isolée, et (3) elles chevauchent des zones importantes aux espèces de poissons et de mammifères vulnérables.

Les zones à scores composés élevés et modérés pour la faune et les traits durables couvrent 83% du Greater Muskwa-Kechika. Divers scenarios indiquent le besoin de protéger entre 64% et 76% du GMK. La majorité des zones importantes se trouve à l'intérieur de la MKMA ; cependant, d'autres sont localisées à l'extérieur.

Afin de construire un réseau de zones protégées plus représentatif, mieux connecté et plus résilient, commensurable avec la vision pour le Greater Muskwa-Kechika, je recommande la protection de plusieurs nouveaux sites. Ils ajouteraient 31.149km^2 à l'intérieur de la MKMA, augmentant la superficie des Zones Protégées dans la zone d'origine de 27% à 76%. A l'extérieur de la MKMA, je recommande la mise en place de zones protégées couvrant 11.905km^2. Cela ferait passer la superficie des Zones Protégées de 17% à 54%. **Ces recommandations garantiront une plus grande représentation des terres et des eaux, des zones centrales plus larges et une meilleure connectivité pour la faune vulnérable, et une résilience future plus forte**. Elles rendront aussi possible la réalisation de la vision audacieuse du plan MKMA d'origine pour l'un des derniers paysages intacts en Amérique du Nord.

Parmi les zones clé :

Le bassin versant de la Rivière Kechika peut être considéré comme le joyau du Greater Muskwa-Kechika. Il contient la section la plus sauvage du Sillon des Montagnes Rocheuses et englobe plusieurs écorégions boréales et une concentration notable de traits durables variés. Sa section inférieure possède une productivité primaire élevée et une myriade de zones humides. Il comprend les habitats clé de deux hardes de caribou, du mouflon de Stone et de l'omble a tête plate. La vallée de la Rivière Kechika forme une longue « rampe » allant de la forêt boréale dans les sections inferieures aux refuges frais dans les eaux d'amont, pour la résilience dans un monde plus chaud. Cela connecterait et améliorerait les zones protégées existantes : les Parcs Provinciaux Northern Rockies et Dune Za Keyih et le Conservatoire Ne'ah'.

Les Montagnes Rocheuses et Contreforts : appelés le « Serengeti du Nord », les écosystèmes variés le long des Pentes de l'Est soutiennent une diversité notable de prédateurs et de proies (caribou, mouflon de Stone, élans, cerfs, même des bisons). Il y a là une opportunité rare de protéger un paysage spectaculaire à basse altitude et permettrait de connecter et d'améliorer les Parcs Provinciaux Northern Rockies, Redfearn-Keily, et Graham-Laurier.

La Connection du Lac Muncho et les Eaux d'Amont de la Peace : cela fournirait une connexion vitale en travers de l'Alaska Highway pour les caribous et les mouflons Stone, entre les Parcs Provinciaux Northern Rockies et Lac Muncho. Cette zone protègerait l'habitat clé du caribou à la tête de la Rivière Rabbit et aux eaux d'amont de la Rivière Peace. Elle connecterait le Parc Provincial Finlay-Russel avec les Parcs Provinciaux Northern Rockies et Dune Za Keyih.

Au-delà de la MKMA : protéger l'aval de la Rivière Dease au nord du Conservatoire Ne'ha' améliorerait la représentation de la foret boréale (stockage de carbone) et des zones humides de l'écorégion du Bassin du Liard, ainsi que la représentation du territoire hivernal de la harde de caribou Horseranch. Y ajouter la zone au sud du Conservatoire Ne'ah' vers le Lac Cry protègerait le territoire estival de la harde de caribou Horseranch, ainsi que celui du mouflon de Stone.

La conservation concerne les relations humaines entrelacées avec le reste de la magnifique tapisserie terrestre ; trouver le sens de notre place dans un système vasculaire universel tout en affirmant notre propre nature dans le cadre de la plus grande Nature. Une évaluation lucide de l'impact accéléré du développement des ressources industrielles montre que le point de vue et le narratif dominants ont déjà fait subir des coûts importants à nos systèmes naturels et ne sont probablement pas durables. Y a-t-il un meilleur chemin ? Les points de vue indigènes sur les relations avec la Nature ont beaucoup à offrir.

Le chemin vers la cible canadienne de zones protégées en soutien à la biodiversité est plus qu'un nombre minimaliste – il pourrait être le début d'une nouvelle voie vers quelque chose de plus profond et significatif. Comme ça l'a été envisagé il y a 20 ans, le Greater Muskwa-Kechika peut continuer à être le creuset de points de vus nouveaux venant de cultures diverses, de relations approfondies, et d'une riche histoire de terres, d'eaux et de peuples.

Courtesy of © Ryan Dickie

1. GREATER MUSKWA-KECHIKA AREA OF NORTHERN BRITISH COLUMBIA

Introduction: A Place Still Wild and Whole

Indigenous people have inhabited North America since 'time immemorial'. In the not-so-distant past when British Columbia joined the new country of Canada in 1871, the land was whole and healthy. Rivers ran wild and free from headwaters to sea. Native plants and animals occurred across intact and connected landscapes … adapted with a resilient capacity to absorb and recover from dynamic disturbances such as fire and flood. Intact ecosystems provided many natural services such as clean air and water, as well as close connection with the earth.

Historically, the harsh climate, inaccessibility, and low human population of Canada's boreal forest resulted in *de facto* protection from industrial extraction of resources (Andrew et al. 2012). With advent of modern energy, transportation, and expanding population, however, the southern (more productive) part of Canada and British Columbia was transformed by the cumulative network of human developments and roads (Lee et al. 2010, Lee and Cheng 2014, Venier et al. 2014). This brought certain kinds of material benefits but came with a cost … degraded and polluted streams … spread of invasive plants and non-native organisms … loss of habitat and security for fish and wildlife populations … fragmented landscapes that restricted genetic exchange, connectivity and freedom to move in response to changing climatic conditions. Some of these effects occur regardless of traffic volume or good intentions of people.

Roads, vehicle traffic, and associated human activity can have a variety of substantial effects upon species and ecosystems (so thoroughly documented in several reviews and hundreds of references: Forman et al. 2003, Fahrig and Rytwinski 2009, Beckman et al. 2010, Kreutzweiser et al. 2013, Selva et al. 2015, Brady and Richardson 2017).

Of great concern is when a new road for a single mine penetrated deeply into 'wilderness' often at the very headwaters of a watershed. Not only did this open up large areas for increased access with substantial impacts on wildlife populations, the road could serve as a catalyst for other industrial uses ('contagious effect'). Subsequently, the spreading and intensifying effect of all linear features (highways, roads, seismic lines, trails) resulted in cumulative effects – a wicked problem accruing from the 'tyranny of many small decisions.'

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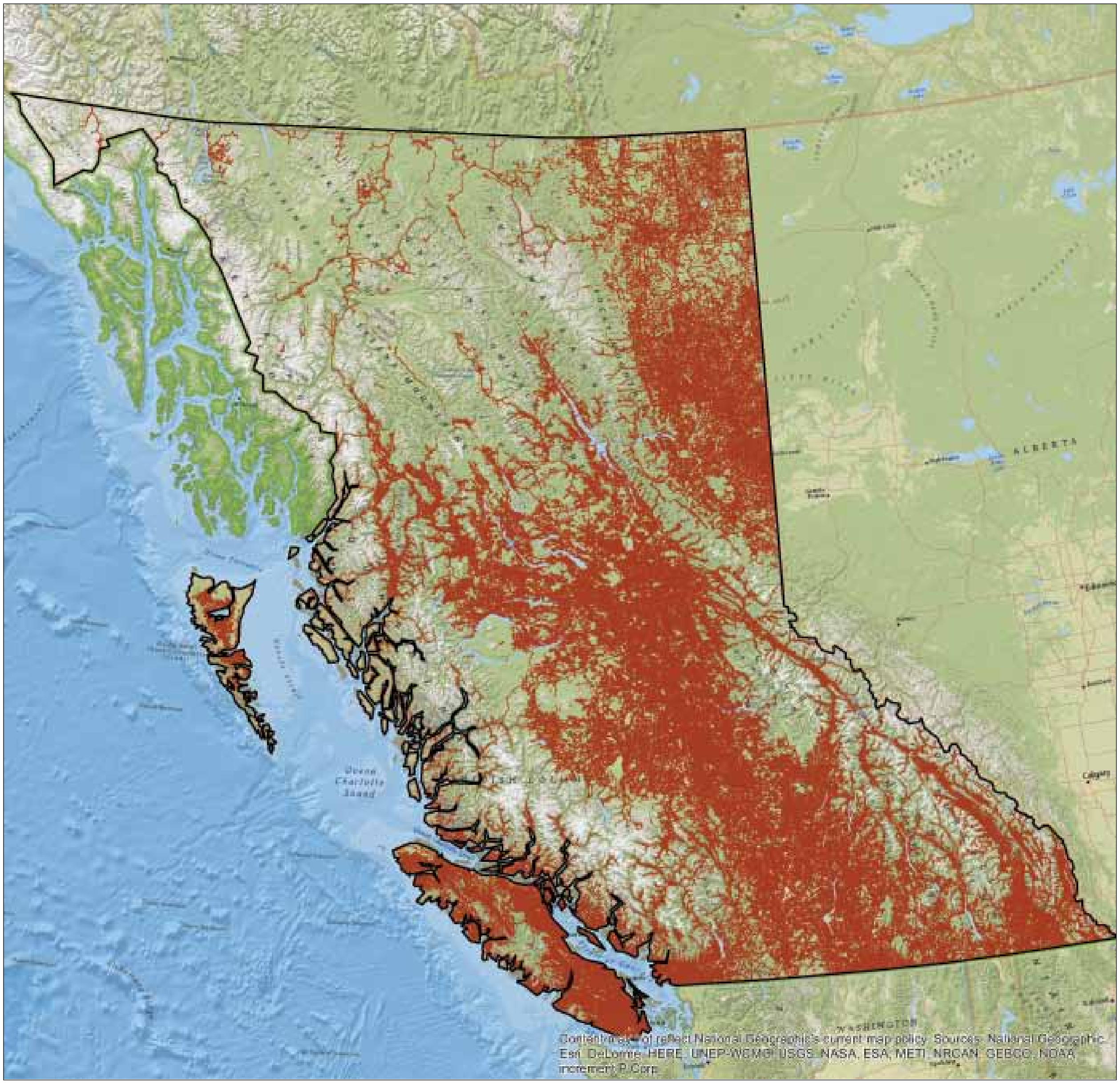
Over time, the human enterprise of resource developments moved steadily northward across the province … with significant impacts on ecosystems and species such as woodland caribou. In northeastern British Columbia, roads and seismic lines proliferated dramatically starting in the 1950s. The initial purpose of these new roads and lines was to extract oil and gas and timber. At present, British Columbia has approximately 719,000 kilometres of roads, with unpaved roads comprising 92% that have accumulated from the long history of natural resource use in the province (Figure 1). Recent improvements in the capability of OHV vehicles and snow machines has enabled deeper access into remote areas and difficult terrain. And the relentless pressure of industrial extraction of resources has not abated; there are 10 large mines under development and the webs of gas wells and pipelines is expanding in the surrounding region.

John Weaver

Figure 1. Map of roads in British Columbia based on the B.C. Digital Road Atlas, considered the best available single source of road data for British Columbia (Environmental Reporting BC 2018). All paved roads and unpaved roads and trails that *allow* motorized vehicle use were included in their analysis. Roadless areas were determined by applying a conservative 500-metre buffer on either side of all roads.



Yet, in this time of relentless expansion and impact of the industrial juggernaut, there is a place in northern British Columbia that is still wild … still beautiful … still whole and healthy. Here, storm-tossed seas of snow-capped mountains stretch beyond the far horizon, each peak both a particle and a wave. Verdant boreal forests of thick spruce and pine cover the broad valleys and lower slopes … silently storing carbon from a laden atmosphere that is heating up the planet. Sapphire lakes and wetlands mirror a summer sky and contribute to the biological diversity and beauty of the valleys.

Here, a remarkable rift in the earth's surface called the Rocky Mountain Trench is so prominent that it's visible to astronauts in space. The 'trail of the ancient ones' still follows the Trench for 300 km to connect indigenous communities of the Kaska people at each end. The diversity of the region from valley to mountaintop is a natural store where Kaska and other indigenous people have long hunted, fished, and gathered foods and medicinal plants through the seasons in their traditional territory. Here remains a place so large and wild that a local conservationist-guide can lead a horse pack string and friends for a month without encountering another person!

Across these boreal forests and mountains roams one of the most iconic but vulnerable wildlife species of Canada: the woodland caribou. One of the principal strategies of these northern woodland caribou is to 'space out' across the landscape to minimize encounters with predators such as wolves and bears. To be successful with this strategy, caribou need large intact areas to roam free across a terrestrial sea and 'get lost' among the waves. Because caribou thrive best in large, ecologically diverse areas, they likely serve as an 'umbrella' in conservation planning for many other, smaller species of plants and animals.

This place is called the *Muskwa-Kechika* after two of the rivers that run unfettered through the valleys – Muskwa meaning "bear" and Kechika meaning "long inclining river" in Kaska language. Until construction of the Alaska Highway during World War II blasted a road through northern British Columbia, this vast region had *de-facto* protection from industrial activities like mining, oil & gas wells and pipelines, and clearcutting of forests. But, with increasing population, growth-based economic expansion, and technological innovations, these extraction industries slowly but steadily moved northward. Over the next several decades, oil and gas development spread across most of the northeast corner of British Columbia, and long roads were built up remote valleys to access mining sites on mountaintops in the northwestern section of the province.

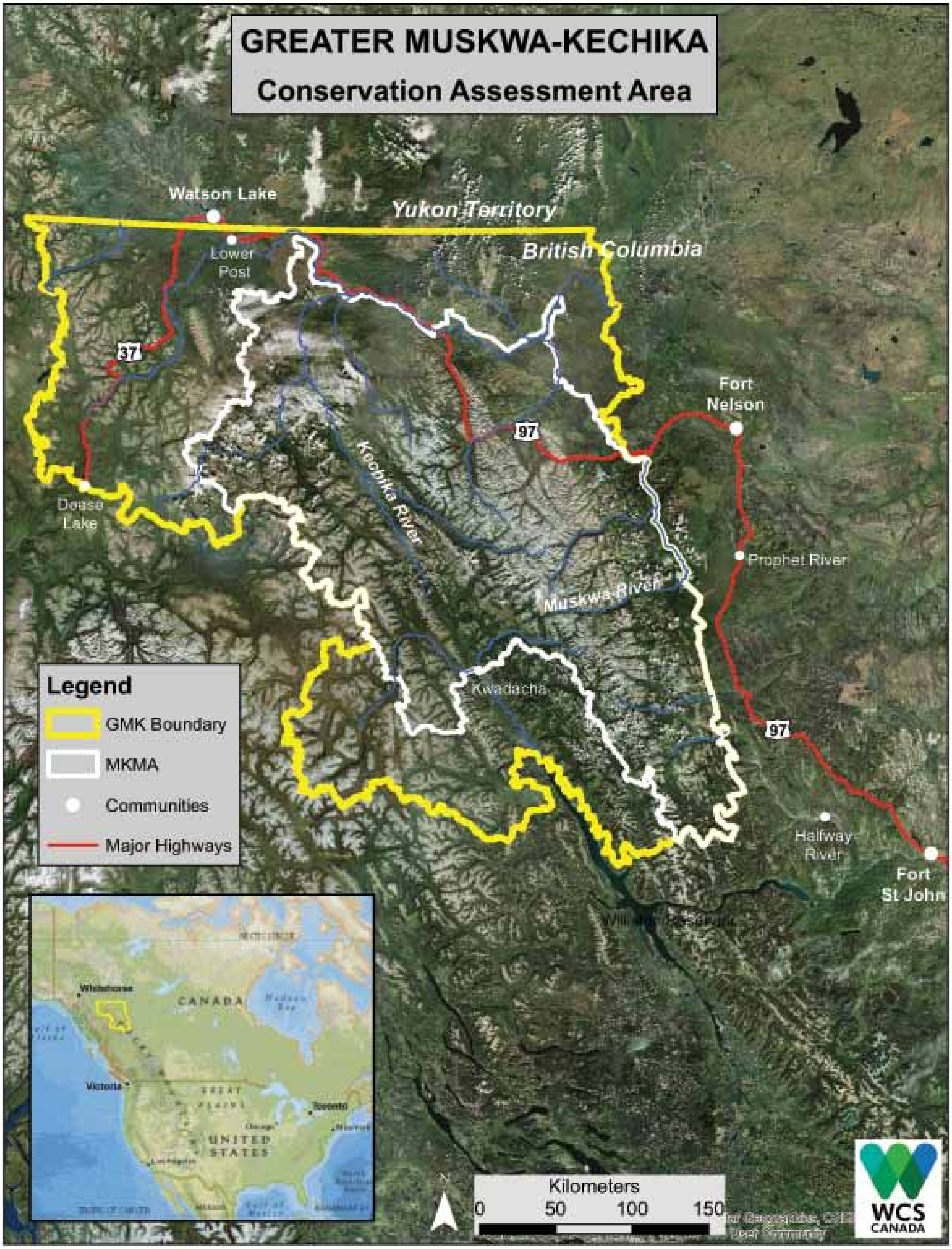
The Muskwa-Kechika lies within the ancestral territories of the Kaska Dena, Treaty 8 and Carrier-Sekani people. First Nations communities include: Treaty 8 First Nations: Halfway River, Prophet River, Fort Nelson; Kaska Dena First Nations: Kwadacha, Daylu Dena Council, Dease River, Fireside, Muncho Lake, and Carrier-Sekani: Tsay Keh Dene.

Courtesy of © Wayne Sawchuck

Courtesy of © Mark Bradley

John Weaver

Figure 2. The Muskwa-Kechika Management Area (white outline) comprises the core of a larger ecosystem encompassing the headwaters of the Liard and Peace Rivers, which is the *Greater Muskwa-Kechika* area (yellow outline) of northern British Columbia.



At the heart of this vast boreal-mountain landscape lies the Muskwa-Kechika Management Area (MKMA), established by provincial order-in-council in 1998 following years of public discussions. The MKMA is 63,845 km^2 in size; or twice the size of Vancouver Island (32,134 km^2) (Figure 2). The vision statement for the MKMA recognizes its world-class wilderness, wildlife, and cultures:

> *"The Muskwa-Kechika Management Area in northern B.C.is a globally significant area of wilderness, wildlife and cultures, to be maintained in perpetuity, where world class integrated resource management decision-making is practiced ensuring that resource development and other human activities take place in harmony with wilderness quality, wildlife and dynamic ecosystems on which they depend."*

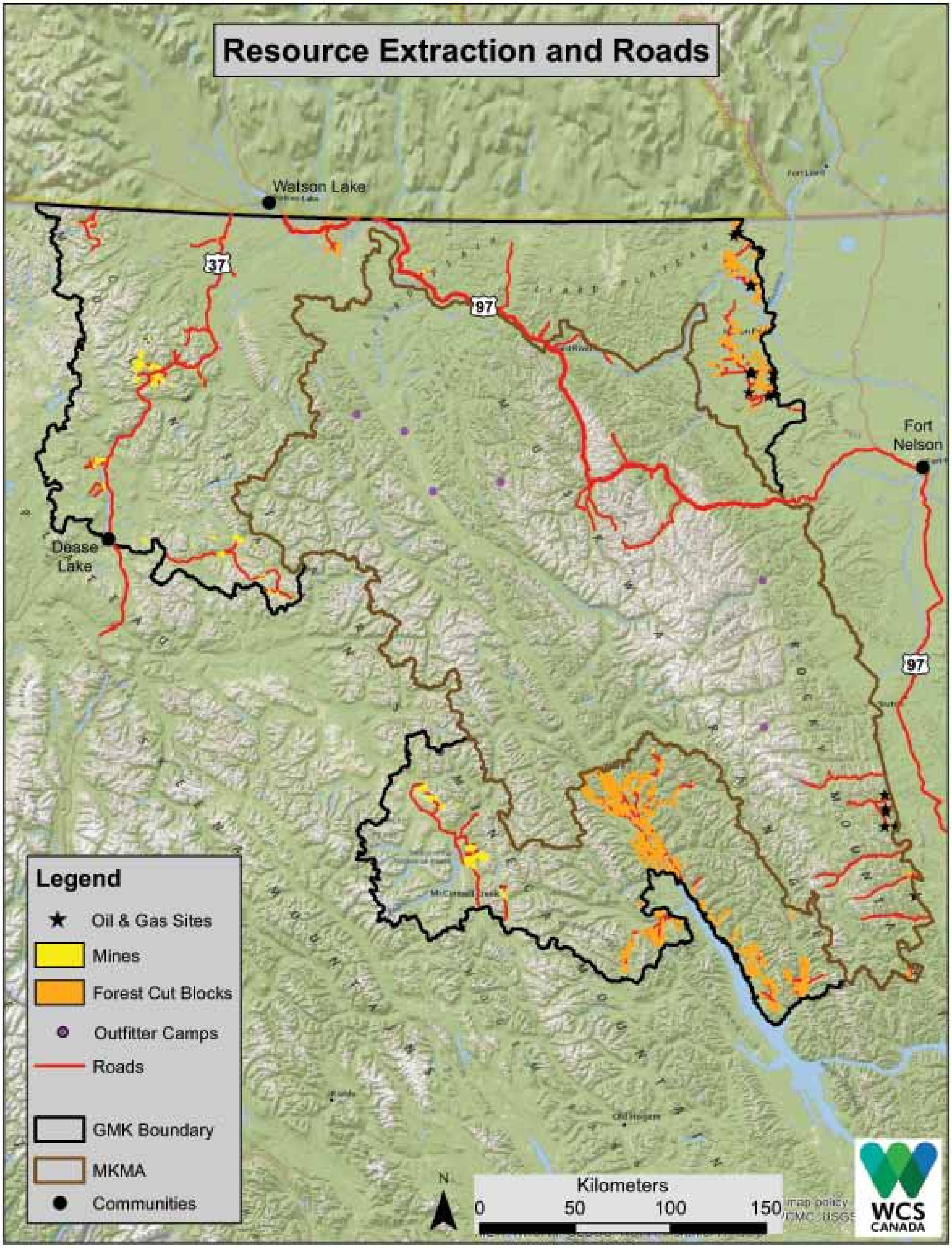
The Muskwa-Kechika Management Area boundary, however, does not include the headwaters of several major rivers that flow through it. Therefore, I expanded the area of this conservation assessment to encompass the headwaters of the Liard River (Little Rancheria and Dease Rivers), the Kechika River (Turnagain River), and the Peace River (Finlay River) for a more complete watershed basin. The boundary also includes areas north of the Liard River to the border of the Yukon Territory (Figure 2). This *Greater* Muskwa-Kechika (GMK) assessment area is 119,371 km^2. It is approximately twice the size of the Muskwa-Kechika Management Area.

Excluding the Alaska Highway which runs east⇔west across the northern sector of the region, the remainder of the area is <u>>99% roadless</u>. Even along the Alaska Highway, there are long stretches without human development. Resource extraction –mines, oil & gas wells, and/or timber harvest along with the associated roads – is clustered in a few places (e.g., Finlay Trench and north-east corner) (Table 1, Figure 3).

Table 1. Area (km^2) of resource extraction and roads ('footprint'), Greater Muskwa-Kechika area (119,371 km^2), northern British Columbia. The footprint of all resource extraction/roads was buffered by 500m (Alaska Highway buffered by 1000 m on each side), a conservative zone of disturbance.

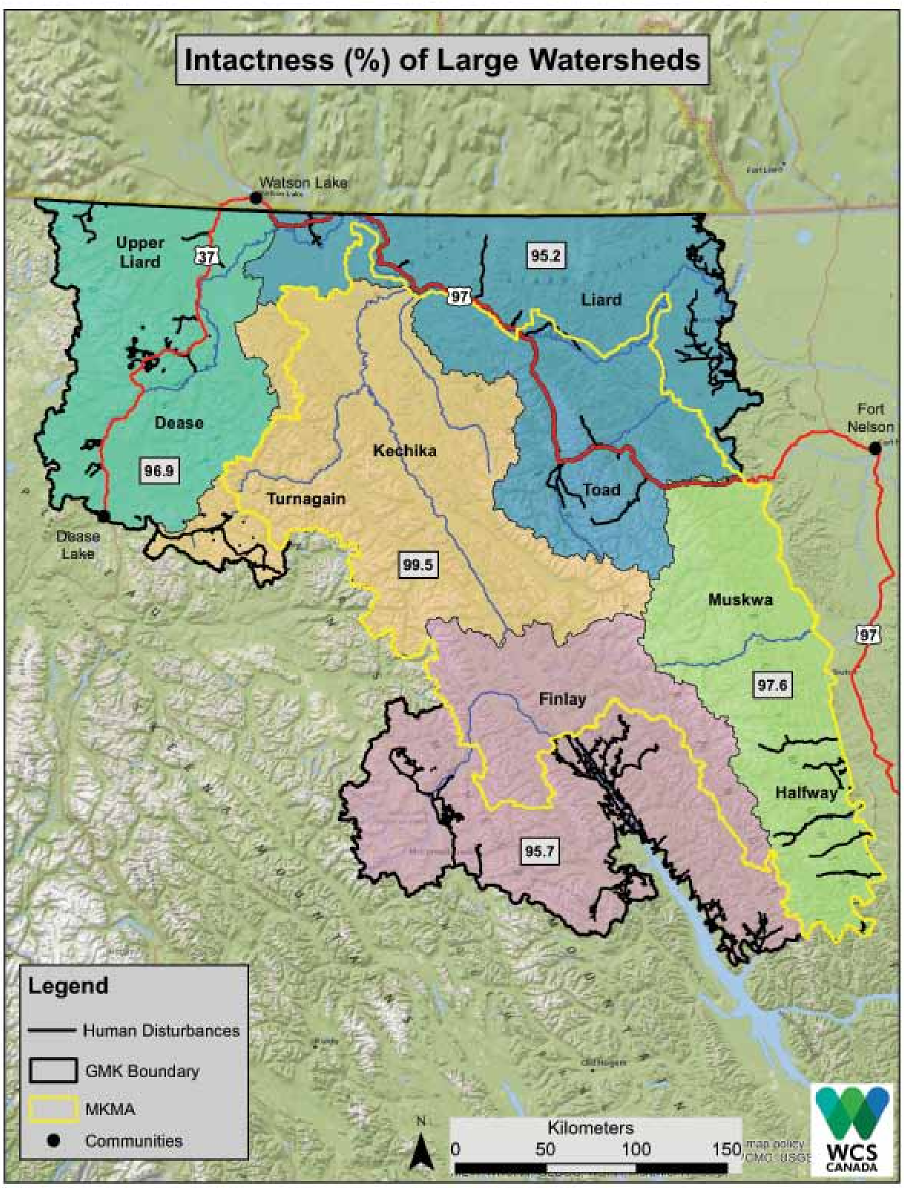
Resource 'Footprint'	Area (km^2)	Proportion (%)
Oil & Gas Sites	18.9	<0.0001
Mines	304.9	0.003
Forest Cut Blocks	1,198.2	0.01
Roads	3,907.3	0.03
Total (w/o overlap)	5,429.3	4.6
Total (with overlap)	4,506.8	3.8

Figure 3. Resource extraction sites such as mines, oil & gas wells/pipelines, timber harvests and their associated roads are clustered in a few places outside the Muskwa-Kechika Management Area, northern British Columbia.



Intactness – 'the absence of [industrial] human – is a useful indicator for conservation purposes (Theobald 2013). Intact wildlands provide multiple benefits for humans: healthy forests that store carbon, pure sources of precious water, and safe havens for vulnerable fish and wildlife. Moreover, vulnerability of ecosystems to climate change is moderated by habitat intactness (Schindler and Lee 2010, Eigenbrod et al. 2015, Martin and Watson 2016). The GMK remains a key stronghold for iconic wildlife (caribou, grizzly bear) (caribou, grizzly bear) that have suffered significant declines elsewhere in British Columbia. The breath-taking reality is that huge watersheds (averaging 23,000 km2) are incredibly wild and whole (Figure 4). In contrast to most areas in the south, the background matrix of the Greater Muskwa-Kechika is one of intact landscapes and fully functioning ecosystems – rather than a modified and fragmented matrix (Schmiegelow et al. 2006).

Figure 4. Excluding a 2-km wide zone along the Alaska Highway, the Greater Muskwa-Kechika area is >99% roadless.

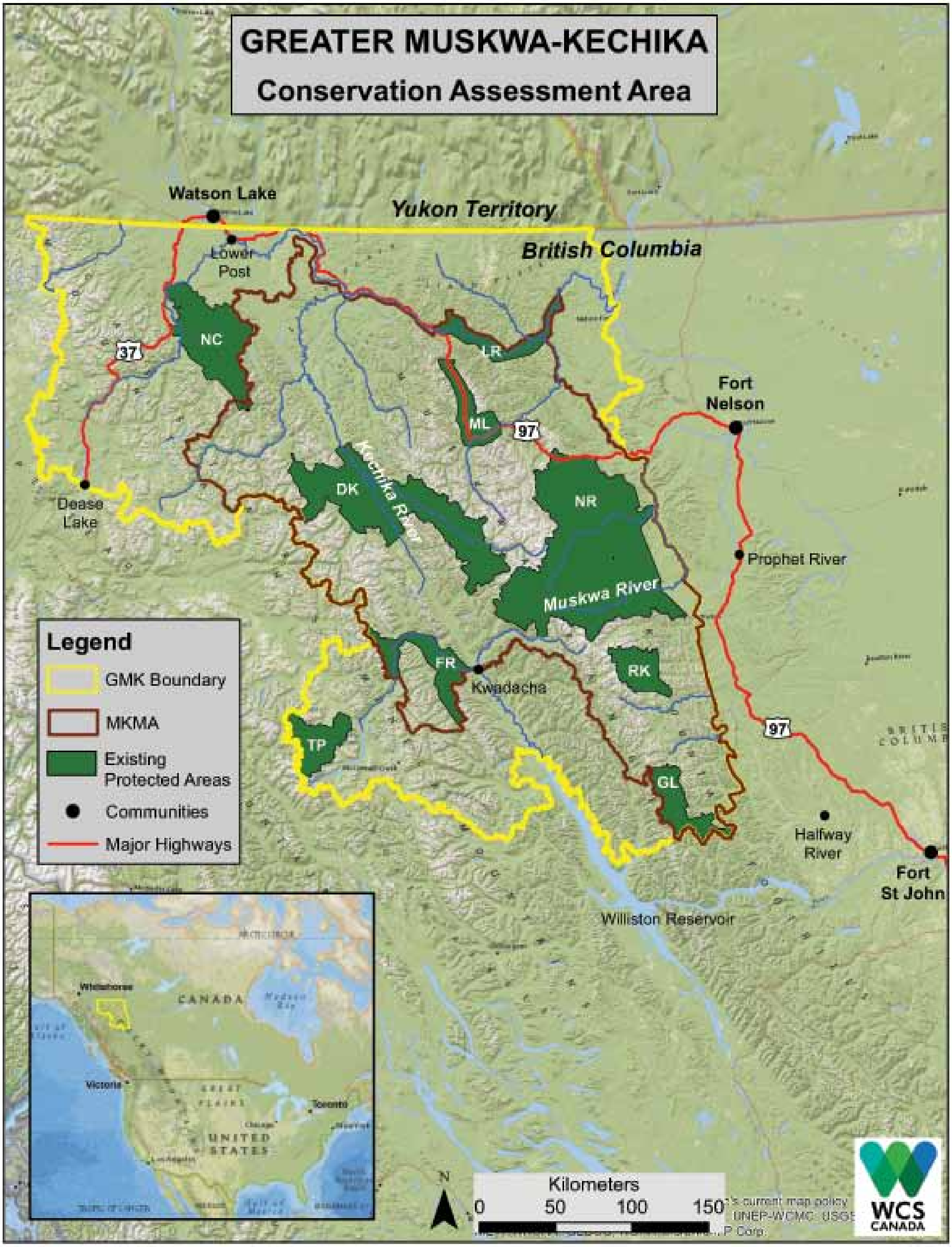


The Muskwa-Kechika Management Area is stratified into several "resource management zones" with varying degrees of protection. According to the MKMA Act, protected areas are to be safeguarded for their natural, cultural heritage, and/or recreational values. Logging, mining, hydroelectric dams, and oil and gas development are prohibited. There are 7 existing Protected Areas which comprise about 27.4% (17,496 km^2) of the MKMA (Table 2, Figure 5). The remaining 72.6% (46,348 km^2) potentially is open to industrial developments, so long as such developments can demonstrate consistency with management objectives for the zone. Even the so-called Special Wildland Zone (16.6%) allows mineral and oil and gas exploration and presumably development, subject to impact assessment and public review. Outside the MKMA, there are two other existing Protected Areas within the Greater MK, which total 3,386 km^2. These are the Ne'āh' Conservancy encompassing the Horseranch Range, and Tulatui Provincial Park at the headwaters of the Finlay River (Table 2, Figure 5). Altogether, existing Protected Areas comprise about 17.5% (20,883 km^2) of the Greater Muskwa-Kechika.

Table 2. Extent (km^2) of protected areas across the Greater Muskwa-Kechika area, northern B.C.

Muskwa-Kechika Management Area = 63,844 km^2	
Existing Protected Area	**Size (km^2)**
Northern Rocky Mountains (NR)	8,227
Redfearn-Keily (RK)	808
Graham-Laurier (GL)	997
Muncho Lake (ML)	862
Liard River Corridor (LR)	912
Dune Za Keyih (DK)	4,463
Finlay-Russel (FR)	1,228
Total M-KMA	**17,496**
Greater Muskwa-Kechika Area = 119,371 km^2	
Ne'āh' Conservancy (NC)	2,372
Tatlatui Park (TP)	1,014
Additional GMK	**3,386**
GRAND TOTAL	**20,882**

Figure 5. Existing Protected Areas across the Greater Muskwa-Kechika (see Table 2 for label names) safeguard some of the important habitats for fish and wildlife, but they do not represent the diversity of ecoregions, are not well connected, and thus do not provide for resiliency in the face of a hotter future.



Since the establishment of the MKMA, two previous reports have examined features of the area. In 2004, Round River Conservation Studies published a multi-faceted assessment of terrestrial and freshwater ecosystems and seven species of fish and wildlife (Heinemeyer et al. 2004). In their Conservation Area Design, they mapped 101 areas totaling 6.2 MM ha as 'primary core' and another 5.8 MM ha as secondary core for regional connectivity. In 2012, the Yellowstone-to-Yukon Initiative sponsored a study carried out by Dr. Jim Pojar and Gregory Kehm which focused primarily on assessments of ecological representation and enduring features, as well as climate change and connectivity. Their qualitative recommendations addressed important conservation principles.

The Muskwa-Kechika Management Area was visionary for its time, but now we can see more clearly its limitations: protected areas are not large enough for wide-ranging species such as woodland caribou, not well-connected to enable secure movements, and 'special management areas' do not have strong enough safeguards from corporate pressure for resource development.

Several considerations prompted this fresh look at the Muskwa-Kechika:

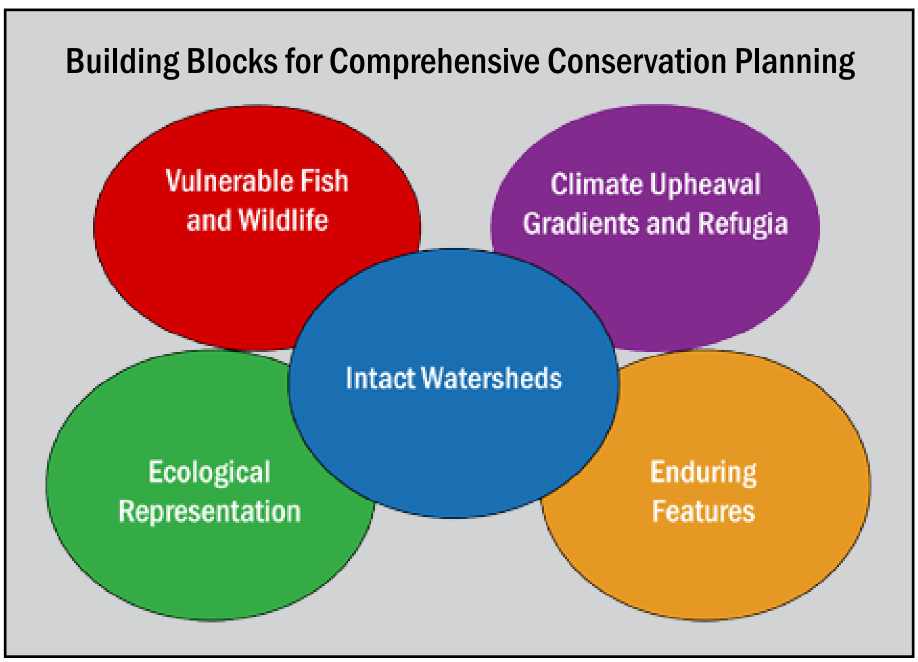
- emergence of new tenets guiding conservation of biodiversity,
- new approaches for promoting resiliency amid hotter climate and upheaval,
- new data on vulnerable wildlife species and their key habitats,
- Canada's commitment to conservation of biological diversity, and
- greater engagement of Indigenous people toward diverse governance.

In 2010, at a meeting of the Convention on Biological Diversity (CBD) in Nagoya, Aichi Prefecture, Japan, countries around the world adopted a Strategic Plan for Biodiversity. The plan included 20 global biodiversity targets, which together became known as the Aichi Targets. Each party to the convention agreed to contribute to achieving these by 2020. In 2015, Canada adopted a suite of national targets known as the "2020 Biodiversity Goals and Targets for Canada." The Pathway to Canada Target 1 states: "*By 2020, at least 17% of terrestrial areas and inland water, and 10% of coastal and marine areas, are conserved through networks of protected areas and other effective area-based conservation measures.*"

The Greater Muskwa-Kechika presents a time-limited opportunity to avoid the piece-meal mistakes of the past and to plan proactively for resiliency. … an opportunity to conserve wild watersheds of remarkable scale and intactness (for stunning photographs and stories, see the book by Wayne Sawchuck 2004: *Muskwa-Kechika: The wild heart of Canada's Northern Rockies*). Proactive conservation can help ensure that intact ecosystems and watersheds, abundant wildlife populations, wealth of ecosystem services, and cultural and social connections to the land are not eroded by the cumulative impacts of expansive resource development (Cooke 2017).

Purpose, Goal and Objectives of the Report

The **purpose** of this scientific assessment is to inform discussions and decisions about the future of the Greater Muskwa-Kechika area in northern British Columbia. The **conservation goal** is to develop a more representative, better connected and more resilient network of protected areas. The **approach** is to integrate several main streams of contemporary thinking about conservation. Specific **objectives** are to compile, critically examine, and synthesize the latest scientific information about (1) ecological representation, (2) enduring features, (3) vulnerable fish and wildlife species, and (4) gradients and refugia for resiliency to climate warming. The final step involves integration of these conservation features using larger-scale intact watersheds to map a new network of protected areas.



In Chapter **2**, I summarize past trends and future projections about climate heating, which has far-reaching implications for human affairs in the context of natural services. A different way of strategic thinking focused on resiliency will help guide conservation planning. In Chapter **3**, I describe and map those enduring features of the lands and waters that will persist as Nature's '*stage*' – even as various plant and animal species ('*actors*') shift in response. A diversity of ecoregions and biogeoclimatic zones will be critical to providing a wealth of options going forward into an uncertain future. Both river valleys and head-water regions may facilitate adaptive movements by wildlife in response to warming climate. In Chapter **4**, I profile the vulnerability (or lack of resiliency) of several fish and wildlife species and map key habitats/areas using data from biologists with B.C. government and various universities. In closing Chapter **5**, I sum up the critical importance of the Greater Muskwa-Kechika as a continental refuge for long-term conservation and offer a new map of connected protected areas for greater representation, better connectivity and stronger resiliency.

John Weaver

Courtesy of © Ryan Dickie

2. OVERARCHING THREAT OF CLIMATE HEATING

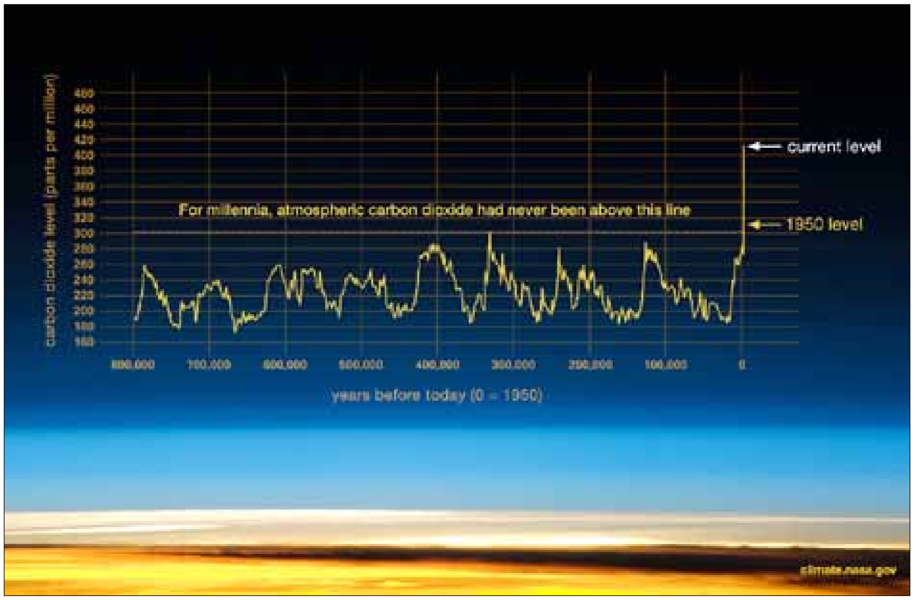
What changes in regional climate can we anticipate over the next 50-100 years? What will be the ecological consequences? What are thoughtful responses to this new challenge? Here, I synthesize the major findings from recent research to describe climate patterns in northern British Columbia over the past 50-100 years as well as projected changes over the next 25-50 years (2040-2070). This lays the foundation for anticipating changes in future conditions that may threaten waters and vulnerable fish and wildlife.

The level of CO_2 in the earth's atmosphere has not been above 300 ppm for the past 650,000 years …. until now. The global average has been rising sharply over the past century, breached 300 ppm in 1950, and reached 408 ppm in 2018 (Figure 6). Moreover, the annual rate of CO_2 increase has risen from 1 ppm to 2.5 ppm in recent years. In fact, the last time the atmospheric CO_2 amounts were this high was more than 3 million years ago, when temperature was 2°–3° C higher than during the pre-industrial era, and sea level was 15–25 meters higher than today (NOAA Climate 2019).

Past Trends, Future Projections, and Far-reaching Implications of a Hotter Climate

To characterize climate change patterns in the Greater Muskwa-Kechika study area, we used the ClimateBC tool developed by climatologists at the University of B.C. (Wang et al. 2018: Version 5.51 released May 2 2018). First, we generated a grid of equally-spaced points (every 5 km) (n= 5,671 points) across the GMK in ArcGIS 10.3. Then we extracted elevation for each point using a 25m DEM and created a continuous raster surface (100 m pixels) by a spatial interpolation technique known as kriging. Because there are typically few weather stations in remote mountains, such modeling necessarily has to rely on the

Figure 6. The level of CO_2 in the earth's atmosphere has not risen above 300 ppm for the past 650,000 years .... until now. The global average breached 300 ppm in 1950 and rose exponentially to 408 ppm in 2019.



closest weather stations which are usually in valleys. Moreover, mountain landscapes are quite complex, which makes spatially precise prediction notoriously difficult. Nonetheless, the broader patterns and implications of climate change are clear and compelling.

To model future climate change possibilities, we followed the current use of '*representative concentration pathways*' (rcp) (*see* van Vuuren et al. 2011, Thomson et al. 2011). Essentially, these are scenarios of carbon emissions projected out to various time periods. In common with other researchers, we chose (a) rcp 4.5, an intermediate-level 'CO_2-Mitigation' scenario such that emissions peak around 2040, then decline by mid-century, and (b) rcp 8.5, a high-level "Business-as-Usual' scenario where emissions continue rising throughout the century.

Δ Warmer winters and hotter summers

Vanishing glaciers worldwide are emblematic of warming trends in climate. For example, large glaciers in the Canadian Rockies have shrunk by ~25% in the last century (Watson and Luckman 2004). According to residents in northern B.C., glaciers in the Greater Muskwa-Kechika appear to be shrinking, too.

In northern B.C., annual temperatures have been getting warmer (on average) in recent decades. The mean annual temperature (MAT) increased 0.88° C from -2.11° C during 1951-1980 to -1.23° C during 1981-2010 (Table 3, Figure 5 a-b). Most of the annual warming has occurred during the winter months (Jan- Mar) as both nighttime lows and daytime highs increased by 2.0° C (BC MOE 2016).

