Potential Conflict between Future Development of Natural Resources and High-Value Wildlife Habitats in Boreal Landscapes

Biodiversity and Conservation

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Online Resource 3. Oil and Gas Potential

We developed a GIS layer of oil and gas potential by integrating spatial data on oil and gas geology, conventional natural gas inventory, oil and gas resource sites and tenures, oil and gas pipelines, and elevation. We condensed information from these original spatial data into 3 key components of oil and gas resource potential: 1) Geo-Resource Potential, 2) Resource-Site Distance, and 3) Resource-Development Potential. After these 3 component layers were developed, we combined them to create the Oil and Gas Potential layers for the Muskwa-Kechika Management Area (hereafter referred to as the Muskwa-Kechika).

1. Geo-Resource Potential

Geo-Resource Potential was created by integrating 2 spatial data layers: geological potential for oil and gas in the Muskwa-Kechika and potential for conventional natural gas in northeast British Columbia (British Columbia Ministry of Energy, Mines and Petroleum Resources, Oil and Gas Division, Resource Development and Geoscience Branch 2006).

Geological Potential of Oil and Gas. Geological potential of oil and gas was based on distributions of geological formations known to produce oil and gas (Fig. S3.1). We obtained 4 polygons of oil and gas geology (Liard Basin, Cordova Basin, Horn River Basin, and Montney Basin) from the British Columbia Oil and Gas Commission. A polygon of the Western Canada Sedimentary Basin (WCSB) was based on Mossop et al. (2004).

We divided the Muskwa-Kechika into 6 areas according to the underlying formations of oil and gas geology (Figs. S3.1, S3.2) and assigned scores of relative likelihood of oil and gas geo-resource potential for these 6 polygons based on density of active oil and gas wells (number of active wells/100,000 ha) for the same underlying oil and gas geology outside of the Muskwa-Kechika (Table S3.1). We initially assigned the highest likelihood score of 100 for the Montney Basin, where the highest density of active oil wells among the 6 areas occurred, and calculated percent of the maximum value of active well density for all the other areas, using active well density of the Montney Basin (173.37/10,000 ha) as the maximum value. We then adjusted these calculated percent-of-maximum values for the Rocky Mountains and the Liard Basin. For the Rocky Mountains area, we assigned the average value between Rocky Mountains Foothills and

Outside of the Western Canada Sedimentary Basin and assigned a new value of 0.266 because the Rocky Mountains area is still within the oil and gas-bearing Western Canada Sedimentary basin. Hence, the resource potential should be higher than outside of the Western Canada Sedimentary Basin, where there is virtually no potential for oil and gas development. The initial percent-of-maximum value based on active well density also likely underestimated oil and gas potential for the Liard Basin, where oil and gas development has not yet progressed and well density is low relative to the actual resource potential of the area. The Liard Basin has been considered to have high potential for oil and gas development and was recently reported to be a reservoir of 6196 billion m^3 of marketable unconventional gas, most of which is likely located in BC (National Energy Board et al. 2016). This volume is 48.7% of the 12,719 billion m^3 marketable potential of unconventional natural gas estimated for the Montney Basin (National Energy Board et al. 2013, 2016). When only considering the 2 basins within BC, the Liard Basin is expected to contain 4731 billion m^3 or 61.6% of 7677 billion m^3 ultimate potential of marketable natural gas estimated for the Montney Basin (National Energy Board et al. 2013 and 2016). Therefore, our initial relative likelihood value of 3.56 for the Liard Basin compared to the 100 value for the Montney Basin is probaby an underestimate. For that reason we replaced the value for the Liard Basin with 61.6, which is the volume of ultimate potential of marketable natural gas estimated for the Liard Basin as a percentage of that estimated for the Montney Basin. Liquid natural gas and oil also may be found in small proportions. In the Montney Basin 79.2% of oil and gas resources was unconventional natural gas, 20.7% was liquid natural gas, and 0.05% was oil (National Energy Board et al. 2013). Because the information on liquid natural gas and oil inventory was not available for the Liard Basin for comparison, we relied on the ultimate potential of marketable natural gas and assumed the proportions of liquid natural gas and oil were the same for the Montney Basin and the Liard Basin.

Table S3.1 Relative likelihood of oil and gas geo-potential based on density of active oil and gas wells in 6 geological areas outside of the Muskwa-Kechika Management Area, northeast British Columbia, Canada

		Oil and Gas Geo-Resource Potential	
Geological areas relevant to oil and gas potential	Active oil and gas wells /100,000 ha	Initial relative likelihood (percent of maximum well density[b])	Final relative likelihood (adjusted from initial relative likelihood[c])
Montney Basin	173.37	100.00	100.00
Liard Basin	6.18	3.56	61.63
Alberta Basin	76.25	43.98	43.98
Rocky Mountain Foothills	0.92	0.53	0.53
Rocky Mountains	0.00	0.00	0.27
Outside WCSB[a]	0.00	0.00	0.00

[a] Western Canada Sedimentary Basin

[b] Initial relative likelihood values for the Liard Basin (3.56) and the Rocky Mountains (0.00) are probablu underestimates and were adjusted in the final relative likelihood values

[c] Final relative likelihood value for the Liard Basin (61.63) was based on new information indicating that the volume of natural gas in the basin is estimated to be 61.63% of that in the Montney Basin (National Energy Board et al. 2016). For the Rocky Mountains area, the mean value (0.27) between Rocky Mountain Foothills (0.53) and Outside Western Canada Sedimentary Basin (0.00) was assigned because it is still within the WCSB and likely to have higher oil and gas potential than outside of the WCSB