Table 3. Mean Annual Temperature (MAT° C) (±SD) for various past and future time periods, Greater Muskwa-Kechika area, northern British Columbia. Change is relative to the 1951-1980 baseline.

Time Period	Mean MAT° C	SD MAT° C	∆ Mean MAT° C	% Change
1951-1980	-2.11	1.09		
1981-2010	-1.23	1.10	+ 0.865	+ 41
2040-2070 RCP45	0.93	1.10	+ 3.030	+ 144
2040-2070 RCP85	1.74	1.10	+ 3.838	+182

Projections indicate that the MAT will increase an *additional* 2.16° C and 2.97° C over the next 20-50 years under scenario models rcp 4.5 and rcp 8.5, respectively (Figure 5 c-d). Even under the 'CO_2-Mitigation' scenario (rcp 4.5), this warming trend extends progressively westward into the montane and subalpine natural regions of the Greater Muskwa-Kechika. Under the "Business-as-Usual' scenario (rcp 8.5), lower elevations may warm by 3° - 4° C compared to the 1951-1980 baseline due to increased extraction and burning of fossil fuels (especially coal) for energy (IPCC 2016 citations). The coldest areas (MAT < -2° C) vanish completely under either scenario, while the extent of the next coolest class (MAT from -2° to 0° C) may shrink by 35% and 80% under scenarios rcp 4.5 and 8.5, respectively (compare Figures 5a and 5d). The stabilizing CO_2 scenario would increase MAT by 3.04 °C above the baseline period (1951-1980), whereas the rising CO_2 scenario would increase MAT by 3.85 °C above

Figure 7a-b. Change in Mean Annual Temperature (MAT° C) for past (1951-1980) and recent (1981-2010) time periods, Greater Muskwa-Kechika area, northern British Columbia. Source: ClimateBC (2018).

MAT = -2.11° C (± 0.72) | **MAT = -1.23° C (± 0.74)**

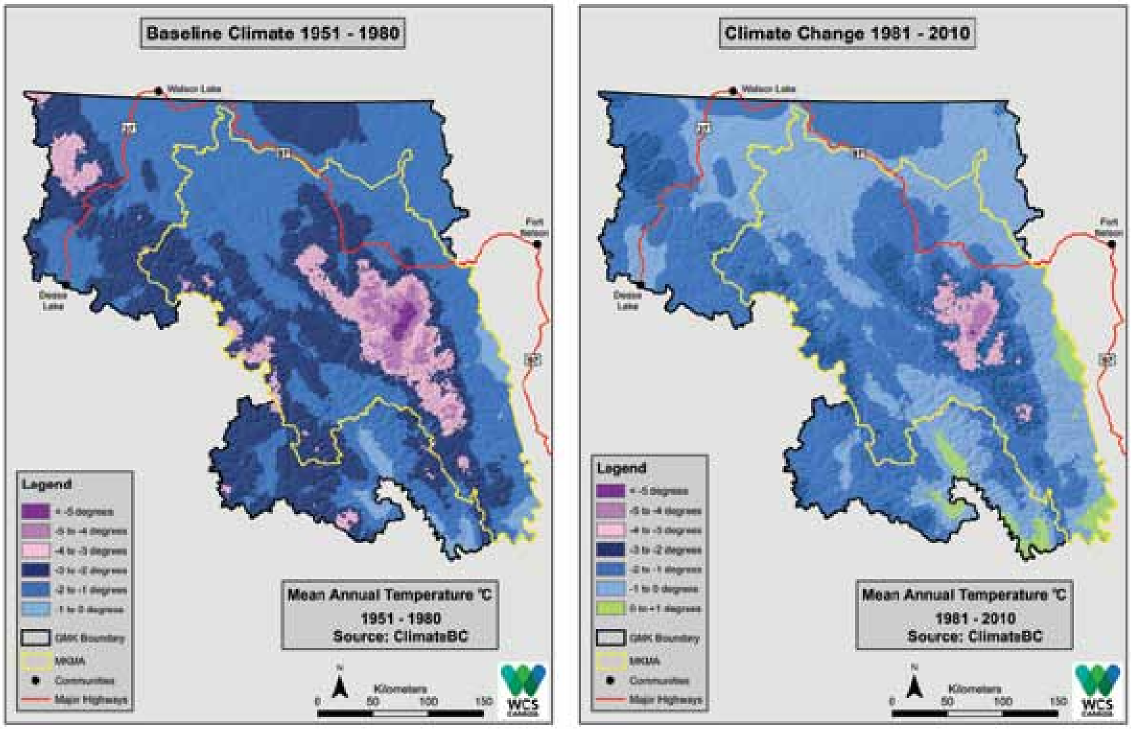
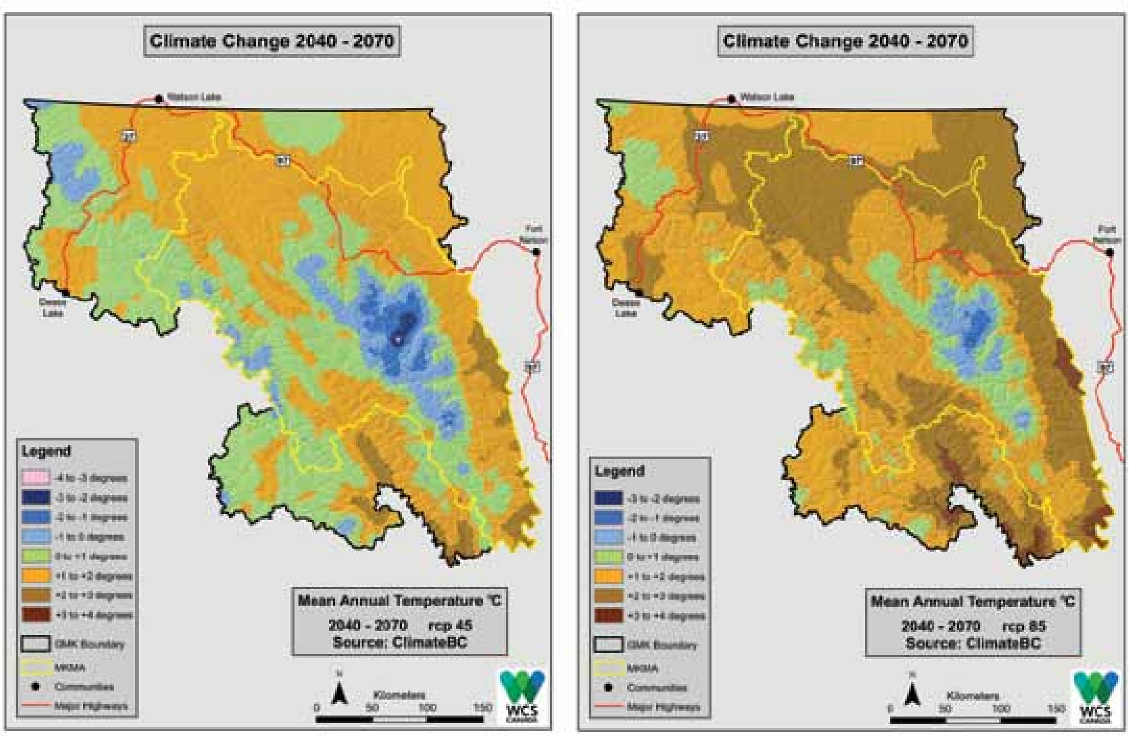


Figure 7c-d. Projected change in MAT° C for mid-century time period (2040-2070), Greater Muskwa-Kechika area, northern British Columbia. The scenario on the left (c) (rcp 45) assumes mitigation and stabilizing of CO_2 emissions by mid-century, whereas the scenario on the right (d) (rcp 85) assumes business-as-usual and continued rising of CO_2 emissions. Source: ClimateBC (2018).

MAT = + 0.93 °C (± 0.74) | **MAT = + 1.74 °C (± 0.74)**



baseline. The hotter summers in recent years may become common in the future a (Li et al. 2017). Higher elevations have been warming at a faster rate, a trend reported from many areas across the globe (Pepin et al. 2015). Embedded within these trends, however, is notable variability in temperatures between decades due to ENSO and PDO events.

Δ Velocity or pace of climate heating

The consequence of climate warming will be a function not only of the magnitude but also the pace of warming temperatures: how fast? Survival of species will depend upon keeping pace with moving climate to track their preferred environmental conditions. 'Climate velocity' is a recent concept and index for measuring and mapping the pace of temperature warming across a landscape (Loarie et al. 2009). It is calculated by dividing the rate of warming through time (degrees C per year) by the spatial gradient in warming at that location (degrees C per km), which yields the speed (km/year) of temperature change. *Forward* velocity is the distance which a species must move to reach a similar climate in the future; backward velocity is the distance an organism must move from to colonize a target patch of habitat with specific temperature (Hamann et al. 2015). Low forward velocity values indicate that suitable habitat can be found nearby, which is why mountains with high topographic variety have low velocity. Backward velocity may be considered as the relative difficulty for a species to colonize new habitat. For example, alpine habitat on mountain plateaus lack similar habitats upslope; consequently, if/when warming facilitates shrubs taking over alpine tundra on plateaus, dependent species would have to move long distances to colonize similar habitat. Maximum shifts for tree species following the retreat of glaciers in flatter boreal zones of Canada average about 0.1 km/year; most boreal tree species may not be able to keep pace with faster climate velocity (Corlett and Westcott 2013, Price et al. 2013).

Climate velocity can help identify location of future refugia – places where plants and animals can find tolerable conditions (Brito-Morales et al. 2018). Because average temperature generally decreases latitudinally from south to north, long S⇔N oriented mountain ranges and river valleys of western North America provide important pathways for movements in response to climate heating (Carroll et al. 2017, Carroll et al. 2018). With its many S⇔N mountain ranges and valleys coupled with sharp elevation gradients form valley to peak, the Greater Muskwa-Kechika is projected to have a slower pace of climate heating (0.1 km/year to 3 km/year for most of the area; source: AdaptWest 2018). Hence, the Greater Muskwa-Kechika offers important options for cooler climate refugia.

Δ Decreasing snowpack

In the Greater Muskwa-Kechika area, the mean annual precipitation (MAP) changed very little (1.8% decrease) between 1951-1980 and 1981-2010 periods (Table 4, Figure 6 a-b: ClimateBC). Climate models indicate a modest increase in annual precipitation over next 20-50 years of 10% to 13% for the rcp 4.5 and 8.5 scenarios, respectively (Table 4, Figure 6 c-d: ClimateBC). In some areas, however, summers likely will become hotter and evapotranspiration rates

Table 4. Mean Annual Precipitation (MAP) (±SD) for various past and future time periods, Greater Muskwa-Kechika area, northern British Columbia. Change is relative to the 1951-1980 baseline.

Time Period	Mean MAP mm	SD MAP mm	Δ Mean MAP mm	% Change
1951-1980	707.7	148.7		
1981-2010	695.1	144.8	-12.6	-2
2040-2070 RCP45	765.3	157.2	+57.6	+10
2040-2070 RCP85	787.5	160.7	+79.8	+11

likely will be higher. This could overwhelm any small increases in precipitation and result in progressively drier soils and vegetation (BC MOE 2016).

From the perspective of streamflow, mountain snowpack serves as 'water in the bank' – with accumulation during the cold winter, melting in late spring, and moderate baseflows lasting through late summer. Snowpack in western North America has been declining in recent decades (Mote et al. 2005).

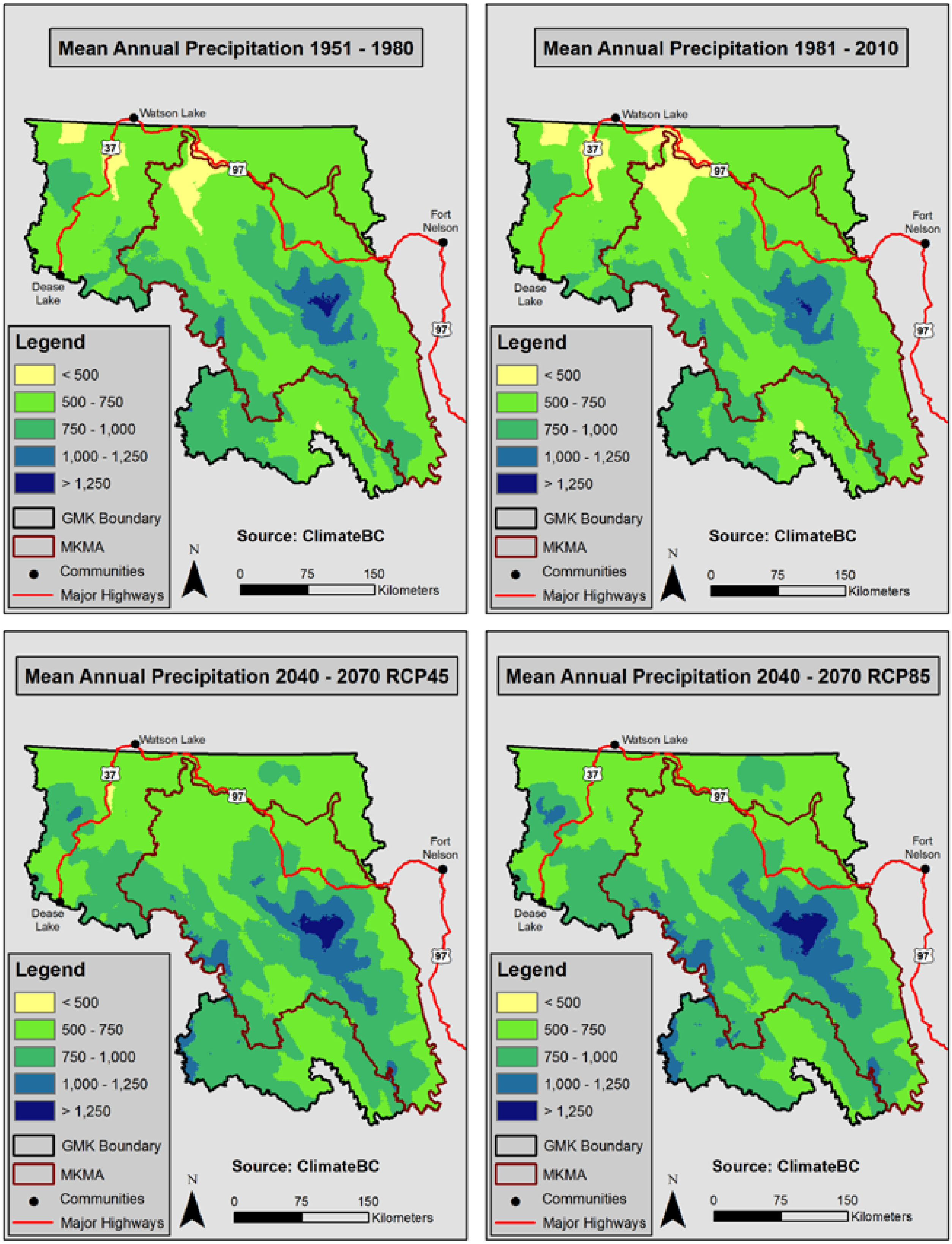
The amount of snowpack varies, however, not only with the amount of precipitation but with its form (snow or rain). A greater proportion of precipitation has fallen as rain rather than snow – especially at lower elevations (Dettinger et al. 2015). Low and mid-elevations in the Greater Muskwa-Kechika are projected to have a 14-15% decrease in precipitation falling as snow, whereas higher subalpine and alpine area may experience slightly less changeover from snow to rain (11-13%) (ClimateBC).

In western North America, rain-on-snow events have become more frequent at low to mid-elevations, increasing the prospects for winter flooding (Musselman et al. 2018). Warmer temperatures have led to earlier runoff by several weeks, but shallower snowpack at lower elevations may melt more slowly in late winter due to lower sun angles. Continuing decline in mountain snowpack, earlier spring runoff, and a reduction in snow season are projected by 2050 (Gergel et al. 2017). This suite of hydrological changes leading to lower base flows by mid-summer is consistent with recent trends and future predictions elsewhere along the Rocky Mountains of western Canada (e.g., Rood et al. 2008). There will continue to be annual/decadal variability of wetter and drier years due to Pacific influence.

Δ Spread of insects and invasive plants

In the wake of milder winter temperatures, populations of mountain pine beetle have exploded in recent years across northwest USA and British Columbia. The mountain pine beetle epidemic in BC peaked in 2004 and 2005 and devastated 18.3 million hectares of lodgepole pine forests (~20% of BC's land area) (Corbett et al. 2016). In addition, warmer summers with longer droughts have compounded stress for many coniferous tree species, enabling bark beetles to expand to higher elevations. Along with warmer temperatures and prolonged droughts, roads and land disturbances have promoted spread of invasive plant species.

Figure 8. Mean annual precipitation (mm) for time periods 1951-1980 (upper left), 1981-2010 (upper right), and projected for 2040-2070 rcp 45 (lower left), and 2040-2070 rcp 85 (lower right), Greater Muskwa-Kechika area, northern British Columbia. Source: ClimateBC (2018).



Δ Severe fires across wider landscape

Wildfires, of course, have always been a driver of ecological change across landscapes of western North America. Changes in climate such as diminished snowpack, earlier snowmelt, and hot drought conditions affect the timing, extent, and severity of wildfire (Westerling 2016). In Canada, the area burned by wildfires have increased over the past 50 years as summer temperatures have increased with climate change (Gillette et al. 2004). Increased risk of large fires with extreme behavior – including the massive fires in British Columbia in 2018 and 2019 – has been attributed to climate heating due to CO_2 emissions (Kirchmeier-Young et al. 2019). Canadian studies project that average area burned per decade in the western boreal forest will double by 2041–2050 and 3.5-5.5 *x* by end-of-century (Balshi et al. 2009), with larger and more severe fires over a longer fire season (Price et al. 2013, Wang et al. 2015).

These findings parallel those reported for climate change and fire in the Northern Rocky Mountains of the U.S. (Westerling 2016) Beginning in the mid-1980s, forest fires there have become more frequent, larger and much more severe than in previous decades. Notably, much of the increased fire activity has occurred in forests at higher elevations (1700 to 2600 m), where snowpack levels normally keep wildfire activity low. More intense fires have swept across streams, and the loss of critical shading has exacerbated warming of streams (Dunham et al. 2007). As temperatures continue to climb in the future accompanied by earlier snowmelt and warmer summers, there will likely be a longer fire season with severe fires across more of the landscape.

Δ Shifting distribution of plants and animals

During warming episodes in past millennia, distribution of plants and animals in North America generally shifted north in latitude and upward in elevation (Huntley 2005). In the mountains, various mammals moved upward in elevation or perhaps to a different aspect and so did not have to travel as far north as those in flatter areas (Guralnick 2007, Lyons et al. 2010). But there may be niche or physiological constraints to such adaptive movements. Alpine animals like pikas and hoary marmots may find temperatures too warm on lower mountaintops as suitable conditions and connectivity shrink (Stewart et al. 2015). Due to projected increase in variability/extreme episodes of temperature and precipitation, animals may incur more variation in their reproductive and survival rates and need more room to find adequate resources (Verboom et al. 2010).

Furthermore, because species respond individualistically to changes in temperature and precipitation, composition and structure of ecosystems will change in the future as novel assemblages come together (Williams and Jackson 2007, Rapacciuolo et al. 2014 for review, Mahoney et al. 2018). Complicated ecological interactions may affect species beyond simply changes in their climatic ‘envelope’ (Blois et al. 2013). The take-home message is to anticipate complex and unpredictable responses by plants and animals and to provide a full range of options (Wang et al. 2012).

Steven Pavlov

Δ Intensification of Resource Use and Movements by Humans

Sometimes, the flurry of new information about climate change can override the consideration of current and future impacts from human developments (Maxwell et al. 2015). As climate heating and upheaval proceeds, it is likely that humans will intensify exploitation of energy and water resources and move to less-impacted areas (Turner et al. 2010). It is crucial to keep in mind that both of these substantial influences comprise a joint threat to conservation of biodiversity and ecosystem services.

‘Thinking Resiliency’ Amid Change

British Columbia has been getting warmer over the past hundred years (BC MOE 2016). If CO_2 emissions continue to rise unabated, the future will become steadily hotter – and likely much hotter – by the end of the century (ClimateBC 2018). Projected warming will set many environmental changes cascading into motion: warmer winters and hotter summers … less snowpack and earlier run-off … more floods and fire… and extreme events will become more frequent. Amid the trends may be unanticipated interactions or ‘surprises’ that could be significant. To emphasize a hotter and more chaotic future, many scientists have shifted from using the terms ‘greenhouse’ and ‘climate change’ to ‘**hothouse**’ and ‘**ecological upheaval**’.

In the face of uncertainty, the conventional response has been to call for more narrowed research and more top-down management in hopes of gaining greater predictability or ‘command and control’ (Holling and Meffe 1996). Accumulated experience indicates, however, that command-and-control often results in unforeseen consequences for both natural ecosystems and human welfare in the form of collapsing resources, losses of biological diversity, as well as social and economic strife. Continuing such reductionist thinking can be counter-productive to constructing new paradigms that may lead to more sustainable practices.

An alternative response is to ‘**think resiliency**’ (Walker and Salt 2006). *Resilience* can be defined as the capacity of species or system to withstand disturbance and still persist (Holling 1973). Importantly, the resilience framework does not require an ability to precisely predict the future, but only a qualitative capacity to devise systems that can withstand disturbance and accommodate future events in whatever surprising form they may take. One of the key messages of resilience thinking is to keep future options open through an emphasis on ecological variability across space and time, rather than a focus on maximizing production over a short time (Walker and Salt 2006). The resiliency approach emphasizes diversity and redundancy, wide distribution across all scales, and connected networks of protected areas.

In thinking resiliency, several key questions arise: what features of the land and waters imbue an ecological system with greater resiliency? What attributes endow plants and animals with greater resiliency in the face of change?

One of the robust principles is that *complex terrains* with high diversity in topographic and geomorphic features, elevation, variety of landforms, lakes and wetlands, and processes provide greater array of local options for plants and animals in the face of changing climate (Anderson et al. 2014, Morelli et al. 2016). This physical complexity at local or regional scale facilitates short-distance movements and greater likelihood of successful tracking of changing conditions.

Obviously, plants and animals will start their responses from where they occur now. They will likely follow *gradients* to find new suitable conditions, responding to elevation and/or latitude and aspect as modifiers of temperature and precipitation. Populations that can sequentially colonize areas along these gradients may be better able to keep pace with climate change (Beier 2012).

Populations linked across climatic gradients are more likely to maintain existing genetic diversity, too (Sgr`o et al. 2011). Watersheds at various scales are a natural spatial and hydrographic unit for providing environmental gradients from river valley to mountain peak.

Plants and animals evolved in ecosystems where natural disturbances varied in frequency, intensity, duration, and extent – thereby resulting in different spatial and temporal patterns of change (Pickett et al. 1989). Over millennia, animals developed important behaviors and ecological traits that imbued them with resilience to certain kinds and levels of disturbance: (1) flexibility at individual level in foraging behavior and habitat selection, (2) high reproductive capacity to compensate for excessive mortality at a population level, and (3) sufficient dispersal capability to colonize distant habitats at a meta-population level (Weaver et al. 1996). In the modern era, other important considerations involve: (4) sensitivity to human disturbance, and (5) response to climate warming (Weaver 2013). Species can be assessed for their different combinations of these attributes to develop a profile of their comparative vulnerability (lack of resilience).

This resiliency, though, has definite limits. As human activities have accelerated rates of disturbance across a greater portion of the landscape, the combination of speed and simplification has undermined the resiliency mechanisms of many species and negatively impact populations. Cumulative impacts have accrued that threaten their persistence. For plants and animals to persist, human disturbance must be constrained within the bounds of the species' capacities for resilience.

A common strategy of managers facing similar uncertainty in other arenas is to minimize exposure to risk by placing valued assets in safe *refugia*. Indeed, the powerful role of refugia in population persistence has emerged as one of the most robust concepts of modern ecology. In the broader sense, refugia are safety nets from habitat loss and overexploitation. Both the resiliency profiles and the historical record attest to the need for some form of refugia for vulnerable fish and wildlife. In a world where impacts of habitat loss and fragmentation, invasive species, and climate heating are accelerating, vulnerable species will persist longer with well-designed networks of core refugia ('safe havens') and connectivity ('safe passages') that offer ecological options (Rose and Burton 2011, Keppel et al. 2012, Weaver 2013).

This kind of resilience thinking is reflected in several 'climate-smart' strategies identified by scientists and managers from around the world (Heller and Zavaleta 2009, Hansen et al. 2010). A broad consensus has emerged on the following actions to enhance resiliency in the face of climate change:

3. CONSERVING NATURE'S STAGE: ENDURING FEATURES AND ECOLOGICAL REPRESENTATION

Introduction

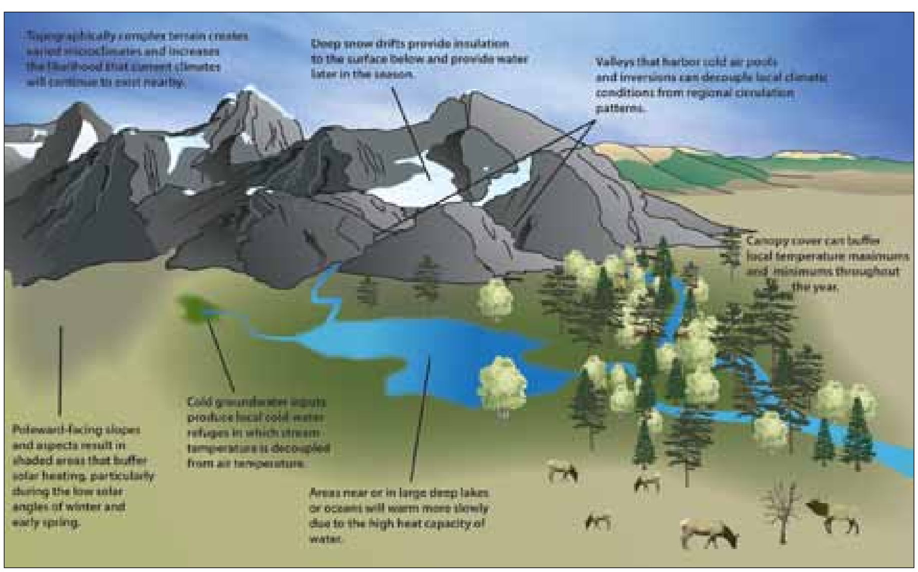
Both the paleo-environmental record and reconstruction of climate patterns over long millennia attest to the dynamic nature of Nature (Overpeck et al. 2005, Gill et al. 2015). Indeed, the earth has gone through numerous periods of great change accompanied by varying consequences for plants and animals. The fossil record indicates that species responded individualistically to these changes in climate and shifted in different directions and at different rates – resulting in novel assemblages (Graham 2005). Thus, the Quaternary paleoecoological record suggests that some or all 'ecological communities' may be *assemblages at a point in time* driven by environmental factors and not necessarily durable units *per se* for conservation (Meachen and Roberts 2014). The biologist G.E. Hutchinson presaged this understanding with his memorable metaphor of the "ecological theatre and the evolutionary play" meaning that the actors (plants and animals) may change but the stage (geophysical features such as geology, elevation, water bodies) is more lasting (Hutchinson 1965).

In a seminal paper, Hunter et al. (1988) argued that physical environments should serve as a coarse-filter for conservation planning as a more durable surrogate for conserving biodiversity. This conservation strategy based upon geophysical features has become known as conserving nature's stage (hereafter CNS) (Anderson and Ferree 2010, Beier et al. 2015). In practice, the CSN typically focuses on features such as geology or soils, elevation, and topography that influence the face of the land (Lawler et al. 2015). Geology affects patterns of plant diversity through its influence on the chemical and physical properties of soil and water, and nutrient availability (Kruckeberg 2002). Elevation and topography (slope, aspect) at various scales determine the effect of temperature, moisture and solar radiation on sites and provide a range of habitat options. It's the variation in these features that sustain the rich tapestries of life that we call biodiversity.

Conserving the full breadth of variety in the physical template is not only a sound strategy for maintaining biodiversity today but also a smart one for resiliency as climate changes and ecosystems transform in the future (Ashcroft 2010, Keppel et al. 2012). High-topographic diversity enhances potential resilience because organisms can find suitable habitat conditions in shorter time at nearby locations (Figure 7: Morelli et al. 2016). The pace of climate change (*velocity*) is lower in mountains because altitudinal shifts tend to be shorter than latitudinal movements to track climates (Carroll et al. 2018). Finally, the *relative* conditions along elevation gradients will persist (e.g., higher elevations will remain cooler than lower elevations) even as overall climatic conditions change. Mountains have served as important refuges because their environmental heterogeneity provide diverse microclimates (Dobrowski 2011, Ford et al. 2013).

Patterns of biodiversity, however, are not solely a function of abiotic conditions; they are also the outcome of interactions between species (such as pollinators, competitors) (Blois et al. 2013)._Conservation of different abiotic settings must always be complemented with conservation efforts that attend to species themselves (Anderson et al. 2015, Lawler et al. 2015) – particularly species sensitive to human actions as the climate changes (Watson et al. 2013). Conserving Nature's Stage should be viewed as a robust, coarse-scale approach that complements efforts to conserve species – especially in terms of resiliency going into the future. In the final analysis, conservation is "*a stage with many settings and many actors playing many parts*" (Redford et al. 2011).

Figure 9. Enduring features (geologic features, elevation gradients, land forms, and waters) are Nature's Stage. A topographic diverse landscape provides many options for species to shift in response to changing climate. Source Graphic: Morelli et al. 2016.



Courtesy of Toni Lyn Morelli

Enduring Features: The Land

Bedrock Geology

A variety of 7 major bedrock types occur across the Greater Muskwa-Kechika area (Table 5, Figure 10). These bedrock types typically follow the orientation of the mountain ranges, which is slightly southeast↔northwest. The Rocky Mountains and Foothills are primarily sedimentary bedrocks, with calcareous (calcium carbonates) formations comprising 10% of the Greater Muskwa-Kechika area. These calcareous types are especially important because rare plants often occur in limestone formations, and the vegetation is particularly beneficial for ungulates. Calcareous formations are found along the Eastern Slopes of the Rocky Mountains northward to the Alaska Highway and the west side of Liard Plateau (Figure 10). The area between Muncho Lake and the Northern Rockies Provincial Parks merits conservation recognition due to its calcareous bedrock.

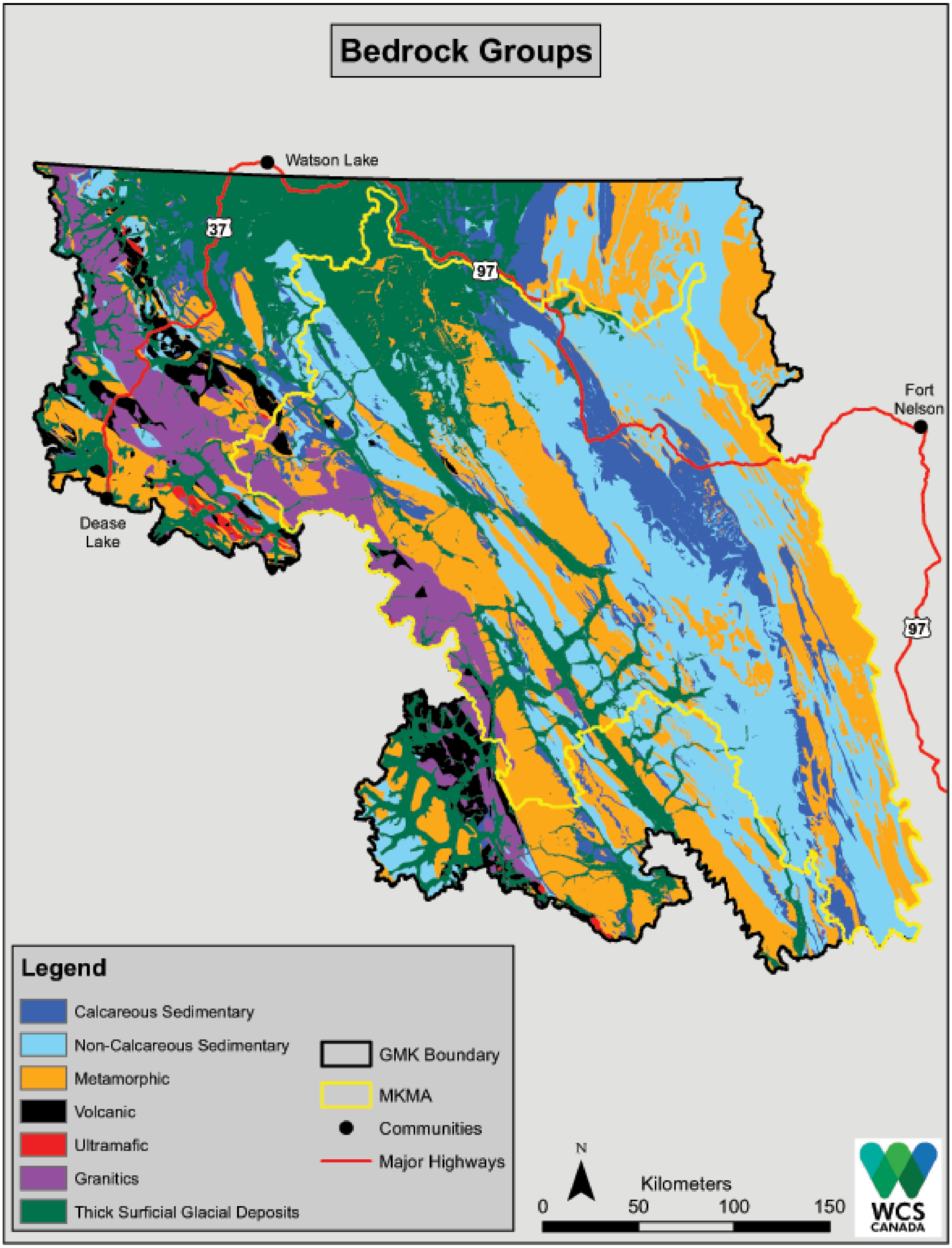
Surficial deposits of glacial till (22%) cover the extensive lowland of the Liard Plain and the Northern Rocky Mountain Trench. Bedrock types are more diverse in the Cassiar and Omineca Mountains west of the Rocky Mountain Trench, with occurrence of granitic, volcanic, and ultramafic types in addition to the sedimentary types. The rare (0.4%) ultramafic type warrants attention because it may have serpentine soils that harbor rare plants, as well as deposits of valuable minerals.

From a conservation perspective, it is important to represent the east↔west diversity of bedrock types across the entire Greater Muskwa-Kechika area. In the existing protected areas, the sedimentary and metamorphic types are moderately represented compared to their occurrence (Table 5). But the ultramafic, volcanic, and granite types west of the Rocky Mountain Trench are significantly under-represented. Diversity of bedrock types is particularly compact in two areas (1) between the Horseranch Range/Ne'āh' Conservancy and Cry Lake, and (2) headwaters of the Finlay and Ingenika Rivers.

Table 5. Extent and representation of bedrock types across the Greater Muskwa-Kechika area, northern British Columbia. EPAs = Existing Protected Areas.

Bedrock Type	Area (km^2)	% GMK	% in EPAs
Calcareous Clastic Sedimentary	12,003	10.1	33.5
Non-Calcareous Sedimentary	34,351	28.8	32.5
Metamorphic	33,532	28.1	39.4
Volcanic	3,913	3.3	2.0
Ultramafic	515	0.4	0.4
Granitic	8,888	7.4	3.6
Thick Surficial Deposits	26,142	21.9	12.3
TOTAL	**119,344**	**100.0**	

Figure 10. Location of bedrock geology types across the Greater Muskwa-Kechika area, northern British Columbia.



Elevation Gradients

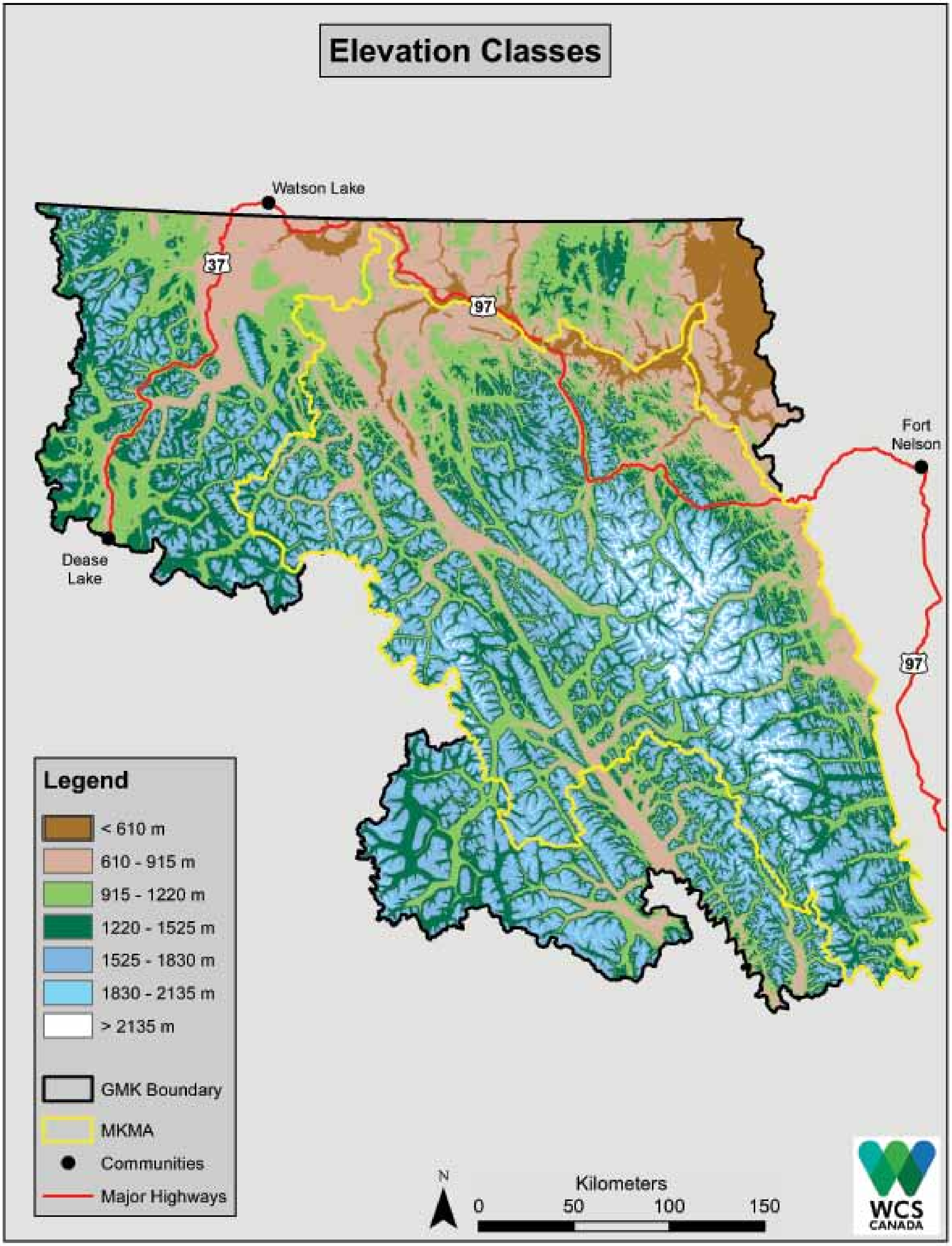
The Greater Muskwa-Kechika varies widely in elevation from <300 metres along the lower Liard River to mountain peaks rising to 2,200 metres (Table 6, Figure 11). About 55% of the Greater Muskwa-Kechika lies above 1,220 m elevation. These higher elevations will be less impacted by climate heating compared to lower zones and should provide refugia of cooler temperatures. The highest elevations are well represented (50%) in existing protected areas, which is often the case because these are areas of least conflict with human development interests (Venter et al. 2018).

The natural and compact gradients in range-of-elevation (and variation in aspect) in mountains will provide important options for plants and animals over time in response to climate warming. Researchers reported that Yukon's mountains, especially those in the south with higher average elevation and greater range-of-elevation, may provide climate refugia for some boreal species while experiencing less cumulative change in cliomes (Rowland et al. 2016).

Table 6. Area within elevation zones, Greater Muskwa-Kechika area, northern British Columbia.

Elevation Zone (ft)	Elevation Zone (m)	Area (km^2)	Percent	% in EPAs
< 1000'	< 305	261	0.22	4.7
1000 – 2000'	305 – 610	4,885	4.10	12.4
2000 – 3000'	610 – 915	21,731	18.22	10.9
3000 – 4000'	915 – 1220	26,899	22.55	16.4
4000 – 5000'	1220 – 1525	29,892	25.06	17.4
5000 – 6000'	1525 – 1830	23,355	19.58	18.5
6000 – 7000'	1830 – 2135	10,014	8.39	22.5
> 7000'	> 2135	2,257	1.89	50.2

Figure 11. Elevation classes (305-m/1000-ft interval) across the Greater Muskwa-Kechika area, northern British Columbia.



Enduring Features Concentration of Variety and Rareness

In assessing the enduring features of a region, ecologists often focus on geology or soils, elevation zones, and land forms comprised of slope, aspect, and topographic position (Anderson et al. 2014, Anderson et al. 2015). In an earlier report, ecologists Gregory Kehm and Jim Pojar did a similar assessment of enduring features across the Muskwa-Kechika area (see Y2Y 2012 report for detailed methods). Essentially, they (1) stratified elevation into nine classes to delineate altitude gradations, (2) grouped bedrock geology and surficial deposits into ten types, and (3) defined 23 macro-land forms by combining slope, topographic position and (where appropriate) aspect. They also included glaciers, wet flats and major lakes, rivers and streams. (Note: Their did not include the continuation of the Cassiar Mountains into the northwest corner of the GMK; but, the pattern of enduring features is probably similar).

Their final model integrated these various categories into 1648 unique combinations of enduring features mapped as 90m x 90m grid cells. Realizing the difficulty of comprehending the visual complexity of such a map, they carried out a spatial analysis with each grid cell informed by the values of surrounding cells in a 5-km radius neighborhood. For 'Variety of Enduring Features', the *Very-High* (scores 250-448) and *High* (scores 173-249) comprised 52% of their study area (Table 7). Based upon a similar analysis, their top most-rare combinations of enduring features (e.g., uncommon volcanic rock known as ultramafic or serpentine rock) comprised 8%.

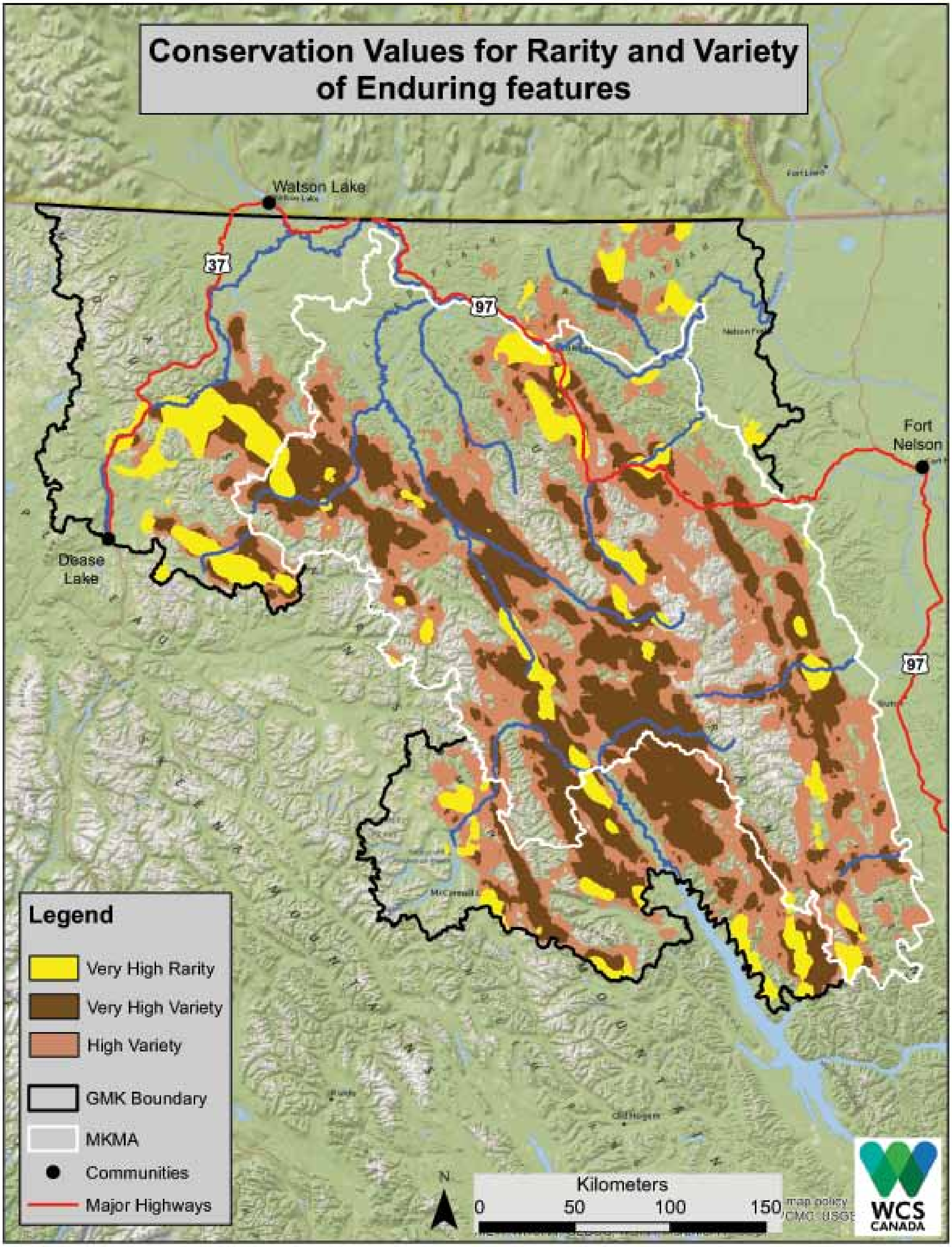
Areas with higher variety of enduring features are especially important for resiliency in the face of climate change because they provide a compact set of options for tracking suitable conditions. Very-High variety and high variety of enduring features comprise about 8% and 15%, respectively, of the Greater Muskwa-Kechika area (Table 7). The following areas are notable for Very High-High variety (Figure 12): (1) east and west sides of the Rocky Mountain Trench from south of Kwadacha northward to below confluence of the Gataga with the Kechika River, (2) Rocky Mountain Foothills and west into the Rocky Mountains, (3) Turnagain River watershed and east side of Dease River watershed, (4) between Stone Mountain and east side of Muncho Lake Provincial Park, and (5) Liard Plateau. Areas of moderate variety are found on another 28% of the area. These often surround the higher classes and follow a similar geographical distribution.

The Very-Rare and Rare types of enduring feature, of course, are more discrete and limited in their distribution. Nonetheless, 75% are embedded within the higher classes of variety (Figure 12). The largest concentrations of rare features are found in (1) the headwaters of the Turnagain River watershed, and (2) southwest of the Horseranch Range/ Ne'āh' Conservancy.

Table 7. Amount of area (km^2) and representation of enduring features that are the most diverse or most rare, Greater Muskwa-Kechika, northern British Columbia. Source of Enduring Features: Y2Y (2012), courtesy of Gregory Kehm.

Enduring Feature	Area (km^2)	% GMK (Y2Y)	% in EPAs
Very High and High Variety	24,452	23.6	25.6
Moderate Variety	29,354	28.3	22.3
Very Rare and Rare	8,915	8.6	11.9

Figure 12. Location of enduring features (variety and rarity) across the Greater Muskwa-Kechika area, northern British Columbia. Source of Enduring Features: Y2Y (2012), courtesy of Gregory Kehm.



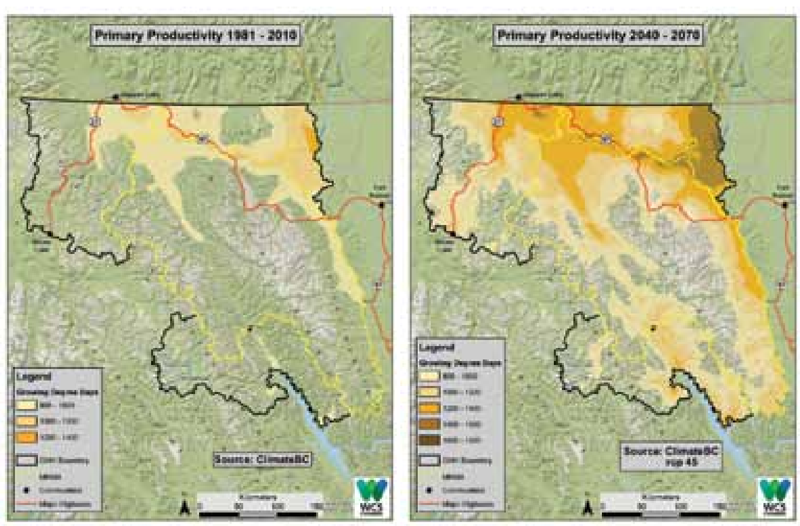
Primary Productivity

Low-elevation river valleys typically correspond with areas of high biological productivity due to the accumulation of organic material, rich soils, and warmer temperatures during the growing season. These areas are often a nexus of biodiversity and may also serve as important wildlife connectivity corridors. They comprise a key component in conservation planning – especially in a mountainous landscape. Because some areas of high primary productivity occur in fairly uniform landscapes, they may be missed by assessments of high topographic variety (G. Kehm *personal communication*).

We mapped areas of primary productivity based upon the number of Growing Degree Days (GDD), which are an indicator of total heat available for plants in the growing season. GDD each day is the average temperature for the day minus the base temperature sufficient for plant growth, which we defined as 5° C. We used ClimateBC temperature records and future projections to map GDD. Areas with annual GDD above 800 were used as the basis for determining locations of high productivity.

During 1981-2010, primary productivity in the Greater Muskwa-Kechika was 600 GDD. By 2055, GDD across the Greater Muskwa-Kechika is projected to increase + 320-450 (per century) due to continuing increases in the mean annual temperature. At present, about 22% of the Greater Muskwa-Kechika is covered with areas of high primary productivity; key areas include the Liard Plain and lower Kechika River valley and the boreal plain/ Muskwa Plateau to the east (Figure 13, left). In the future, these areas are projected to become ever more productive, accompanied by expansion into the Dease Lake area, the entire Northern Rocky Mountain Trench, and along all of the Eastern Slopes of the Rocky Mountains (Figure 13, right). This projected increase could be beneficial in some cases (faster growth of trees, up to a point), detrimental in others (shrub encroachment of alpine tundra). In Canada's current network of Protected Areas, the larger parks are biased against areas with higher productivity (Andrew et al. 2011, Venter et al. 2018). In the Greater Muskwa-Kechika, only 8% of areas with high primary productivity are included in existing protected areas.

Figure 13. Primary productivity across the Greater Muskwa-Kechika area, northern British Columbia. Left panel 1981-2010, right panel projected for 2040-2070.



Enduring Features: The Waters

Lakes and Wetlands

There are numerous lakes and wetlands across the Greater Muskwa-Kechika, which contribute significantly to biodiversity of the area (Table 8, Figures 14 and 15). The larger lakes (>250 ha) are scattered across the area, but smaller ones are commonly found in the same lowland areas as the wetlands. Density of wetlands is especially high (1) across the Liard Plain (lower sections of the Dease, Kechika, Liard and Rabbit Rivers), and (2) lowlands of the Muskwa Plateau/ Boreal Plain (between lower Toad River and Dunedin River). Other areas of high concentration include the upper Kechika River and upper Fox River in the Northern Rocky Mountain Trench, middle sections of the Gataga and Rabbit Rivers, Blue and Little Rancheria Rivers, upper Finlay River, and upper section of the Sikanni Chief River. About 24% of the lakes are found in existing protected areas, but only 10% of the wetlands.

Safeguarding precious freshwaters in protected areas is a sound conservation strategy (Abell et al. 2007, Nel et al. 2011, Hermoso et al. 2016).

Table 8. Area and representation of lakes (different size classes) and wetlands (different density), Greater Muskwa-Kechika area, northern British Columbia.

Water Body	Area (km^2)	% GMK	% in Existing Protected Areas			
			Large	Medium	Small	Total
Lakes	1,044	0.87	39.9	16.4	13.2	24.06
Water Body	Area (ha)	% GMK	% in Existing Protected Areas			
			High	Moderate	Low	Total
Wetlands	2,294	2.01	7.4	10.5	12.0	9.68

Figure 14. Conservation value of lakes by size class, Greater Muskwa-Kechika area, northern B.C.

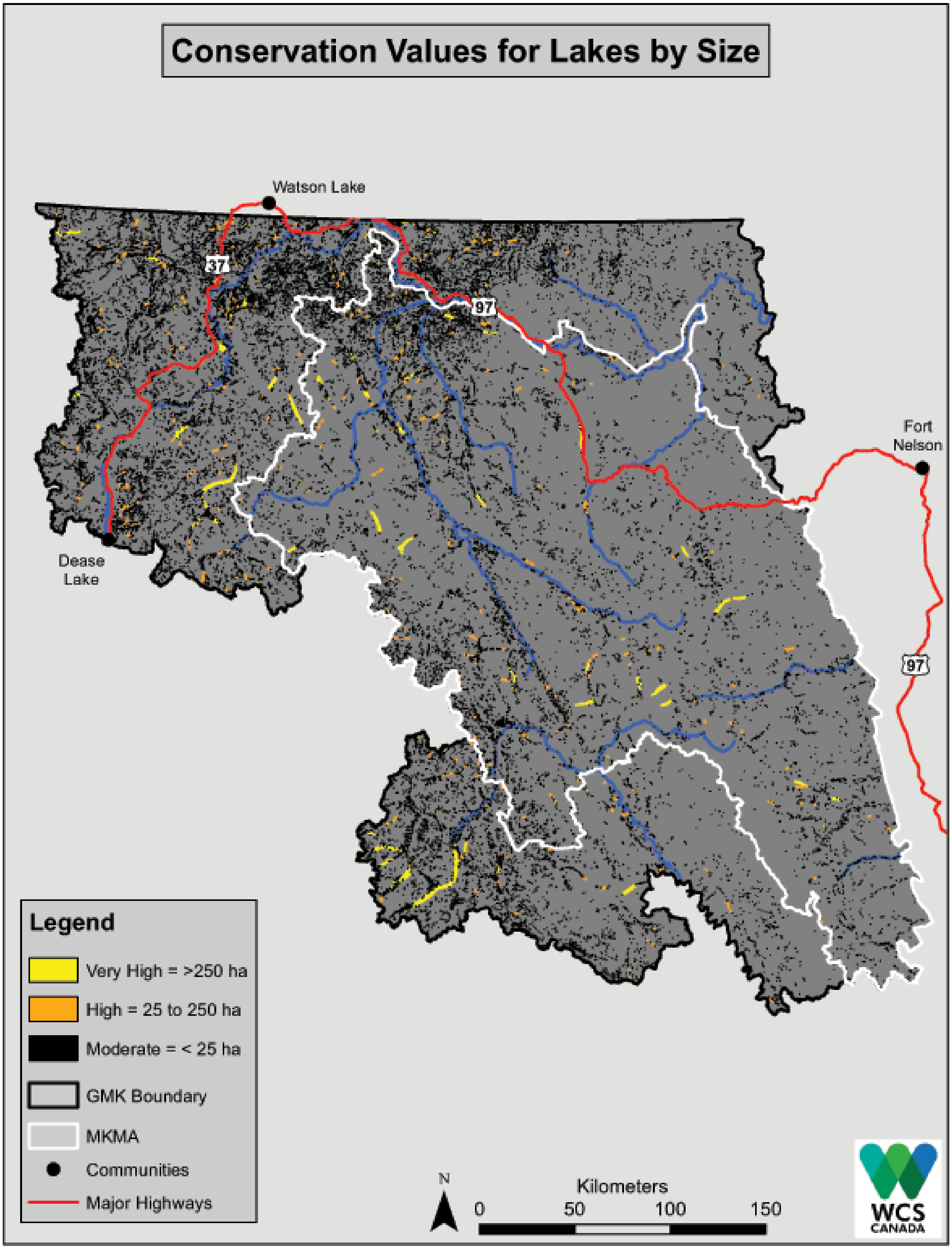
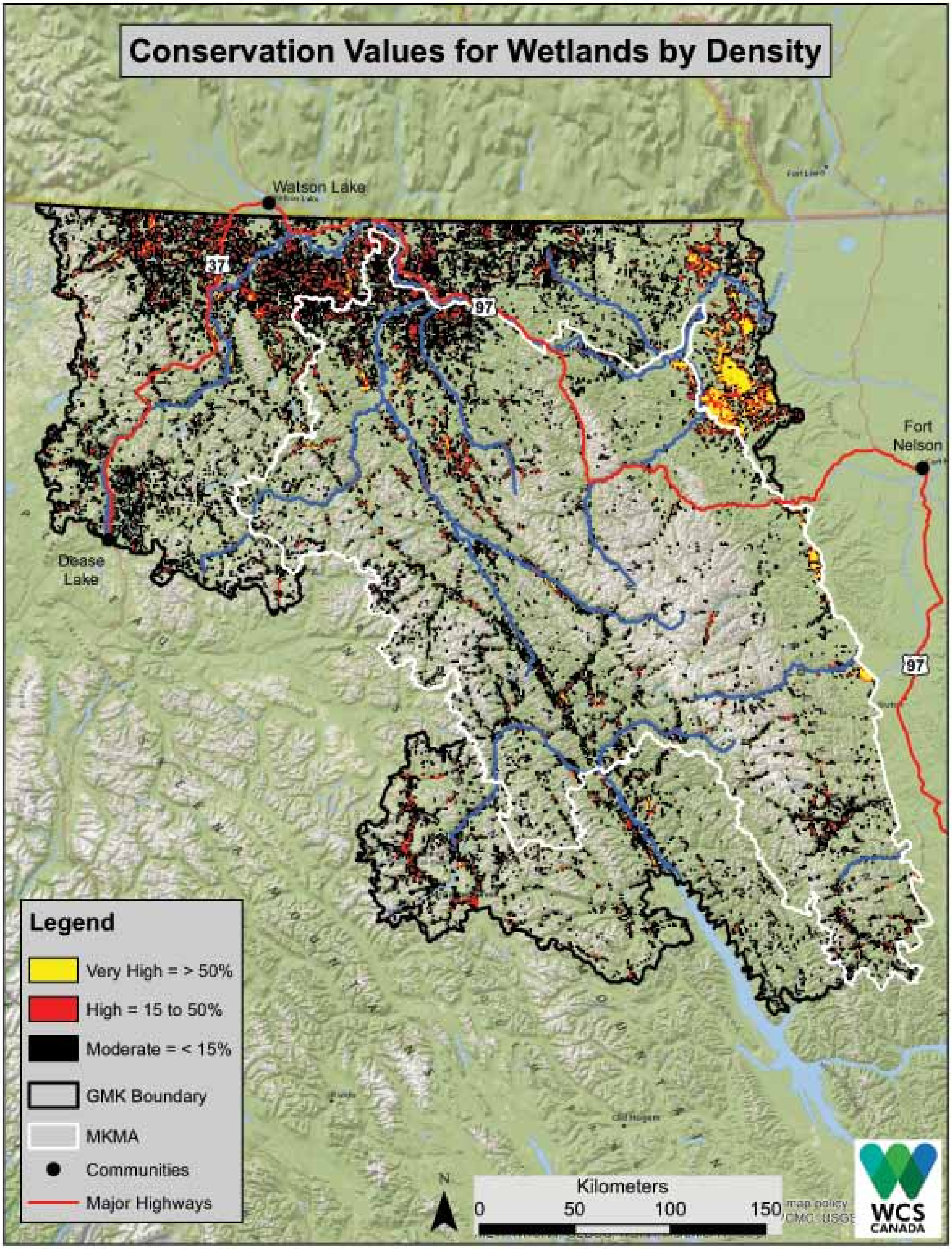


Figure 15. Conservation values of wetlands by density class (% cover of 1-km^2 grid cell), Greater Muskwa-Kechika area, northern British Columbia.



River Valleys: Nexus of Biodiversity

The riparian zone adjacent to rivers and streams has been noted for its dynamic complexity, biodiversity, and ecosystem or natural services (Naiman et al. 2005). Gravel-bed river floodplains in the valleys of the Rocky Mountains are exceptionally important to regional biodiversity of aquatic, avian, and terrestrial species (Hauer et al. 2016). These complex and dynamic landscapes concentrate diverse habitats at small scales, cycle nutrients, and provide natural corridors for movement. They are the ecological stage where daily dramas shape the survival and behaviour of prey and predator alike (Figure 16).

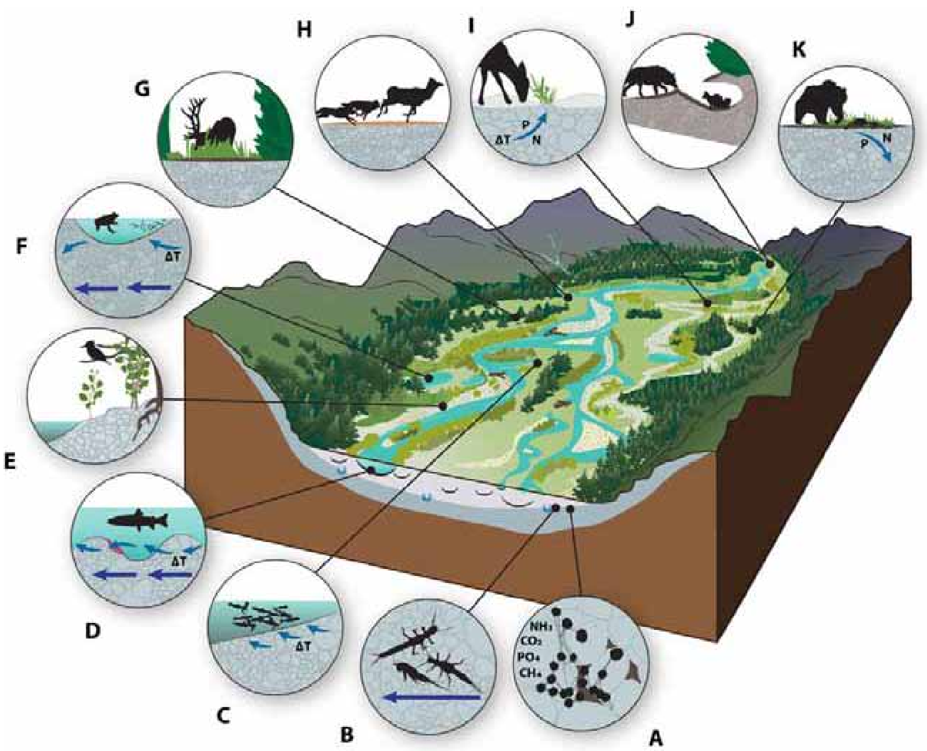
Broad U-shaped river valleys are characteristic of glaciated mountain landscapes where large alpine valleys have been deepened and enlarged in the aftermath of Pleistocene glaciation. Their gravel-bed floodplains are extremely complex, creating an extraordinary diversity of habitats that support diverse communities of aquatic, avian, and terrestrial species. By contrast, canyon sections along the same river support comparatively less biodiversity because the narrow, linear corridor of confined river segments has much less physical complexity and habitat diversity. Over time, flooding creates a shifting mosaic of habitats – including very old channels, new channels, ponds, barren gravel bars, young vegetation stands, and gallery old-growth forests that are hundreds of years old. Throughout the year, water is constantly flowing out of the river channel down into the gravels below and laterally beyond the channel often from valley wall to valley wall. Thus, the complex mosaic of surface and subsurface habitats is interconnected *longitudinally* downstream, *laterally* from the river channel across the floodplain, and *vertically* from the river channel into the aquifer below.

River valleys typically have an extraordinarily high diversity of plant species. In many regions, majority of all plant species from valley floor to alpine occur on gravel-bed floodplains which comprise <5% of the area. Expansive floodplains containing a variety of aquatic and terrestrial habitats, large and complex patches of deciduous gallery forests, and a range of successional plant communities support both high diversity and high density of birds. Beaver (*Castor canadensis*) are well-known 'ecological engineers' whose dam building creates ponds and wetlands in the side-channels of major rivers, where they reside year-round. These river valleys typically provide good habitat for moose, too.

Organic nutrients, microbes, and aquatic insects in the river form the foundation of the fresh-water food web. Native fish like bull trout find their critical spawning sites where cool groundwater upwells into the river gravels, which also are ideal overwintering habitat because relatively warm waters bubbling up help to maintain ice-free conditions in the river.

In most mountainous systems, river valleys are the first places to be converted to permanent human settlement, agriculture, industry, and transportation corridors. Structural modifications to floodplains such as roads, hydroelectric or water-storage dams. and tailings-dams and reservoirs associated with mining have severe impacts to floodplain habitat diversity and productivity, restrict local and regional connectivity, and reduce the resilience of both aquatic and terrestrial species. Maintenance of the dynamic processes and the resulting complex of habitats along the length and breadth of floodplain rivers is a smart strategy for conserving the biodiversity of the Greater Muskwa-Kechika area.

Figure 16. The gravel-bed river floodplain as the ecological nexus of regional biodiversity. Illustration shows the complexity of the shifting habitat mosaic, the biophysical interactions among organisms from microbes to grizzly bears, and the importance of gravel-bed river floodplains. (A) Microbes of the interstitial spaces of the gravel bed showing the products of processing of organic matter in the subsurface. (B) Crustaceans and insects that inhabit the gravels of the floodplain. (C) Temperature modification of surface habitats from upwelling hyporheic zone waters. (D) Native fishes spawning in floodplain gravels. (E) Riparian obligate birds. (F) Amphibian spawning in floodplain ponds and backwaters. (G) Ungulate herbivory of floodplain vegetation. (H) Wolf predation on ungulate populations. (I) Early-spring emergence of vegetation. (J) Wolf dens located along floodplain banks. (K) Use by grizzly bears and other carnivores as an intersection of landscape connectivity and sites of predation interactions (used with permission: Hauer et al. 2016: E. Harrington, *eh illustration*, Missoula, MT).



River Valleys: Corridors for Climate Adaptation

Because many species will have difficulty tracking rapidly-shifting climatic conditions across fragmented landscapes, protecting and restoring ecological connectivity has been consistently identified as a 'smart climate-adaptation strategy' for biodiversity conservation (e.g., Heller and Zavaleta 2009, Hansen et al. 2010, Hilty et al. 2019). River valleys have been identified as natural corridors for climate-driven movements because they span temperature gradients or *ramps* from mouth to headwaters (Capon et al. 2013). Plants and animals will use other pathways to track suitable conditions (ridges, different aspects of a mountain side) too, but river valleys likely will be an important one. We mapped these gradients up the major rivers of the Greater Muskwa-Kechika by adapting a method developed by researchers at University of Washington (Krosby et al. 2018).

Harvey Locke

Broad, floodplain river valleys are a hotspot for biological diversity and a natural corridor or 'ramp' for fish and wildlife movements in response to warming climate.

Methods for Ranking Riparian Climate-Corridors

Krosby et al. (2018) developed a method for identifying priority riparian areas for climate-adaptation corridors. It identifies riparian areas that span high temperature gradients, have high levels of canopy cover, are relatively wide, have low solar insolation, and low levels of human modification – characteristics expected to facilitate movement to cooler micro-climate refugia in response to hotter climate. They developed a 'Riparian Climate-Corridor Index' (RCI) using the following formula:

$RCI = \Delta MAT \times [(RA + CC)/ (PRR + LC)]$

Where MAT= Mean Annual Temperature (° C) along length of river
RA = Riparian Area
CC = % Tree Canopy Cover
PRR = Potential Relative Radiation
LC = Landscape Condition due to human modification

We followed their approach for the Greater Muskwa-Kechika but modified their methods due to lack of certain data sets. We call it *River* Climate-Corridor Index (RCI) and modified their formula to:

$RCI = \Delta MAT \times (VB/RL - RI/RL)$

Where MAT= Mean Annual Temperature for period 1981-2010 in spatial increments of 1° C for length of river
VB = Valley Bottom
RL = River Length
RI = Road Impact

Note that we *subtracted* the road impact (rather than use it as a divisor) to ensure the relative influence of the MAT and VB values on the derived score.

We followed these steps to determine the River Climate-Corridor Index (see Figure 17):

Step 1. Spatial Variation in Mean Annual Temperature (MAT)

We used a grid of evenly-spaced points (1km) and the ClimateBC tool (Wang et al. 2018) to generate Mean Annual Temperatures across the GMK for the recent period 1981-2010. We converted the output to integers, resulting in 6 classes of Δ1° C from the warmest 0° to +1° C to the coolest -5° to -4° C. Spatial variation in MAT is the number of Δ1° C classes for each river from study area boundary to headwater. Because there were long stretches of rivers without a change in MAT (mostly -1° to 0° C class) in this landscape, we used only those sections where a detectable gradient began as the modifier in the formula.

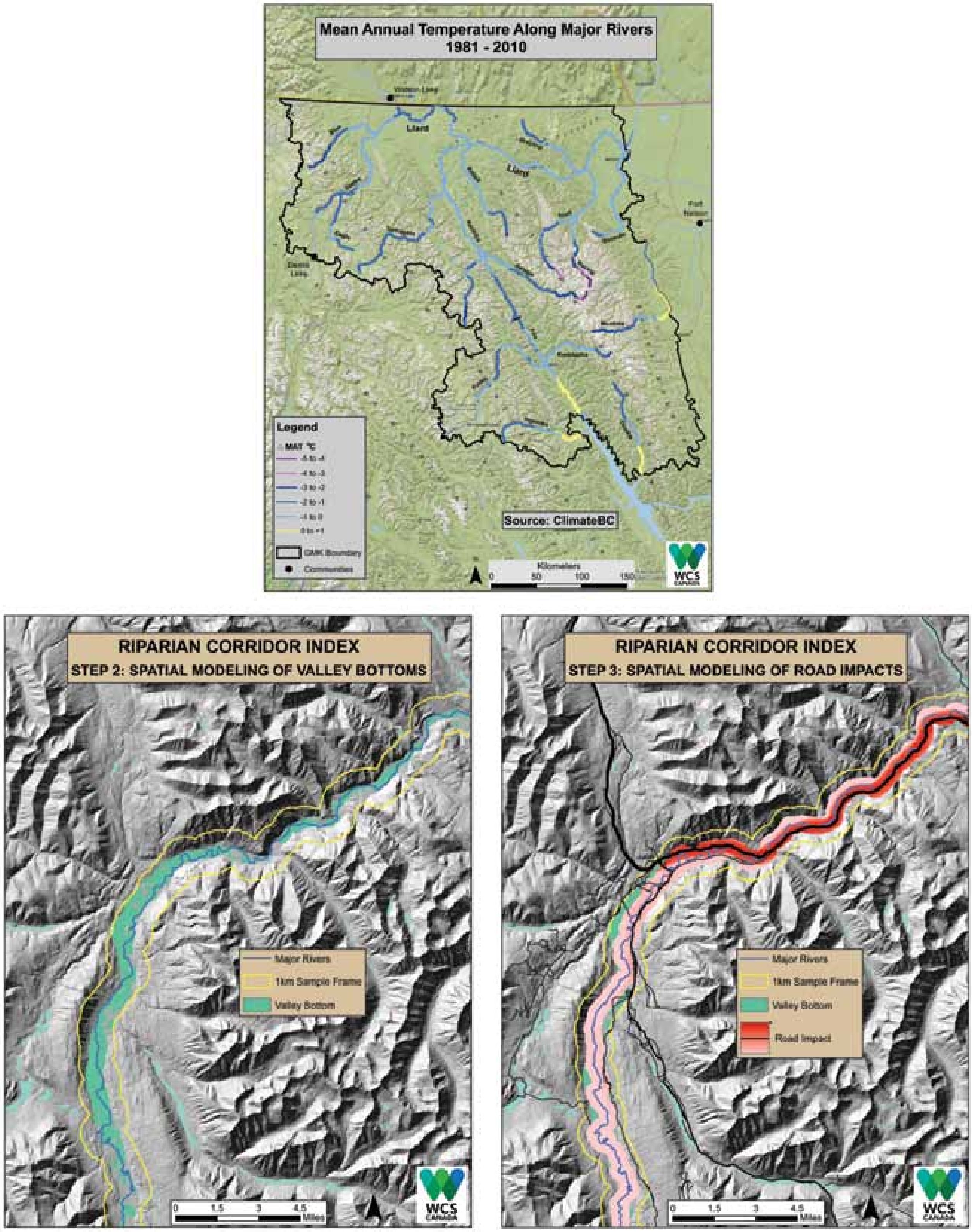
Step 2. Extent of valley bottom (VB), including riparian area

We used a python script from the USDA Forest Service - Remote Sensing Application Center to model valley bottoms as a proxy for riparian areas (Housman et al. 2012). For our study area, we used a DEM-derived hillshade, high-resolution BING imagery to guide the on-screen digitizing of 750 valley bottom and 750 non-valley bottom training points. Our model is based on 3 predictor variables: Topographic Wetness Index, Height Above Channel, and Slope (radians). We used a threshold of 0.75 to turn the continuous output into a binary one: model value ≤ 0.75 is valley bottom, model value > 0.75 is not). We buffered major rivers by 1 km on each side for mapping extent of valley bottom.

Step 3. Road Impact (RI)

We used roads from our GIS layer of roads and human developments and the Line Density command in ArcGIS with a search radius of 500m to calculate road density (km/km^2). We applied the following weights to reflect different amounts of traffic: 4 = Alaska Highway 97; 3 = Cassiar highway 37; 2 = road; and 1 = all other paved or gravel roads. Resulting raster values ranged from 0 to 23 km/km^2 after conversion from floating point to integer. They were normalized to a 0-1 range and multiplied by the corresponding number of pixels, then summed within each 1-km river buffer to obtain a Road Impact value (ha) for each river.

Figure 17. Steps in determining the RCI score of river valleys based upon (step 1) spatial gradient of Mean Annual Temperature in 1° C spatial increments, (step 2) width of valley bottom, and (step 3) zone of disturbance along roads, Greater Muskwa-Kechika area, northern British Columbia.

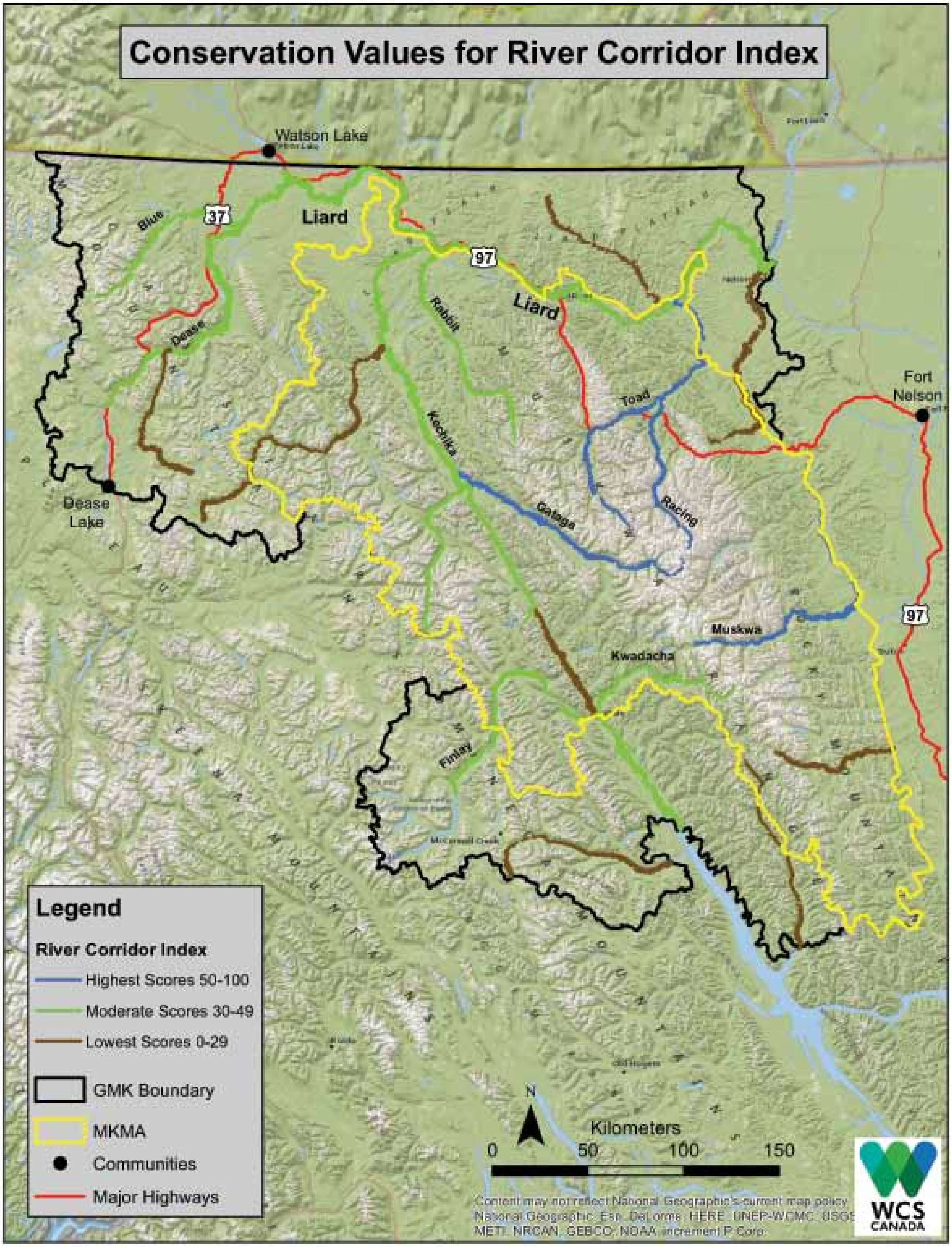


Not surprisingly, rivers with headwaters in the higher Rocky Mountains ranked highest for the River Corridor Index (Table 9, Figure 18). These included the Gataga, Racing, Muskwa, and Toad Rivers. Others with a moderate or low ranking (e.g., Turnagain River) may have scored higher if the increment had been more fine-scale (i.e., 0.5° C). Several rivers were notable for the cumulative breadth of valley bottoms – including the Liard, Kechika, Dease, and Finlay.

Table 9. Parameters for calculating the River Corridor Index (RCI) for climate-change resiliency in the Greater Muskwa-Kechika area, northern British Columbia. RCI = Δ MAT° C (VB/L – RI/L).

River	Δ MAT° C	Length (L) (km)	Valley Bottom (VB) (km^2)	Road Impact (RI) (km^2)	River Corridor Index	RCI Normalized
Gataga	4	183.3	76.2	0.0	166.2	100.0
Racing	4	101.2	39.1	3.7	139.8	84.1
Muskwa	2	256.1	122.2	0.2	93.5	56.2
Toad	3	138.7	81.2	15.8	92.7	55.8
Dease	1	256.3	204.0	4.7	77.8	46.8
Liard	1	504.0	436.6	47.2	77.3	46.5
Kechika	1	342.5	246.3	0.3	71.8	43.2
Kwadacha	2	133.3	47.6	7.4	70.3	42.3
Rabbit	2	166.9	56.6	0.7	67.0	40.3
Frog	2	105.7	32.2	0.0	60.9	36.7
Blue	2	145.4	44.8	0.9	60.4	36.4
Finlay	1	261.1	160.5	10.5	58.6	35.3
Fox	1	102.9	46.4	0.4	44.7	26.9
Ingenika	1	141.1	56.7	2.2	39.3	23.6
Sikanni Chief	1	97.8	39.5	1.8	38.6	23.2
Turnagain	1	208.6	79.5	0.9	37.7	22.7
Eagle	1	97.6	35.4	0.0	36.3	21.8
Dunedin	1	196.0	62.6	0.6	31.6	19.0
Ospika	1	211.5	38.2	2.4	25.4	15.3
Grayling	1	127.0	19.0	0.3	14.7	8.9

Figure 18. Location and relative ranking of river valleys as climate-corridors for adaptation to warming climate, Greater Muskwa-Kechika area, northern British Columbia.



Headwater Refugia at the Crown of Watersheds

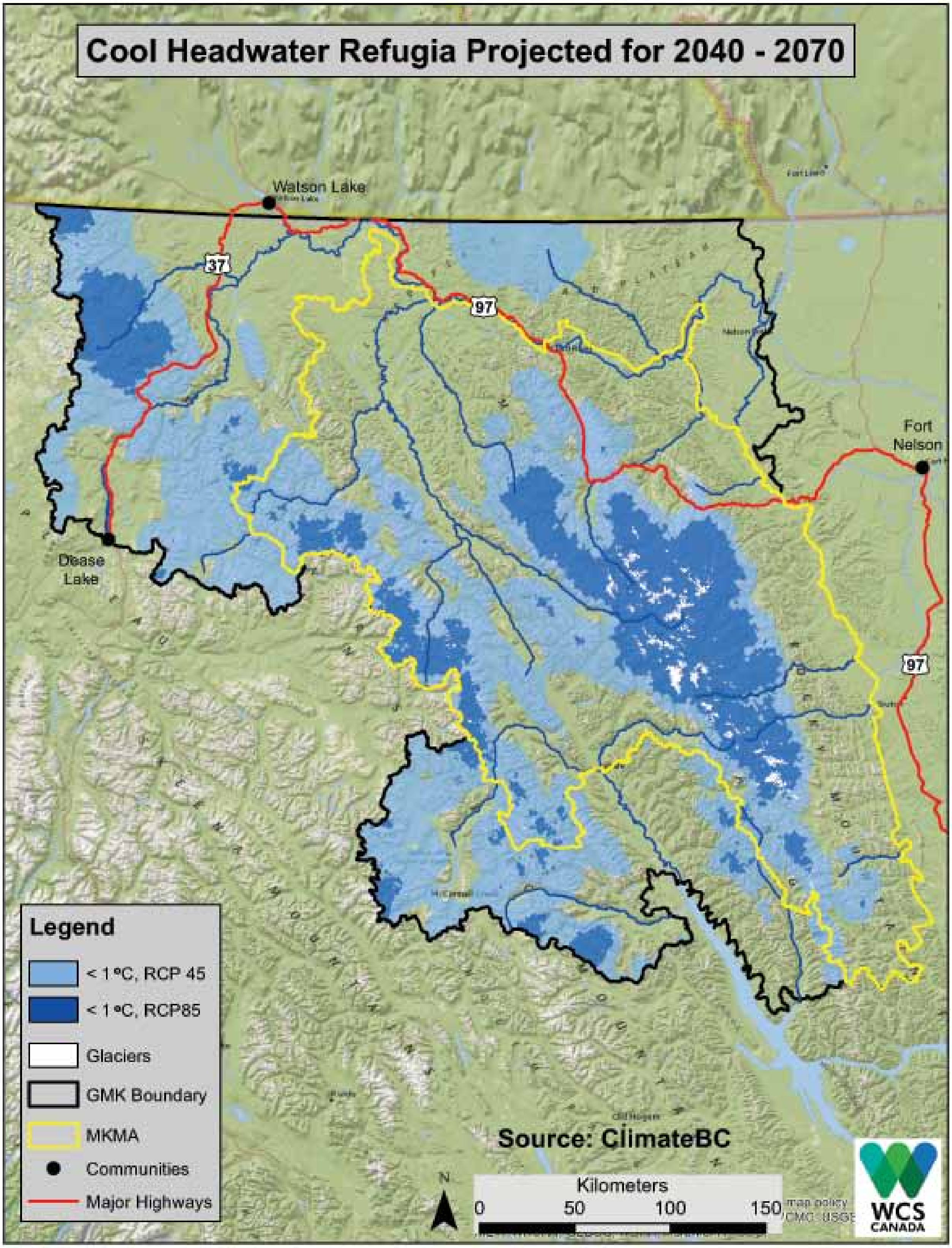
Headwaters – literally the fountains at the crown of the earth – are keystone sections of rivers. The diversity of life in headwater streams contributes to the biodiversity of a river system and its riparian network (Alexander et al. 2007, Meyer et al. 2007). Headwaters provide (1) a refuge from temperature and flow extremes, as well as from competitors, predators, and introduced species; (2) serve as a source of colonists; (3) provide spawning sites and rearing areas; and (4) create migration corridors throughout the landscape. In the context of warming climate in the future, headwater areas will also provide cooler refugia – sites that can support isolated populations of species within favorable micro-climates during periods of unfavorable regional climate (Carroll et al. 2017). Macro-refugia for forests and songbirds in North America were concentrated in western mountains (steep elevation gradients), especially in the headwaters (Stralberg et al. 2018). Degradation and loss of headwaters and their connectivity to ecosystems downstream threaten the biological integrity of entire river networks (Hauer et al. 2007). Headwaters are emphasized rightly so in the BEACONs project (Lisgo et al. 2017).

We delineated refugia in the headwater sections of watersheds based upon a simple proposition: that the threshold of Mean Annual Temperature (MAT) that characterizes <u>all</u> of the Greater Muskwa-Kechika area <u>currently</u> may reasonably serve as suitable refugia as temperatures escalate in the future. Currently, that MAT threshold is ≤1 °C (refer back to Figure 7b). We then used ClimateBC to model MAT for the time period 2040-2070 under the scenarios rcp 45 and rcp 85. Cooler refugia so delineated comprise 47.1% of the Greater Muskwa-Kechika under the rcp 45 scenario, but shrink down to 13.7% under the hotter scenario rcp 85. Not surprisingly, they are found at the upper elevations of the major watersheds (Table 10, Figure 19). The more persistent cool refugia will likely be in the Rocky Mountains section of the Greater Muskwa-Kechika, an area where most of the remnant glaciers are found today. Others closer to the Continental Divide seem likely to persist as well.

Table 10. Area (km^2) of cool climate refugia, Greater Muskwa-Kechika area, northern British Columbia.

Scenario	Area (km^2)	Percent
rcp 45	56,258	47.1
rcp 85	16,303	13.7

Figure 19. Areas where future temperatures remain at levels that typify current temperatures (<1° C) across the Greater Muskwa-Kechika area may serve as cool refugia. These refugia are located in the headwater sections of the watersheds.



Ecological Representation: Ecoregions and Ecosections

The complexity of ecosystems in North America have been stratified into various hierarchical levels using different approaches. In such hierarchical classifications, climate might dominate at continental scale, geodiversity might be strongest at mid-sized spatial extents (landscape to region), whereas biotic interactions might dominate at local extents (Lawler et al. 2015). The middle/lower levels have been used widely for assessment at regional scales (Groves 2003). The Convention on Biological Diversity (2010) recommends that Protected Area networks be representative of ecoregions as the appropriate conservation feature and level for Aichi Target 11 for 2020.

In British Columbia, the *Ecoregion Classification* system is used to stratify the Province's terrestrial and marine ecosystems into discrete geographical units at five hierarchical levels or scales (Demarchi 2011). The two lower levels – Ecoregions and Ecosections – are progressively more detailed and narrower in scope and relate segments of the Province to one another. They describe areas of similar climate, physiography, hydrology, vegetation and wildlife potential. Within each terrestrial ecoregion, biogeoclimatic zones occur at different elevation zones due to the interaction of temperature and precipitation gradients. These zones are best defined within the Biogeoclimatic Ecosystem Classification system (Meidinger and Pojar 1991).

Ecoregions have major physiographic and minor macroclimatic variation. mapped at 1:500,000 for regional planning. There are 7 ecoregions within the Greater Muskwa-Kechika area. *Ecosections* have minor physiographic and macroclimatic variations (Table 11, Figures 19). Some 19 ecosections occur within the Greater Muskwa-Kechika area mapped at small scales (1:250,000) for resource planning (Figure 20). In this report, I will emphasize **ecoregions** for their ecological importance and appropriate scale for strategic planning. (Note: Physiographic Provinces mapped by Holland (1964) [used by Kehm and Pojar in the Y2Y 2012 report] are quite similar to the mapping of ecoregions/ecosections in the Greater Muskwa-Kechika.)

The longitudinal axis of the boreal mountains in northern British Columbia is oriented southeast↔northwest; hence, the diversity of ecoregions runs across the GMK in an east↔west gradient. The Rocky Mountain Trench – a major landscape feature of British Columbia – also runs this same direction and bisects the study area. The Rocky Mountains are east of the trench, and the Cassiar and Omineca Mountains occur west of the trench. At the north end of the Greater Muskwa-Kechika area, the Liard River valley presents a major break in the northward extension of these mountain ranges. Here, a low-elevation boreal plain comprises much of the Liard Basin. Going eastward, the Liard Plateau rises up some 1000 m in elevation as a distinctive feature.

Below, I provide a synopsis of the various ecoregions extracted from the report An Introduction to the Ecoregions of British Columbia by Dennis Demarchi (2011). Refer to Table 11 for extent of ecoregions and ecosections and Figures 20 and 21 for maps of distribution. Existing protected areas vary in their representation of ecoregions from 15% - 29% for the mountainous ecoregions but only 5% - 7% for the lowland boreal plains and plateaus (Table 11).

Table 11. Extent of ecoregions and ecosections across the Greater Muskwa-Kechika area, northern British Columbia. Percent of ecoregion within Existing Protected Areas (EPAs).