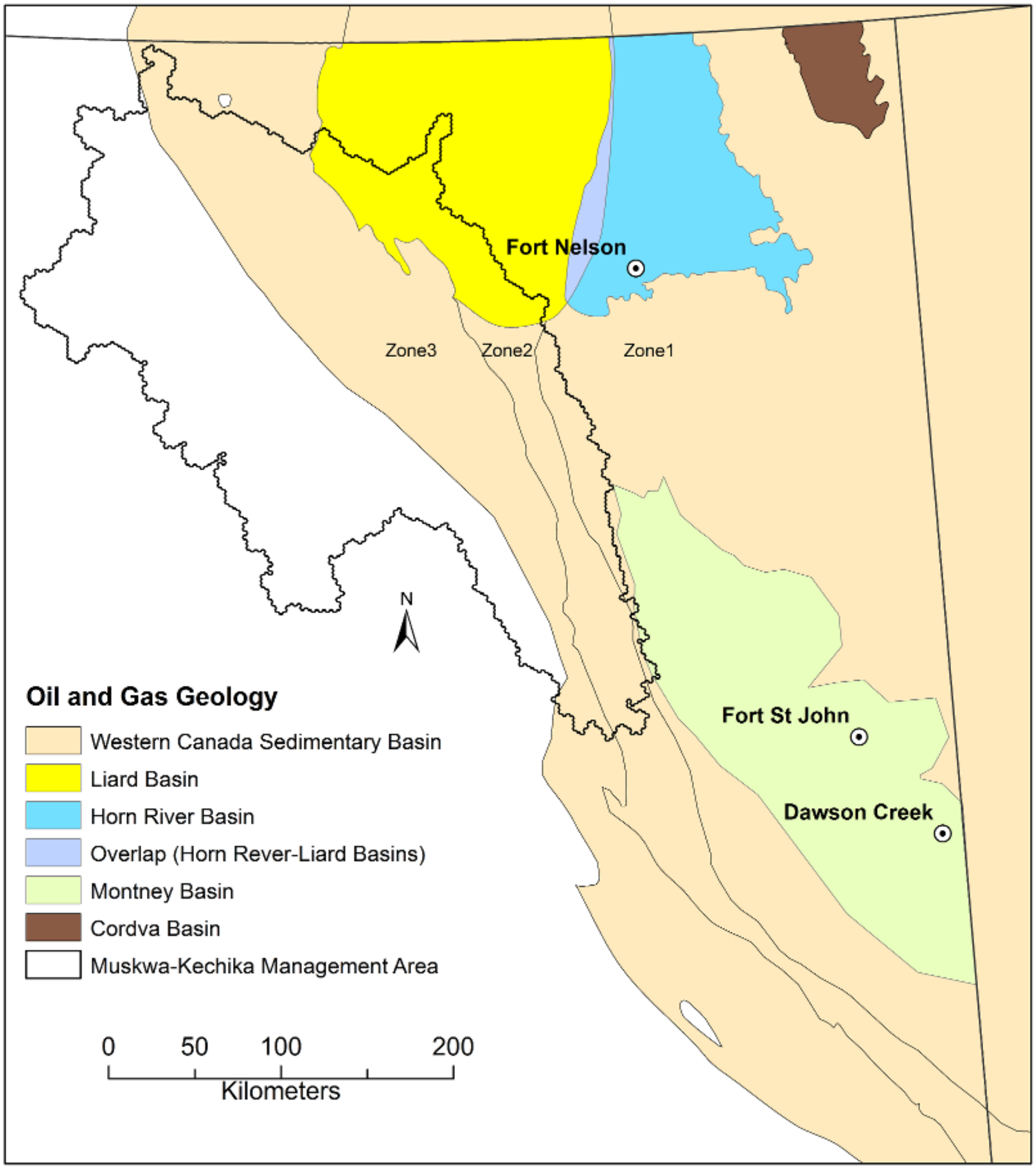

Fig. S3.1 Locations of oil and gas geology in relation to the Muskwa-Kechika Management Area, northeast British Columbia. Within the Western Canada Sedimentary Basin, zones 1, 2, and 3 are recognized as Alberta Basin, Rocky Mountain Foothills, and Rocky Mountains, respectively (Mossop et al. 2004)

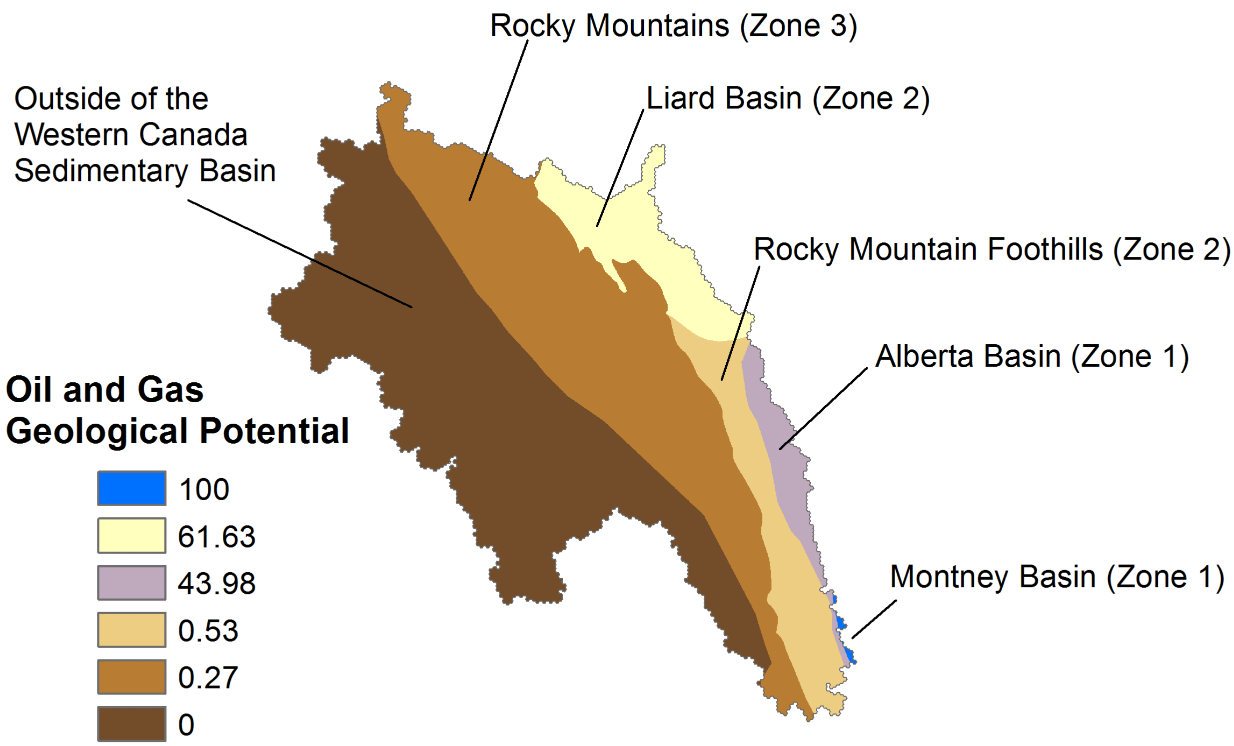

Fig. S3.2 Six polygons in the Muskwa-Kechika Management Area representing underlying oil and gas geology and relative likelihood of oil and gas geo-potential associated with 6 geology types (Table S3.1). The large dark brown polygon on the west portion of the Muskwa-Kechika Management Area is outside of the Western Canada Sedimentary Basin and considered to have relatively little oil and gas potential