Ecoregion and Ecosection	Area (km^2)	Percent	% in EPAs
Pelly Mountains (PEM)	**4,836**	**4.1**	**-**
Tuya Range	4,836	4.1	
Boreal Mountains and Plateaus (BMP)	**42,776**	**35.8**	**14.9**
Cassiar Ranges	14,439	12.1	
Finlay River Trench	1,287	1.1	
Kechika River Trench	1,407	1.2	
Kechika Mountains	6,350	5.3	
Northern Omineca Mountains	12,832	10.8	
Southern Boreal Plateau	3,648	3.1	
Stikine Plateau	2,813	2.4	
Liard Basin (LIB)	**12,616**	**10.6**	**4.5**
Liard Plain	12,429	10.4	
Simpson Upland	187	0.2	
Hyland Highland (HHI)	**5,034**	**4.2**	**7.2**
Hyland Plateau	5,034	4.2	
Northern Canadian Rocky Mountains (NRM)	**40,752**	**34.1**	**29.5**
Eastern Muskwa Ranges	16,941	14.2	
Muskwa Foothills	10,350	8.7	
Rabbit Plateau	3,335	2.8	
Western Muskwa Ranges	10,126	8.5	
Central Canadian Rocky Mountains (CRM)	**5,004**	**4.2**	**19.4**
Misinchinka Ranges	3,320	2.8	
Peace Foothills	1,684	1.4	
Muskwa Plateau (MUP)	**8,354**	**7.0**	**6.8**
Muskwa Upland	7,599	6.4	
Sikanni Chief Upland	755	0.6	
SUM	**119,371**	**100.0**	

Figure 20. Location of ecoregions across Greater Muskwa-Kechika area, northern British Columbia. See Table 11 for names and acronyms of ecoregions.

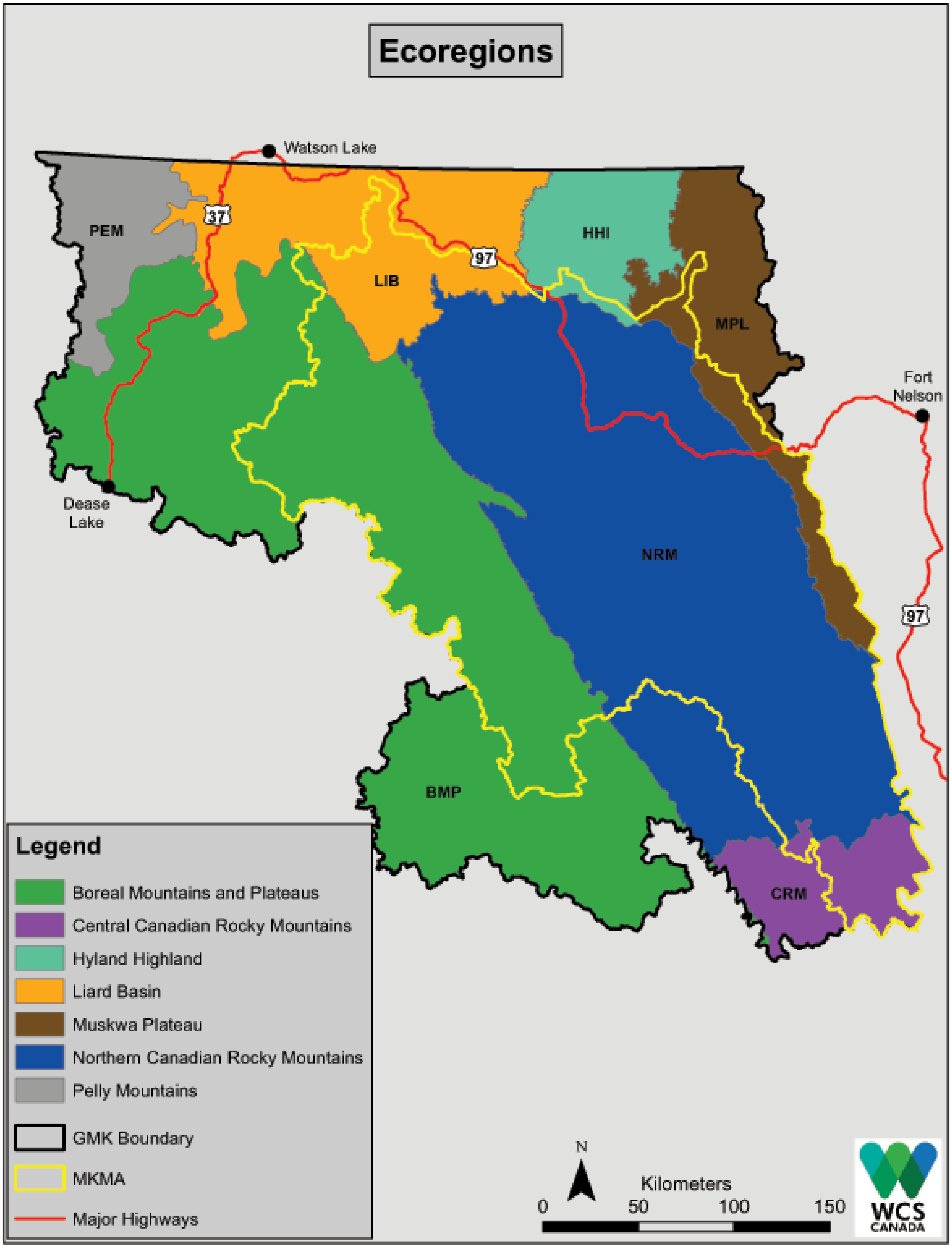
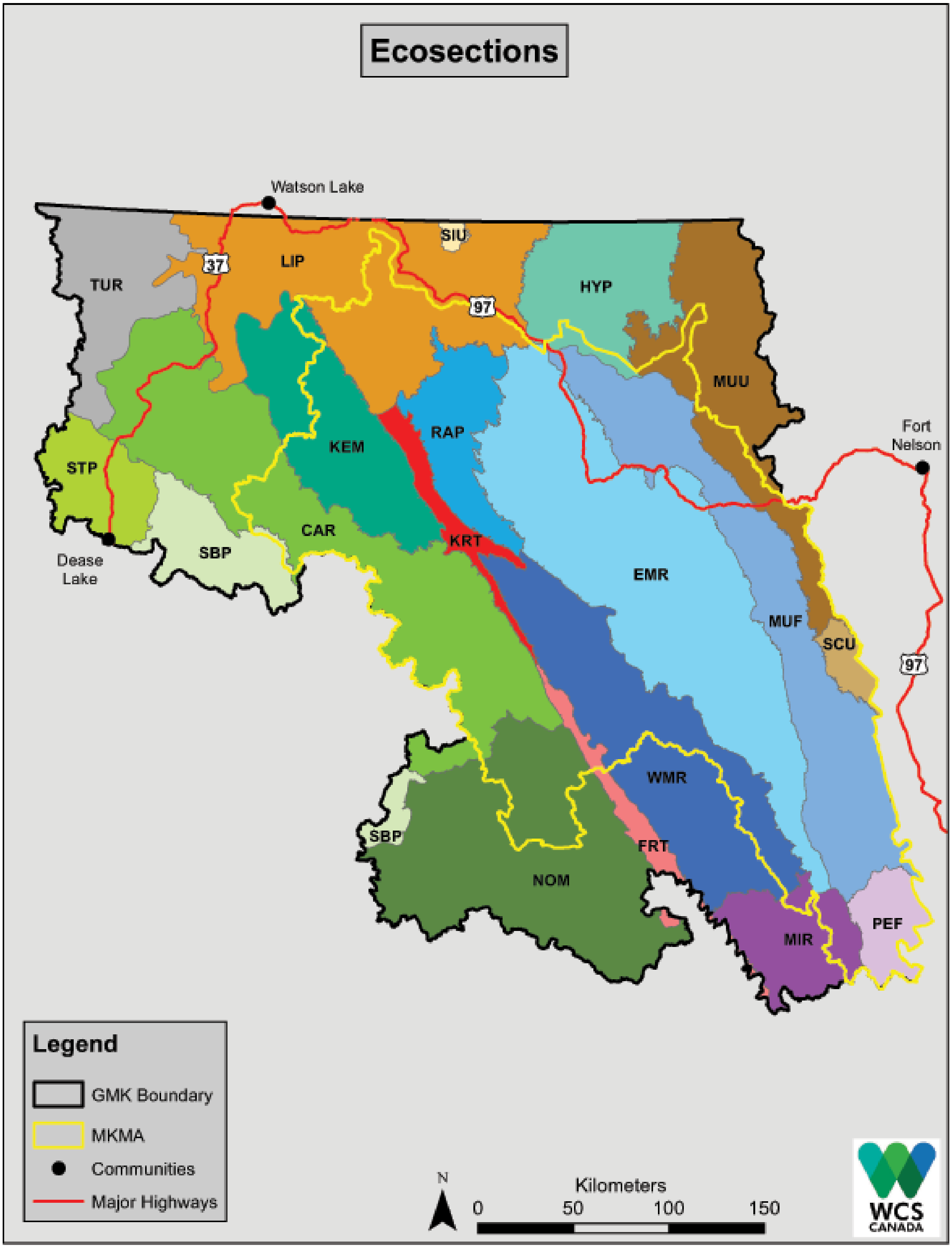


Figure 21. Location of ecosections across Greater Muskwa-Kechika area, northern British Columbia. See Table 11 for names and acronyms of ecosections.



Boreal Mountains and Plateaus (BMP) Ecoregion – 35.8% of GMK

This large ecoregion west of the northern Rocky Mountain Trench is characterized by a complex of rugged mountains and riverine valleys, as well as high, rolling plateaus. At higher elevations, barren rock is not uncommon. Winters are long and persistent, with frequent outbreaks of Arctic air; the growing season is relatively short.

Vegetation is characterized by 3 biogeoclimatic zones, which are prevalent across the entire Greater Muskwa-Kechika: (1) Boreal White and Black Spruce (BWBS) throughout the valley bottoms and extensive plains, (2) Spruce-Willow-Birch (SWB) in the higher valleys and middle slopes of the mountains, and (3) Boreal Altai Fescue Alpine (BAFA) zone on the upper slopes, ridges, and plateaus of most mountains.

Lower elevations are usually forested with white spruce and subalpine fir, which dominates on higher slopes. Permafrost may be found in some valleys, and massive cold air pooling leads to a mosaic of shrubfields, fens and open grassland complexes. Upper elevations of the extensive subalpine zone are essentially a scrub/parkland, dominated by scrub birch and several willow species. Wetlands are usually rich, with white spruce, tall willows, scrub birch, sedges and cottongrass. Subalpine grasslands (fescue) are frequent, on either steep south-facing slopes, or on flat to gently rolling uplands. Alpine tundra (BAFA) is widespread ranging from extensive, sparsely vegetated or lichen-covered rocks at highest elevations to alpine grasslands, wet herb meadows, and dwarf shrub elsewhere.

A notable part of this ecoregion is the **Northern Rocky Mountain Trench**. The Rocky Mountain Trench is a remarkable physiographic unit formed by a stick-slip displacement fault which extends in a NW⇔SE (340°) direction for ~ 1500 km across nearly all of British Columbia. With its inter-montane position, the portion of the Rocky Mountain Trench from Williston Reservoir southward is occupied by people and associated developments. The Northern Rocky Mountain Trench bisects the Greater Muskwa-Kechika area. The ***Finlay River Trench ecosection*** extends for 130 km and varies from 12 km in width at the upper end of Williston Reservoir to 6 km at Sifton Pass north of Kwadacha. It is especially rich in small lakes and wetlands. The ***Kechika River Trench ecosection*** extends for 147 km and varies from 12 km wide at the northern end (where the Turnagain River comes in) to 6 km wide at its headwaters at Sifton Pass. <u>There are no roads or human settlements here</u>.

The Cassiar Ranges ecosection has mountain ranges with a core of granite that has intruded into folded sedimentary and volcanic layers. Glaciers carved out many cirque basins. This area is affected by moist Pacific air to the west that brings heavy rain throughout the summer and into the fall, followed by extremely cold temperatures and heavy snow in winter. The climate of the ***Northern Omineca Mountains ecosection*** to the south is similar but the geology is more diverse.

East of the Cassiars, the ***Kechika Mountains ecosection*** exhibits more rounded mountains built of folded sedimentary quartzite, limestone, and slate.

The ***Southern Boreal Plateau ecosection*** consists of several deeply-incised plateaus and wide river valleys. A distinctive feature is the close juxtaposition of different bedrock types at the head of the Turnagain River and Eagle River. The ***Stikine Plateau ecosection*** in the upper Dease River watershed is a partly dissected upland with wide-flaring valleys and rounded ridges formed on folded sedimentary and volcanic rocks.

Northern Canadian Rocky Mountains (NRM) Ecoregion – 34.1% of GMK

This large ecoregion lies east of the northern Rocky Mountain Trench and is comprised of high, rugged mountains and rounded isolated foothills separated by wide valleys. It can experience extremely cold temperatures and heavy cloud cover for extended periods. Cold Boreal White and Black Spruce forests are limited to the lower valleys. The Spruce – Willow Birch zone dominates the middle and higher valleys and lower to mid slopes. The alpine (BAFA) zone is extensive, but vegetation is generally sparse and barren rock is common with elevation.

The ***Western Muskwa Ranges ecosection*** is an area of deep, narrow valleys and rugged, limestone mountains east of the northern Rocky Mountain Trench. This area has a cold, wet climate caused by Pacific air passing over low mountain ranges bringing heavy rainfall or snow.

The ***Eastern Muskwa Ranges ecosection*** has the highest, most rugged mountains and the only glaciers in the Greater Muskwa-Kechika area. The castellated mountains are composed primarily of limestone rocks. Several large glaciers remain on the highest summits – especially at the head of the (1) Toad-Racing and Gataga Rivers, (2) Tuchodi-Muskwa and Kwadacha Rivers, and (3) and Besa-Redfern and Akie Rivers.

The ***Muskwa Foothills ecosection*** lies further east and has more rounded, subdued mountains separated by wide valleys. These foothills are comprised of limestone, siltstones and sandstones that are folded and cut by southwesterly thrust faults. Spruce-Willow-Birch forests and shrublands are abundant in the valleys and lower to mid-elevation slopes. Alpine areas are small and scattered, but the vegetation is often lush grasses, though barren rock is common at higher elevations.

The ***Rabbit Plateau ecosection*** is a rolling upland composed of folded sedimentary rocks that have been greatly eroded by glaciers moving north up the Rocky Mountain Trench. The retreating glaciers left many drumlins and glacial deposits that have subsequently filled with small lakes, wetlands and muskeg. This area has some large rain shadows as it is protected from both moist Pacific air and from low-pressure storms in Alberta. Alpine areas are uncommon, and occurring only on the few highest ridges.

Pelly Mountains (PEM) Ecoregion – 4.1% of GMK

This ecoregion lies in the northwest corner of the Greater Muskwa-Kechika area. It is a rolling upland dominated by the SWB zone (mainly shrubs) in the valleys and lower slopes, and extensive areas of the BAFA alpine zone on the mid to upper slopes. It consists of granitic rocks (Cassiar batholith) that have intruded into folded sedimentary and volcanic rocks. The Little Rancheria River is the primary drainage on the B.C. side. Winters can be very cold, with heavy cloud cover for extended periods. Cold BWBS forests grow only in the wider Rancheria valley and a few of the other deeper valleys. SWB shrublands dominate the uplands. Extensive alpine areas contain lush grasses of the BAFA zone, but barren rock is common at higher elevations. It has only one ecosection, the Tuya Range.

Liard Basin (LIB) Ecoregion – 10.6% of GMK

The Liard Basin is a broad, glacial plain at low elevation in northern B.C. The area clearly shows the effect of glaciation with extensive drumlins, eskers, and lake-filled kettles. It is drained chiefly by the Liard River, which is joined by the Dease, Kechika, Rabbit and Trout rivers from the south and the Smith, Coal and Hyland rivers from the north. In the summer, surface heating of the many lakes and wetlands creates convective currents bringing localized showers, high humidity and cumulus clouds. In the winter and early spring, cold Arctic air can invade this area from the north, resulting in extremely cold temperatures and heavy cloud cover for extended periods. Black spruce grows commonly around wetlands and muskeg, while white spruce grows on the deeper alluvial soils. Lodgepole pine forests are prevalent due to frequent wildfires. Spruce-Willow-Birch forests and shrublands occur on the few higher uplands. The Liard Plain is the primary ecosection; only a tiny portion of the Simpson Upland ecosection extends south from the Yukon into B.C. Ecoregions like the Liard Plain may be more *susceptible* to climate changes due to their low topographic variability.

Hyland Highland (HHI) Ecoregion – 4.2% of GMK

This is a rolling plateau that rises up 1000 m above the lowlands in the Liard Basin to the west and those in the Muskwa Plateau to the east. This highland consists of rounded, flat-topped mountains underlain by sedimentary bedrock. It is drained by the Grayling and Smith Rivers. In the winter and early spring, arctic air can invade this area resulting in extremely cold temperatures and heavy cloud cover for extended periods. Spruce-Willow-Birch forests and shrublands dominate the uplands. A narrow band of alpine BAFA extends along the crest. Boreal White and Black Spruce forests grow on the lower slopes and along the Liard River valley, including the tributary Grayling River. It has only one ecosection, the Hyland Plateau.

Muskwa Plateau (MUP) Ecoregion – 7.0% of GMK

This is a rolling and hilly upland that lies between the Rocky Mountain Foothills to the west and the lower Fort Nelson Lowlands to the east. The upland consists of gently folded sedimentary bedrock, which often has been incised by the larger streams to expose shales. In the ***Muskwa Upland ecosection***, the Liard, Dunedin, Muskwa, and Prophet Rivers cut through the glacial till to form wide, intermountain valleys. On the eastern side, extensive muskeg, wetlands and small lakes dominate a surface that has remained unmodified since its emergence from the covering of Laurentide ice. In winter, arctic air can bring extended periods of clear skies and extreme cold. In summer, surface heating of the many wetlands and streams can generate convective showers, high humidity and cumulus clouds. The dominate forest type is the Boreal White and Black Spruce. Extensive fires over time has resulted in large areas of seral deciduous forests (aspen, balsam poplar, and birch) interspersed with black spruce bogs and wetlands. The deeply dissected river valleys of the Sikanni Chief, Buckinghorse, and Prophet Rivers differentiate the ***Sikanni Chief Upland ecosection***.

Central Canadian Rocky Mountains (CRM) Ecoregion – 4.2% of GMK

The Central Canadian Rocky Mountains ecoregion covers the southeastern portion of the Greater Muskwa-Kechika area, with drainages flowing into the Peace River. The upper surface of the continental ice-sheet once lay 1,800m - 2,100m thick on the mountains. Some of the rounded summits were overridden, with others little affected by alpine and valley glaciation. The combination of greatly lessened elevation and relief, different bedrocks and structure, and reduced alpine glaciation has resulted in a subdued topography. Just south of the Greater Muskwa-Kechika boundary, damming of the Peace River created the Williston Reservoir, forming a barrier to movements of terrestrial animals northward.

This ecoregion includes the ***Misinchinka Ranges ecosection*** east of the Finlay Reach of the Willinston Reservoir. Moist Pacific air often stalls over these mountains, resulting in high rainfall in summer and cold, heavy snowfall in winter. The ***Peace Foothills ecosection*** is a rounded, blocky set of mountains on the east side of the Rocky Mountains from the Halfway River south to Graham-Laurier Provincial Park. In the foothills, the valleys have eroded along belts of soft rock and fault zones and are generally wide and flaring. Pacific air spills over these mountains bringing moist, mild air to the eastern valleys, while arctic air moves unhindered southward bringing very cold, dense air to the western valleys and lowlands and heavy snowfall in the mountains. Low-pressure systems in central Alberta can push moist air westward causing heavy precipitation events, especially in the Rocky Mountain Foothills. The BWBS zone occurs in the outer eastern valleys; the SBS Zone occurs in the interior and western valleys, the Engelmann Spruce Subalpine Fir (ESSF) zone occurs on all the middle and upper mountain slopes; and the BAFA alpine zone occurs on the mountain summits. Logging and its attendant roads have occurred in many valleys, including the Ospika and Graham River basins.

Ecological Representation: Biogeoclimatic Zones

Biogeoclimatic (BGC) zones represent zonal ecosystems where certain plant and animal 'communities' are expected under the prevailing topo-climatic zones. There are 14 zones (and 76 subzones) in B.C. mapped at a general scale of 1:100,000 for biodiversity planning. Currently, 5 BGC zones occur in the Greater Muskwa-Kechika area (Table 12, Figure 22). Three biogeoclimatic zones predominate: (1) Boreal Altai Fescue Alpine (BAFA) up in the alpine, (2) Spruce-Willow-Birch (SWB) across the subalpine, and (3) Boreal White and Black Spruce (BWBS). The Engelmann Spruce-Subalpine Fir (ESSF) and Sub-boreal Spruce (SBS) zones comprise minor potions of the landscape. As climate changes through time, biogeoclimatic zones will also shift in response to changing patterns in temperature, precipitation, and disturbances depending upon elevation.

At present, the alpine zone (BAFA) covers 22% of the Greater Muskwa-Kechika. It is most contiguous and extensive in the Rocky Mountains east of the Rocky Mountain Trench, and there are even patches of alpine in the Rocky Mountain Foothills and the Hyland Highland (Liard Plateau) rising out of the boreal plain. The alpine zone becomes smaller and more fragmented in the Cassiar Mountains and Omineca Mountains to the west of the Rocky Mountain Trench.

In subalpine areas, the Spruce-Willow-Birch zone comprises 41% of the Greater Muskwa-Kechika. Currently, it covers not only the mountain plateaus and slopes but also higher valleys in the mountains and foothills. In the southern part of the GMK, the ESSF zone comprises 8%, whereas the SBS covers <1% east of Williston Reservoir.

The BWBS zone covers 29% of the GMK. It is the principal forest type across the boreal plains in the northern sector, lower plateaus and northern foothills, and the northern Rocky Mountain Trench.

Table 12. Area (km^2) of current and future biogeoclimatic zones (BGC), Greater Muskwa-Kechika area, northern British Columbia.

	2020		2080	
Biogeoclimatic Zone	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
Boreal Altai Fescue Alpine (BAFA)	26,574	22.28	7,838	6.58
Boreal White and Black Spruce (BWBS)	34,080	28.58	48,518	40.73
Engelmann Spruce Subalpine Fir (ESSF)	9,138	7.66	38,500	32.32
Interior Cedar Hemlock (ICH)	-	-	5,738	-
Sub-Boreal Spruce (SBS)	695	0.58	9,051	7.60
Spruce Willow Birch (SWB)	48,749	40.88	9,484	7.96
SUM	**119,236**	**100.0**	**119,129**	**100.0**

*see text for BGC types. Some trace and doubtful occurrence of projected future zones not included.

Due to climatic warming in the coming decades, the BAFA zone in alpine area is projected to decrease from 23% to 7% of the Greater Muskwa-Kechika area by the year 2080 (Table 12, Figure 23) (Wang et al. 2012). The SWB in the subalpine may decrease from 41% to 8%. The Engelmann Spruce – Subalpine Fir (ESSF) is projected to expand substantially (4-fold) across the GMK, displacing the SWB in the subalpine in the Rocky Mountains and upper Finlay River (Figure 22). The BWBS is projected to expand more modestly (40%), displacing SWB at mid-elevations in some areas. It's important to note that eminent plant ecologists in B.C. suggest that such changes may be delayed and/or limited due to inherent resistance of certain zones in certain areas (J. Pojar, *personal communication*). For example, Spruce-Willow-Birch may persist in cold-air drainage sites, and Boreal White-Black Spruce may continue in water-laden soils in lowland sites. Nonetheless, shrinkage of the BAFA zone in the alpine may impact Stone's sheep and northern woodland caribou, whereas diminished occurrence of SWB in subalpine could impact moose populations. In the Yukon, alpine and subalpine vegetation zones could be much reduced in Yukon mountains by the end of the century, too (Rowland et al. 2016).

In terms of representation of the current biogeoclimatic zones, existing protected areas include about 21-22% of the alpine BAFA and the subalpine SWB. The lowland boreal types BWBS have lower representation at 13% (Table 13).

Table 13. Representation of current biogeoclimatic zones in existing protected areas (EPAs), Greater Muskwa-Kechika area, northern British Columbia.

	Within EPAs	
Biogeoclimatic Zones	**Area (km^2)**	**Percent**
BAFA	5,833	21.96
BWBS	4,900	13.03
ESSF	869	9.52
SBS	-	-
SWB	9,266	20.50

Representation of ecoregions and biogeoclimatic zones is helpful in conservation planning, but it does not necessarily equate to adequate conservation of species nor issues of sufficient amount of area and location. So, we now turn to a suite of vulnerable fish and wildlife species whose biological needs may help guide the process of protecting and connecting key areas now and going forward into changing conditions (Visconti et al. 2019).

Figure 22. Location of biogeoclimatic zones/subzones across Greater Muskwa-Kechika area, northern British Columbia.

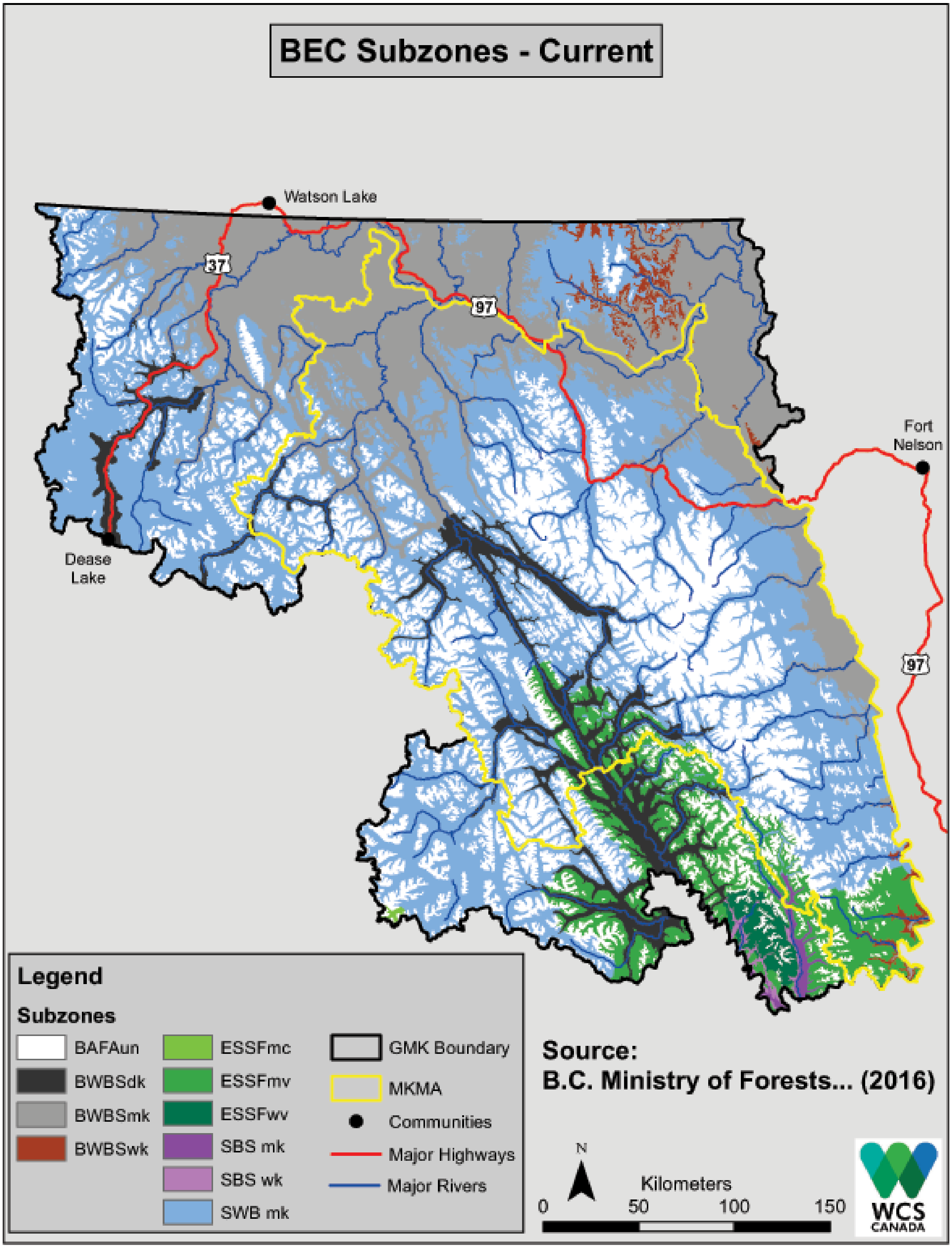
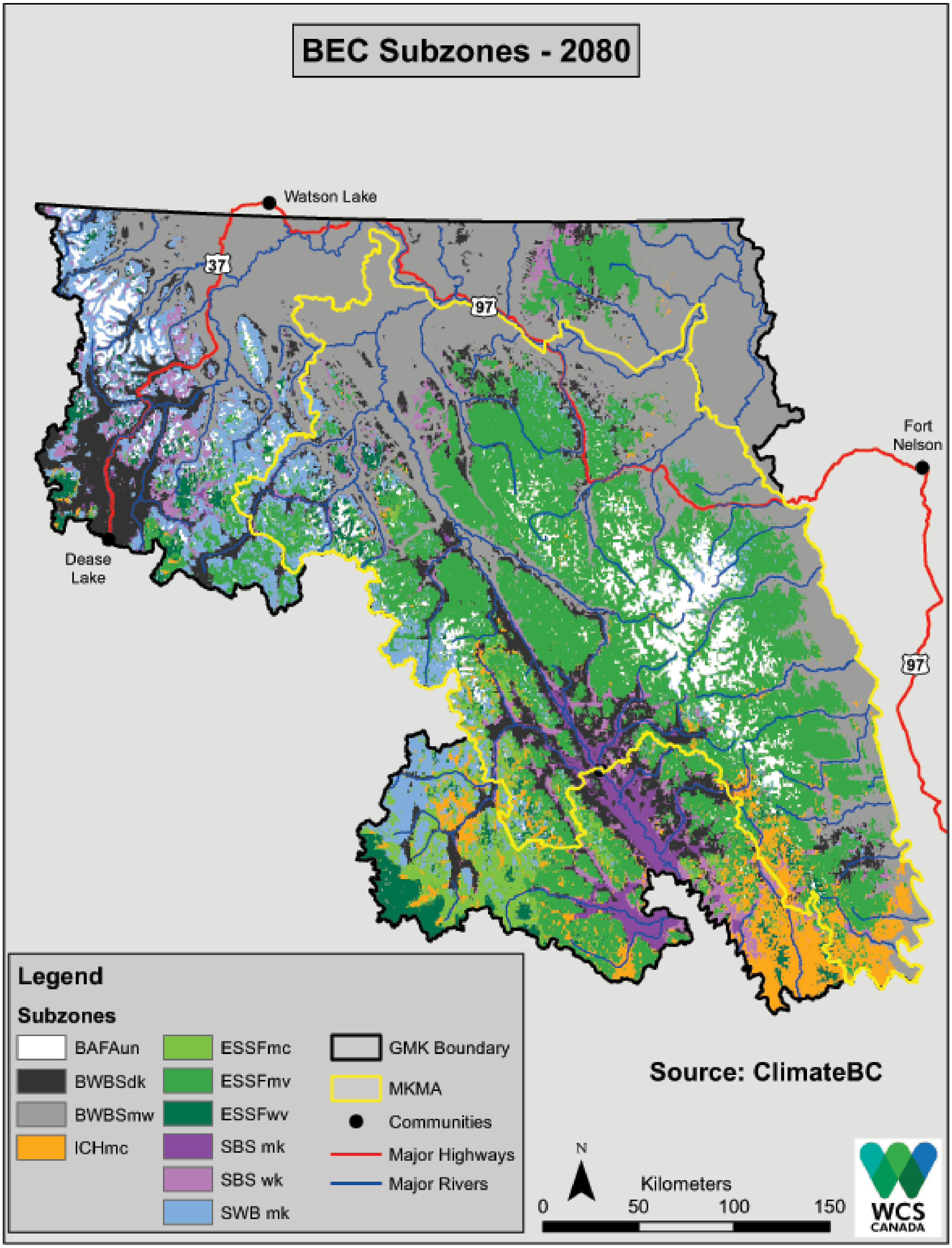


Figure 23. Projected shifts of biogeoclimatic zones/subzones by year 2080 across Greater Muskwa-Kechika area, northern British Columbia. Extensive shrinkage of alpine types is likely but projected expansion of ESSF types is more problematic, depending upon disturbance.



4. SENTINELS OF THE WILD: VULNERABLE FISH AND WILDLIFE SPECIES

Introduction

After consideration of Nature's stage, the next act in conservation planning is to bring the actors onto that stage (Lawler et al. 2015). Because it's not feasible to plan for each and every animal species, the Wildlife Conservation Society wove together several lines of contemporary thinking into a concept called 'landscape species' (Sanderson et al. 2002). It is based on the notion that species that use large, ecologically diverse areas can serve as useful surrogates for conservation of other species. For example, woodland caribou can provide an 'umbrella' cover for biodiversity of mammal and bird species across boreal landscapes (Drever et al. 2019). Importantly, a suite of species is chosen considering area requirements, heterogeneity of habitats, ecological functionality, and socioeconomic significance. For assessing the conservation value of the Greater Muskwa-Kechika area, I selected the following suite of fish and wildlife species: bull trout (*Salvelinus confluentus*), moose (*Alces alces*), Stone's sheep (*Ovis dalli stonei*), and woodland caribou (*Rangifer tarandus*). As a group, these species represent both aquatic and terrestrial habitats, a full range of elevation from river valley to mountain peak, prey species for predators such as wolves and grizzly bears, and importance for cultural and economic activities. These species are not only important from a conservation perspective but also to galvanize public interest and support. (Although I have used grizzly bear as a focal species in other assessments, I decided not to include it here due to lack of available data.)

Vulnerability refers to the susceptibility – or lack of resilience – of species to disturbances of various kinds. Over millennia, animals have persisted by a variety of mechanisms that buffered environmental disturbance at various spatial and temporal scales. Certain species have life history and spatio-ecological traits that make them vulnerable to human impacts, including climate change (Weaver et al. 1996, Pearson et al. 2014). What factors contribute to their vulnerability? How sensitive and how much flexibility does the species have to adjust to changes in the contemporary scene?

Vulnerability Profiles and Mapping Key Conservation Areas

Species can be considered as nested hierarchies of individuals, populations, and meta-populations in which the higher levels provide context for mechanisms at lower levels. Because disturbances occur at different spatial and temporal scales, no single level of organization provides sufficient response to all disturbances. Hence, the nested structure increases resilience by linking the system across hierarchical levels (Pickett et al. 1989). Following Weaver et al. (1996), I postulate a basic mechanism of resistance or resiliency at each of three hierarchical levels: individual, population, and metapopulation.

At the individual level, an animal can exhibit physiological tolerance to changes in environmental conditions or behavioral flexibility in food acquisition and selection of habitat. For example, in the face of environmental change, an individual may substitute one resource for another in its diet, thereby ameliorating flux in food availability.

At the population level, native fish may have little resistance to invasion by non-native fish and are vulnerable to hybridization and/or competition. Some mammals cannot readily compensate for excessive mortality with increased reproduction and/or survivorship, and populations will decline. High survivorship and longevity of adult females typically is critical to the continued well-being of many mammal populations.

At the metapopulation level, dispersal enables animals to augment an existing population or re-colonize an area where a population has been extirpated. Dispersal usually refers to movements by juvenile animals when leaving their natal range after reaching the age of independence (adults occasionally disperse, too). Dispersal is successful only if the individual survives, establishes a home range, finds a mate and produces offspring that survive through maturity. In landscapes fragmented by human disturbance, successful dispersal is the mechanism by which declining populations are supplemented, genes are shared across the landscape, and functional connectivity of meta-populations is established and maintained (Hanski 1999).

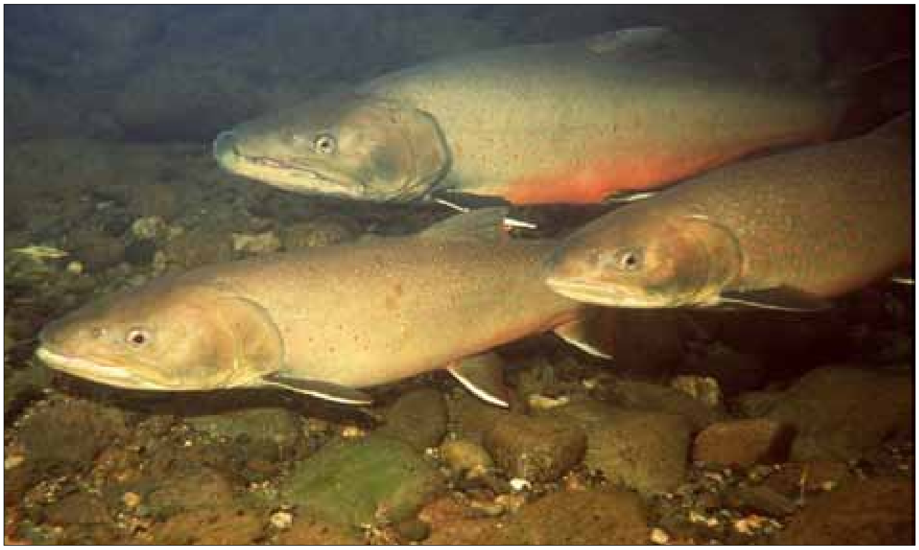
In reference to human disturbance, niche flexibility addresses the problem of loss or change in habitat conditions. Capacity for greater productivity enables populations to compensate for overexploitation or to come through population or genetic 'bottlenecks' more quickly. Dispersal addresses the problem of habitat fragmentation at a landscape scale. Resiliency, however, have definite limits. As human activities accelerate rates of disturbance across a greater extent of the landscape, the combination of rapid change and simplification can undermine the evolved resiliency and negatively impact populations. Cumulative effects can accrue that threaten their persistence. One of the key messages of resilience thinking is to *keep future options open through an emphasis on ecological variability across space and time*, rather than a focus on maximizing production over a short time (Walker and Salt 2006).

In this section, I use this framework of resilience to assess vulnerability for each of the 4 species of native fish and wildlife – bull trout, moose, Stone's sheep, and northern woodland caribou. Each profile addresses the following factors: (1) niche flexibility, (2) resistance to hybridization (fish) or reproductive capacity and mortality risk (mammals), (3) dispersal and connectivity, (4) sensitivity to human disturbance, and (5) response to climate change.

Next, I describe the data sources and methods for modelling and mapping key habitat for the species. I developed a scoring system to quantify the conservation values for each species. The scoring system comprised 3 relative ranks: High Importance = 3, Moderate Importance = 2; and Low Importance = 1.

I customized the scoring criteria for each species to reflect attributes that are important to the long-term persistence of that species – with particular consideration of changes in future conditions due to warming climate. It is important to keep in mind that areas with moderate (or sometimes low) scores may be vital because the species is listed as a threatened species or special concern (bull trout, northern woodland caribou), iconic prominence (Stone's sheep), or is a foundation species important to indigenous/local cultures (moose). Details of the scoring system are provided under each species. I used the scored maps to identify key conservation areas for each species. Although synthesis of existing information was central to this assessment, I made several reconnaissance flights over the remote sections of the vast Greater Muskwa-Kechika area and spent numerous days on the ground to evaluate habitat conditions.

Bull Trout (*Salvelinus confluentus*)



U.S. Fish & Wildlife Service

The Western Arctic population of bull trout (including northern B.C.) was assessed as a species of ***Special Concern*** by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2012). On March 23, 2019, the Federal government added the Western Arctic population to schedule 1 of the Species at Risk Act (SARA) as a ***Species of Special Concern***. The province of British Columbia offered its support for the listing of the species.

Vulnerability = High

Niche Flexibility: Bull trout select streams that are cold, clean, complex, and connected. In fact, they are one of the most thermally-sensitive coldwater species in western North America. Laboratory studies suggest that peak growth occurs between 10° and 15° C (Selong et al. 2001). Published studies indicate that maximum temperatures during the August-September spawning period are typically <13° C (Dunham et al. 2003, Jones et al. 2014). Based upon extensive stream sampling in the Flathead River basin of Montana and southeast British Columbia, researchers reported that 94% of the spawning habitat had August stream temperatures > 8° C but < 13° C (Jones et al. 2014). The Montana researchers defined foraging, migrating, and over-wintering suitability as <14° C. Alberta fishery biologists selected 7.7° C to 12.4° C as suitable for juvenile occupancy (Alberta Environment and Parks 2013)

Hybridization and Competition: Bull trout are susceptible to hybridization by brook trout (*S. fontinalis*), resulting in mostly sterile hybrids. Brook trout also displace bull trout from streams at lower elevations, particularly as waters warm (McMahon et al. 2007, Warnock and Rasmussen 2013) yet appear less likely to penetrate the shield of cold headwaters (Isaak et al. 2015).

Migration and Connectivity: Some adult bull trout in the Rocky Mountains migrate long distance (hundreds km) from wintering areas in lower rivers to spawning areas in the headwaters; dams and poorly-installed hanging culverts can block vital connectivity (Warnock 2008).

Sensitivity to Human Disturbance: Bull trout are vulnerable to a wide range of human impacts. The combination of slow growth, late age at maturity, low fecundity, longevity, and high catchability render bull trout particularly susceptible to overfishing, even with per-capita angler restrictions (Post et al. 2003). Improper timber harvesting practices and associated roads/culverts can increase sedimentation into spawning streams, block access for trout, remove riparian cover and increase stream temperatures (Ripley et al. 2005, Hagen and Decker 2011). Roads also increase ready access for angler mortality and poachers –particularly in small lakes and tributary streams where bull trout are especially vulnerable (Parker et al. 2007). Dams can block fish movements and alter temperatures and flow regimes downriver, resulting in genetic isolation and loss of migratory populations that require diverse, connected habitats for different life stages (Muhlfeld et al. 2011).

Response to Climate Change: Warming climate may heat lower elevation streams beyond the tolerance of bull trout, resulting in smaller, more isolated and less viable populations. Some of the most dramatic increases in stream temperatures could occur in areas that are burned severely by wildfire and lose the shading cover of streamside trees and tall shrubs (Issak et al. 2010).

Identifying cold-water 'climate shields' or refugia at higher elevations is an important, proactive step toward long-term conservation of bull trout (Issak et al. 2015). Within the mountains of the northwestern United States, streams warmed at half the rate of air temperatures during 1968–2011 (Isaak et al. 2016). Many genetically-pure populations of bull trout occur in headwater streams where climatic conditions limit the upstream expansion of species like brook trout. These high-elevation areas serve as refugia for aquatic species that are constrained to stream networks and elevational retreat (rather than latitudinal) as temperatures increase.

Methods for Scoring Conservation Importance

Many streams in the remote headwater portions across the Greater Muskwa-Kechika have not been surveyed. Therefore, we modeled distribution of thermal suitability for (1) spawning and rearing (SR), and (2) adult occupancy in lower sections of rivers used for foraging, migrating, and/or over-wintering (FMO). Due to absence of available data on stream temperature, we followed the approach used by Alberta fishery biologists and modeled stream temperature as a 1:1 linear relationship with air temperature, which appears valid below a 10° C threshold (Isaak et al. 2016). We generated a grid of equally-spaced points (every 5 km) (n= 5,671) across the GMK study area in ArcGIS 10.3. Next, we extracted elevation for each point using a 25m DEM. In the program ClimateBC (Wang et al. 2018), we selected mean warmest month (August) temperature for the period 1981-2010. From the output, we created a continuous raster surface of August temperatures (100 m pixels) by extrapolating the point file by kriging. We mapped 3 classes of thermal suitability: (1) unsuitable habitat < 7.7° C, (2) spawning/rearing habitat with temperatures 7.7° to 12.4° C, and (3) adult occupancy 12.4° C to 15.0° C (maximum in the GMK area). Average temperatures for August across the GMK during 1981-2010 ranged from 3.2° C to 15.0° C.

We also plotted available records (n = 1,582 from B.C. Data Warehouse) of bull trout. (Note: Some of these records were labeled 'dolly varden', which were considered synonymous with bull trout until recently. The range of the Pacific population of dolly varden [*Salvelinus malma lordi*] does not appear to extend into the Liard River basin of the Muskwa-Kechika [COSEWIC 2010]). Most locations (88%) fell within the temperature range currently suitable for spawning/rearing; 11.3% occurred in warmer areas yet still suitable for occupancy. Only a few (0.7%) occurred in areas deemed too cold for reproduction.

Key Areas for Conservation

Mapping of thermal suitability suggests that about 83% of waterways across the Greater Muskwa-Kechika currently have suitable temperatures for spawning/rearing (Table 14, Figure 24, left panel). As temperatures continue to increase in coming decades, suitability of rivers and streams for spawning/rearing will shrink to about 53% (Figure 24, right panel). Most affected will be the Liard Basin, up the northern Rocky Mountain Trench, and lower elevations along the Rocky Mountain Foothills. These areas should remain suitable, though, for over-wintering and migration by bull trout. It's possible that the Liard River could become too warm even for occupancy.