Conventional Natural Gas Potential. Spatial data on resource potential for conventional natural gas in the Muskwa-Kechika were based on documentation and accompanying spatial data created by the British Columbia Ministry of Energy, Mines and Petroleum Resources, Oil and Gas Division, Resource Development and Geoscience Branch (2006). Specifically, we used a shapefile entitled "final ultimate" from the group of cumulative resource/reserve mapping shapefiles. The final ultimate shapefile included 2 attributes that are relevant to natural gas potential in the Muskwa-Kechika: Ultimate Marketable Gas (ULMARKT) and Ultimate Remaining Marketable Gas (ULREMMARKT). ULMARKT is a measure of the combined amount of Initially Established Gas Marketable (IEGM) and Undiscovered Marketable Gas (UMARKT), whereas ULREMMARKT is a measure of the combined amount of Remaining Gas Marketable (RGM) and Undiscovered Marketable Gas (UMARKT).

We created a raster layer with 50-m cell size for both ULMARKT potential and for ULREMMARKT potential by separately extracting the 2 attributes, ULMARKT and ULREMMARKT, from the original polygon shapefile for all of northeast BC. After the conversion, we combined the ULMARKT potential and ULREMMARKT potential together by averaging values from the 2 raster layers across pixels. We assigned the value of 100 to the highest values of averaged pixels, which represented the highest conventional natural gas potential within the range of conventional natural gas in northeast BC and we assigned percent of the highest value for all other pixels in the combined ULMARKT-ULREMMARKT layer (Fig. S3.3a). In the final process, we cropped the area of the Muskwa-Kechika (Fig. S3.3b) from the combined natural gas potential layer for northeast BC. The highest value of conventional natural gas potential in the Muskwa-Kechika was only 18% of the highest value of conventional natural gas potential in northeast BC.

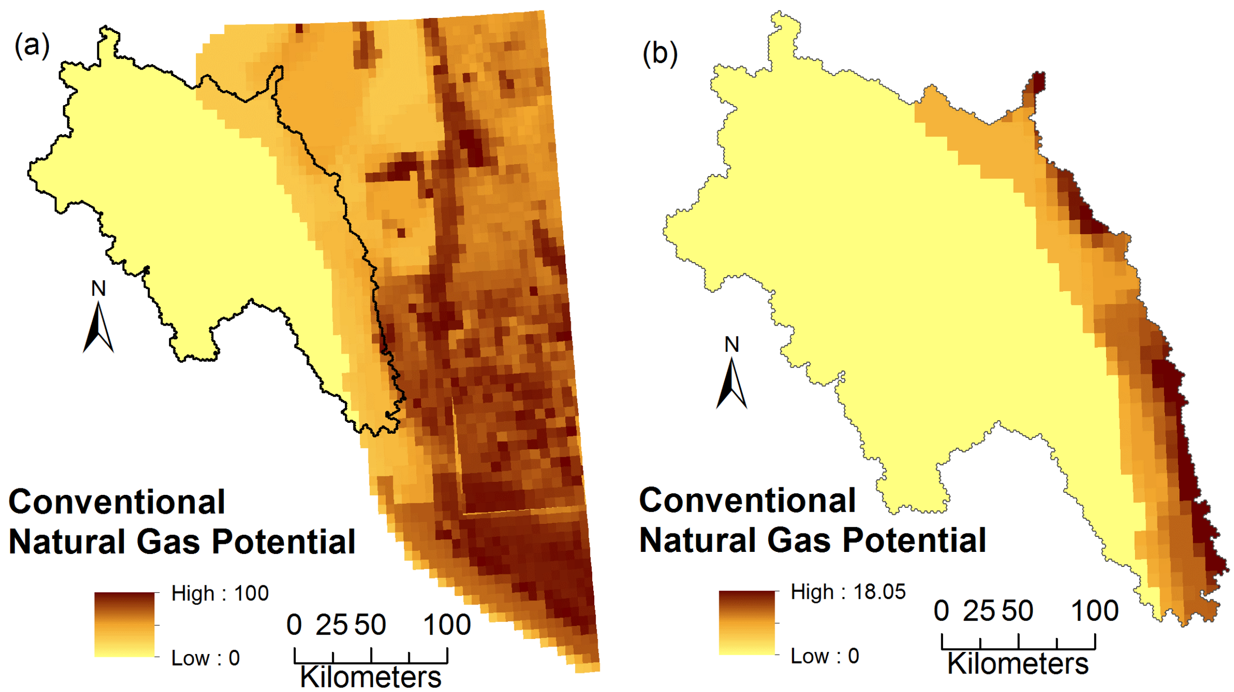

Fig. S3.3 Conventional natural gas potential shown as a percentage of highest estimated volumes in northeast British Columbia (a) and then extracted specifically for the Muskwa-Kechika Management Area (b)

Final Geo-Resource Potential Layer. We combined the geological potential of oil and gas (Fig. S3.2) and the conventional natural gas potential (Fig. S3.3b) into a raster layer of Geo-Resource Potential by summing pixel values together. We did not average values from the 2 layers because values for the conventional natural gas potential are small relative to those for geological potential of oil and gas (maximum value of 100). Highest values for conventional natural gas potential in the Muskwa-Kechika were 18 and values ≥ 5 only occur on <1% of the land area, near the southeast border. Geo-Resource Potential for most of the Muskwa-Kechika was not affected by the addition of the conventional natural gas potential and remained almost identical to the geological potential of the Muskwa-Kechika.

2. Resource-Site Distance

The GIS layer of Resource-Site Distance contained distance values (m) from each pixel in the Muskwa-Kechika to the nearest, currently existing oil and gas resource site, all of which are located outside the Muskwa-Kechika. Our assumption was that exploration and development of oil and gas would generally expand from the nearest resource sites into areas of the Muskwa-Kechika where Geo-Resource Potential is high. Oil and gas resource sites included oil and gas fields, pools, tenure sites, and wells in production (Fig. S3.5). We used the path distance tool in ArcGIS with a 50-m digital elevation model (DEM) as a surface raster and calculated distance (m) from each pixel in the Muskwa-Kechika to the nearest oil and gas resource site. Once the distance measures were obtained, we reversed the distance measures, so that pixels closer to resource sites would have higher values than those farther away. Reversed distance was calculated for all pixels by the following equation: reversed distance of a pixel = (minimum value of original distance values among all pixels – original distance value of each pixel) + maximum original distance value among all pixels. Reversed distance measures maintained exactly the same differences in distance relationships among pixels as original distance measures. We then replaced the pixel values with percent of the highest reversed distance measure. As such, pixels closest to oil and gas resource sites have the highest value of 100, hence the highest likelihood of being targeted for resource extraction if resources are present, and those farthest away have the lowest value of 0.