A similar study was carried out on the effects of climate change on bull trout habitats in the Cariboo-Chilcotin region of central B.C. (Porter and Nelitz 2009). They also found that the (1) extent of coldwater habitats for bull trout will decrease considerably under the varied climate-change scenarios, and (2) extent of habitats considered thermally sub-optimal or potentially unusable by bull trout will increase. Coldwater habitats could disappear almost entirely from 2 of the 3 current strongholds for bull trout by the 2080s. As waters become warmer, identifying cold-water 'climate shields' or refugia at higher elevations is an important, proactive step toward long-term conservation of bull trout (Issak et al. 2015).

We also fashioned a map of streams with <u>known</u> records of bull trout and their most-proximate watershed (Figure 25). Looking ahead to a future of hotter temperatures in August, we assigned a high priority to headwater sections of streams that will remain thermally suitable (≤12° C) for spawning/rearing in the 2040-2070 period. Those areas where future conditions will still be suitable (13°-15° C) for occupancy (e.g., over-wintering) were assigned a moderate priority. Finally, those areas where bull trout reside today but may become unsuitable in the future were assigned a low value because they represent a place from which adaptive shifts will start.

Under current suitability of thermal suitability, existing protected areas include about 17% of spawning/rearing habitat and 21% of foraging/migrating/over-wintering (Table 15). Under warmer conditions in the future, however, the percent of SR habitat in EPAs is projected to decrease to 7%, while FMO habitat will increase to about 15%. Considering habitat suitability in a warmer future, existing protected areas include about 21% of both the high priority areas (spawning/rearing) and moderate value areas (foraging, migrating, over-wintering) (Table 15). Typically, future spawning/rearing habitat will persist primarily in the headwaters, whereas areas suitable for occupancy will be at the mid-elevation sections of major streams and rivers (Figures 24 and 25). As these suitable habitats diminish over time, bull trout will likely require larger areas to persist as viable populations than has been the case historically (Rieman et al. 2007).

Figure 24. Areas of suitable thermal habitat for bull trout currently (left panel) and future (right panel), Greater Muskwa-Kechika area, northern British Columbia. Colder areas suitable for spawning/rearing by bull trout may diminish by upwards of 36%, with refugia remaining in higher headwaters.

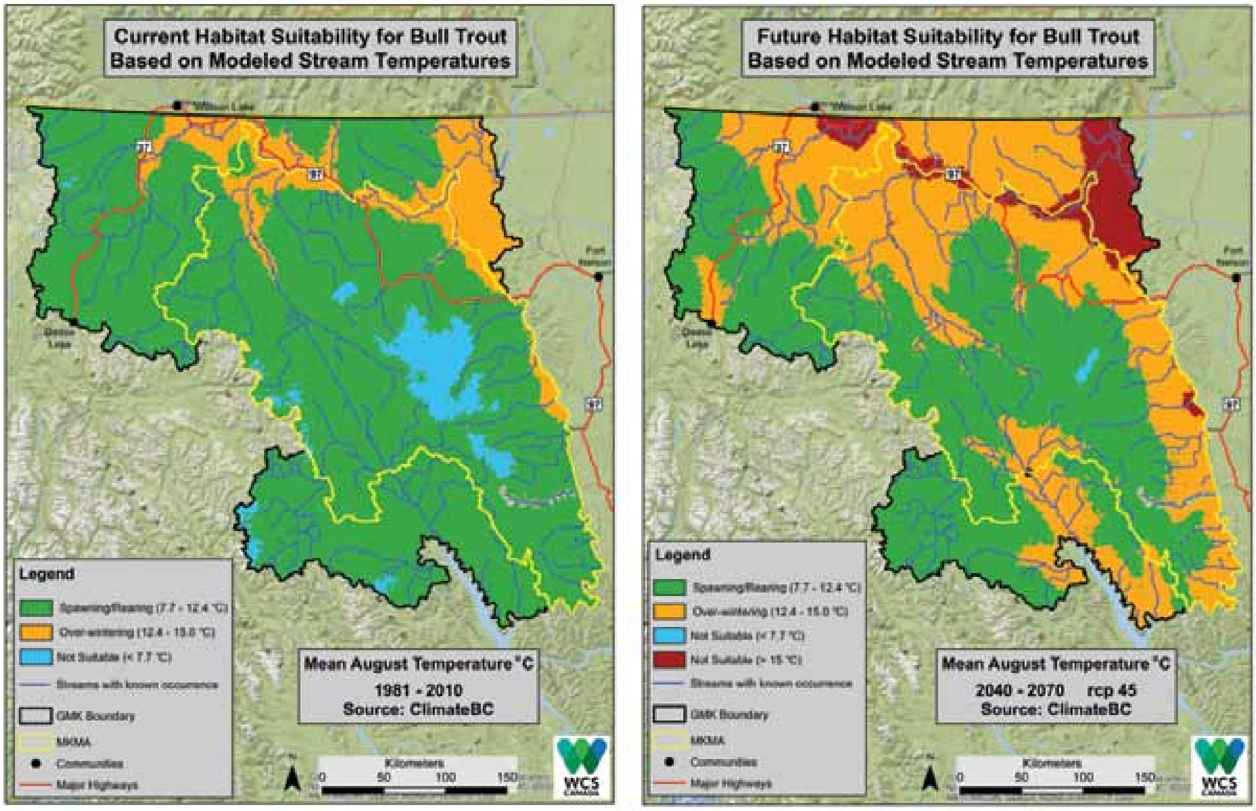


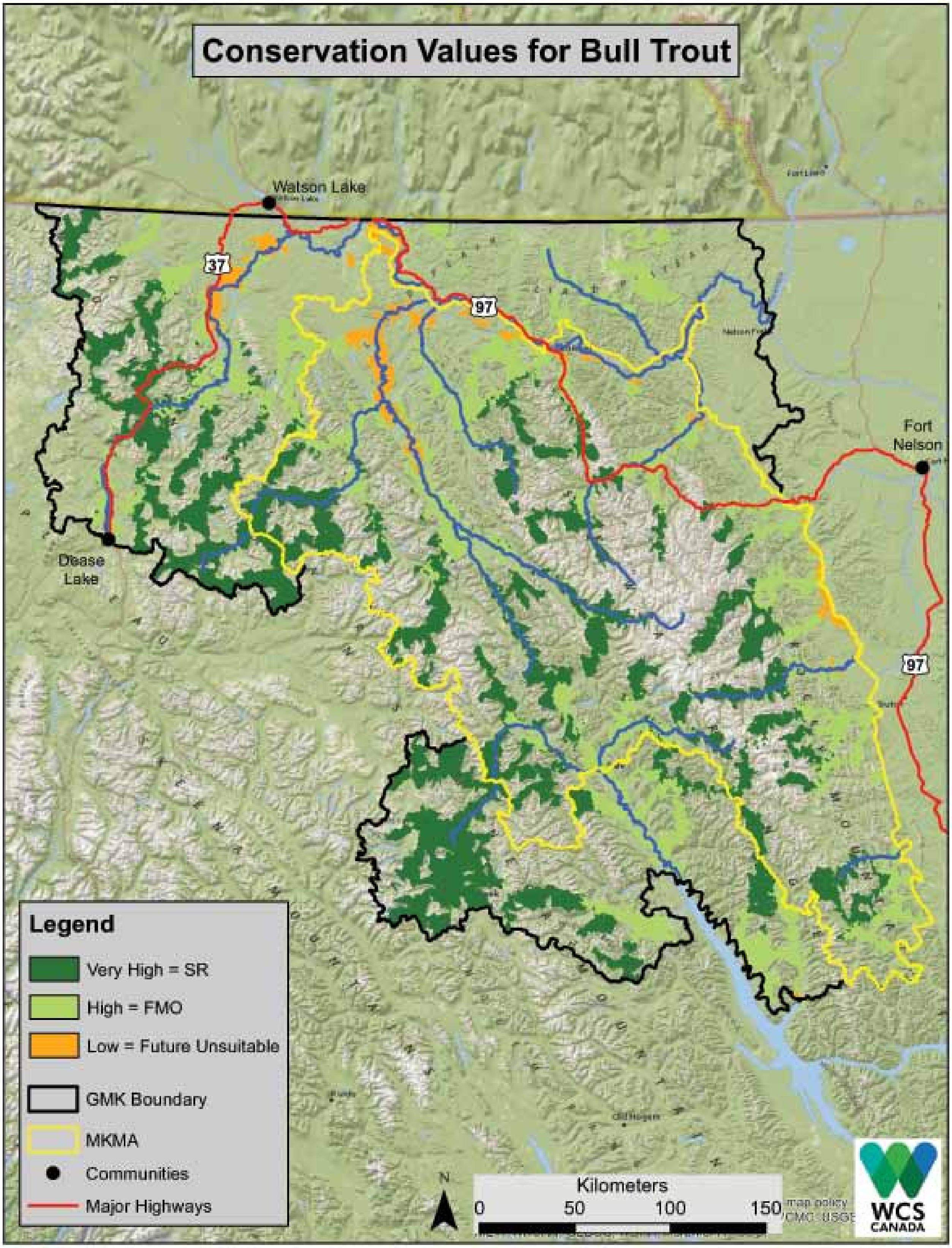
Table 14. Land area (km²) in which streams are projected to have suitable temperatures for bull trout, Greater Muskwa-Kechika area, northern British Columbia. SR = Spawning and Rearing, FMO = Foraging, Migration, and Over-winter. Future is 2040-2070 period, rcp 45.

	SR		FMO	
Land Area	**Current**	**Future**	**Current**	**Future**
Land Area (km²)	98,711	62,929	14,503	48,373
% of Land Area	82.7	52.7	12.1	40.5
% in EPAs	17.2	20.6	7.1	14.7

Table 15. Extent and proportion of top scores for bull trout in Existing Protected Areas (EPAs), Greater Muskwa-Kechika area, northern British Columbia.

	High = 3		Moderate = 2		Low = 1	
	Area (km²)	**Percent**	**Area (km²)**	**Percent**	**Area (km²)**	**Percent**
TOTAL GMK	19,029	15.9	13,845	11.6	2,057	17.2
Locations	914	57.8	283	17.9	42	2.7
TOTAL in EPAs	3,998	21.0	2,893	20.9	157	7.6

Figure 25. Key habitat where bull trout have been recorded, Greater Muskwa-Kechika area, northern B.C. Headwater streams that remain cold enough for spawning/rearing were accorded very high value, whereas those still suitable for foraging, migrating, and over-wintering were assigned high value.



Moose (*Alces alces*)

Susan Morse

Moose are a cultural keystone species for Indigenous peoples across Canada – a species vital for many northern communities for subsistence, cultural, and local economic values (Indigenous Circle of Experts 2018). Numerous examples of successful co-management of moose involving indigenous and non-indigenous governments have emerged across Canada in recent years (Popp et al. 2019). Managed as a 'big-game' species in British Columbia, moose are an ecological keystone species of boreal forests and play important roles in predator-prey dynamics and forest succession (Kuzyk 2016, Timmerman and Rodgers 2017).

Vulnerability = Low

Niche Flexibility: The widespread distribution of moose attests to their ability to use a variety of habitats and successional stages across boreal forests. Moose are generalist herbivores that feed on a variety of herbaceous plants, leaves and new growth of shrubs and trees in summer and twigs of woody vegetation during winter. Aspen, birch and willow constitute major portions of their diet across their range (Renecker and Schwartz 2007). During summer, aquatic plants associated with wetlands ponds may be important sources of sodium (Fraser et al. 1982). Riparian areas also provide a variety of tree and shrub species used for cover and forage, and moose may use willows extending up into the subalpine and alpine zone (Spruce-Willow-Birch: Gillingham and Parker 2008). Deeper snow in late winter often confines moose movements to smaller areas at low elevations where they feed on shrubs (Poole and Stuart-Smith 2006, Gillingham and Parker 2008, McCulley et al. 2017a). There can be considerable variation in selection of resources among individuals, especially during summer (Gillingham and Parker 2008). The affinity of moose for early-successional vegetation following timber harvests, however, comes at the expense of caribou because increased density of moose can attract/support more predators.

Reproductive Capacity and Mortality Risk: Moose usually have a high reproductive rate (Schwartz 2007). Across North America, adult pregnancy rate averaged 82-96% and 40-65% for yearlings, and twinning rates can range between 25% and 50%.

Dispersal and Connectivity: Young moose have capability to disperse upwards of several hundred kilometers, which enables them to exploit new habitats following fire or other disturbances in the boreal forest (Geist 1971, Hundertmark 2007). Because moose are susceptible to highway collisions, safe passages could be constructed in areas of concern.

Sensitivity to Human Disturbance: Although moose may be displaced by recreation activities such hiking and snowmobiling, responses tend to be of short duration (1-2 hours) (Neumann et al. 2011).

Response to Climate Change: Moose populations have been declining significantly in the southern portion of their range in north-central U.S., in part due to climate heating (Timmerman and Rodgers 2017). Moose appear sensitive to heat during spring and summer and spend more time resting (Ditmer et al. 2018). Climate heating may also be increasing the impacts of winter ticks (*Dermacentor albipictus*) on moose survival, especially calves (Rempel 2011, Weiskopf et al. 2019). Projected warming in winter may increase survival of these ticks, and rain events in winter could increase hypothermic mortality for moose with heavy tick loads (Musante et al. 2010).

Methods for Scoring Conservation Importance

To map suitable habitat for moose, we used seasonal habitat models (winter and spring→fall) constructed by Round River Conservation Studies (Heinemeyer et al. 2004:85-87). Young deciduous forests were rated important for foraging potential. Dense, mature forests were rated high for thermal cover in both seasons. During winter, forested habitats enable moose to escape deep snows. Wetland habitats were considered important year-around. Suitability values were increased when feeding and thermal habitats juxtaposed within 200 m of each other. Boreal White and Black Spruce (mw) zone is considered the Provincial benchmark type for both seasons. Spruce-Willow-Birch zone was rated low value in winter but good in spring-fall; Alpine zone received a low rating. Gentler slopes were rated higher than steep ones. slopes.

There has only been one telemetry study of moose in the Greater Muskwa-Kechika area, which occurred in the Besa-Prophet area along the Eastern Slopes (Gillingham and Parker 2008a). We used their locations (courtesy of M. Gillingham and K. Parker) and survey locations elsewhere (courtesy B.C. MOE) to evaluate performance of the Round River model. Overall, the model performed adequately, given the considerable individual variability of moose in habitat selection.

In winter, the top 6 HSI classes (5-10) accounted for 93.4 % of telemetry locations (n=7,644) and 77.3 % of survey locations (n=458) (Table 16). These classes comprised 55.6 % of the Greater Muskwa-Kechika study area. In the Besa-Prophet area, 91% of both winter and spring-fall locations occurred in the Spruce-Willow-Birch (SWB) zone. Most locations (78%) occurred on slopes <26°, and most locations occurred between 1,200 m and 1,700 m in that area (Gillingham and Parker 2008b). Moose observed during a winter survey in the Toad River/Moose Lake area occupied slightly higher elevations in tributary valleys. For spring→fall, the top 5 HSI classes (6-10) accounted for 95.8% of the telemetry locations (n = 7,603) for moose (Table 16) (there were no survey locations for this season). These classes comprised 63.6 % of the Greater Muskwa-Kechika study area.

I assigned High conservation importance to winter/year-round habitat, which is a critical season. Moderate importance was accorded to spring-fall habitats at higher elevations (which may become even more important as temperatures increase in the future). The alpine zone was deemed of low importance.

Key Conservation Areas

Based on the Round River model, year-round habitat for moose comprised about 53% of the Greater Muskwa-Kechika area and winter-only habitat covered another 3% (Table 17, blue areas in Figure 26). Much of the Boreal White and Black Spruce (BWBS) zone in the Liard Plain, Interior Boreal Plain (Muskwa Plateau), and the northern Rocky Mountain Trench was mapped as year-round habitat. Other areas included the valleys of principal rivers such as the Dease, Turnagain, Gataga, Kwadacha, Finlay, and Ingenika. Areas suitable during spring→fall (green areas in Figure 25) comprised another 11%, typically along the higher tributary valleys with riparian stringers and lower slopes in the mountains across the Greater Muskwa-Kechika area.

Only 16% of the year-round/winter and 16% of spring→fall habitats in the model occur within Existing Protected Areas, which reflects the poor representation of the Liard Basin, Northern Rocky Mountain Trench and mid-elevation areas along the Eastern Slopes (Table 17).

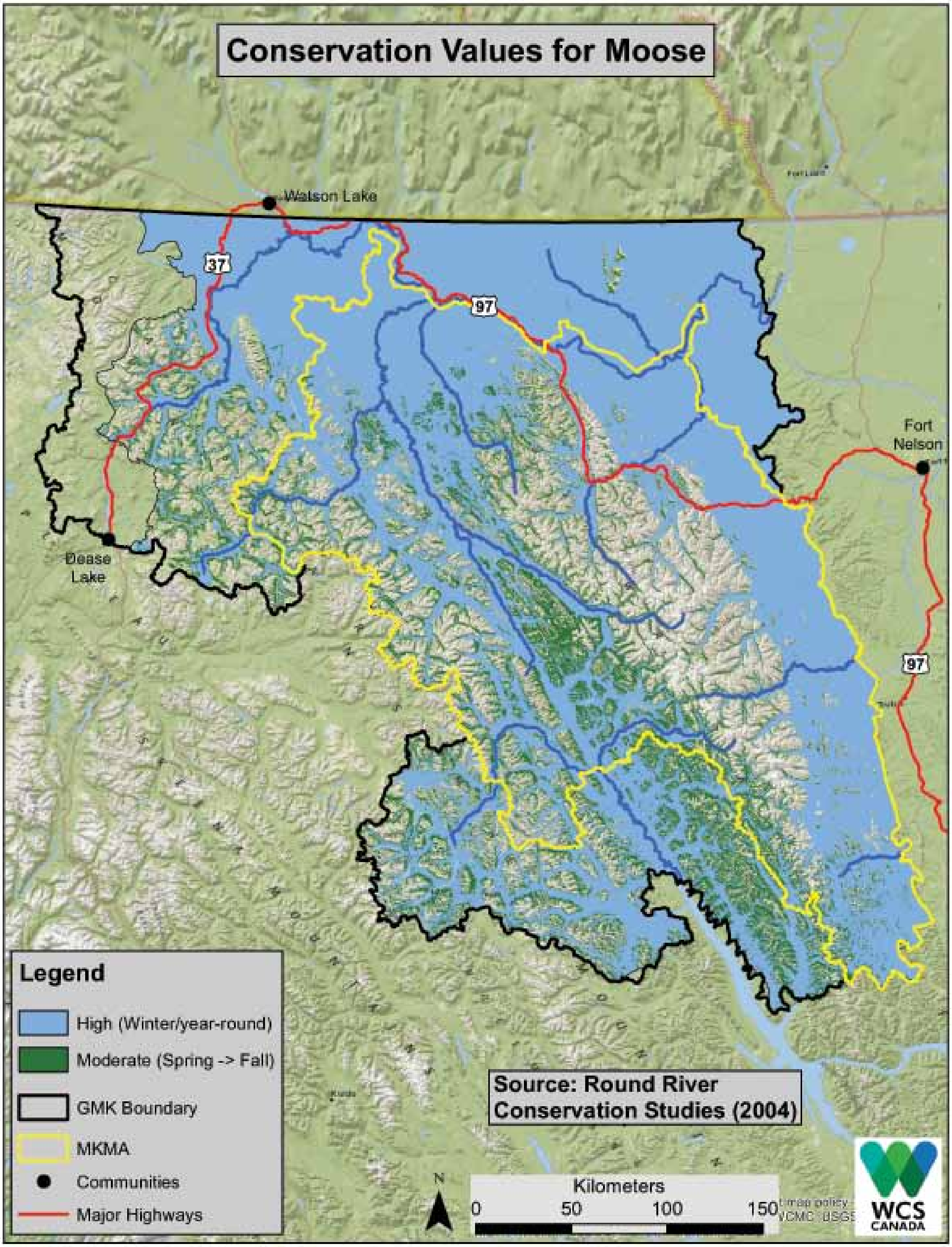
Table 16. Concurrence of moose locations in winter (Nov-Apr) and Spring-Fall (May-October) with a moose seasonal habitat suitability model, Greater Muskwa-Kechika area, northern British Columbia. Source for model: Round River Conservation Studies (Heinemeyer et al. 2004).

Model	Telemetry Locations		Survey Locations
RSF Bins	Winter (n=7,643)	Spring-Fall (n=7,602)	Winter (n=458)
Highest 10	0.20	0.55	1.97
9	3.18	6.60	7.64
8	12.99	22.71	8.95
7	10.37	26.79	22.71
6	17.65	39.14	13.10
5	48.98	0.51	22.93
4	1.52	3.58	9.39
3	5.06	0.03	12.45
2	0.00	0.00	0.22
Lowest 1	0.04	0.07	0.66

Table 17. Extent (km^2) of seasonal habitats for moose, Greater Muskwa-Kechika area, northern British Columbia. Only a small proportion occurs within existing protected areas (EPAs).

Seasonal Habitat	Area (km^2)	Percent GMK	Percent in EPAs
Year-Round	62,953	52.7	16.5
Winter Only	3,468	2.9	
Spring→Fall only	12,951	10.8	16.2
SUM	**79,372**	**66.5**	

Figure 26. Distribution of suitable moose habitat by season, Greater Muskwa-Kechika area, northern British Columbia. Source for model: Round River Conservation Studies (2004). Note: Their model did not extend into the northwest corner of the study area but a similar pattern of suitable habitat in the river valleys likely exists.



Stone's Sheep (*Ovis dalli stonei*)

Krystal Kriss

Stone's sheep have been classified as a distinct (darker) sub-species of thin-horned sheep in North America based largely upon color differences in pelage from the white Dall's sheep. Observations of considerable variation in coat color *within* a population and the absence of sharp geographical breaks in color, however, undermine the conventional mapping of these sub-species (Sheldon 1911, Demarchi and Hartwig 2004).Very recent genetic analyses indicate that nearly all of the world's population of Stone's sheep (~15,000) occur exclusively within British Columbia and are more rare than previously thought (Sim et al. 2019). Stone's sheep are highly prized by hunters.

Vulnerability = Moderate

Niche Flexibility: Stone's sheep forage primarily on grasses (fescues and bunch-grasses) on wind-swept or south-facing sites in the alpine and subalpine which are in close interspersion with cliffs or rocky terrain for escape (Geist 1971, Demarchi and Hartwig 2004, Walker et al. 2007). Due to their strong affinity and perhaps physiological dependence on mineral licks during late spring-summer, sheep may travel several miles (even through forests) to visit such sites (Ayotte et al. 2008).

Reproductive Capacity and Mortality Risk: Female sheep have their first lambs at 2-3 years (or later) but carry only a single lamb. Pregnancy rates can exceed 80% but survivorship of lambs in their first year can be low (30-60%) due to inclement weather, poor nutrition, and occasional predation (Demarchi and Hartwig 2004). Hunting of rams may be additive to 'natural' levels of mortality (rather than compensatory) for prime age classes (Festa-Bianchet et al. 2014).

Dispersal and Connectivity: Mountain sheep find their niche in patches of montane and alpine grassland that remain stable through time, and they exhibit high fidelity to these ranges (Geist 1971). Consequently, they do not disperse very readily and have a low capacity for re-colonizing distant vacant patches.

Recent genetic studies indicate that broad river valleys may impede gene flow and partition Stone's sheep into genetic clusters (Sim et al. 2019) as they appear reluctant to cross wide valleys in the absence of escape terrain (Roffler et al. 2014).

Sensitivity to Human Disturbance: Although sheep appear to habituate to predictable motorized disturbance along highways, helicopter overflights within 400 m can be quite stressful (Stockwell et al. 1991). Severe and/or chronic disturbance and subsequent abandonment of critical ranges (lambing and wintering areas, mineral licks) can compromise the health and productivity of sheep populations.

Response to Climate Change: Warmer winters with less snow could ameliorate harsh conditions but promote encroachment of lower elevation sites in the montane by shrubs and trees. Increase in natural fire and/or prescribed burning could enhance populations of elk, which compete directly with Stone's sheep for forage (Sittler 2013). Rain-on-snow events following periods of deep snowfall can create a hard-crusted snow that would reduce sheep access to ground forage.

Methods for Scoring Conservation Importance

We used two independent sources of data to identify and map key conservation areas for Stone's sheep.

First, we used a map of current sheep occupancy prepared by biologists with B.C. Ministry of Environment (Kuzyk et al. 2012, updated 2015) primarily for regional planning (Figure 27). This effort mapped sheep occupancy at a scale of mountain blocks and assumes all habitat therein is suitable. We overlaid this map with a map of relative sheep abundance ('plentiful',' moderate', and 'few') prepared by Demarchi and Hartwig (2004).

We also evaluated the performance of a previous model of habitat suitability for Stone's sheep developed by Round River Conservation Studies (Heinemeyer et al. 2004:69-73). The model rated herbaceous and alpine sites as the most suitable foraging habitat and steep, rocky areas in alpine/upland areas as most suitable escape terrain in both seasons. Warm aspects (135°-285° azimuth) were assumed to be important in winter for both feeding and security and for early green-up areas. Steep slopes (67-100%) were rated as highest security, with moderate slopes (45-67%) next highest. The model assumes that foraging value was realized only within 500 m of escape terrain.

Initially, we evaluated the Round River model using telemetry locations form the Besa-Prophet area along the Eastern Slopes (courtesy of Professor Kathy Parker, UNBC). The top 3 classes (8-10) of the RR model accounted for 73.4 % of the winter locations (n=14,385) and 73.1 % of the summer locations (n=10,584).

Upon further inspection of the locations not predicted by the Round River model, we observed that many of them occurred on narrow ridgetops sandwiched between other habitat used by sheep as predicted by the model. We used a topographic position index (TPI) conceived by Weiss (2002) and operationalized by Jenness (2006) to map ridges. Specifically, using a 25-m Digital Elevation Model, we selected a 120-cell (3000 m) radius within a Circle Neighborhood Shape and a cutoff value of TPI >1 to define mountaintops and ridges. These ridges were added to the Round River model for mapping suitable habitat for Stone's sheep. Subsequently, we evaluated performance of the revised model using all 36,547 available locations across the Greater Muskwa-Kechika area. Most of these were telemetry locations from the Besa-Prophet study (Walker et al. 2007: n = 24,969) and the Sulphur-8 Mile study (Hengeveld and Cubberly 2011: n = 9,811). Aerial surveys provided additional locations throughout the GMK area (n = 1,767).

The revised model accounted for a very high percentage of sheep locations (Table 18). For winter season, the top 3 HSI classes (8-10) accounted for 91.3 % of locations (19,240). Another 5.8% of winter locations fell within 100m of areas predicted by the model. For the spring→fall season, the top 3 HSI classes accounted for 85.0 % of the telemetry locations (n=17,307). In several places, it appeared that sheep locations were tightly clustered in a valley location distant from escape terrain, which we interpreted as a possible mineral lick. If we merged the seasonal models, the top 3 classes accounted for 88.3 % of all locations. The mean elevation of all locations was 1666 m (± 215), with 89% > 1400 m. The mean slope was 64.3% (± 23.2), and southerly aspects were selected by sheep.

Table 18. Number and percentage of telemetry locations for Stone's sheep by habitat suitability class year-round in the Greater Muskwa-Kechika area, northern British Columbia. The model developed by Round River Conservation Studies (Heinemeyer et al. 2004) was modified to include ridgetops using a topographic position index (TPI) conceived by Weiss (2002) and operationalized by Jenness (2006).

HSI Bins	Telemetry		Survey	
	No.	%	No.	%
10	26,589	76.46	686	39.96
9	2,943	8.46	360	19.40
8	1,497	4.30	193	10.40
8-10	**31,209**	**89.2**	**1,239**	**66.7**
7	1,128	3.24	87	4.69
6	49	0.14	33	1.78
5	796	2.29	109	5.87
4	1,022	2.94	149	8.03
3	575	1.65	91	4.90
2	9	0.03	110	5.93
1	0	0	38	2.05
No model	169	0.49	0	0
SUM	**34,777**	**100.00**	**1,856**	**100.00**

Overall, there was good concurrence in performance between the B.C. map of occupancy and the Round River (modified) map of habitat suitability (Figure 27). Based upon experience/advice of local biologists, we eliminated some areas indicated by the Round River model because deep snow precluded occupancy by Stone's sheep. The two maps coincided substantially in the Rocky Mountains. On the western side of the study area in the less rugged Cassiar Mountains, the

Figure 27. The finer-scale mapping of Stone's sheep suitable habitat (yellow) by the Round River model (modified) compared to the coarser mapping of occupancy by the regional B.C. Fish & Wildlife Branch (black). The two overlapped extensively in the more rugged Rocky Mountains. The smaller proportion of a mountain block that actually had suitable habitat was more apparent on the western side of the study area in the less rugged Cassiar Mountains. Note: The Round River model did not cover the northwest corner of the study area.

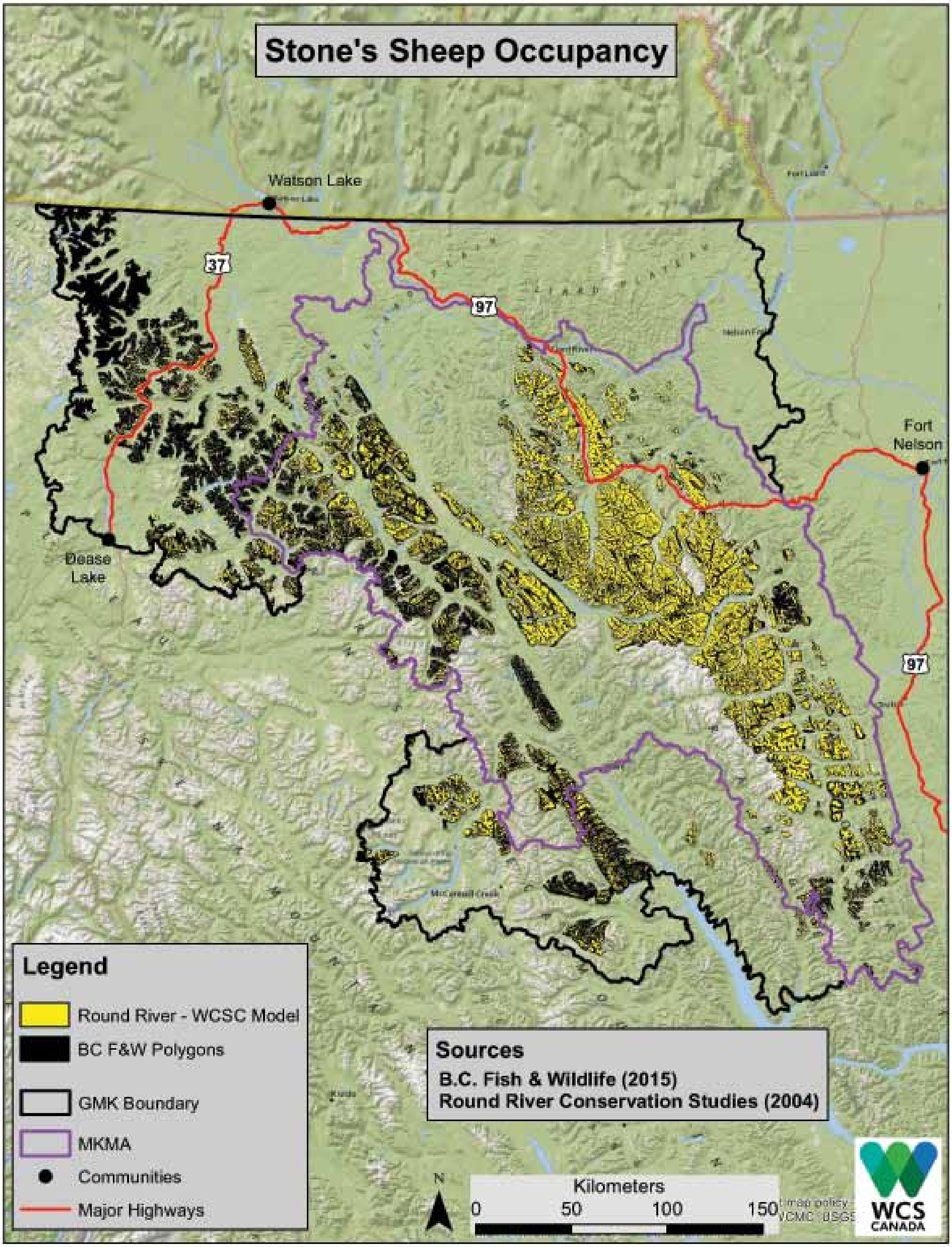
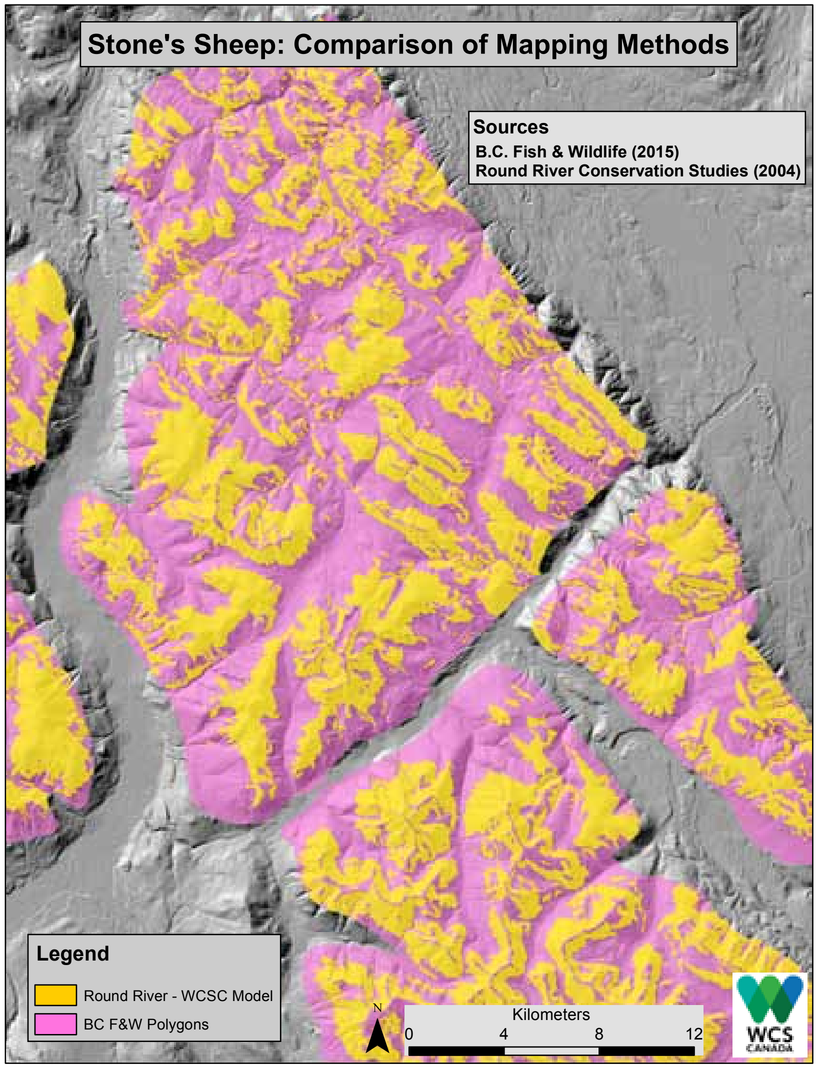


Figure 28. Areas of high habitat value for Stone's sheep (orange) predicted by the modified Round River model (Heinemeyer et al. 2004). The model identified smaller areas compared to the areas (pink) mapped by B.C. Fish & Wildlife.



smaller proportion of a mountain block that actually had suitable habitat was more apparent (Figure 28). I used the coarser mapping from the B.C. Fish & Wildlife Branch for public display in this report but also used the more refined Round River model for some data analyses and recommendations.

Sheep habitat at higher elevations may persist longer, but climate warming may result in encroachment of alpine areas by shrubs and/or trees over time (especially where alpine occurs at lower elevations). In addition, larger populations of sheep occupying more expansive blocks of habitat are likely to persist longer than smaller, more isolated populations. Accordingly, we assigned conservation importance as follows:

High = sheep in plentiful abundance at moderate to high elevation

Moderate = sheep in moderate abundance at moderate to high elevation

Low = sheep plentiful or moderate abundance but at low to very low elevation

Perhaps the best conservation strategy for now is to provide stress-free security along an elevation gradient of south-facing or wind-swept slopes interspersed with cliffs. This would allow bighorn sheep options for moving up or down in response to changing conditions.

Key Conservation Areas

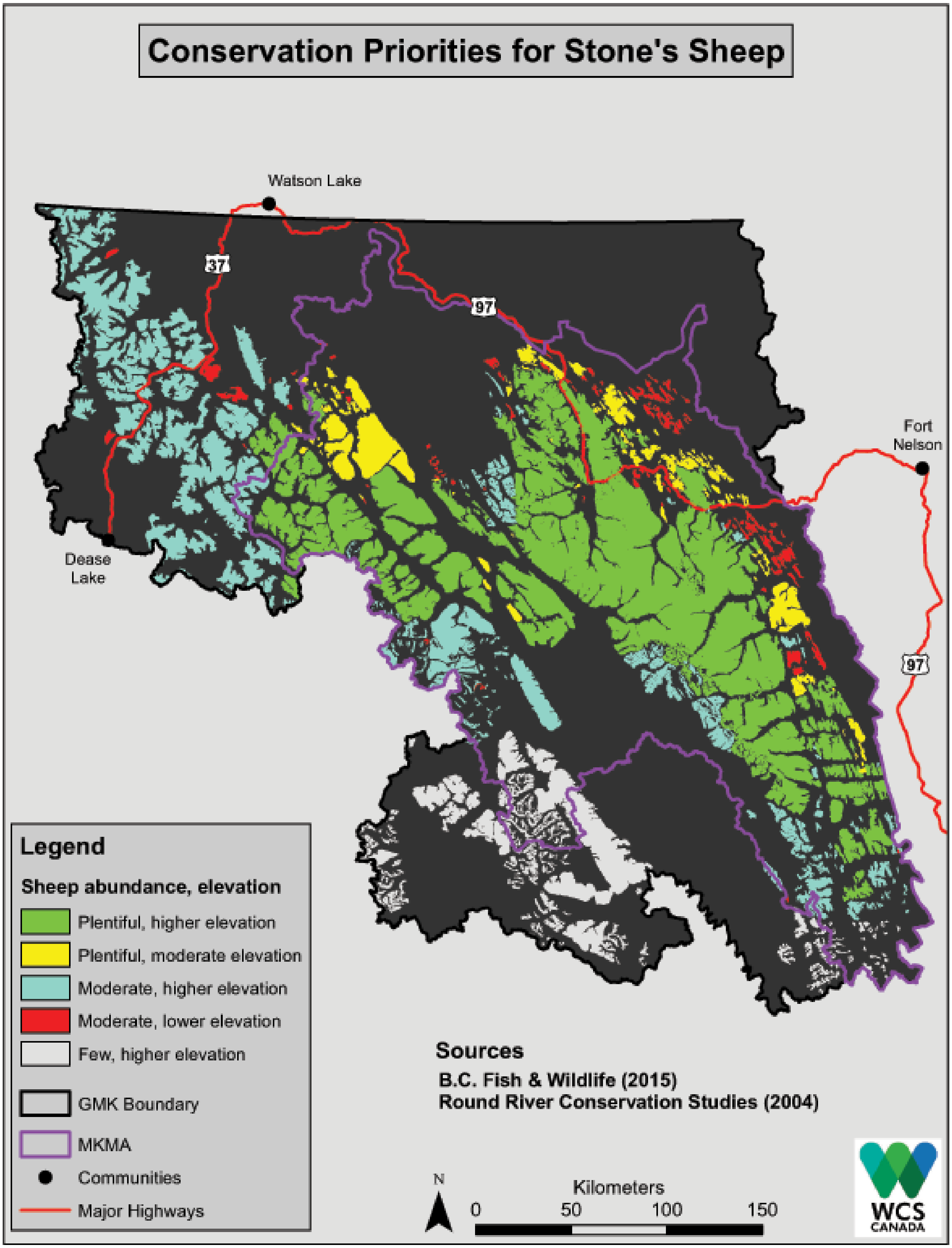
The highest priority habitats are those where Stone's sheep are considered plentiful at high to moderate elevation, which comprises 1,726,555 ha or 14.5 % of the Greater Muskwa-Kechika area (Table 19 & 20, Figure 29: green areas). This high-priority area covers much of the Rocky Mountains from Muncho Lake south through the Northern Rocky Mountain Provincial Park and southeast to the Halfway River on the Eastern Slopes. It extends across the Northern Rocky Mountain Trench and on westward through the Cassiar Mountains to the headwaters of the Turnagain River.

Moderate priority areas include those sites where sheep are moderately abundant at high to moderate elevations, which comprises 837,854 ha or 7.0 % of the Greater Muskwa-Kechika area (Figure 29: aqua areas). These occur primarily in the Cassiar Mountains from the Cry Lake-Horeseranch Range areas northwest across the Cassiar Highway (south of Good Hope Lake) and along the Continental Divide to the Yukon border. Note: Those sheep blocks in the headwaters of the Little Rancheria River represent the only link of regional connectivity to thinhorn sheep extending into the Yukon (Sim et al. 2019). Otherwise, the Liard River presents a formidable barrier to crossing by sheep.

Areas where sheep are plentiful or moderate abundance but reside at low-very low elevations may become jeopardized in the future if climate change results in shrubs and/or trees overtaking grass habitat in the alpine. Some of the larger patches where sheep are plentiful may persist for a longer period; they comprise about 229,446 ha or 1.9 % of the Greater Muskwa-Kechika area (Figure 29: yellow blocks). Smaller patches with fewer sheep occurring at lower elevations may not persist (Figure 29: red patches), but these occur mostly around the periphery of sheep range on about 70,000 ha (0.6% of GMK).

Recent genetic studies have revealed an interesting story about genetic history of the northern thin-horned sheep. The two species differentiated because they occupied different glacial refugia during the last glacial maximum (21,000 years ago) of the Pleistocene. The northern clade of thin-horned sheep persisted in the Beringia of Alaska and western Yukon and became Dall's sheep, whereas a Southern clade occupied a minor refugium along the Rocky Mountain foothills of northern British Columbia (vicinity of the Halfway River) in-between asynchronous advances of the Cordilleran and Laurentide ice sheets and became Stone's sheep (Loehr et al. 2006, Sim et al. 2016). Subsequently, Dall's sheep expanded south-easterly, whereas Stone's sheep expanded their range northwestward. Eventually, individuals from each lineage met in a contact zone in southern Yukon. The northwest corner of the Greater Muskwa-Kechika area (Tootsee Ridge area and headwaters of Little Rancheria River) appears to be a such contact zone for genetic admixture of Stone's sheep and Dall's sheep (Sim et al. 2019).

Figure 29. Distribution and habitat suitability of Stone's sheep across the Greater Muskwa-Kechika area. Northern British Columbia. The highest priorities are plentiful abundance at higher elevations.



The Kechika River separates genetically-distinctive clusters of Stone's sheep in the Rocky Mountains (east) from those in the Cassiar Mountains (west) (Sim et al. 2019). It's important to note the area where the distribution of sheep narrows down in the northern Rocky Mountain Trench as this represents a pinch-point for regional connectivity of Stone's sheep (see Figure 4 *in* Sim et al. 2019). The likely connection starts about 20 km north of the confluence of the Gataga River with the Kechika River and extends southward for about 60 km. At the north end, the distance between patches of sheep occupancy is about 8 km across the Trench. Further south, there are three small habitat patches which may serve as stepping-stones between larger blocks (see yellow patches in Figure 29).

About 38% of the high priority areas for Stone's sheep are found in existing protected areas, but < 9% of the moderate priority blocks are protected (Table 20). Important areas for Stone's sheep that are <u>outside</u> Protected Areas include: (1) Prophet River south through the Rocky Mountains and Foothills to the Halfway River, (2) Sentinel Range east of Muncho Lake Provincial Park and eastward to the Stone Range north of Summit Pass along the Alaska Highway, and (3) mountain blocks in the Cassiar Range in the middle sections of the Turnagain River watershed (Figure 29).

Table 19. Area (km^2) of relative abundance of Stone's sheep by elevation class, Greater Muskwa-Kechika area, northern British Columbia.

Elevation	Relative Abundance		
	Plentiful	Moderate	Few
Very Low	918	167	2
Low	1,377	533	16
Moderate	4,965	4,923	1,726
High	3,635	2,417	1,278
Very High	8,665	1,039	810
SUM	19,560	9,078	3,831
Percent	60.2	28.0	11.8

Table 20. Area (km^2) and percent of priority lands for Stone's sheep. High priority areas represent those where sheep are 'plentiful' at high to moderate elevations. Moderate priority areas include those where sheep occur in moderate abundance at higher elevations. Where sheep occur in moderate abundance or even plentiful at low to very low elevations are designated as low priority as climate change may degrade habitat suitability there. Areas with few sheep were not assigned any priority.

	Greater Muskwa-Kechika		Existing Protected Areas	
Conservation Priority	Area (km^2)	% GMK	Area (km^2)	% Conservation Priority
High	17,266	14.5	6,548	37.9
Moderate	8,379	7.0	722	8.6
Low	2,994	2.5	705	23.5

Woodland Caribou (*Rangifer tarandus caribou*)

Courtesy of © Mark Bradley

All of the caribou herds in the Greater Muskwa-Kechika area belong to the Northern Mountain population of caribou assessed as "**SPECIAL CONCERN**" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2014). This designated population is listed as 'Special Concern' under SARA (Species At Risk Act) (Ray et al. 2015).Within British Columbia, Northern Woodland caribou are currently *Blue-listed* with a conservation status of S2/S3 due to sustained declines in some subpopulations, uncertainty in the population trend of others, and high threats from predation and anthropogenic disturbance (BC Conservation Data Centre 2017).

Nonetheless, it is important to note that caribou herds in the Greater Muskwa-Kechika are in good shape RELATIVE to the very tenuous status of caribou in the southern half of the province (Wittmer et al. 2010). This offers an opportunity for proactive conservation before they become threatened by similar factors in the south (Ray et al. 2015).

Vulnerability Profile = High

Niche Flexibility: Caribou are adapted to feed on lichens, with specialized microbes in their stomachs that digest and extract nutrients from lichens efficiently (Parker et al. 2005). In winter months, northern woodland caribou forage primarily on terrestrial lichens – either in older and/or open-canopy coniferous forests at low elevations or on windswept alpine slopes (Jones et al. 2007). They also may forage on arboreal lichens in older forests, especially during late winter or periods of snow crusting (Johnson et al. 2000). During calving from mid-May to mid-June, many females seek high-elevation sites above treeline while others calve in subalpine conifer forests prior to moving to higher elevation summer ranges. Habitat selection may vary between herds and even individuals, as well as seasonally (Gustine and Parker 2008).

Reproductive Capacity and Mortality Risk: Caribou have low reproductive capacity compared to other northern ungulates (COSEWIC 2014). The combination of single calves, high calf mortality (often >50%), and variable mortality of adult females (5-15%) limits the ability of woodland caribou to recover from population declines. Predation (primarily by wolves and bears) has been the major cause of death of radio-collared adults and calves (Bergerud and Elliott 1998). To reduce the risk of predation, pregnant females travel to isolated areas in the mountains to calve – a critical behavioral strategy known as "spacing out" across the landscape (Bergerud and Page 1987, DeMars et al. 2016). This movement separates them from other ungulates (moose, elk) and their generalist predators but often comes with the cost of lower forage quality (James et al. 2002, Gustine et al. 2006a).

Dispersal and Connectivity: Although caribou in past circumstances may have radiated widely (Alaska: Hinkes et al. 2005), juveniles and adult caribou in the southern population of B.C. showed little dispersal (<1.5%) between caribou subpopulations (van Ort et al. 2011). In the Northern Mountains, caribou generally migrate between summer and winter ranges (Culling et al. 2005, Gustine and Parker 2006b, Weaver 2008).

Sensitivity to Human Disturbance: Caribou (especially females) are sensitive to various and cumulative human disturbances, such as industrial activities, roads and other linear features, recreational activities, or over-hunting (Festa-Bianchet et al. 2011, Florkiewicz et al. 2007, Freeman 2008, Williamson-Ehlers 2012, Johnson et al. 2015). In general, caribou avoid vehicle disturbance that is associated with roads and useable seismic lines (Polfus et al. 2011, Dickie et al. 2016, DeMars and Boutin 2017). In addition to direct impacts on lichen cover and displacement from preferred sites, forestry harvests can exacerbate predation rates by increasing populations of other ungulates (moose, deer, elk). This, in turn, can support more wolves and bears and ultimately lead to greater predation on caribou (Williamson-Ehlers 2012, Witmer et al. 2013). Conventional seismic cut-lines can enable faster and further penetration by wolves into previously-secure habitats (Dickie et al. 2016). Intensive activity by snowmobile recreationists displaced southern woodland caribou in British Columbia from suitable habitat (Seip et al. 2007).

Response to Climate Change: Warmer winter temperatures and fewer cold weather extremes could enable greater abundance and activity by forest insects (Price et al. 2013). Greater mortality of trees by bugs coupled with hotter, drier conditions in summer could result in more area burned by fire and loss of lichens (Barber et al. 2018, Kirchmeier-Young et al.2019). Warmer temperatures could lead to ecological conditions that favor vegetation species that can outcompete terrestrial lichens and/or that are preferred by other prey species (Hamann and Wang 2012). Warmer winters may impact availability of terrestrial lichens by increasing frequency of icing events (Hansen et al. 2011). A warming climate and fires (including prescribed burns) may increase abundance and expand distribution of alternate prey (elk and maybe white-tailed deer) and their generalist predators, potentially increasing rates of predation on caribou (Robinson et al. 2012, Dawe and Boutin 2016, Barber et al. 2018). Collectively, these relationships suggest that warmer winter temperatures and lowered snowfall may have a negative effect on caribou population dynamics (DeMars et al. 2017).

Providing caribou with large blocks of land where they can (1) separate themselves from other prey and predators, and (2) shift their range use in response to various natural processes (e.g. fire, snow conditions) and human disturbances is the key to their long-term resilience and conservation.

Caribou Herds across the Greater Muskwa-Kechika

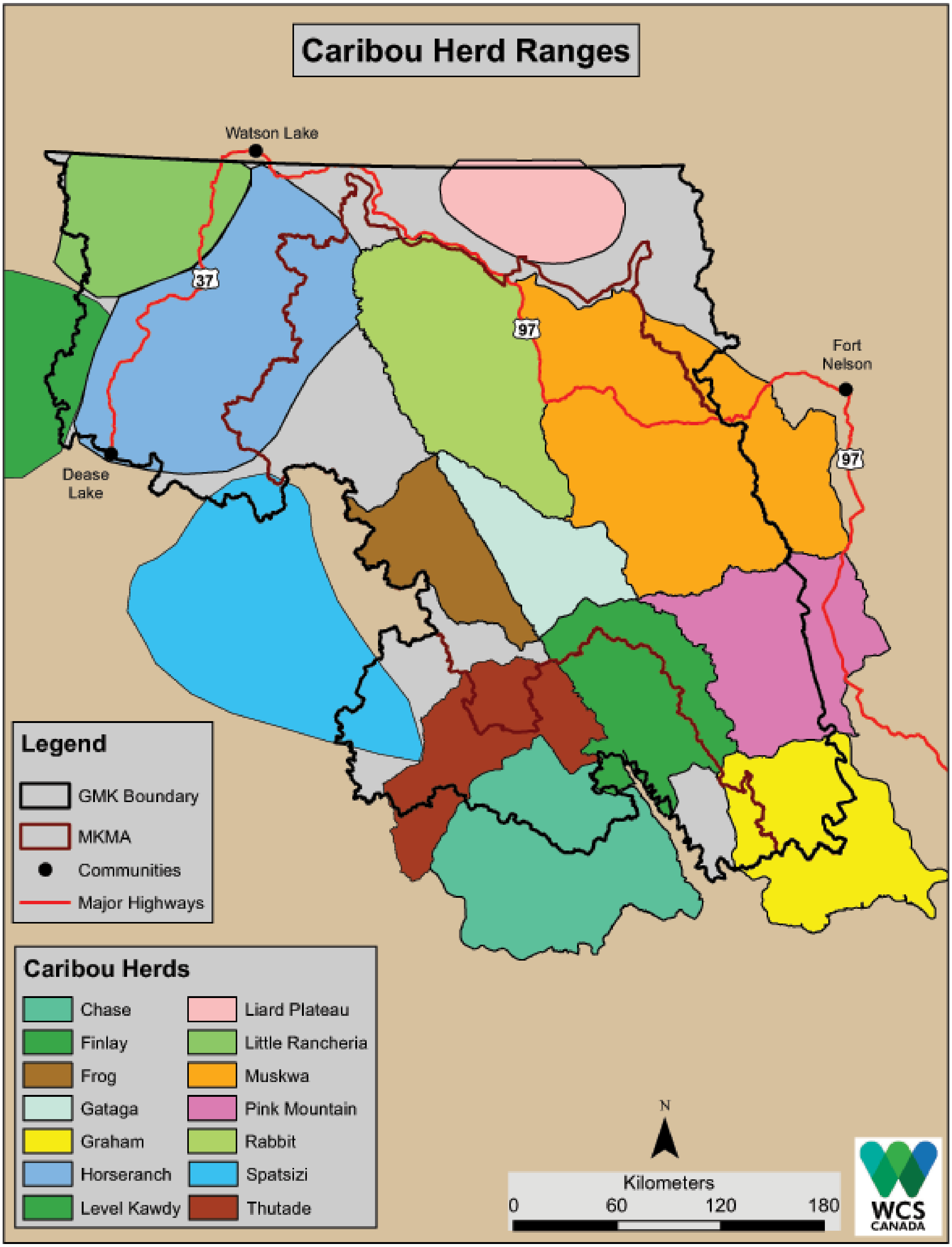
Herd ranges of 14 caribou herds overlap with the Greater Muskwa-Kechika area (Table 21, Figure 30). These herd ranges cover 82% of the Greater Muskwa-Kechika area. The most recent compilation of population estimates from various surveys across the Greater Muskwa-Kechika sums to ~5,000 caribou (Table 21: B.C. Provincial Caribou Recovery Plan 2018). It should be noted that these estimates represent 30-40% smaller population size compared to those provided in the COSEWIC assessment (2014), and much lower compared to earlier counts by Tom Bergerud (1978). Only 3 herds (Horseranch, Little Rancheria, and Rabbit) are estimated to have > 500 animals, and some may have fewer than 250 (Finlay and Liard Plateau). There is little reliable information on population trends. For conservation planning of these wide-ranging animals, it's important to note that the annual ranges of these herds average 8,139 km^2 (median of 6,487 km^2).

Table 21. Population estimates for 12 herds of northern woodland caribou across the Greater Muskwa-Kechika (GMK) area, northern British Columbia. Source: BC Caribou Plans (draft 2018).

Caribou Herd	Population Size	Year of Estimate	Herd Range (km^2)
Chase	290	2017	3,416
Finlay	<25	2018	7,953
Frog	250	2010	5,039
Gataga	340	2001	5,008
Graham	230	2016	4,038
Horseranch	600	1999	17,720
Liard Plateau	150	2017	4,753
Little Rancheria	1200	1999	6,538
Muskwa	450	2018	16,789
Pink Mountain	350	2018	6,487
Rabbit	1000	2018	11,791
Thutade*	90	2015	7,002
Total Number	**4,950**		
Mean Herd Range			**8,139**
Median Herd Range			**6,487**

*Note: Caribou occurring east and northeast of Thutade Lake are now considered a separate herd based on research by Sittler et al. (2013).

Figure 30. Location of 14 caribou herd ranges, Greater Muskwa-Kechika area, northern British Columbia. Source: B.C. Caribou Recovery Program (2018).



Methods for Scoring Conservation Importance

In collaboration with Professor Mark Hebblewhite and Ph.D. candidate Eric Palm

See Appendix 1 for full details

We developed Resource Selection Function (RSF) models using location data from 217 radio-collared adult female caribou, as well as aerial surveys throughout the Greater Muskwa-Kechika area. Locations from these collared caribou were collected during 1988–2013 across eight herds in the southern and central portions of the GMK: Chase, Finlay, Frog, Gataga, Graham, Muskwa, Pink Mountain, and Spatsizi populations. Aerial survey data was collected from 1976–2018 from the Liard Plateau, Little Rancheria, Horseranch, and Rabbit ranges, as well as each of the others (Figure 30).

To investigate caribou RSFs, we used a 250-m resolution landcover layer which included temperate needleleaf forest, temperate broadleaf forest, mixed forest, temperate shrubland, temperate grassland, sub-polar grassland (includes sub-polar barren-lichen-moss, wetland, barren, water, and snow and ice. We used 30-m resolution elevation data to derived slope and aspect. To account for the effect of human disturbance on caribou resource selection, distance from road and distance from forest cut-block were included.

We analyzed GPS data in a used-available framework to compare proportionate use of resources (e.g., elevation, landcover) relative to their availability on the landscape. We conducted separate RSF analyses for growing season (May 1–October 31) and winter (November 1– April 30). We included only individuals with ≥ 30 locations spanning ≥ 3 months in a season. For each caribou with a GPS collar (n = 91), we generated a 99% kernel density estimate of seasonal range and randomly generated 10 locations for each *used* location to identify resources *available* to that animal. We used GPS data to train RSF models and locations from VHF collars and surveys to validate the models.

Caribou in the Liard Plain ecoregion (which includes portions of the Little Rancheria, Horseranch and Rabbit caribou ranges) wintered in low-elevation forests far from mountains and foothills. Therefore, we used survey location data to estimate a separate winter RSF for the Liard Plain ecoregion and substituted these RSF values into our GMK-wide winter map of resource selection. For each model, we categorized RSF probabilities into 10 equal-area bins or classes, where 1 was the lowest relative probability of use and 10 was the highest. To validate models, we extracted the RSF bin for each VHF and survey location. For the winter season, the top 3 classes (bins 8-10) accounted for 58.3% of 16,168 locations and classes 6-7 accounted for another 22.8% (total = **81.1%**). For spring-fall, the top 3 classes (bins 8-10) accounted for 78.1% of 22,027 locations and classes 6-7 accounted for another 13.1% (total = **91.2%**).

Topographic variables were important predictors of caribou resource selection in both seasons (see Table 1 in Appendix I). Caribou moved to higher elevations during the growing season (spring→fall) and avoided steep slopes all year. Caribou selected temperate needleleaf forest in both seasons despite its widespread availability (53% of GMK). Wetlands were selected by caribou during the winter but not the growing season. During winter, caribou avoided areas closer to roads and cutblocks, but they selected areas closer to cutblocks during the growing season. Within the Liard Plain ecoregion, wintering caribou selected lower elevations, lower slope angles and temperate needleleaf forest (open canopy). Our top RSF models relied only on GPS locations from the southern and central GMK but were highly predictive of VHF and survey locations throughout the entire study area (>0.97).

Key Conservation Areas

The habitat-selection analysis revealed that the top 3 classes (8-10) comprised 42,935 km^2 (36.0%) of the Greater Muskwa-Kechika, whereas the next 2 lower classes (6-7) covered 21,078 km^2 (17.6%) usually in proximity to the very high classes (Table 22). Altogether, these important habitats for caribou comprised 64,013 km^2 or 53.7% of the GMK. Most of the important habitat occurs in subalpine-alpine areas but also includes wintering sites in boreal conifer forests with more open canopy (Figure 32). The lowest-ranking habitat for caribou occurs in the broader river valleys, where terrestrial lichen may be less abundant and/or caribou avoid valleys due to predator risk (Gustine et al. 2006a, Gustine and Parker 2008).

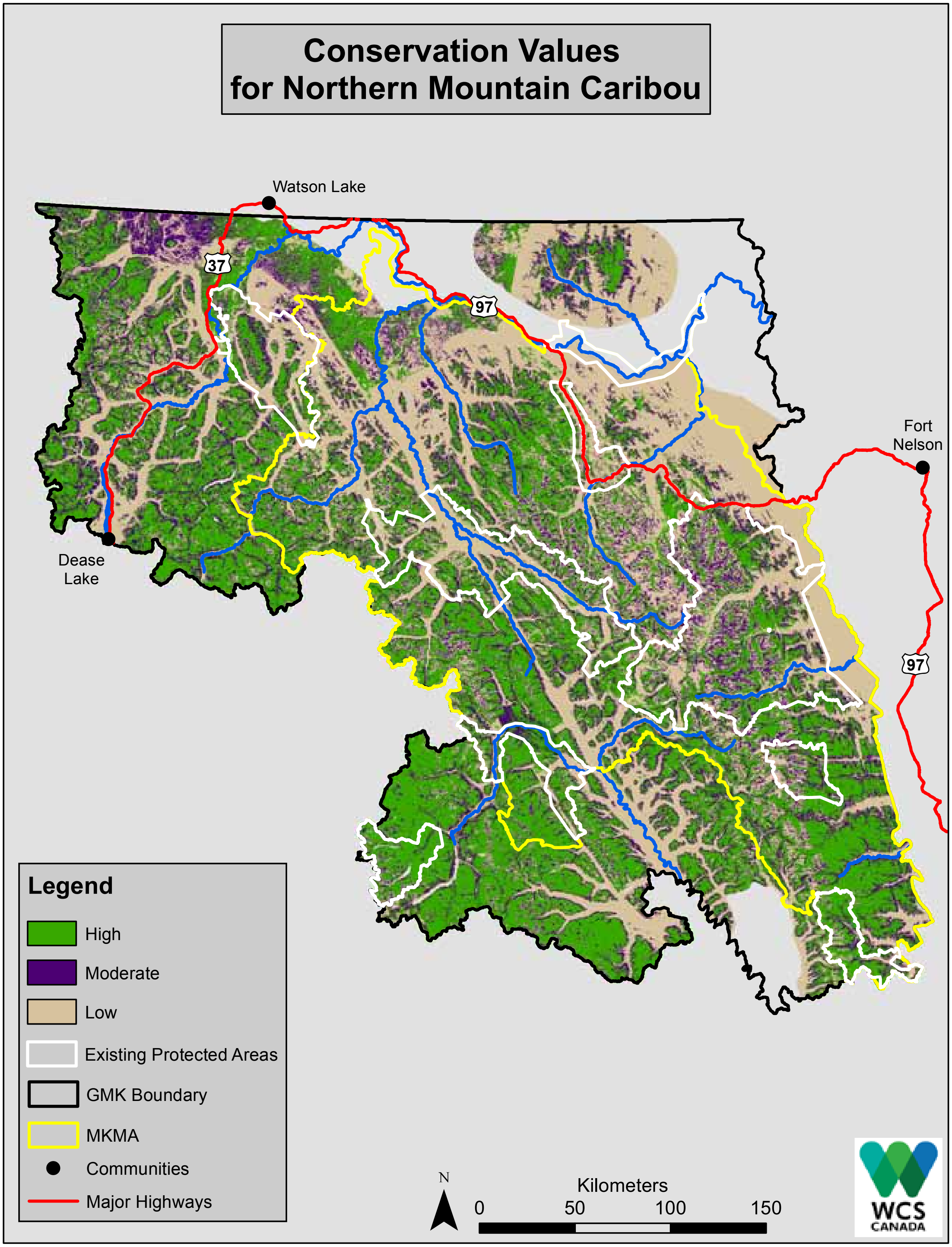
The amount of suitable habitat for northern woodland caribou is poorly represented by existing protected areas across the Greater Muskwa-Kechika area. Only 17% of the high habitat value and 20% of the moderate value occurs in EPAs (Table 23).

Table 22. Amount of area (km^2) and percent of suitable caribou habitat, Greater Muskwa-Kechika, northern British Columbia.

Caribou Habitat	Year-round		Within EPAs	
	Area (km^2)	Percent	Area (km^2)	Percent
High Value (classes 8-10)	42,935	36.0	7,170	16.7
Moderate Value (classes 6-7)	21,078	17.7	4,216	20.0
SUM	**64,013**	**53.7**	**11,386**	**17.8**

Courtesy of © Ryan Dickie

Figure 32. Habitat suitability for northern woodland caribou based upon Resource Selection Function (RSF) model, Greater Muskwa-Kechika area, northern British Columbia. High = RSF classes 8-10, moderate = 6-7, and low =1-5.



The number and proportion of caribou locations occurring within existing protected areas varies widely between herds and between seasons across the Greater Muskwa-Kechika area (Table 23). Of the 13,993 caribou locations occurring within the GMK during winter, existing protected areas account for only 6.0 %. Winter locations of several herds are not protected by existing Provincial parks: Chase, Finlay, Graham, Little Rancheria, and Pink Mountain. Representation does not improve much for the spring→fall locations, either; only 9.4 % occur within existing protected areas.

Table 23. Proportion (%) of caribou locations by season encompassed in Existing Protected Areas (EPAs), Greater Muskwa-Kechika area, northern British Columbia.

Caribou Herd	# Locations		% in GMK		% in EPAs	
	Winter	Spring-Fall	Winter	Spring-Fall	Winter	Spring-Fall
Chase	3,230	5,039	30.5	45.6	0.0	0.0
Finlay	1,239	1,403	97.4	99.3	0.0	0.1
Frog	827	2,049	100.0	100.0	30.6	1.0
Gataga	46	243	100.0	100.0	71.7	14.0
Graham	25,954	26,027	11.9	27.3	0.5	6.2
Horseranch	248	242	96.8	41.3	39.5	45.5
Liard Plateau	6	0	100.0	-	0.0	-
Little Rancheria	507	402	100.0	100.0	0.6	0.0
Muskwa	683	994	97.2	100.0	49.2	72.3
Pink Mountain	10,653	1,167	59.4	85.5	1.5	20.0
Rabbit	95	181	100.0	100.0	24.2	13.8
Total/ Weighted x	**43,488**	**37,747**	**13,993**	**15,763**	**6.0**	**9.4**

There are numerous key wintering areas for northern woodland caribou that are NOT within a Protected Areas. Here is a list of key areas for each caribou herd (see Figure 32 for high-value habitat, and Figures 33-34 for home ranges)

- Pink Mountain herd: area east and southeast of Redfearn-Keily Provincial Park from middle Prophet-Richards Creek south through Keily Creek-Besa River and south to Halfway River; east of Klingzut Mountain beyond the MKMA boundary to the Alaska Highway (Figure 34).
- Graham herd: area east of Graham-Laurier Provincial Park from Halfway River south to Graham River (and Butler Ridge) and extending some 20-40 km east-southeast of the MKMA boundary Caribou in the Pink Mountain and Graham herds share a common pattern of higher-elevation alpine areas during summer and moving down to lower-elevation winter ranges (Figure 34).

- Muskwa herd: area between north end of Northern Rocky Mountain Provincial Park and northwest across Alaska Highway to Muncho Lake Provincial Park (Figure 33).
- Frog herd: area south of Finlay-Russel Provincial Park to Bower Creek and north side of Finlay River.
- Horseranch herd: area north of Ne'āh' Conservancy along lower Dease River and also adjacent to the southeast corner of the Conservancy.
- Rabbit herd: area between upper Rabbit River and Netson Creek.
- Spatsizi herd: north of Tatlatui Provincial Park to Metsantan Pass at head of Toodoggone and Stikine Rivers.
- Chase herd: area east of Tatlatui Provincial Park past Thutade Lake to headwaters of Ingenika River.
- Little Rancheria herd: area between headwaters of Little Rancheria River and Toosuza Creek.

Courtesy of © Mark Bradley

Woodland caribou range far and wide across the Greater Muskwa-Kechika, spacing themselves away from other prey and their predators.

Figure 33. Home ranges (MCP) of northern woodland caribou spanning the Alaska Highway between Northern Rockies and Muncho Lake Provincial Parks, Greater Muskwa-Kechika area, northern B.C.

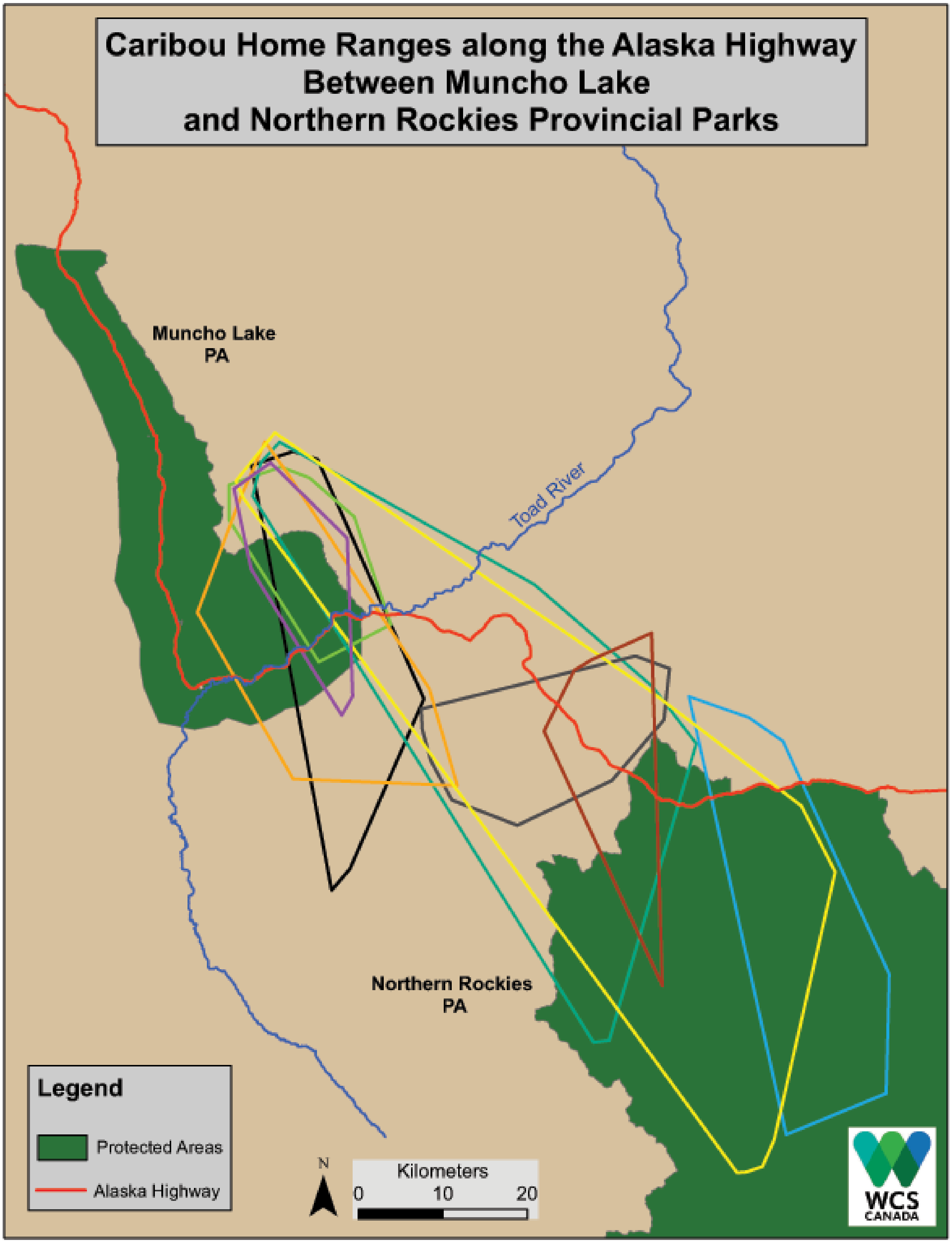
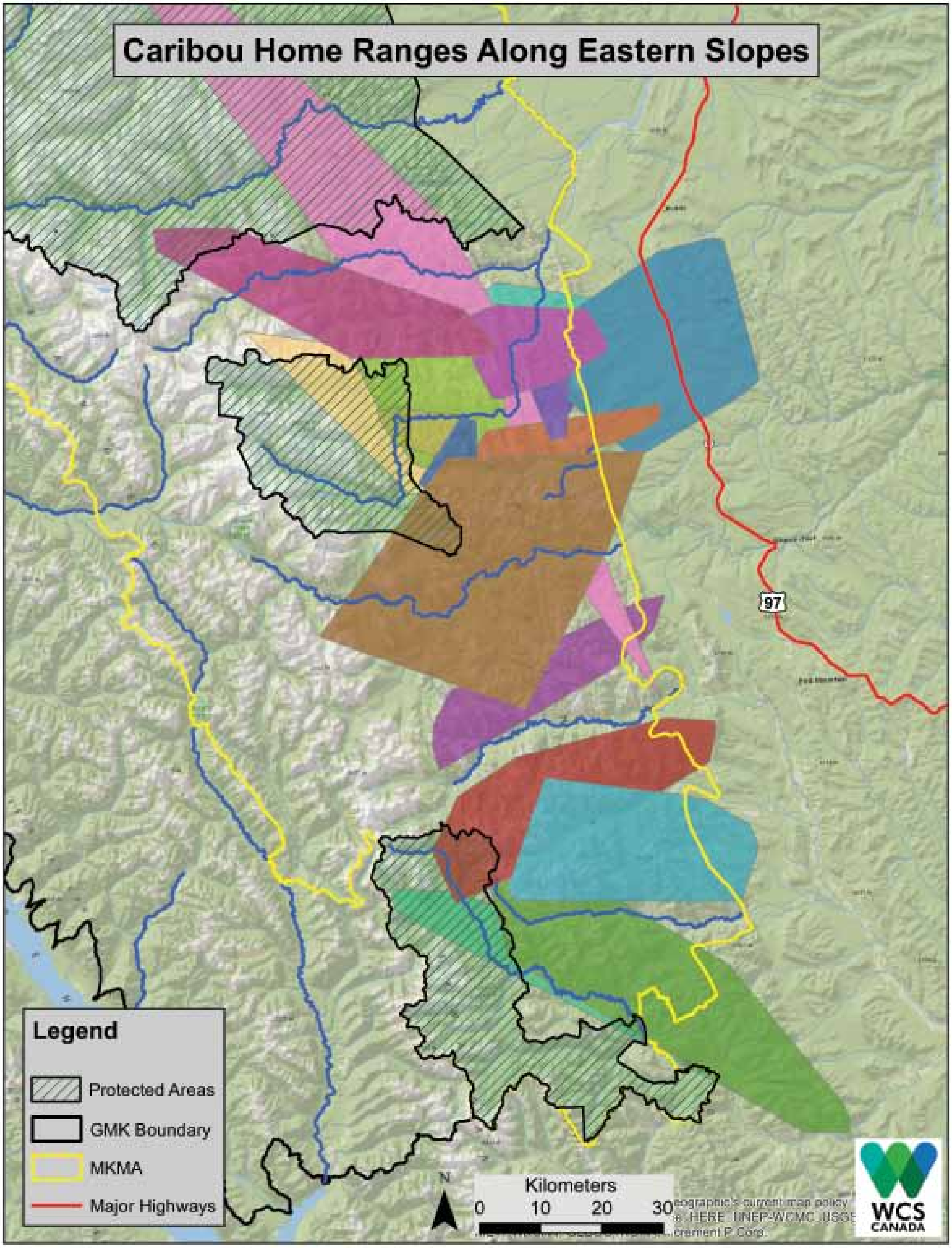


Figure 34. Home ranges (MCP) of some northern woodland caribou spanning from headwaters to lower boreal forest along the Rocky Mountain Eastern Slopes, Greater Muskwa-Kechika area, northern B.C.



Connectivity for Woodland Caribou and Stone's Sheep

The Alaska Highway is an important transportation and infrastructure corridor providing the only direct ground route from the contiguous United States to Alaska through British Columbia, Canada. Completed in 1942, it serves as an engineering and historical monument of World War II and attracts thousands of travelers and tourists each year. Many enjoy opportunities to view wildlife along the highway. Both northern woodland caribou and Stone's sheep cross the Alaska Highway to reach seasonal ranges on each side. Thus, the highway fragments the habitat and movements to key seasonal ranges and/or mineral licks. Vehicle collisions with sheep on the Alaska Highway are a significant mortality factor for sheep in the Sulphur-8 Mile area (Hengeveld and Cubberly 2006: Chapter 6). Ten-year average traffic volume (2009-2018) at Fireside, B.C. was recorded at 391 vehicles/day, peaking to 666 vehicles/day in July (http://www.th.gov.bc.ca/trafficData).

Stone's Sheep

For relevant information about use and crossing of the Alaska Highway by Stone's sheep, we relied upon findings of the 'Sulphur-8 Mile' study conducted 2005-2010 (Hengeveld and Cubberly 2006: see Chapters 6-8). Researchers obtained daily location data for 26 females and 17 males wearing GPS radio-collars.

Stone's sheep used two sections of the Alaska Highway for access to mineral licks (road use) and/or movements between seasonal ranges (road *crossing*) (Cubberly 2011). Well-used licks along the Alaska Highway include the 'Rock Cut' near Summit Pass and Petersen Canyon south of Muncho Lake (Figures 35-36). Highway crossing locations were influenced by the presence of topographical features such as incised draws, canyons, and stream fans on both sides of the highway. Almost two-thirds of GPS collared sheep licked mineral salts on the Alaska Highway at least once during the study. Telemetry locations and direct observations corroborate that sheep have well-defined and predictable places and times of highway use.

Those sheep inhabiting the Stone Range crossed the Alaska Highway (south⇔north) at the 350-m-wide "Rock Cut" in the same section of highway as did northern woodland caribou (Figure 35) (Cubberly 2011). This segment of road bisects a naturally occurring mineral lick where sheep congregate and mineral characteristics are enhanced due to road salt application during winter months. Several sheep mortalities due to vehicle collisions have occurred here.

Sheep inhabiting the Sentinel Range crossed the Alaska Highway (east⇔west) at Peterson Canyon about 5 km south of the south end of Muncho Lake (Figure 36). These crossing events occurred October-December (Cubberly 2011).

Woodland Caribou

We examined sequential telemetry locations (VHF collars) for caribou of the Muskwa herd to ascertain crossings of the Alaska Highway. Data were collected between 2000 and 2004 by researchers with Madrone Environmental Services (Tripp et al. 2006). We determined that 17 individual caribou had crossed the highway a total of 36 occasions for an average rate of 2.1 per animal (range 1-5). In most cases, the interval between recorded locations was too long to accurately determine the actual crossing site. On 4 occasions involving 4 different caribou, however, there was a recorded location ≤ 1.6 km close to the highway during the time period when that animal crossed the highway. On 8 other occasions involving 7 caribou, the animal was ≤ 1.6 km from the highway, but it cannot be determined whether it crossed at that time. Some of these locations occurred where salting of the highway provided an artificial 'mineral lick', and locations may have represented road *use* rather than *crossings*.
Based upon the general pattern of locations, we mapped broad sections of the Alaska Highway that encompassed the most likely crossing areas. Several radio-collared caribou (n = 10) crossed the Alaska Highway (south⇔north) in the vicinity of Summit Pass/Lake along the Stone Mountain Range (Figure 35). The most likely stretch extended from about 10 km west (One Ten Creek) of Summit Pass to 12 km east of the Pass. Other collared caribou (n = 7) using the Sentinel Range crossed the Alaska Highway west of the community of Toad River. The most likely stretch extended from One Fifty-One Creek eastward about 12-15 km to Nonda Creek (Figure 36). There are also mineral licks along this section of the Alaska Highway (Hengeveld and Cubberly 2006).

Courtesy of © Ryan Dickie

Figure 35. Key crossing sites for caribou and sheep along the Alaska Highway at Summit Pass, Greater Muskwa-Kechika area, northern British Columbia.

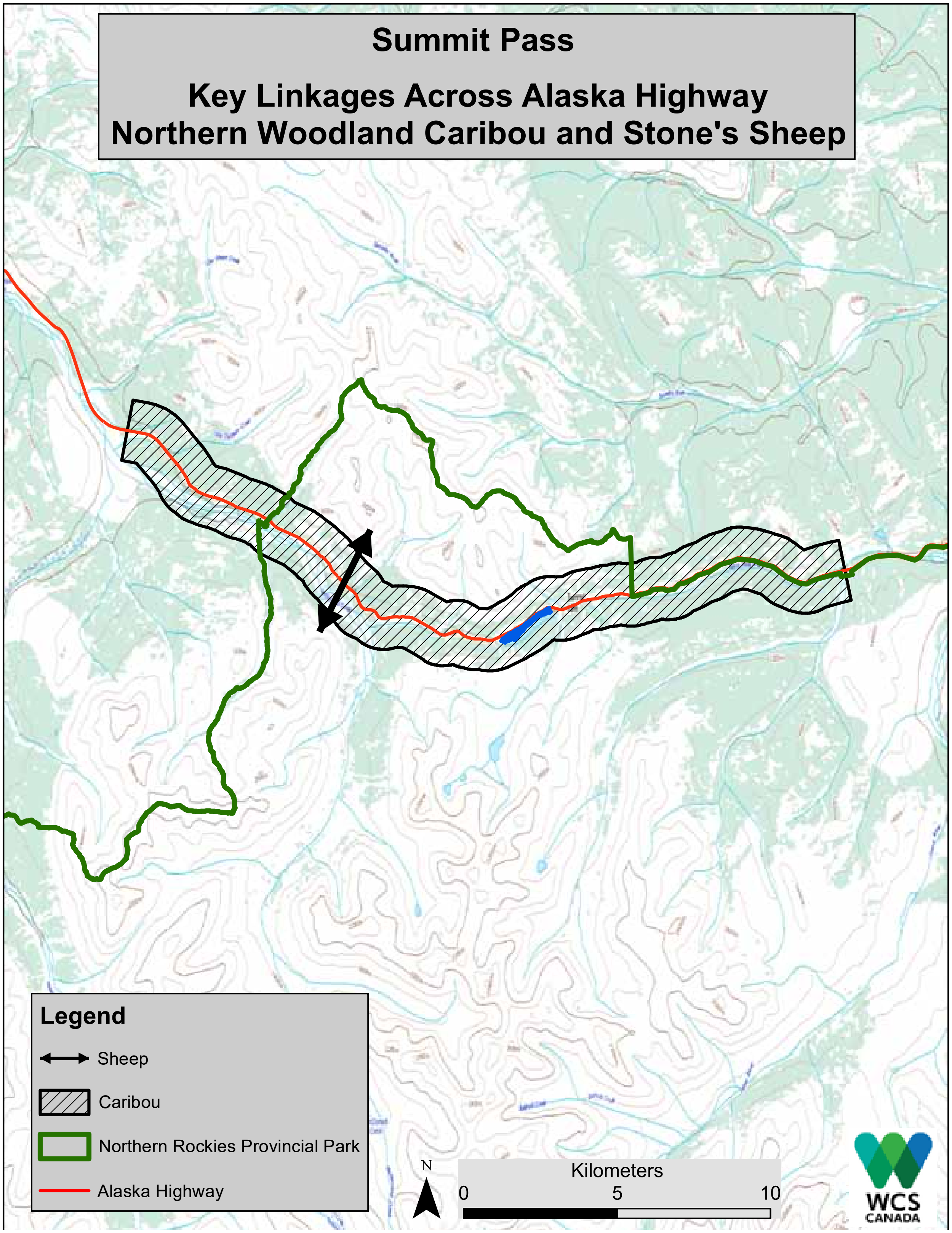
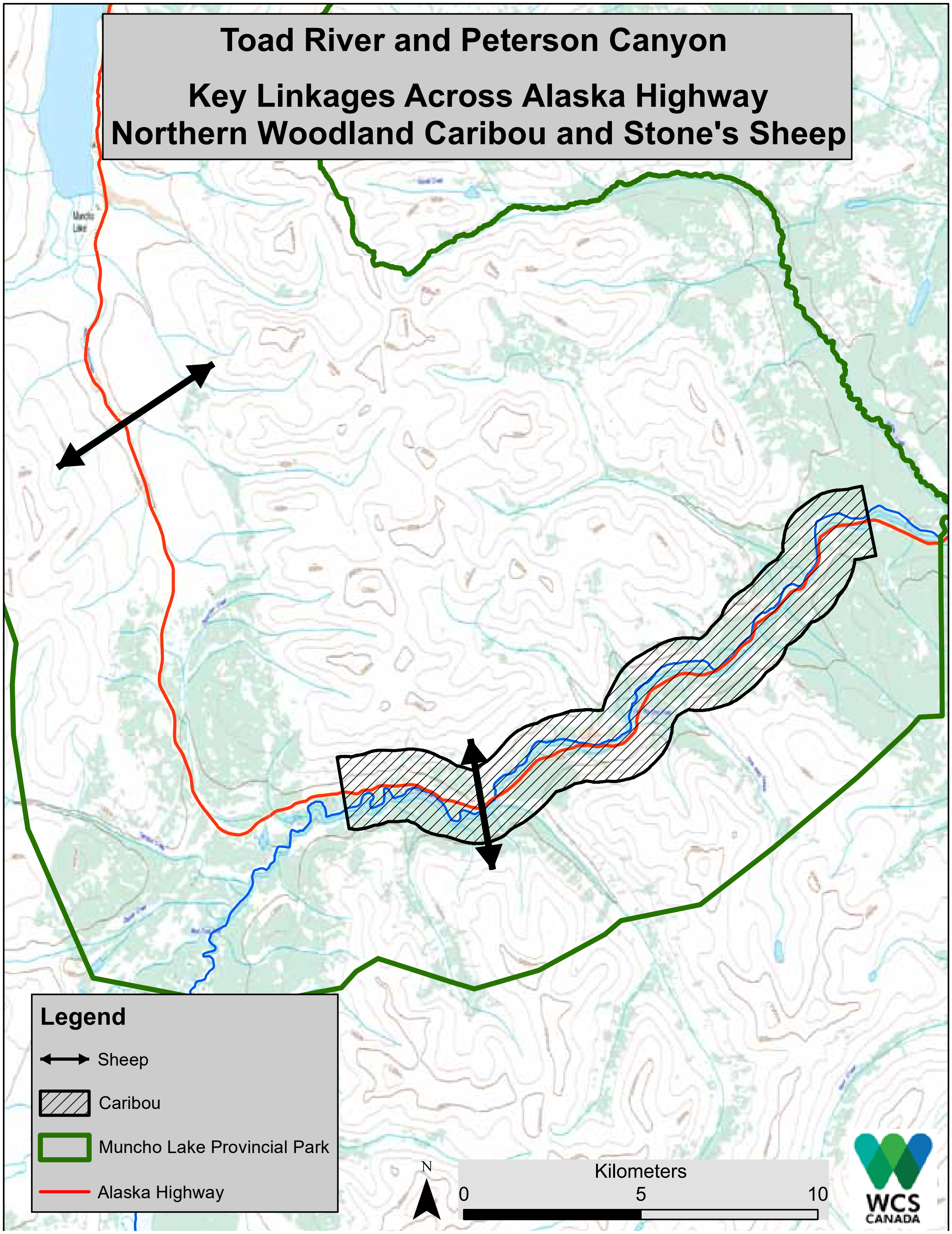


Figure 36. Key crossing sites for caribou and sheep along the Alaska Highway along Toad River and Peterson Canyon, Greater Muskwa-Kechika area, northern British Columbia.



5. A NEW CONSERVATION MAP FOR THE GREATER MUSKWA-KECHIKA

Introduction

Conservation is about the relationship of people with Nature. It involves both the values and emotions that people hold for all things natural and wild as well as an ecological understanding of lands and waters.

People clearly care about the Greater Muskwa-Kechika area. The Kaska and other indigenous peoples have long expressed their deep feelings and beliefs through stories and traditional practices since time immemorial. The diverse group of people who came together to call for establishment of the Muskwa-Kechika Management Area 20-25 years also expressed a vision for this area: "*to maintain in perpetuity this globally significant area of wilderness, wildlife and cultures" by ensuring that human activities take place in harmony with wilderness quality, wildlife and dynamic ecosystems on which they depend*."

This vision for the Muskwa-Kechika establishes a <u>very high</u> and bold conservation standard that embodies values of wildness, ecological integrity and resiliency for the long term. The MKMA plan was visionary for its time, but we can now see its limitations in this era of unrelenting expansion of human developments: protected areas are not large enough for wide-ranging animals like caribou and grizzly bears … not connected to facilitate seasonal movements by wildlife now or in response to climate heating … not representative of all the ecological diversity across the area … and 'special management' areas do not have strong enough safeguards against industrial development. .

Contemporary efforts by national governments to protect areas have relied upon politically-based targets of some percent, such as the current Aichi 2020 Target 11 of 17% of land (CBD 2010) and the previous Brundtland Commission target of 12%. These top-down targets have been criticized because they are arbitrary and political, rather than derived from scientific evidence about the biological needs of species. and environmental representation (Visconti et al. 2019). An extensive review found that conservation approaches based upon evidence led to recommendations 3x larger than those based upon policy-driven targets which are woefully low (Svancara et al. 2005). Empirical estimates of what is needed to represent and protect habitat and ecosystems vary roughly between 25% and 75%, depending upon the set of features considered for conservation (Watson et al, 2016). Moreover, the top-down political targets can lead to perverse outcomes because the simple metric of percent-area may have little to do with protection of key biodiversity areas (Visconti et al. 2019).