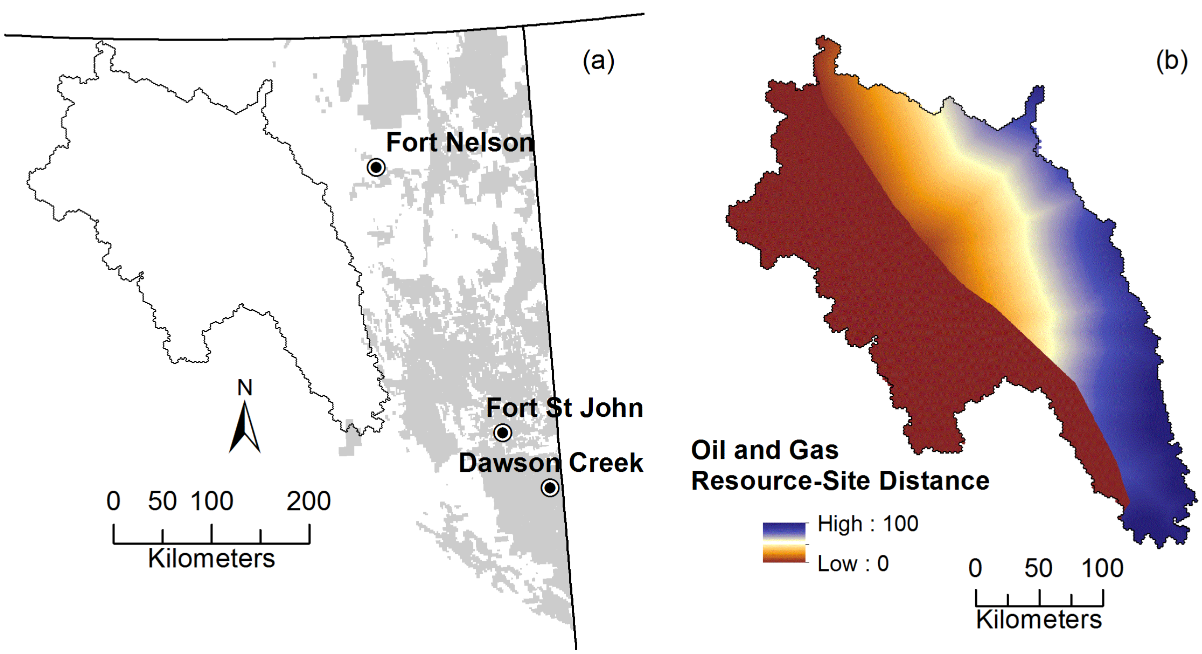

Fig. S3.4 Distribution of oil and gas resource sites; including oil and gas fields, pools, tenures, and active wells – all shown in gray – in relation to the Muskwa-Kechika Management Area (a) and Resource-Site Distance (b) in the Muskwa-Kechika Management Area. The higher the value, the closer the location is to a resource site, and therefore, more likely to be developed when the resource is present. A value of 0 was assigned to areas outside of oil and gas geology (Fig. S3.2), where resource potential for oil or gas is presumed to be very low

3. Resource Development Potential

We created a GIS layer of Resource Development Potential by combining the spatial data on distance to oil and gas pipelines from each pixel and elevation of each pixel, within the known oil and gas geology of the Muskwa-Kechika based on the assumption that a site would more likely be developed to provide a technologically and economically viable resource output of oil and gas if it were closer to a pipeline at a lower elevation than farther away from a pipeline at a high elevation. Pipelines were distinct from the oil and gas resource sites used to define Resource-Site Distance (above). We used the path distance tool in ArcGIS with a 50-m DEM as a surface raster and calculated ground distance (m) from each pixel in the Muskwa-Kechika to the nearest pipeline (Fig. S3.5). We reversed the distance measures so that pixels closer to pipelines had higher values than those farther away from pipelines (See Section 2. Resource-Site Distance for a description of reversed distance). We then replaced the pixel values with percent of the highest reversed distance measures, which gave pixels closest to pipelines the highest value of 100 (Fig. S3.5b and S3.6a). Similarly, we reversed elevations in pixels within the oil and gas geology, so that pixels with the lowest actual elevation had the highest value for resource development potential related to elevation and those with the highest actual elevation had the lowest values. We then replaced these pixel values with percent of the highest reversed elevation values, such that pixels lowest in actual elevation had the highest value of 100 (Fig. S3.6b). We created the layer of Resource Development Potential by simply averaging pixel values from the Pipeline Reverse Distance measures and the Reverse Elevation measures, both of which are in the unit based on percent of highest value (Fig. S3.6c). The lower the pixel value of this Reverse Elevation-Pipeline Distance raster, the less likely the location is to be developed because it is farther away from a pipeline and at a higher elevation. The higher the value of a pixel, the more likely a location would be developed because it is closer to a pipeline and lower in elevation.