In this assessment, we follow a science-based, empirical process for deriving and mapping our recommendation for an expanded network of protected areas for the Greater Muskwa-Kechika area. Thus, a percent-area recommended for protection emerges from the bottom-up, based upon sound ecological principles and empirical analyses, rather than a top-down target based upon an arbitrary percent-of-area.

We have gathered together various kinds of ecological information about this vast and beautiful land… about its vulnerable fish and wildlife and location of their key habitats … its bedrock, elevation gradients, and plant communities that characterize the land from river valley to mountain peak … and the darkening clouds of climate heating that require a new thinking about resiliency amid change. In this chapter, we seek to integrate these tributaries of information into a coherent plan for a more representative, better connected and more resilient network of protected areas than exist today. The final step involves integration of these conservation features using appropriate-scale intact watersheds to map a new network of protected areas.

Guiding Principles and Scenario Analyses

We incorporated several contemporary principles of conservation planning to guide our recommendations for a new network of protected areas for the Greater Muskwa-Kechika area in northern British Columbia (Hansen et al. 2010, Groves and Game 2015, Beloit et al. 2017). In particular, the principles summarized by the Canadian BEACONs project provide excellent guidance for proactive planning of the whole landscape to maintain biological diversity, ecological representation, and ecosystem integrity (Schmiegelow et al. 2014, Lisgo et al. 2015).

- **Represent the full range of environmental variation across the region – including diversity of ecoregions, enduring features, and freshwaters (lakes, rivers, and wetlands).**
- **Conserve high-value habitat for populations of vulnerable fish and wildlife species.**
- **Provide for gradients of landscape diversity and cooler refugia for greater resiliency in a hotter future.**
- **Embed hydrologic and terrestrial connectivity *within* core areas (or otherwise provide it between core areas) to facilitate fish and wildlife movements for population and genetic**

- ➢ **Identify areas large enough to accommodate scale of natural disturbances (e.g., fire) and at least average size of individual home ranges for caribou in the region (>3,500 km^2).**
- ➢ **Safeguard intact watersheds – especially in the headwaters – as the gold standard in conservation planning (and a natural mapping unit).**

We begin by examining two approaches for informing our final recommendations for a network of new protected areas to fully realize the vision for the Greater Muskwa-Kechika area. One involves a straight-forward, composite overlay of the various conservation features, and the second explores various scenarios to optimize a spatial solution that meets high standards for conservation features.

Composite Score for Species' Habitats and Landscape Features

We selected 6 important features for deriving a composite score across the Greater Muskwa-Kechika area: key areas for northern woodland caribou, Stone's sheep, moose, and bull trout; variety of enduring features; and climate refugia. For each feature, we scored their importance based upon conservation values as described in earlier chapters: High = 3, Moderate = 2, Low = 1. We draped a grid of 1-km^2 cells across the GMK (n = 121,041 cells) and tallied the scores for each conservation feature in each cell. Maximum **composite** tally for a cell could have been 18 (6 features x highest score of 3), and some cells did reach the maximum score. We segregated the composite scores as follows: High = 10-18, Moderate = 5-9, and Low = 1-4.

High composite scores occur on 36 % (42,854 km^2) of the Greater Muskwa-Kechika, with moderate composite scores on another 47 % (56,105 km^2) for a combined total of 83 % (98,959 km^2) (Figure 37). Two-thirds of the areas with high composite scores and exactly half of the moderate composite scores occur within the Muskwa-Kechika Management Area. High-scoring areas include:

- ✔ (1) middle-upper Kechika River-Gataga River-Turnagain River watershed,
- ✔ (2) upper Rabbit and upper Toad River over to Muncho Lake Provincial Park,
- ✔ (3) Muncho Lake across Alaska Highway to Northern Rocky Mountain Park,
- ✔ (4) Rocky Mountains and Foothills from Alaska Highway south through the Muskwa and Prophet River down to Halfway and Graham River.

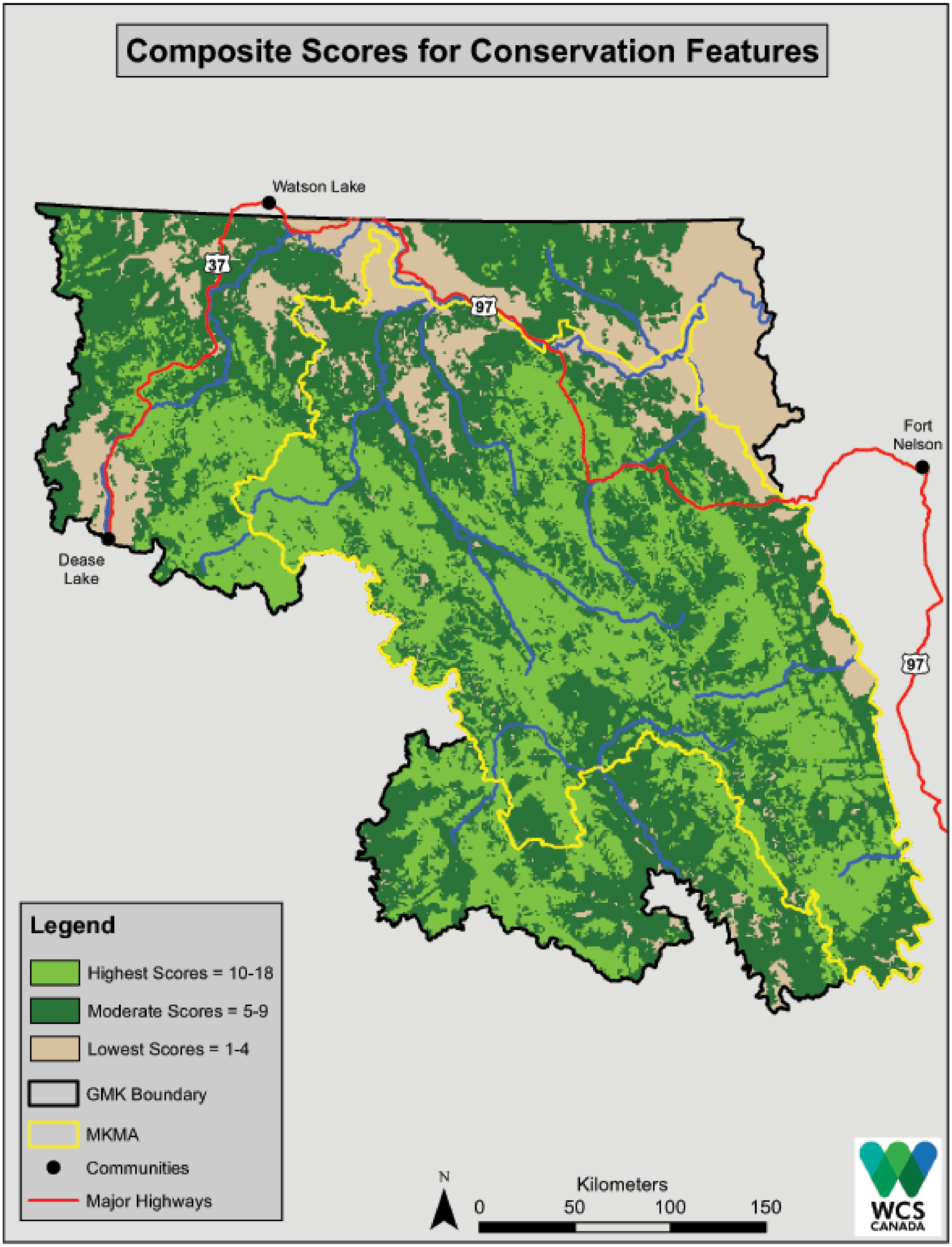
Several areas with high composite values beyond the MKMA also warrant strong conservation:

- ✔ (1) upper section of the Finlay River (headwaters of the Peace River).
- ✔ (2) Horseranch Range, upper tributaries to Dease River south to Cry Lake and upper Turnagain River.

Other areas with moderate scores are nonetheless important include:

- (1) Liard Plateau, and
- (2) Little Rancheria River

Figure 37. Location of composite scores for selected conservation features, Greater Muskwa-Kechika area, northern B.C. Conservation features included northern woodland caribou, Stone's sheep, moose, bull trout, variety of enduring features and headwater refugia (see text for scoring methods).



Systematic Planning Scenarios with Assigned Conservation Targets

In the past, conservation practioners used *ad hoc* methods or *opportunism* to select protected areas. In the early 1990s, a systematic approach emerged that was more rigorous, repeatable, and structured to efficiently meet conservation objectives (Pressey et al. 1993). Over the past 25 years, advances in computer software have facilitated this approach, with the program *Marxan* being commonly used (Ball et al. 2009). Most recently, a program called *Prioritizr* has been developed which finds an optimal spatial solution using integer linear programming in *R*, can read data formatted for Marxan, but runs in a much shorter time (Beyer et al. 2016).

We explored different planning scenarios to examine the effects of varying the targets and the potential effect of mining. Although we specified targets to frame the planning exercise, they differ from an arbitrary target for area-only because our targets are for ecological features (Pressey et al. 2017). We identified the same conservation features as in the composite analysis but added several others: notably ecoregions but also large lakes and wetlands. Dr. Sara Williams (Univ. Montana) carried out several planning scenarios using *Prioritizr* and contributed both insights and skill in conservation planning.

To guide our framing of scenarios, we examined potential for various commodity resources – oil & gas, minerals, timber, and wind-power – as modelled and mapped by Suzuki and Parker (2016) for the Muskwa-Kechika Management Area. We extended their analyses to the Greater Muskwa-Kechika by following their methods closely (details shared courteously by N. Suzuki). We confirmed that our methods produced identical / essentially the same maps within the MKMA. We then applied our methods consistently across the entire GMK because higher potentials of certain resources (oil & gas, and minerals) outside the MKMA shifted the relative ranking of some sites.

Oil & gas basins occur extensively across northeast B.C. and have been developed intensively. The salient geologic formation extends into the northeast corner of the Greater Muskwa-Kechika west of Ft. Nelson, north of the Alaska Highway (Figure 38, upper left). This area has lower conservation value and already has some existing wells and roads, and timber clearcuts. Although timber potential appears extensive across the GMK, only some areas with road accessibility and proximity to mills and markets are economically viable (closer to Fort Nelson, Watson Lake, and Kwadacha). High potential for wind power is restricted to a few sites along the eastern foothills (Table 24, Figure 38).

Table 24. Extent (km^2) of potential resource development ranked by 3 highest classes, Greater Muskwa-Kechika area, northern British Columbia. Methods followed Suzuki and Parker (2016).

Percent Rank	Oil & Gas	Mineral	Timber	Wind Power	Sum*
90-100 %	37.3	599.6	619.8	30.0	1,286.3
80-90 %	11.0	504.4	7,433.8	30.0	7,937.6
70-80 %	2,768.9	1,758.4	13,635.0	75.0	16,428.4
SUM	2,817.2	2,862.4	21,688.6	135.0	25,652.3
% Study Area	**2.35**	**2.39**	**18.08**	**0.11**	**21.38**

Mines has the most potential for conservation impacts for several reasons: (1) their location at headwaters and risk of catastrophic consequences should dams/reservoirs of tailings collapse, (2) often require inaugural access into remote areas, and (3) overlap with important areas for vulnerable fish and wildlife. Therefore, we chose to evaluate a scenario with mining potential.

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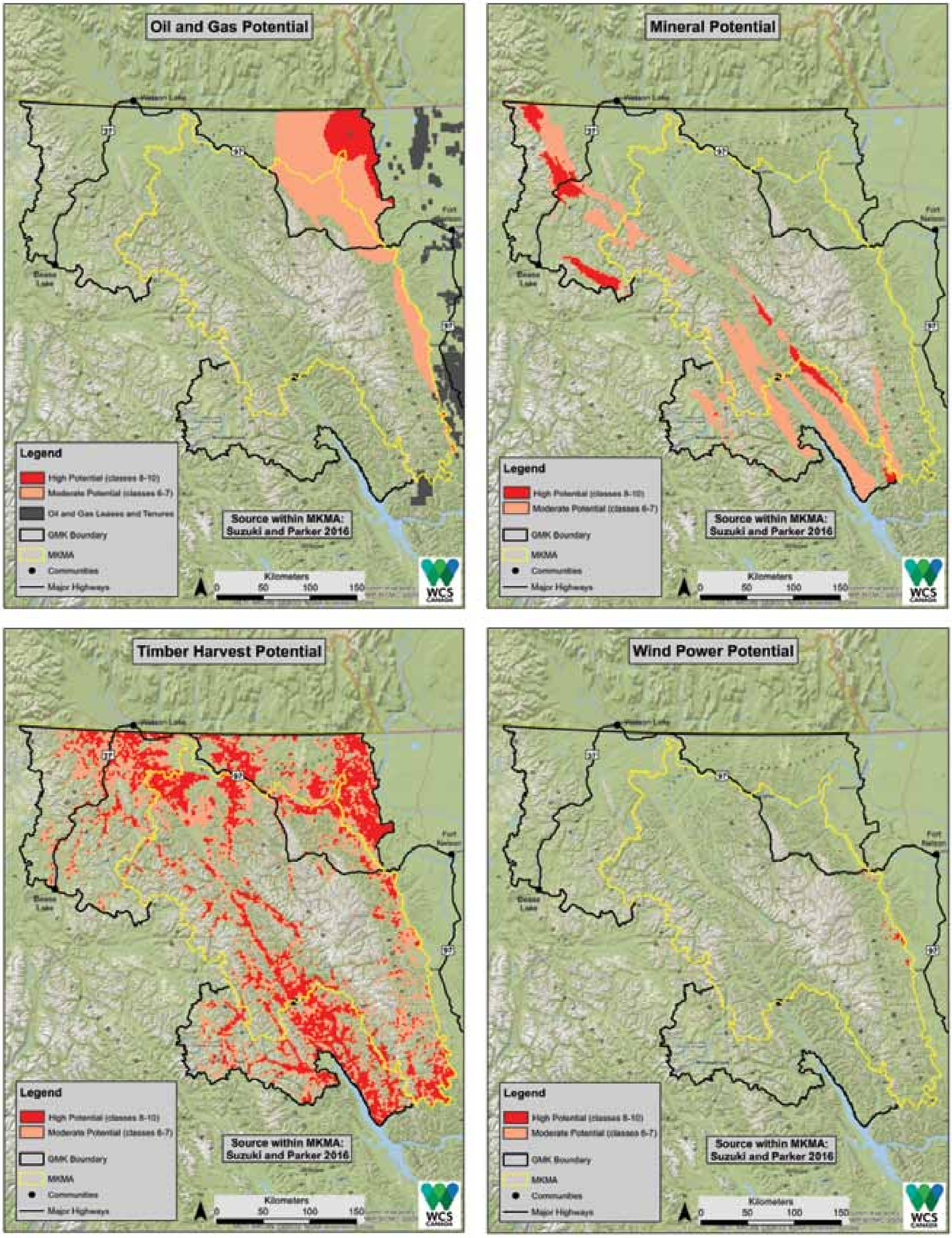
Figure 38. Modeled location of potential commodity resources for oil & gas, minerals, timber, and wind energy, Greater Muskwa-Kechika area, northern British Columbia. Model methods and parameters followed Suzuki and Parker (2016) for the Muskwa-Kechika Management Area. See text for details.



We present the following scenarios (see Table 25 for specific targets and outcomes, and Figure 39 for maps): Existing protected areas were 'locked-in' in each of these scenarios.

Scenario 1: *Very* High Conservation Emphasis. Targets 'locked-in' (100%) for high values for fish and wildlife species, cool refugia, large lakes, wetland density, and variety and rare enduring features. Target values set at 60% for moderate values and 30% for low values of these features. Representation target for ecoregions set at 50%.

Scenario 2: High Conservation Emphasis: Similar to Scenario 1 but all targets relaxed downward by 10%. Representation target for ecoregions set at 35%.

Scenario 3: *Very* High Conservation Emphasis with Mitigation for Mining Influence. Similar to Scenario 1 but 3,687 km^2 of current and likely mining activity 'locked-out' from consideration for protected areas. Moderate-value habitats added for mitigation.

Scenario 1 yielded a 'spatial solution' of 90,650 km^2 or 75.9% of the Greater Muskwa-Kechika area (Figure 39b). About 57% occurred with the Muskwa-Kechika Management Area. This solution met (by rule) the locked-in target of 100% for the high-value habitats and conservation features and slightly exceeded the target of 60% for the moderate-values (Table 25). For low-value features, it exceeded the lower target of 30% substantially in most cases. It met the target of 50% representation of all ecoregions.

Scenario 2 yielded a 'spatial solution' of 76,307 km^2 or 63.9% for the Greater Muskwa-Kechika area (Figure 39c). Existing protected areas accounted for 21,207 km^2 (17.7 %), while 55,100 km^2 (46.2%) of important conservation features occurred elsewhere across the GMK. Again, about 57% of the total coverage fell within the MKMA. This solution met (or slightly exceeded) the high target of 90% and the moderate target of 50% in nearly all cases (Table 25). For the ecoregions, the target of 35% was exceeded significantly in 5 of 7 ecoregions due to the presence of other outstanding conservation features. Modeling resulted in addition of areas in the lower-elevation, more boreal ecoregions – Liard Basin, Muskwa Plateau, and Hyland Highland – to reach that target of 35% representation. Lowering the conservation target by 10% appeared to reduce coverage of some areas along the Rocky Mountain foothills, the lower Kechika River, and north of the Liard River around Liard Plateau.

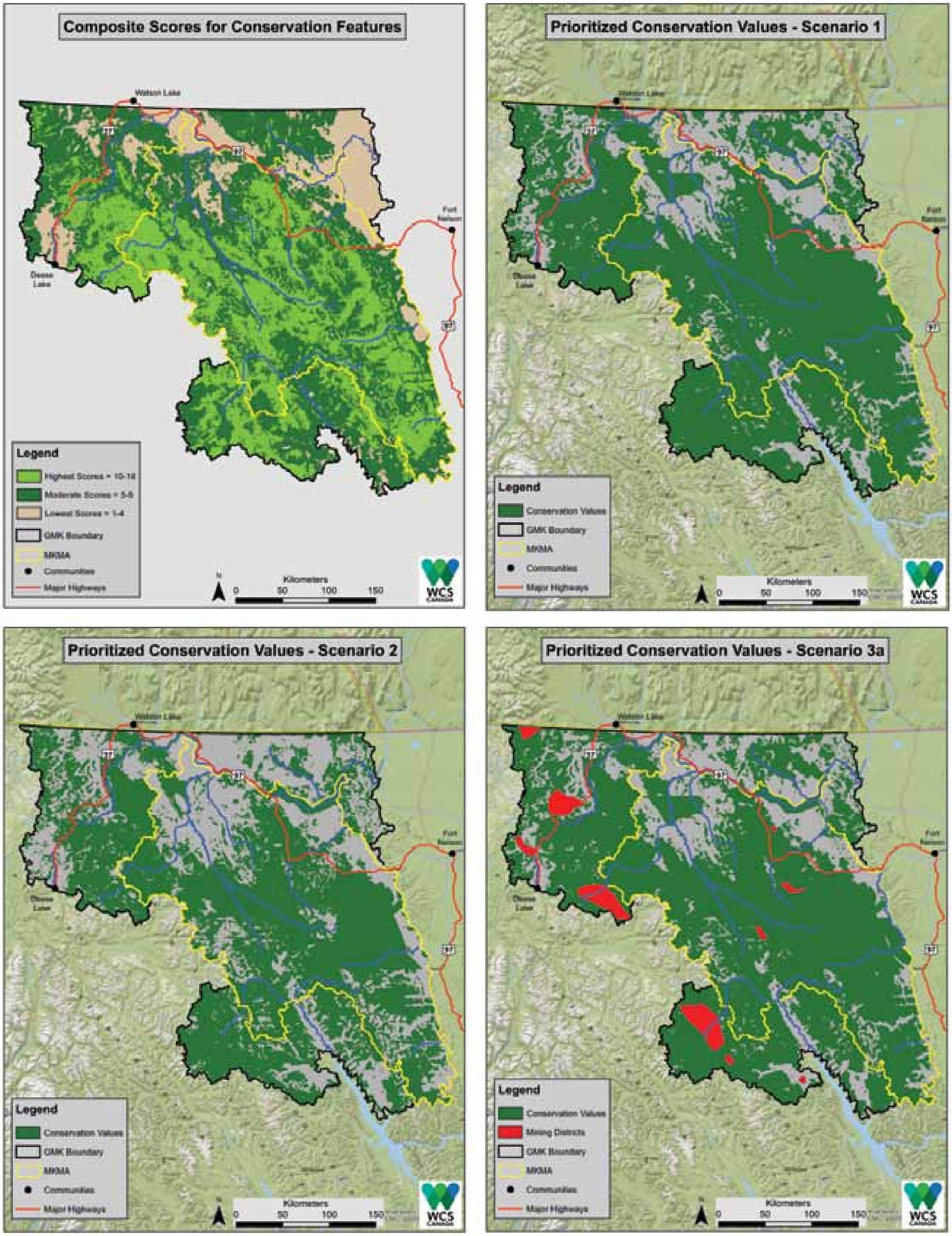
Scenario 3 yielded a 'spatial solution' of 87,533 km^2 or 73.3% for the Greater Muskwa-Kechika area (Figure 39d). About 66,326 km^2 (55.6%) of important conservation features occurred outside of the existing protected areas. Again, about 57% of the total coverage fell within the MKMA. The mining areas resulted in a shortfall of meeting species targets by 8% for bull trout, 5% for caribou, and 1% for Stone's sheep. Other features also fell short of target by 3-11%. Mining footprint in the upper Turnagain River (19.4%) and upper Finlay (14.7%) had more impact on the set of conservation features compared to the other areas (1.4-4.6%).

Table 25. Targets and outcomes for selected conservation features under different planning scenarios, Greater Muskwa-Kechika area, northern British Columbia. See text for description of scenarios.

		Scenario 1		Scenario 2		Scenario 3	
Conservation Feature	**Habitat**	**Target**	**Outcome**	**Target**	**Outcome**	**Target**	**Outcome**
Caribou	H	100	**100**	90	**90**	100	**93**
	M	60	**73**	50	**59**	60	**76**
	L	30	**62**	20	**44**	30	**64**
Stone's Sheep	H	100	**100**	90	**92**	100	**99**
	M	60	**83**	50	**72**	60	**77**
	L	30	**60**	20	**48**	30	**61**
Bull Trout	H	100	**100**	90	**90**	100	**91**
	M	60	**68**	50	**53**	60	**76**
	L	30	**61**	20	**45**	30	**61**
Moose	H	60	**70**	50	**60**	60	**71**
	M	30	**53**	20	**29**	30	**72**
Cooler Refugia	H	100	**100**	90	**92**	100	**97**
Large Lakes	H	100	**100**	90	**92**	100	**96**
Wetland Density	H	80	**80**	70	**58**	80	**91**
	M	50	**65**	40	**50**	50	**81**
Enduring Features							
Variety	H	100	**100**	90	**90**	100	**97**
Rare	H	100	**100**	90	**89**	100	**89**
Ecoregions							
Central Canadian Rockies	H-M	50	**90**	35	**58**	50	**90**
Muskwa Plateau	H-M	50	**73**	35	**34**	50	**51**
Pelly Mountains	H-M	50	**51**	35	**62**	50	**71**
Boreal Mountains and Plateaus	H-M	50	**80**	35	**70**	50	**76**
Liard Basin	H-M	50	**54**	35	**35**	50	**54**
Hyland Highland	H-M	50	**59**	35	**44**	50	**59**
Northern Canadian Rockies	H-M	50	**86**	35	**77**	50	**90**
Area Covered by Outcome		**9,065 km^2**		**7,631 km^2**		**8,754 km^2**	

The map of composite scores and the scenario maps appears similar in identifying important area for protection based upon the set of conservation features (Figure 39). In both approaches, much of the Muskwa-Kechika Management Area stands out as important for wildlife and landscape features in support of diversity and resiliency. One important difference between the approaches, however, is that ecoregions could not be incorporated into the framework of composite scoring using the grid. Because the vulnerable species and cool refugia tend to result in higher-elevation areas mapped as more important, the boreal ecoregions – Liard Basin, Muskwa Plateau, and Hyland Highland – at lower elevations are not well represented. An additional value associated with boreal forests in the lower sections of the Dease, Kechika, Rabbit, and Liard Rivers (not quantified in this assessment) is storage of carbon (Pojar 2010).

Figure 39. Location of prioritized areas for selected conservation feature under different scenarios, Greater Muskwa-Kechika area, northern B.C. See text for description of different scenarios and Table 25 for specific targets of conservation features.



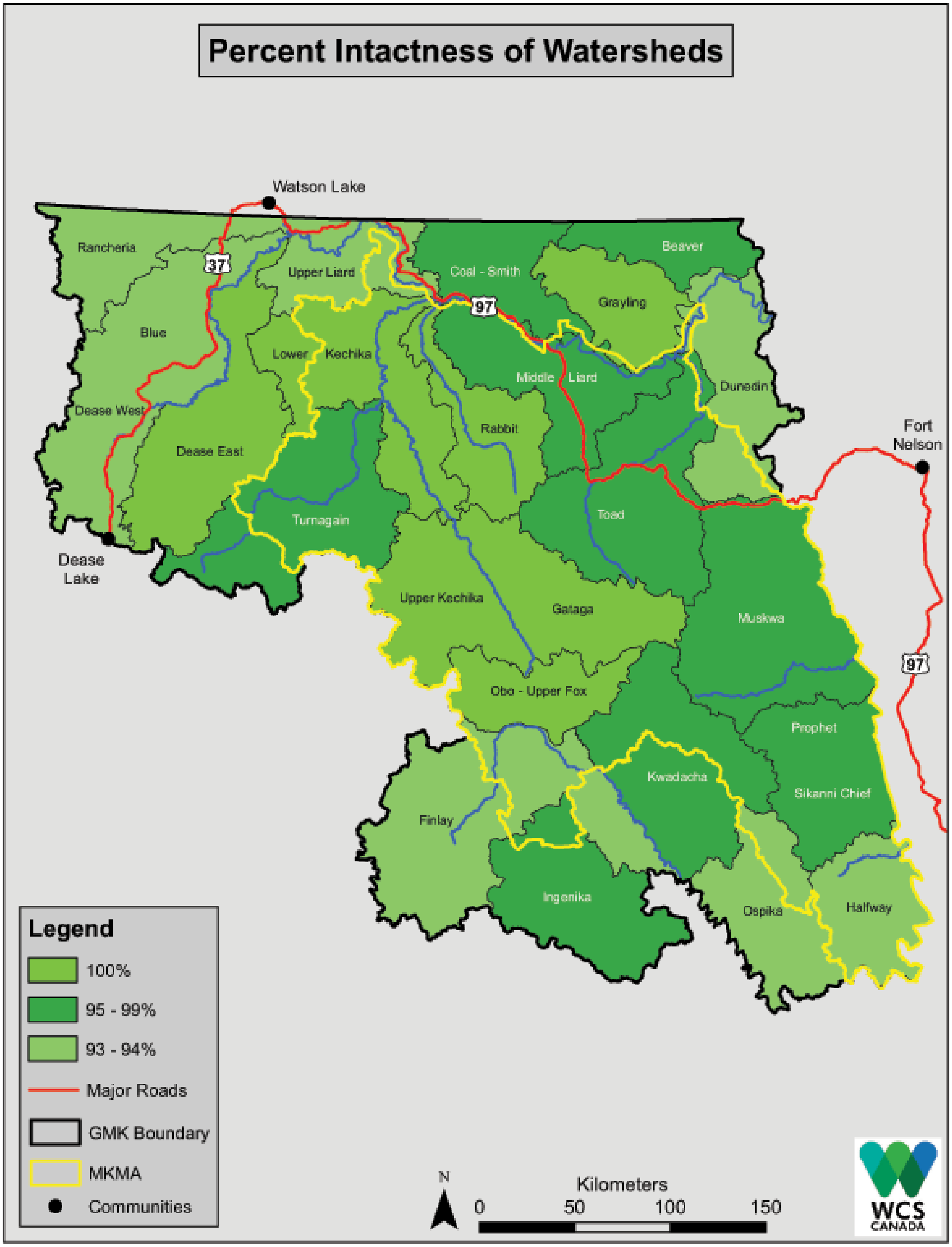
Intact Watersheds

Watersheds at various scales are natural units for conservation planning and protection. As our last step for informing a new conservation blueprint for the Greater Muskwa-Kechika, we mapped watersheds at a scale that matched the size of natural disturbances (fire) and home ranges of wide-ranging animals (caribou). A Minimum Dynamic Reserve (MDR) is the area needed to maintain internal colonization in the face of maximum size of disturbance such as fire (Leroux et al.2007). Based upon data collected by the BEACONs project (2017), the average MDR in the 5 ecoregions across the GMK was 2,682 km^2 (range 1,089 km^2 – 5,329 km^2). For northern woodland caribou herds across the Greater Muskwa-Kechika, the average home range size (kernel density estimator) of 66 individuals was 3,263 km^2 (range 672 km^2 – 8,540 km^2) (Eric Palm *unpublished data*). For onservation planning, we segregated the Greater Muskwa-Kechika into 22 watersheds that averaged 5,684 km^2 in size (std dev. = ± 2,077 km^2) (Table 26, Figure 40). These watersheds have remarkably high degree of intactness, with an overall intactness of 96.9%. The core area comprising the Muskwa-Kechika Management Area is essentially intact, with an intactness of 99.3% (excluding the Alaska Highway). Seven watersheds are 100% intact.

Table 26. Area (km^2) of watersheds, Greater Muskwa-Kechika area, northern British Columbia.

Major/minor Watershed	Area (km^2)	% GMK	% Intactness
Dease-Upper Liard River	**21,644**		
Dease East	6,403	5.36	99.88
Blue River - Dease West	8,359	7.00	94.40
Rancheria River-Upper Liard River	6,882	5.77	94.94
Kechika-Turnagain River	**26,696**		
Lower Kechika River	6,720	5.63	100.00
Rabbit River	3,714	3.11	99.99
Turnagain	7,009	5.87	97.91
Upper Kechika Gataga	9,253	7.75	100.00
Liard-Toad River	**25,848**		
Beaver River	2,277	1.91	95.08
Coal River-Smith River	3,439	2.88	95.35
Dunedin River	4,665	3.91	93.49
Grayling River	3,182	2.67	99.83
Middle Liard	4,971	4.16	95.41
Toad River	7,314	6.13	95.54
Muskwa-Halfway River	**16,323**		
Halfway River	3,372	2.83	94.71
Prophet Besa Sikanni	4,676	3.92	97.48
Muskwa	8,275	6.93	98.87
Finlay River	**28,852**		
Finlay River	9,182	7.69	94.36
Kwadacha River	6,774	5.67	95.47
Ingenika River	5,371	4.50	96.62
Ospika River	4,451	3.73	94.47
Obo River-Upper Fox River	3,074	2.58	100.00
TOTAL	119,363	100.00	
Mean ± SD	**5,684 ± 2,077**	**4.76 ± 1.74**	**96.85 ± 2.31**

Figure 40. Intactness of watersheds across the Greater Muskwa-Kechika area, northern British Columbia. The average size of 5,684 km^2 (± 2,077) (Table 26) accommodates the scale of natural disturbance by fire (BEACONS 2017) and average size of home ranges for caribou in the GMK.



A New Conservation Map for the Greater Muskwa-Kechika

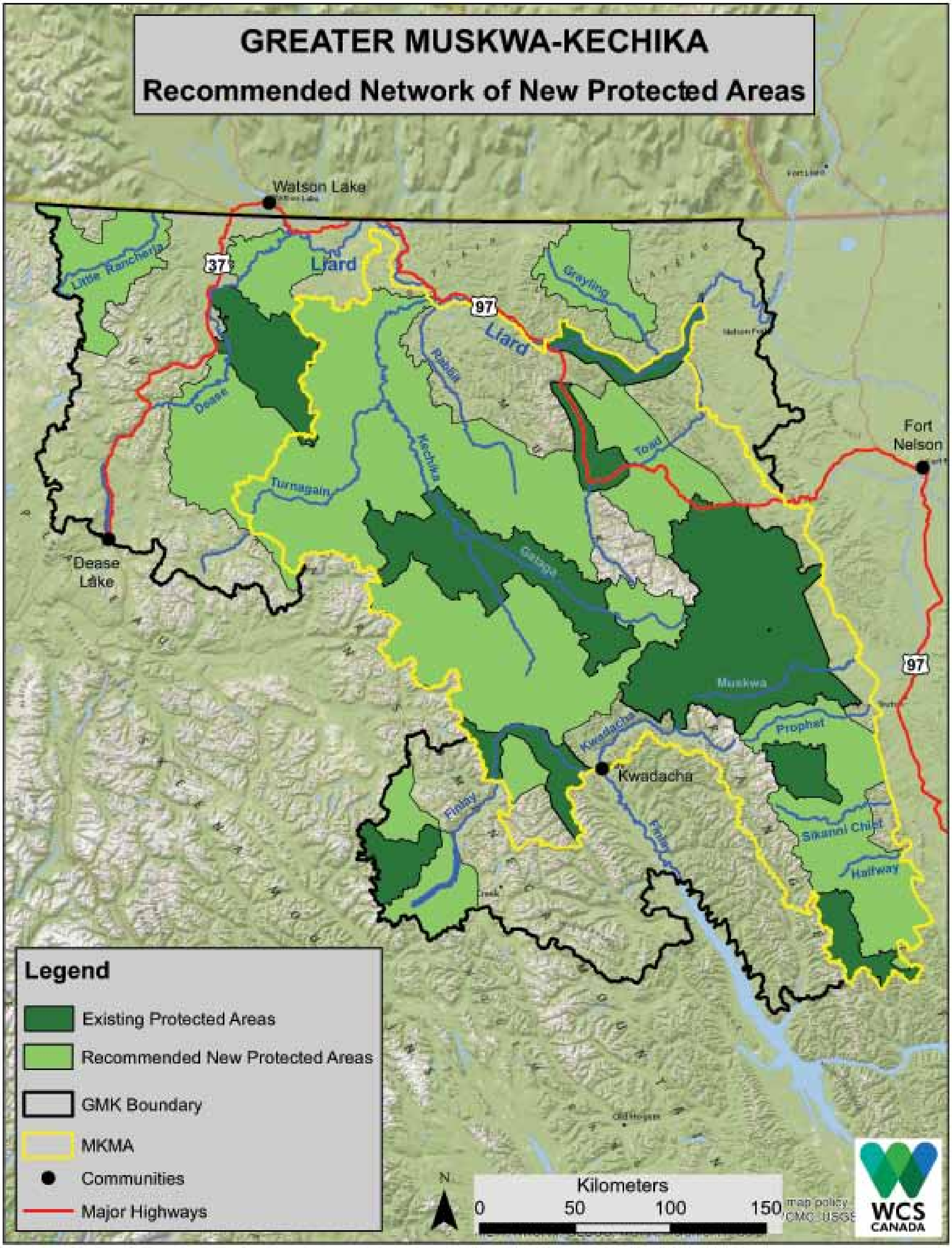
The vision statement for the Muskwa-Kechika Management Area (and, by ecological implication, the Greater Muskwa-Kechika area) speaks to maintaining its world-class values of wildlife and wilderness in conjunction with indigenous cultures. This calls for a high standard of conservation objectives and performance commensurate with the vision. To build a more representative, better connected, and more resilient network of protected areas across the Greater Muskwa-Kechika than exists at present, I recommend protection of several new areas. The recommended network is based upon guiding principles of conservation, empirical data analyses and models of important habitat for vulnerable fish and wildlife, connectivity, and refugia in a hotter climate. Our recommendation is informed by the maps of composite scores, various scenarios using program *Prioritizr*, and watershed intactness. Lastly, we aligned the boundaries of recommended protected areas to watershed boundaries at various hydrological levels.

Existing protected areas (EPAs) comprise **27.4 %** (17,496 km^2) of the Muskwa-Kechika Management Area (63,844 km^2) and **17.5 %** (20,882 km^2) of the Greater Muskwa-Kechika (119,371 km^2) (Table 27, Figure 41). The recommended protected areas (RPAs) would secure an additional **48.8 %** (31,149 km^2) of the MKMA and **36.1 %** (43,054 km^2) of the GMK. Overall, the total Protected Areas network would comprise **76.2 %** (48,645 km^2) of the MKMA and **53.6 %** (63,936 km^2) of the Greater Muskwa-Kechika.

Table 27. Size (ha) of Existing Protected Areas (EPAs) and Recommended Protected Areas (RPAs), Muskwa-Kechika Management Area (M-KMA) and Greater Muskwa-Kechika Area (GMKA), northern British Columbia. Projection is B.C. Albers.

Muskwa-Kechika Management Area = 63,844 km^2			
Existing Protected Area	**Size (km^2)**	**Recommended Protected Area**	**Size (km^2)**
Northern Rockies	8,227	Kechika	15,523
Redfearn-Keily	808	Upper Rabbit-Toad	3,401
Graham-Laurier	997	Muncho Lake-NRM	2,999
Muncho Lake	862	Eastern Slopes	5,592
Liard River Corridor	912	Obo	1,590
Dune Za Keyih	4,463	Upper Fox	1,487
Finlay-Russel	1,228	Middle Finlay	557
Total M-KMA	**17,496**		**31,149**
Greater Muskwa-Kechika Area = 119,371 km^2			
Ne'āh' Conservancy	2,372	Cry Lake	3,339
Tatlatui Park	1,014	Lower Dease-Kaska Creek	1,549
		Liard Plateau	2,276
		Tatlatui -Thutade	2,120
		Upper Rancheria	2,620
Additional G-MKA	**3,386**		**11,905**
GRAND TOTAL	**20,882**		**43,054**

Figure 41. Recommended network of new protected areas, Greater Muskwa-Kechika area, northern British Columbia.



Narrative on the Network of Protected Areas across the Greater Muskwa-Kechika

Here, I offer a short narrative and geographic perspective about the network of existing and recommended protected areas. The purpose is to depict how the recommended protected areas connect with existing parks and with each other to form a cohesive network. A series of maps to accompany the narrative in shown in Figure 42. In each map, the area of focus is highlighted in yellow, and the cumulative build-up of new protected areas in shown in light green as we proceed through the series.

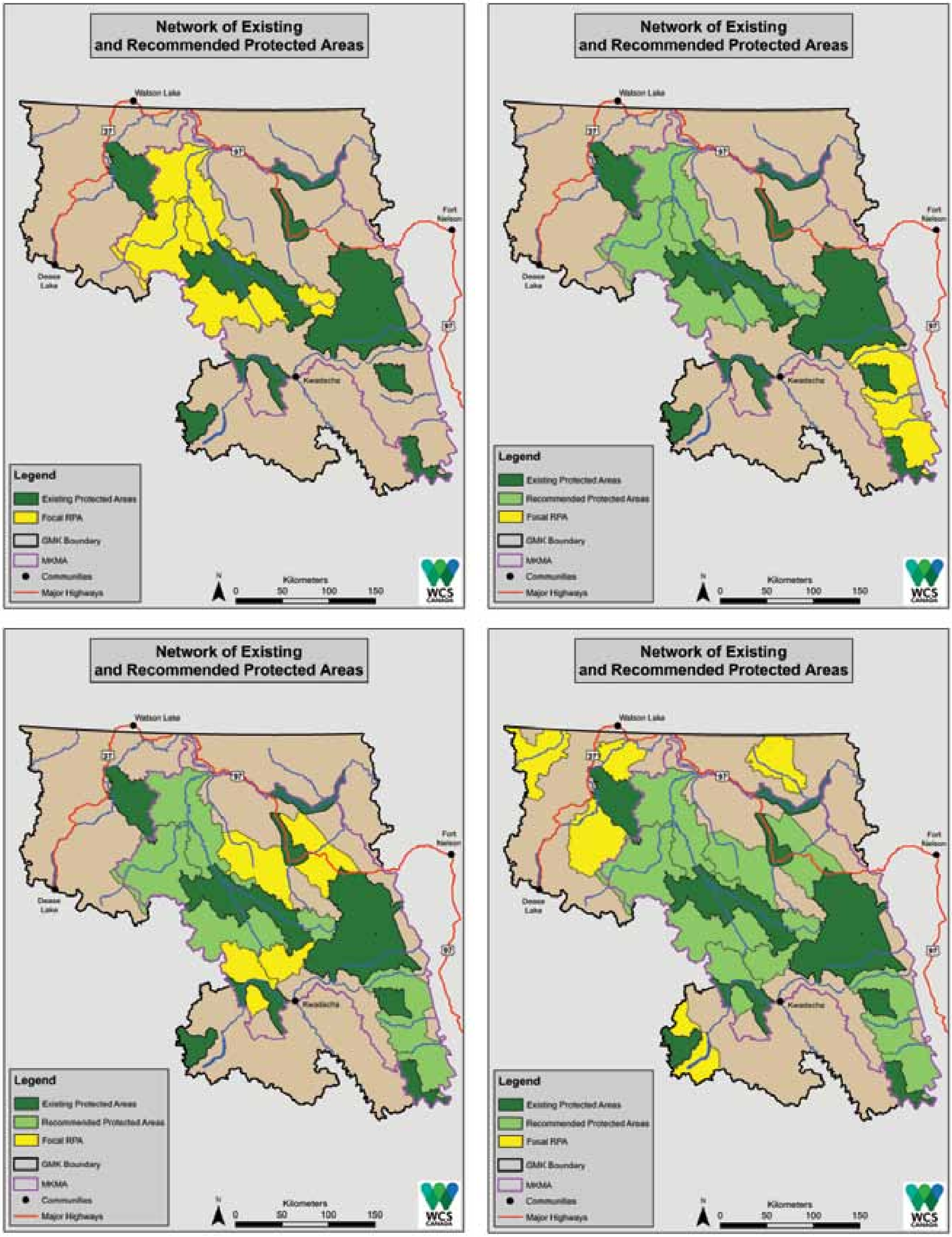
(1) **Kechika River watershed** (upper left): The Kechika River watershed can be considered the showpiece at the heart of the Greater Muskwa-Kechika area. This huge (15,000 km^2) area contains the wildest section of the Rocky Mountain Trench and encompasses several boreal ecoregions and notable concentration of diverse enduring features. The lower section has high primary productivity and myriad wetlands. It includes key habitat for two caribou herds, Stone's sheep, and bull trout. The Kechika River valley provides a long 'ramp' from boreal forests in lower sections to cool refugia in the headwaters for resiliency in a hotter world. This would connect and enhance existing protected areas: Northern Rockies and Dune Za Keyih Provincial Parks and Ne'āh' Conservancy. The headwaters of the Turnagain River were not included due to a legacy of mining activity and some renewed interest. Failure of any dam/reservoir containing mine tailings could send toxic heavy metals far downstream

(2) **Rocky Mountains and Foothills** (upper right): Called the "Serengeti of the North", the diverse ecosystems along the Eastern Slopes support a notable diversity of predators (wolves and bears) and prey (2 herds of caribou, plentiful Stone's sheep, moose, elk, and even bison). This is a rare opportunity to protect a spectacular landscape at lower elevations; where the east-west river valleys provide a short ramp to cool refugia at the headwaters. This would connect and enhance existing Provincial Parks: Northern Rockies, Redfearn-Keily, and Graham-Laurier.

(3) **Muncho Lake Connection and Headwaters of the Peace** (lower left): The upper yellow area would provide a vital connection across the Alaska Highway for caribou and Stone's sheep between Northern Rockies and Muncho Lake Provincial Parks. The middle area would include key habitat for caribou at the head of Rabbit River and augment the size of the Kechika protected area. To the south, the recommended protected area would encompass the headwaters of the Peace River (upper Finlay, Fox and Obo Rivers), which has important habitat for caribou, moose, and cooler refugia for bull trout. This would connect Finlay-Russel Provincial Park with Northern Rockies and Dune Za Keyih Provincial Parks.

(4) **Beyond the MKMA** (lower right): In the southwest corner of the Greater Muskwa-Kechika, expansion of Tatlatui Provincial Park at the headwaters of the Finlay River would include areas used by the Spatsizi and Thutade caribou herds, as well as cooler refugia. It would help offset some impacts of mining immediately to the east. Protecting the lower Dease River north of the Ne'āh' Conservancy would enhance representation of boreal forests (carbon storage) and wetlands in the Liard Basin ecoregion and some winter range for

Figure 42. Key areas in a new network of protected areas for the Greater Muskwa-Kechika area, northern British Columbia. Each panel focuses on a specific area (yellow) as the network (light green) emerges into a cohesive whole.



the Horseranch caribou herd. Adding the area south of Ne'āh' towards Cry Lake would protect summer range of the Horseranch caribou herd, habitat for Stone's sheep in the Cassiar Mountains, and a concentration of diverse types of bedrock formations that are not represented elsewhere. Both of these would build out the Kechika centerpiece. In the northwest corner, the headwaters area of the Little Rancheria River in B.C. includes both alpine and boreal habitat for that caribou herd. It also provides a narrow connection with other thinhorn sheep populations between B.C. and the southern Yukon.

Representation of Important Conservation Features within Existing and Recommended Protected Areas

A vital question for conservation planning across the Greater Muskwa-Kechika area is: how well (or not) do existing protected areas safeguard important conservation features? And, how much would the recommended protected areas add to the network and bring such representation up to a high conservation standard? In this section, I address these questions for each of the key conservation features.

Representation of Enduring Features

Bedrock Types

The recommended protected areas would substantially enhance representation of the diversity of bedrock types arrayed east↔west across the Greater Muskwa-Kechika area (Figure 8). In particular, it would substantially increase representation of the granitic, volcanic, and ultramafic types as well as the surficial deposits in the Rocky Mountain Trench and the Liard Plain. The new network of protected areas would represent an average of 52% (range: 18.0% - 73.6%) of the various bedrock types.

Variety and Rare Enduring Features

The recommended protected areas would increase representation of areas with the most variety of enduring features across the Greater Muskwa-Kechika area. It would elevate the classes of highest variety from 25% up to 63% and moderate variety from 22% to 61%, respectively (Figure 43). It would raise representation of the rarest classes significantly from 12% up to 44%.

Lakes and Wetlands

Many of the larger lakes across the Greater Muskwa-Kechika area would be included within the network of existing and recommended protected areas. Representation of wetlands would increase substantially, too – especially for the lower (12%→50%) and moderate (10%→47%) density classes. Representation of high-density wetlands would increase from 7% to 22%, A significant concentration of high-density wetlands occurs outside of protected areas, however, between the lower Toad and Dunedin Rivers north of the Alaska Highway. Although management direction in this area is for general resource use such as oil & gas activity and timber harvesting, these wetlands warrant careful stewardship.

River Valleys

Valley bottoms are important habitat for biodiversity and animal movement but typically are not adequately protected. There are about 3,880 km^2 of valley bottoms in the Greater Muskwa-Kechika (3.2%) but only 23% of these lands are included in existing protected areas. The recommendations would add another 25%.

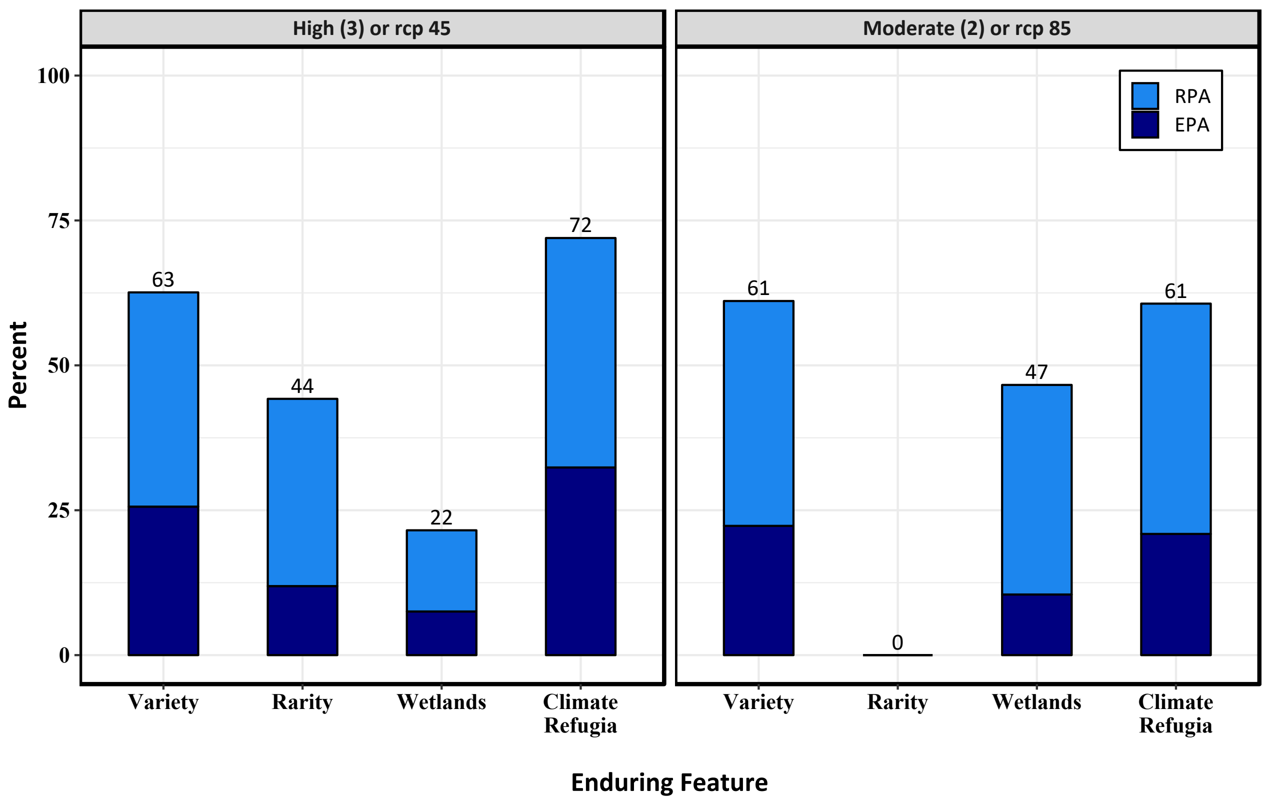
Climate Refugia

Areas with cooler temperatures in the future may serve as refugia in a hotter world. The recommended protected areas would increase protection of these cooler refugia from 21% to 61% under a moderate climate-heating scenario and from 32% up to 72% under a more intense heating scenario (Figure 43, Table 29). These refugia occur in the higher elevations of the Rocky Mountains and in the Cassiar Mountains along the Continental Divide.

Representation of Ecoregions and Ecosections

Representation of ecoregions in the existing protected areas varies from modest to poor (Figure 44). It ranges from 15 to 30% for several mountainous ecoregions, and the Pelly Mountains ecoregion in the northwest corner of the Greater

Figure 43. Representation (percent) of High value (left panel) and Moderate value (right panel) Enduring Features in existing protected areas (EPAs: dark blue) and recommended protected areas (RPAs: light blue).



Muskwa-Kechika is not represented at all. Extensive boreal ecoregions at lower elevations – Liard Plain, Hyland Highland ('Liard Plateau'), and Muskwa Plateau – are poorly represented at only 4 to 7% in existing protected areas.

The recommended protected areas would greatly enhance representation of **ecoregions** across the Greater Muskwa-Kechika area – especially the lower boreal plains and plateaus. The new network of protected areas would raise representation of the Liard Basin boreal ecoregion to 37% and the Hyland Highland to 50% (Figure 41). Only a slight amount of land (<2%) in the Muskwa Plateau is recommended for new protected designation due to lower values for focal wildlife species, enduring features, hotter temperatures in the future, as well as past and current industrial disturbance from oil & gas and forestry activities. The recommended network of protected areas would increase representation of the mountainous ecoregions up to 47% - 66%, including the Pelly Mountains at 54%.

The recommended protected areas also would greatly improve representation of most **ecosections** across the Greater Muskwa-Kechika area. This is particularly notable in some of the lower-elevation boreal ecosections such as Liard Plain (5% → 37%) and the plateau ecosections, including the Hyland Plateau (7% → 50%), Rabbit Plateau (7% → 60%), and Southern Boreal Plateau (4% → 29%) (Figure 45). Many of the ecosections in the mountain ecoregions would be well represented at an average of 64% (range 20% – 100%). Representation would increase substantially for some of the ecosections in the study area outside the core Muskwa-Kechika Management Area. For example, representation would improve significantly in the Tuya Range (0% → 54%), Cassiar Range (9% → 76%), and Peace Foothills (18% → 99%). Representation in the Muskwa Plateau ecoregion would be low but equal between the 2 ecosections at 8-9%.

Importantly, representation of the Rocky Mountain Trench would be complete in the Kechika section (53% → 100%) and improved in the Finlay sections (<1% → 17%).

Figure 44. Representation of **ecoregions** in Existing Protected Areas (EPAs: dark blue) and Recommended Protected Areas (RPAs: light blue). See Table 11 for acronyms.

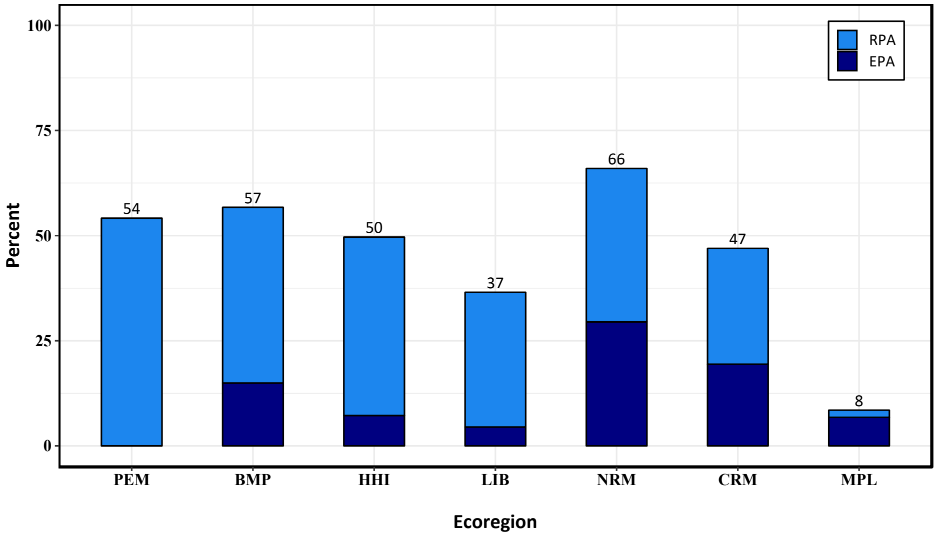
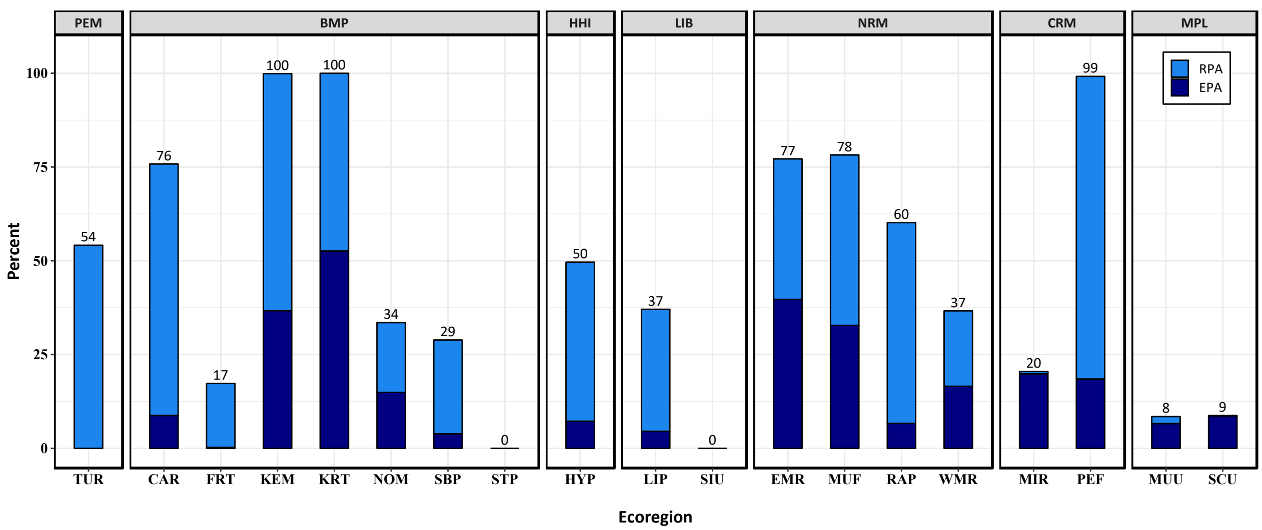


Figure 45. Representation of **ecosections** in Existing Protected Areas (EPAs: dark blue) and Recommended Protected Areas (RPAs: light blue). Ecosection bars are shown within their ecoregion. See Table 11 for acronyms.



Occurrence and Representation of Biogeoclimatic Zones

At present, the BAFA (alpine) (22%) and SWB zone (subalpine shrub) (20%) biogeoclimatic zones are better represented in the existing protected areas than the BWBS (boreal) (13%) and ESSF forests (10%) (Table 30, Figure 46). Addition of recommended protected areas would substantially increase representation of all 4 zones: BAFA (64%), SWB (65%), BWBS (40%), and ESSF (27%).

Due to climatic heating in the coming decades, however, occurrence of various BGC zones will shift and change in coverage across the Greater Muskwa-Kechika area. Based upon projections by researchers at ClimateBC (Wang et al. 2012), BAFA in the alpine area is projected to decrease from 23% to 7%, while the SWB in the subalpine may decrease from 41% to 8% (Table 12). The recommended protected areas would continue to significantly improve representation (73% and 63%) of the remaining sites of these two zones (Table 31, Figure 47). Interestingly, if the Interior Cedar Hemlock (ICH) zone comes into the Greater Muskwa-Kechika area in the future, the RPAs would add 19% more to the 13% representation provided by EPAs for a total of 31%. Lastly, RPAs would ensure good representation of those BGC zones that are projected to expand with warming temperatures (ESSF total = 67%, BWBS total = 45%).

Table 28. Representation of current biogeoclimatic zones in existing protected areas (EPAs) and recommended protected areas (RPAs), Greater Muskwa-Kechika area, northern British Columbia.

	EPAs		RPAs		TOTAL	
Biogeoclimatic Zones	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
BAFA	5,833	21.96	11,236	42.31	17,069	64.27
BWBS	4,900	13.03	9,973	26.51	14,872	39.54
ESSF	869	9.52	1,590	17.42	2,459	26.94
SBS	-	-	-	-	-	-
SWB	9,266	20.50	20,209	44.72	29,475	65.22

Table 29. Representation of future biogeoclimatic zones in existing protected areas (EPAs) and recommended protected areas (RPAs), Greater Muskwa-Kechika area, northern British Columbia.

	EPAs		RPAs		TOTAL	
Biogeoclimatic Zones	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
BAFA	2,178	32.80	2,699	40.63	4,877	**73.43**
BWBS	6,893	13.80	15,342	30.72	22,234	**44.52**
ESSF	9,074	23.63	16,478	42.92	25,552	**66.55**
ICH	722	12.58	1,073	18.70	1,795	**31.28**
SBS	649	8.15	2,139	26.83	2,788	**34.98**
SWB	1,352	12.78	5,281	49.92	6,633	**62.70**

Figure 46. Area (ha) of current and future biogeoclimatic zones in Existing Protected Areas (EPAs: dark blue) and recommended protected areas (RPAs: light blue).

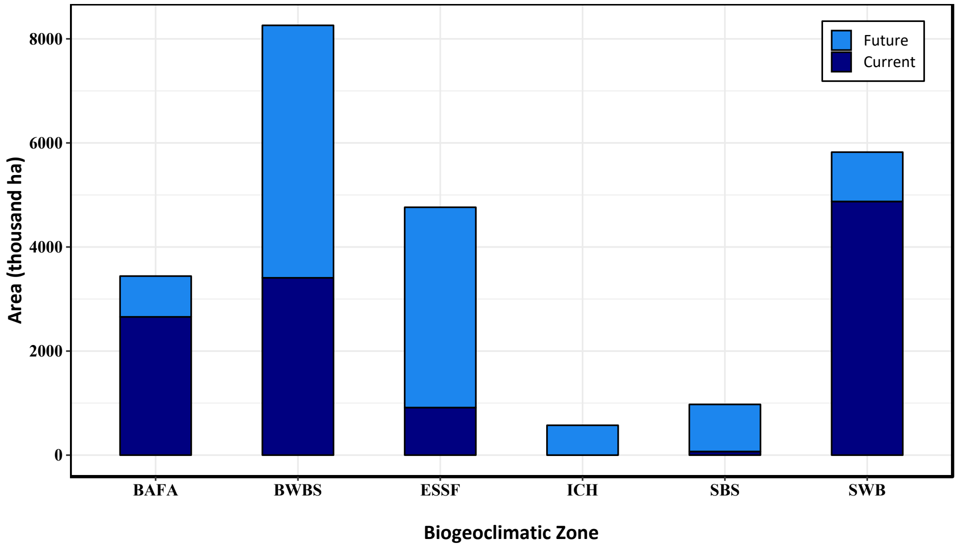
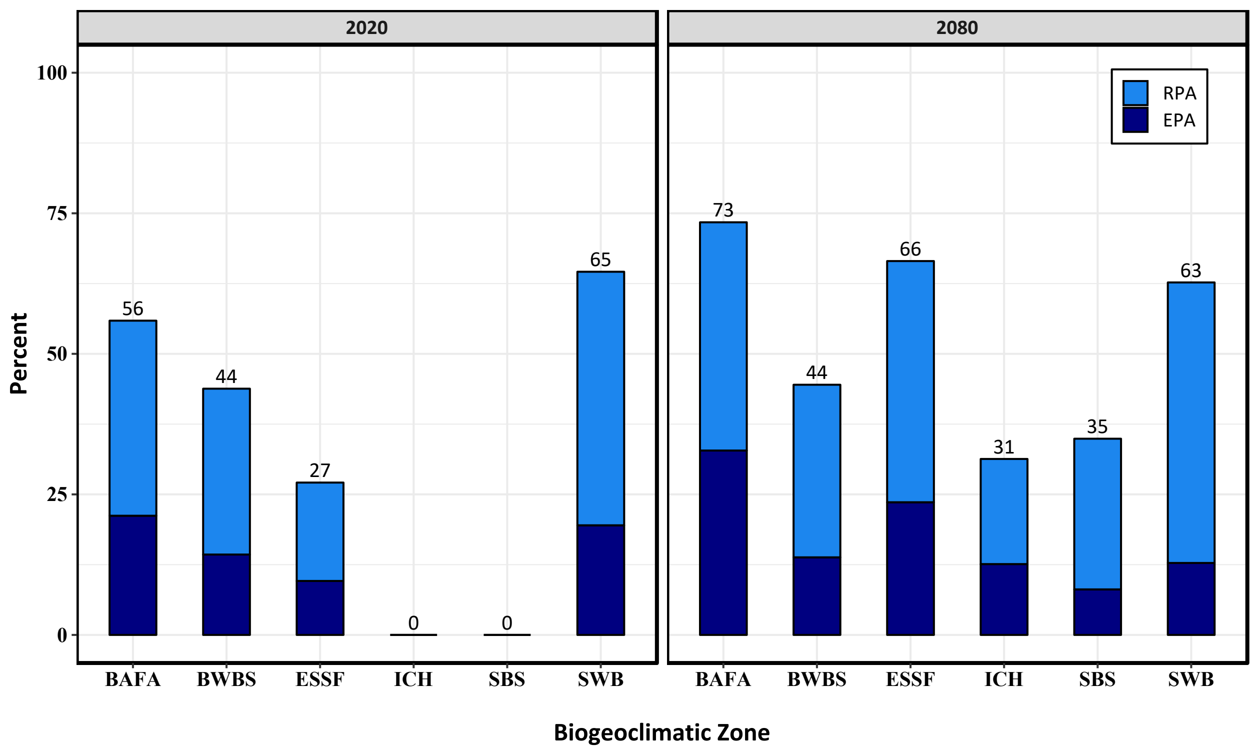


Figure 47. Representation (percent) of current (left panel) and future (right panel) biogeoclimatic zones (BCG) in existing protected areas (EPAs: dark blue) and recommended protected areas (RPAs: light blue).



Representation of Key Habitat for Vulnerable Fish and Wildlife

The new Protected Areas that we recommend would substantially increase protection for the vulnerable species – bull trout, northern woodland caribou, and Stone's sheep – as well as for moose. In general, the new network would protect an average of 65% of the high-value habitats and 58% of the moderate-value habitats, which are often in close juxtaposition (Table 30, Figure 48).

Bull Trout

Under projected increases of August temperatures in the coming decades in the Greater Muskwa-Kechika area, suitable cold-water habitat for bull trout likely will decrease and shift upwards in elevation (see (Figure 23). Suitable habitat for the critical stage of spawning and rearing (SR) is projected to decline by 30%, while suitability of streams for foraging, migrating, and over-wintering (FMO) will replace S/R habitat at lower elevations and may become too warm for occupancy in other areas.

Based upon documented thresholds of thermal suitability for bull trout, we mapped future habitat suitability for the time period 2040-2070 to delineate cold-water refugia. The recommended network of new protected areas would triple representation of areas critical for spawning and rearing (21%→62%) across the Greater Muskwa-Kechika (Table 30). It would also capture a substantial amount of area remaining suitable for FMO occupancy (21%→50%), which occurs at lower elevations often not included in protected areas.

Stone's Sheep

Representation of high-value habitat at higher elevation for Stone's sheep is fairly good (38%) in existing protected areas, but it is poor for moderate-value habitat (8.6%), which is mostly outside the Muskwa-Kechika Management Area in the Cassiar Mountains. The recommended protected areas would improve representation of high-quality sheep habitat to a whopping 86% by adding the following important areas for sheep:

(1) mid-elevation areas between Prophet River and Halfway River, east and south of Redfern-Keily and Provincial Parks, as revealed by the Besa-Prophet studies (Walker 2005),

(2) area between Northern Rockies and Muncho Lake Provincial Parks for both core habitat and connectivity as revealed by the 8 Mile-Sulphur Creek study (Hengeveld and Cubberley 2011),

(3) small but potentially-critical stepping-stone habitat in the Northern Rocky Mountain Trench, specifically slightly north and slightly south of the confluence of Gataga and Kechika Rivers (Sim et al. 2019).

It would enhance representation of moderate-quality blocks of habitat up to 61%, including mountains in the headwaters of the Little Rancheria River. This area appears to be the narrow connection with other thinhorn sheep populations in southern Yukon (Sim et al. 2019).

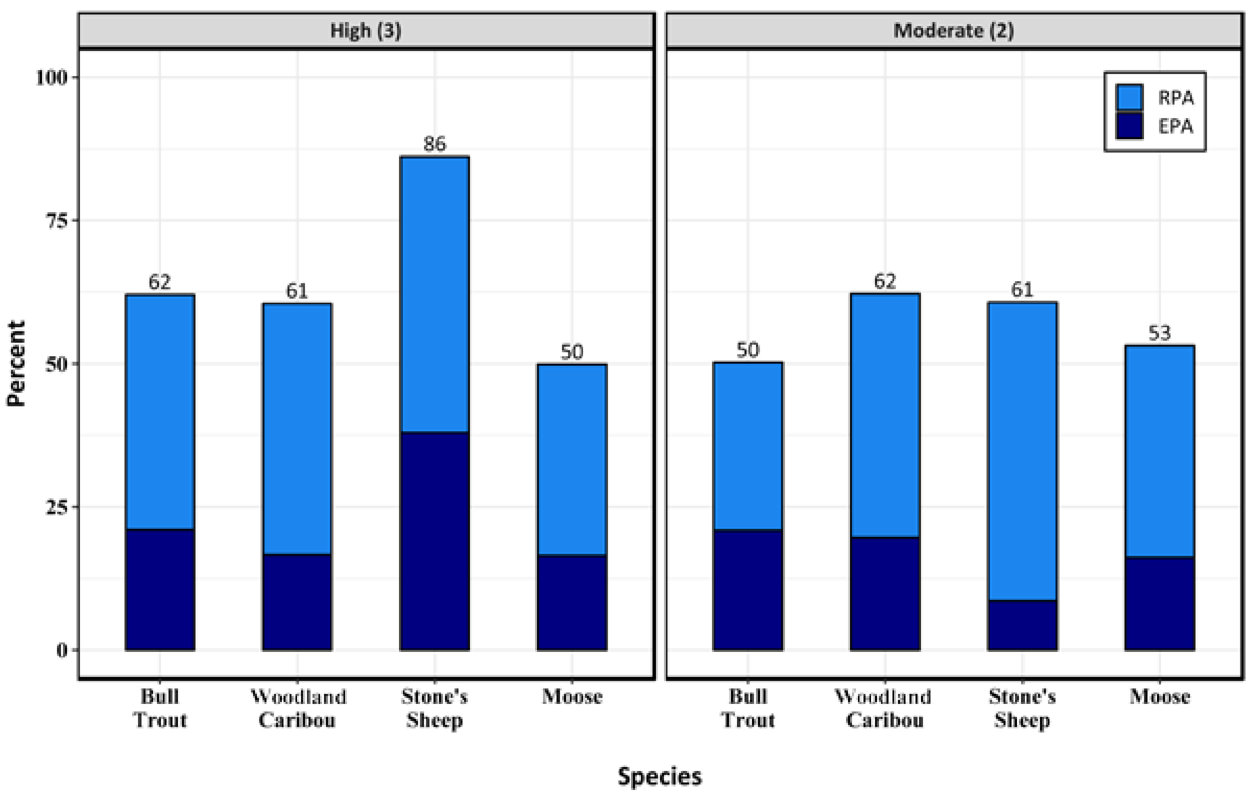
Northern Woodland Caribou

Important habitat for northern woodland caribou is not well represented (17% of High - 20% of Moderate) in existing protected areas (Table 32, Figure 48).

Table 30. Representation (percent) of focal fish and wildlife species in Existing Protected Areas (EPAs) and Recommended Protected Areas (RPAs), Greater Muskwa-Kechika area, northern British Columbia.

Focal Species	EPAs	RPAs	TOTAL
Bull Trout			
High (3)	21.0	41.0	**62.0**
Mod (2)	20.9	29.4	**50.3**
Woodland Caribou			
High (3)	16.7	43.8	**60.5**
Mod (2)	19.7	42.5	**62.2**
Stone's Sheep			
High (3)	37.9	48.2	**86.2**
Mod (2)	8.6	52.1	**60.7**
Moose			
High (3)	16.5	33.4	**49.9**
Mod (2)	16.2	37.0	**53.2**

Figure 48. Representation (percent) of High value (left panel) and Moderate value (right panel) of habitats for fish and wildlife species in existing protected areas (EPAs: dark blue) and recommended protected areas (RPAs: light blue).



The recommended protected areas would improve representation of important caribou habitat substantially to ~62% for each class. Moreover, the recommended network of all protected areas would encompass the complete herd range for several caribou herds: (1) Frog, (2) Gataga, (3) Horseranch, (4) Liard Plateau, and (5) Muskwa (Table 31). It would capture a >90% of known winter locations in B.C. for several herds: Frog, Gatatga, Horseranch, Liard Plateau, Little Rancheria, and Muskwa and 58% for Pink Mountain and Rabbit herds (Table 31). It would also encompass a high percentage (>80%) of spring-fall locations for these herds (Table 32).

Moose

Representation of moose habitat in existing protected areas is fairly low (16%) due to under-representation of the boreal BWBS zone in the Liard Plain and principal river valleys (Figure 45). The recommended network of new protected areas would greatly improve representation of moose habitat to about 50% – especially in the lower boreal plains and river valleys and across a greater spread of smaller watersheds over the Greater Muskwa-Kechika area.

Table 31. Proportion (%) of caribou locations in winter encompassed in Existing Protected Areas (EPAs), Recommended Protected Areas (RPAs), and Total Protected Areas across the Greater Muskwa-Kechika area, northern British Columbia.

Caribou Herd	# Locations	% in GMK	% in EPAs	% in RPAs	% Total
Chase	3,230	30.5	0.0	0.0	0.0
Finlay	1,239	97.4	0.0	0.0	0.0
Frog	827	100.0	30.6	69.4	100.0
Gataga	46	100.0	71.7	28.3	100.0
Graham	25,954	11.9	0.5	11.3	11.8
Horseranch	248	96.8	39.5	50.4	89.9
Liard Plateau	6	100.0	0.0	100.0	100.0
Little Rancheria	507	100.0	0.6	94.1	94.7
Muskwa	683	97.2	49.2	43.2	92.4
Pink Mountain	10,653	59.4	1.5	56.4	57.9
Rabbit	95	100.0	24.2	33.7	57.9

Table 32. Proportion (%) of caribou locations in spring-fall encompassed in Existing Protected Areas (EPAs), Recommended Protected Areas (RPAs), and Total Protected Areas across the Greater Muskwa-Kechika area, northern British Columbia.

Caribou Herd	# Locations	% in GMK	% in EPAs	% in RPAs	% Total
Chase	5,039	45.6	0.0	0.0	0.0
Finlay	1,403	99.3	0.1	0.0	0.1
Frog	2,049	100.0	1.0	99.0	100.0
Gataga	243	100.0	14.0	86.0	100.0
Graham	26,027	27.3	6.2	19.9	26.1
Horseranch	242	41.3	45.5	37.2	82.7
Liard Plateau	0	-	-	-	-
Little Rancheria	402	100.0	0.0	87.8	87.8
Muskwa	994	100.0	72.3	24.8	97.1
Pink Mountain	1,167	85.5	20.0	65.0	85.0
Rabbit	181	100.0	13.8	66.3	80.1

With the advent of modern energy and transportation and driven by expanding human populations, the industrial juggernaut has marched steadily – relentlessly – across the world. This has brought certain kinds of material benefits up to a point but has come with an increasing cost of extinction of species, pollution, and now a hotter climate. In recognition of the unprecedented and dominating influence of the human species, some have labeled the present time as the Anthropocene … literally the geologic Age of Humans (Steffen et al. 2007). A clear-eyed assessment of the accelerating impacts indicates that the dominant viewpoint and narrative has already incurred significant costs to our natural systems and likely is not sustainable (Steffen et al. 2018). At its roots, our dilemma is a matter of deep values. Now, many thoughtful people are questioning: is there a better pathway?

Conservation is about human relationships threaded with the rest of earth's beautiful tapestry … finding a sense of our place in a universal vascular system while affirming our own nature as part of the larger Nature. To do so means nothing less than a shift in our whole frame of reference. In the words of the human ecologist Paul Shepard (1969): "Although ecology can be treated as a science, its greater and overriding wisdom is universal. That wisdom can be approached mathematically with computers, using our senses, or it can be danced or told as story."

In conclusion, the network of existing and new protected areas that we recommend for the Greater Muskwa-Kechika will:

- ✔ **Improve representation of the full range of environmental features across the region -- including diversity of boreal ecoregions, enduring features, and freshwaters (lakes, rivers, and wetlands) – up to 50-60%.**
- ✔ **Conserve 60-80% of high-value habitat for healthy populations of vulnerable woodland caribou, Stone's sheep, and bull trout, as well as moose – a keystone cultural species.**
- ✔ **Provide for full gradients of landscape diversity from river valley to mountain peak and include cooler refugia in the mountains for greater resiliency in a hotter future.**
- ✔ **Embed hydrologic and terrestrial connectivity within core areas and across the Alaska Highway to facilitate present and future movements for fish and wildlife.**
- ✔ **Provide areas large enough to accommodate scale of natural disturbances like fire and still have sufficient habitat elsewhere at the scale needed by wide-ranging wildlife like caribou.**
- ✔ **Safeguard large intact watersheds -- especially in the headwaters -- as the gold standard in conservation planning.**
- ✔ **Enable sustainable forestry in economically-favorable areas, minimize overlap with existing mining and oil & gas sites, and identify the potential mining sites of highest impact to vulnerable fish and wildlife if dams and reservoirs holding toxic metals collapsed.**

Action on these recommendations will secure greater representation of lands and waters, larger core areas and better connectivity for vulnerable fish and wildlife, and stronger resiliency going ahead.

History has been described as many journeys which return to the same starting place in pursuit of answers to ageless questions. None is more fundamental to the human story than its relations with the rest of the community of Nature. "Affirmation of its own organic essence will be the ultimate test of the human mind", said Paul Shepard. As originally envisioned 20 years, may the Greater Muskwa-Kechika continue to be the crucible for fresh viewpoints from diverse cultures, deeper relationships, and a richer story of the lands, waters and people.

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APPENDIX I

RESOURCE SELECTION FUNCTION (RSF) ANALYSIS FOR NORTHERN MOUNTAIN CARIBOU

Ph.D. candidate Eric Palm and Professor Mark Hebblewhite

We developed Resource Selection Function (RSF) models using location data from adult female caribou wearing GPS radio collars (n=91) or VHF collars (n=126), as well as aerial surveys throughout the Greater Muskwa-Kechika study area (GMK). The GPS data included locations of caribou from 1999–2013 across six populations in the southern and central portions of the MK: Graham (n=47), Pink Mountain (n=16), Chase (n=10), Finlay (n=6), Frog (n=4), Spatsizi (n=3), and those inhabited the area between the Spatsizi, Chase and Finlay ranges (n=5) (Figure 30). All GPS location data were available through the BC MOECC Species Inventory Web Explorer or through data-sharing agreements with the BC MOECC. The median interval between successive GPS locations for a collared caribou was between 4 and 12 hours. VHF data included locations from 1988–2013 for the Chase, Finlay, Frog, Gataga, Graham, Muskwa and Pink Mountain populations. The aerial survey data was collected from 1976–2013 and included locations from the Little Rancheria, Horseranch, Rabbit, and Spatsizi ranges in addition to each of the seven population ranges covered by VHF location data.

We used a variety of remote sensing-based spatial covariates in caribou RSFs. We used a 250-m resolution landcover layer created by the Northwest Boreal Landscape Conservation Cooperative (NWBLCC) based on NASA Moderate Resolution Imaging Spectroradiometer (MODIS) data. Landcover types in the GMK included temperate needleleaf forest, temperate broadleaf forest, mixed forest, temperate shrubland, temperate grassland, sub-polar grassland (includes sub-polar barren-lichen-moss), wetland, barren, water, and snow and ice. We used 30-m resolution elevation data from NASA's Shuttle Radar

Topography Mission. From this elevation layer, we derived slope and aspect at 30-m resolution. We converted aspect to two continuous variables (eastness and northness) through cosine-sine transformation (Gustine and Parker 2008). To account for the effect of human disturbance on caribou resource selection, we included distance from road and distance from forest cut-block. We transformed these distance variables to exponential decays of the form ($1-e^{-2.5 \times \text{distance}}$). This decay term ensured that the effects of roads and cut-blocks eroded precipitously beyond 2.5 km (Nielsen et al. 2009).

We analyzed GPS data in a used-available framework to compare proportionate use of resources (e.g., elevation, landcover) relative to their availability on the landscape. We defined two seasons: growing (May 1–October 31) and winter (November 1– April 30) and conducted separate RSF analyses for each season. We included only individuals with ≥ 30 locations spanning ≥ 3 months in a season. We assigned each caribou with GPS location data to one of the six populations and generated a 99% kernel density estimate of seasonal population-level range (Powell 2000). Within each seasonal population range we randomly generated 10 locations per used location and assumed that resources at these locations were available to the animal. Our sampling of available locations within regional-scale seasonal population range approximates Johnson's (1980) second order of habitat selection.

We used GPS location data to train resource selection models and reserved VHF and survey location data for model validation. We estimated RSFs based on GPS location data by running mixed-effects generalized linear models (GLMMs) using the glmmTMB package in Program R (Brooks et al. 2017). Our GLMMs accounted for correlated observations within individual caribou and populations and accounted for differences in sample sizes across individuals and populations (Gillies et al. 2006). A random coefficient allows the effect of a covariate to vary by individual caribou (or by population). Caribou in the Liard Plain ecoregion (which includes portions of the Little Rancheria, Horseranch and Rabbit caribou ranges) wintered in low-elevation forests far from mountains and foothills. Therefore, we used survey location data to estimate a separate winter RSF for the Liard Plain ecoregion and substituted these RSF values into the GMK-wide winter map of resource selection that we created using GPS location data. The Liard Plain model only included fixed effects because the aerial survey data did not include information on individuals or populations.

We used a manual stepwise model selection process, only including spatial covariates that were biologically relevant to caribou resource selection. We screened covariates for collinearity using a Pearson correlation coefficient threshold of $|r| > 0.5$ (Hosmer and Lemeshow 2000). We included quadratic terms for elevation and slope in our candidate models, representing the hypotheses that caribou select intermediate values of those resources. We assessed model fit using Akaike's Information Criterion. For each model, we mapped relative selection probabilities throughout the entire MK study area and categorized them into 10 equal-area bins, where 1 was the lowest relative probability of use and 10 was the highest. To validate models, we extracted the RSF bin for each VHF and survey location and conducted a Spearman rank correlation test. Higher correlations between RSF bin and frequency of observations within those bins indicates better model fit (Boyce et al. 2002).

Results

Topographic variables were important predictors of caribou resource selection in both seasons (Table 1). Caribou moved to higher elevations during the growing season (spring→fall) and avoided steep slopes all year. Caribou selected temperate needleleaf forest in both seasons despite its widespread availability (53% of GMK). Wetlands were selected by caribou during the winter but not the growing season. During winter, caribou avoided areas closer to roads and cutblocks, but they selected areas closer to cutblocks during the growing season. Within the Liard Plain ecoregion, wintering caribou selected lower elevations, lower slope angles and temperate needleleaf forest.

The most parsimonious candidate models for both winter and growing seasons included the full suite of *a priori* spatial covariates. Removing covariates from candidate models always resulted in poorer model fit measured by AIC, indicating little model uncertainty with respect to fixed effects. Therefore, we focused model selection on the random effects structure. Top models for growing and winter seasons across the GMK included random coefficients for temperate shrub, temperate grassland, and temperate needleleaf forest at the individual level, and random coefficients for barren at both individual and population levels. Adding random coefficients improved model fit by accounting for the variation in selection for these covariates across individuals and populations (Bolker et al. 2009). The top fixed-effects winter model for Liard Plain only included three spatial covariates because this area included very few animal locations spread over a relatively small spatial extent. Our top RSF models only relied on GPS locations from the southern and central GMK but were highly predictive of VHF and survey locations throughout the entire study area. The top model for growing season had Spearman rank correlations of >0.99 for VHF data and 0.99 for survey data, while the top model for winter had Spearman rank correlations for VHF and survey data of >0.98 and 0.97, respectively.

Table 1. Selection coefficients (β), standard errors (SE), Z scores and p-values from the most parsimonious generalized linear mixed model describing caribou resource selection at the population-range scale in the Greater Muskwa-Kechika study area.

Season, spatial extent	Covariate	β	SE	Z	p-value
Winter, GMK	Elevation	10.61	0.538	19.73	<0.001
	Elevation^2	−2.16	0.578	−3.75	<0.001
	Slope	−3.85	0.054	−71.26	<0.001
	Eastness	−0.24	0.009	−27.24	<0.001
	Northness	0.09	0.008	11.79	<0.001
	Distance to cutblock	0.50	0.050	9.99	<0.001
	Distance to road	0.59	0.033	18.12	<0.001
	Barren	−2.02	1.313	−1.54	0.124
	Mixed forest	1.49	0.262	5.69	<0.001
	Snow and ice	−1.05	0.637	−1.65	0.099
	Subpolar grassland	0.75	0.285	2.62	0.009
	Temperate broadleaf forest	0.38	0.267	1.41	0.158
	Temperate grassland	1.37	0.333	4.10	<0.001
	Temperate needleleaf forest	2.45	0.330	7.43	<0.001
	Temperate shrub	1.60	0.336	4.76	<0.001
	Wetland	2.25	0.275	8.17	<0.001
Winter, Liard Plain	Elevation	−7.36	1.794	−4.10	<0.001
	Slope	−6.13	1.459	−4.20	<0.001
	Temperate needleleaf forest	1.41	0.248	5.68	<0.001
Growing, GMK	Elevation	31.56	0.683	46.17	<0.001
	Elevation^2	−19.48	0.667	−29.19	<0.001
	Slope	−2.92	0.045	−64.82	<0.001
	Eastness	−0.01	0.008	−1.14	0.253
	Northness	0.17	0.007	24.41	<0.001
	Distance to cutblock	−0.63	0.051	−12.22	<0.001
	Distance to road	0.49	0.045	10.76	<0.001
	Barren	−1.12	0.752	−1.48	0.138
	Mixed Forest	1.12	0.236	4.76	<0.001
	Snow and ice	−3.17	0.425	−7.46	<0.001
	Subpolar grassland	−0.02	0.244	−0.08	0.938
	Temperate broadleaf forest	0.54	0.235	2.30	0.022
	Temperate grassland	0.97	0.254	3.83	<0.001
	Temperate needleleaf forest	1.19	0.258	4.62	<0.001
	Temperate shrub	0.90	0.252	3.56	<0.001
	Wetland	−0.16	0.289	−0.56	0.573

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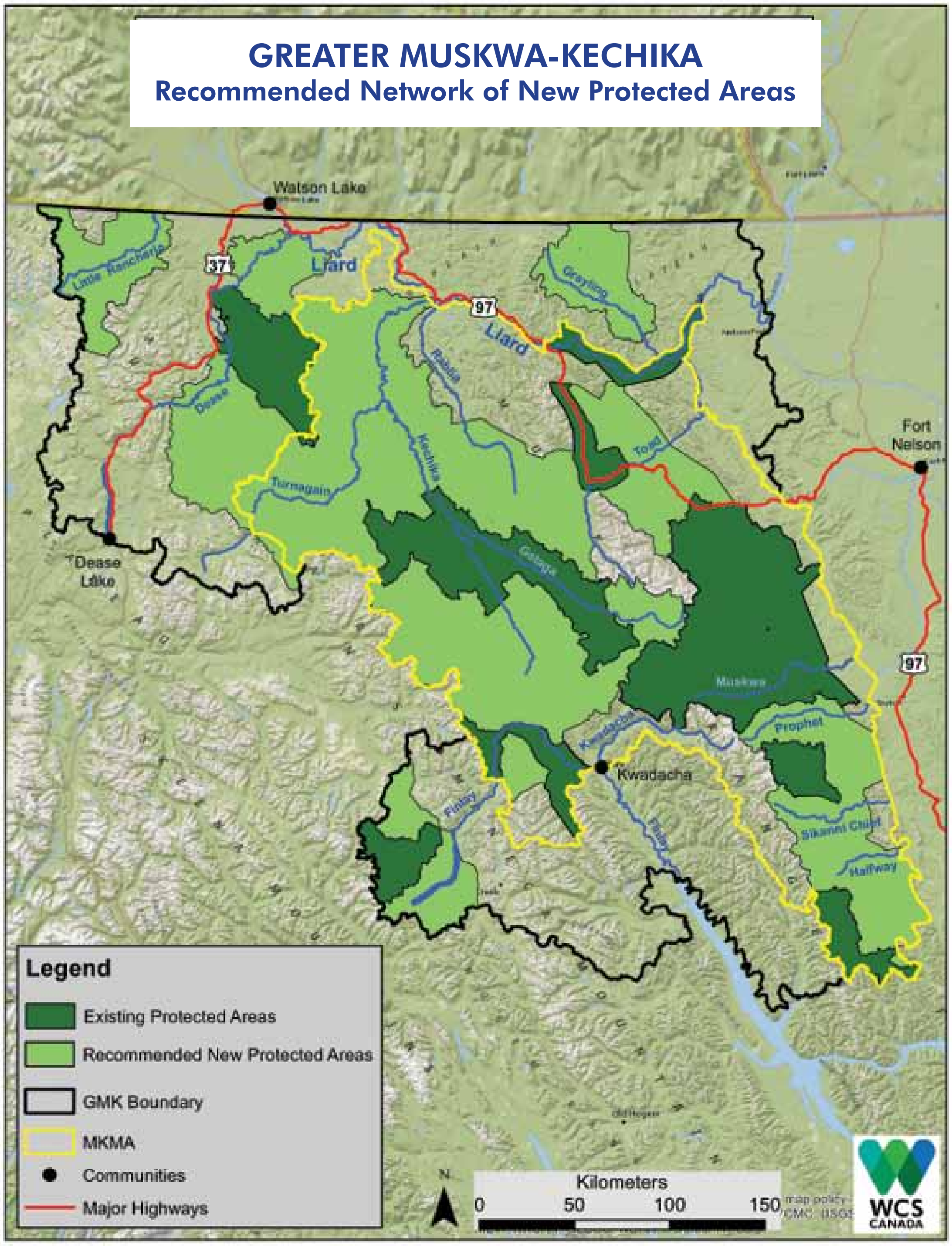

In this era of relentless expansion and impact of the industrial juggernaut, there is a place known as the Muskwa-Kechika in northern British Columbia that is still wild, still beautiful, still whole and healthy. Here, herds of woodland caribou wander the alplands and boreal forests, bull trout spawn in cold crystal rivers, and nearly all of the Stone's sheep in the world scamper across rugged terrain. It is the ancestral homeland of the Kaska and other First Nation people. With scientific projections of hotter climate and many environmental changes over the next 50-100 years, a smart proactive strategy is to protect large watersheds with high topographic and environmental diversity from river valley to mountain peak. A network of connected Protected Areas encompassing the diversity of boreal forests and mountains will provide stronger resiliency for the future. May the Greater Muskwa-Kechika continue to be the crucible for fresh viewpoints from diverse cultures, deeper relationships, and a richer story of the lands, waters and people.

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