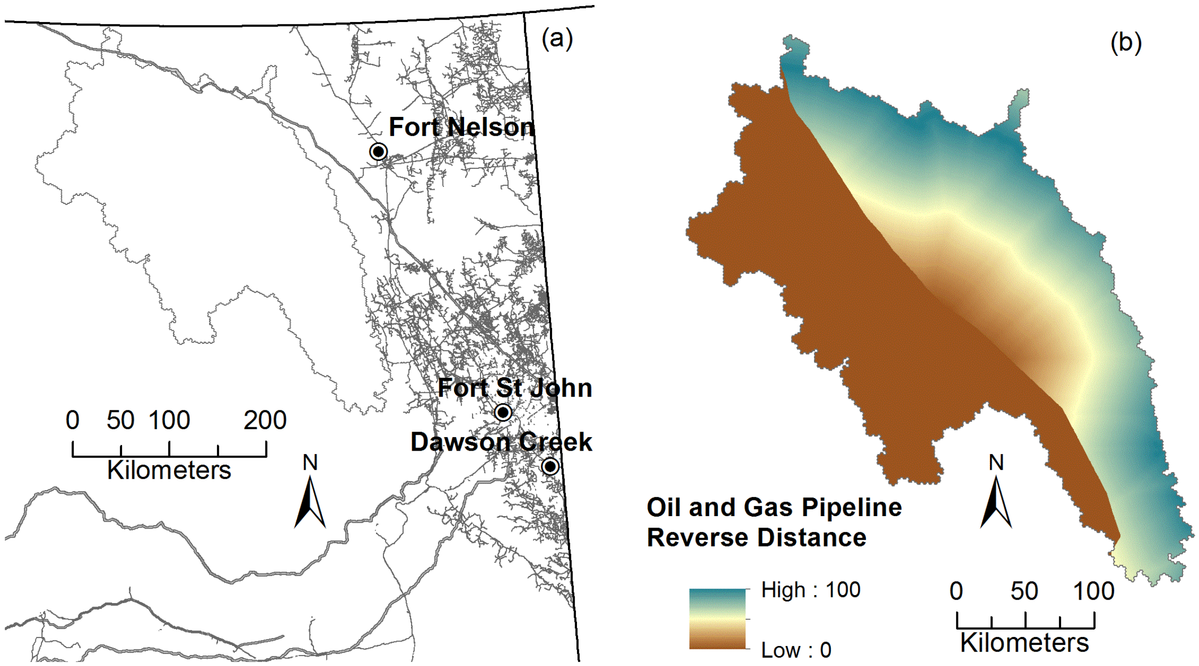

Fig. S3.5 Distribution of oil and gas pipelines in northeast British Columbia in relation to the Muskwa-Kechika Management Area (a) and distance to the nearest oil and gas pipelines. Measured distances were reversed and percent of the highest reversed distance was used as the unit. The higher the value, the closer the location is to a pipeline (b). A value of 0 was assigned to areas outside of oil and gas geology (Fig. S3.2), which are presumed to have very little resource potential for oil or gas

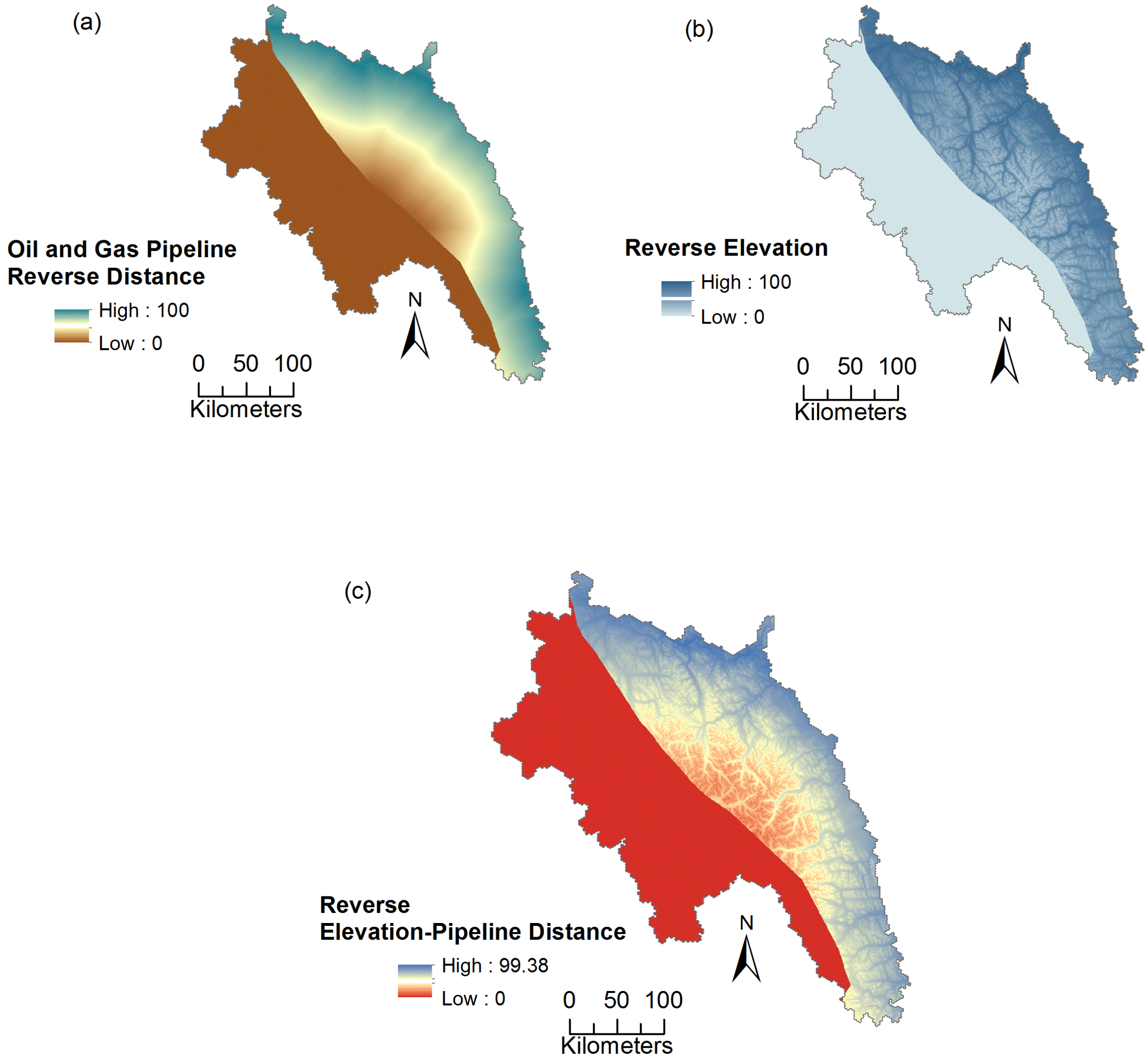

Fig. S3.6 Raster layers of reversed measures of distance to the nearest pipeline (a) and reversed measures of elevation (b), in the unit based on percent of the highest value in each raster, were combined by averaging values across pixels to create a reversed elevation-pipeline distance raster (c). The higher the value of the Reverse Elevation-Pipeline Distance raster, the closer to a pipeline from a particular location and the lower the elevation at that location, in the Muskwa-Kechika Management Area, northeast British Columbia

4. Final Oil and Gas Potential Layer for the Muskwa-Kechika

To complete the layer of Oil and Gas Potential for the Muskwa-Kechika, we combined 1) Geo-Resource Potential, 2) Resource-Site Distance, and 3) Resource Development Potential by multiplying each factor by a weight and then adding them together. We assigned the highest weight of 0.5 to Geo-Resource Potential, the primary factor of oil and gas potential, and 0.25 (half the weight of the primary factor) to both Resource-Site Distance and Resource Development Potential. Therefore, the final Oil and Gas Potential at the pixel level (Fig. S3.7a) was calculated from the following equation: Oil and Gas Potential at pixel level = 0.5 x Geo-Resource Potential + 0.25 x Resource-Site Distance + 0.25 x Resource Development Potential. For the final Oil and Gas Potential at the 500-ha planning unit level, we averaged pixel-level values of oil and gas potential for each planning unit (Fig. 1b, main text) in the Muskwa-Kechika (Fig. S3.7b).

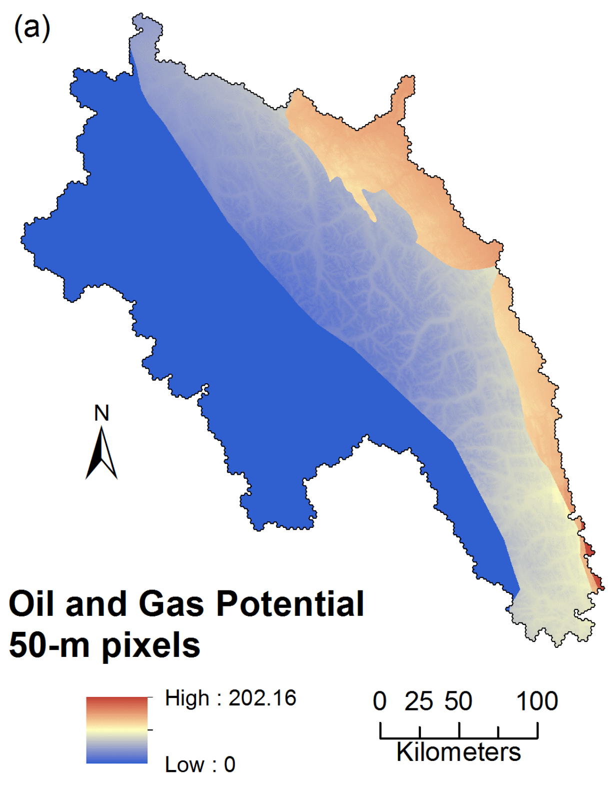

Fig. S3.7 Final oil and gas potential for the Muskwa-Kechika Management Area, northeast British Columbia, at the scales of 50-m pixels (a) and 500-ha planning units (b)

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