A Model of Future Forestry Road Development and Caribou Habitat Disturbance to Assess Future Forestry Effects on Wildlife for Timber Supply Reviews

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1. Introduction

Roads can have significant negative effects on wildlife (Forman and Alexander 1998; Forman 2000). They can block movement of animals between habitat patches and populations, and human activity on roads can both displace animals from habitat and enable human interactions with wildlife that result in wildlife mortalities, e.g., vehicle collisions, legal hunting or illegal poaching. Road development has influenced and will continue to influence many priority management wildlife species in British Columbia. For example, roads are known to have significant effects on grizzly bear (McLellan and Shackleton 1988; McLellan 1989; Proctor et al. 2004). Grizzly bear mortality may reach unsustainable levels (i.e., result in population declines) once road density increases beyond 0.75 km/km^2 on the landscape (Boulanger and Stenhouse 2014), suggesting human activity in these areas becomes so high that human-grizzly bear interactions result in unsustainable mortality rates. Roads can negatively affect the density and distribution of wildlife through various mechanisms, and are therefore a vital consideration in wildlife management.

There is a legal need for the government of British Columbia to adequately consider the effects of land use decisions, including forestry development via allowable annual cut (AAC) determinations, on Aboriginal rights to harvest wildlife.[1,2,3] To effectively address this need, timber supply reviews for AAC determinations will not only need to account for the effects of forest harvest on wildlife, but also the associated forestry road development. In British Columbia, forestry has historically been a significant contributor to road development on the landscape. It is estimated that there has been over 600,000 km of roads developed for resource extraction in British Columbia, of which at least 75% were built by the forestry industry (Forest Practices Board 2015). Simulating future road development from forestry has been outside of the scope of timber supply analysis. However, future forestry road development will need to be considered to adequately assess the effects of future forestry development on wildlife.

Caribou populations in British Columbia are currently a significant conservation concern because many herds are in decline, and they are negatively influenced by both forest harvest and road development. Boreal caribou populations occur in northeastern British Columbia and southern mountain caribou populations occur throughout areas of eastern and north-central British Columbia.[4] Both types of populations are listed as *Threatened* under the Government of Canada's *Species at Risk Act* (SARA) and are provincially red-listed (i.e., species at risk of extinction or extirpation). Therefore, caribou are a priority management species in British Columbia. Caribou critical habitat is legally defined as habitat within caribou population units (i.e., herd ranges) that have not been disturbed. Disturbed habitat is defined as areas burned within the last forty years, or areas that that are within 500 m of areas that have been logged (i.e., cutblocks) within the last forty years or linear features created by humans (i.e., roads, trails and pipelines; Environment Canada 2012; Environment Canada 2014). Environment Canada has set an objective of maintaining greater than 65% undisturbed habitat in boreal caribou ranges

[1] https://www.crownpub.bc.ca/Content/documents/williams_decision.pdf
[2] http://www.courts.gov.bc.ca/jdb-txt/CA/11/02/2011BCCA0247.htm
[3] http://www.courts.gov.bc.ca/jdb-txt/CA/13/00/2013BCCA0001.htm
[4] http://www.env.gov.bc.ca/wld/speciesconservation/caribou_by_ecotype.html

(Environment Canada 2012) and maintaining greater than 65% undisturbed habitat in low elevation winter range (and no disturbance in high elevation winter or summer range) in southern mountain caribou ranges (Environment Canada 2014). Managing habitat disturbance is therefore critical to conserving caribou populations. To effectively assess the influence of future simulated forestry on caribou will require models of how both simulated future forestry cutblocks and roads influence caribou habitat disturbance.

Here I present a modeling approach to predict future forestry road development and caribou habitat disturbance as part of the timber supply review process. I test for a statistical relationship between current cutblock density and forestry road density using a linear regression model at two scales: (1) within landscape units in the Cranbrook, Invermere, and Prince George timber supply areas (TSAs), and (2) within freshwater atlas assessment watershed areas (AWAs) across the province of British Columbia. I test for a statistical relationship between current cutblock density, road density and caribou habitat disturbance density using a linear regression model at the AWA scale across caribou range in British Columbia. I test if and how these statistical relationships differ among timber supply areas (TSAs). The goal is to develop models to estimate future forestry road and caribou habitat disturbance density from simulated future forestry cutblock density at a scale appropriate for assessing the effects of AAC determinations on wildlife.

2. Methods

2.1. Study Area

Road density and cutblock density was measured within landscape units in the Cranbrook, Invermere and Prince George TSAs (Fig. 1) and in AWAs[5] across the province. Landscape units are a relatively moderate-scale resolution (mean area = 867 km^2 for this study) planning unit, and AWAs (n = 19,469) are a relatively fine-scale resolution (mean area = 49 km^2) planning unit in British Columbia. Both scales can be integrated into timber supply models.

2.2. Current Forestry Road Density

Spatial data on roads was obtained by merging digital road atlas[6] and forest tenure road[7] data across British Columbia. To remove duplicate roads, I converted the merged linear road data into a 20 m spatial resolution raster. I then vectorised the raster back into line data using the ArcScan extension in ArcGIS 10.2. Vectorization settings are provided in Appendix A.

I measured the total length of the vectorised road data in each landscape unit and AWA by TSA[8]. I removed any AWA less than 1 km^2 in size from the analysis. AWAs less than 1 km^2 were rare in the data (n = 9), and occurred on small islands. I calculated the length of road attributed to forestry in each landscape unit and AWA according to the Forest Practices Board (2015), which estimated that

[5] https://catalogue.data.gov.bc.ca/dataset/freshwater-atlas-assessment-watersheds
[6] https://catalogue.data.gov.bc.ca/dataset/digital-road-atlas-dra-demographic-partially-attributed-roads
[7] https://catalogue.data.gov.bc.ca/dataset/forest-tenure-road-section-lines
[8] https://catalogue.data.gov.bc.ca/dataset/fadm-timber-supply-area-tsa

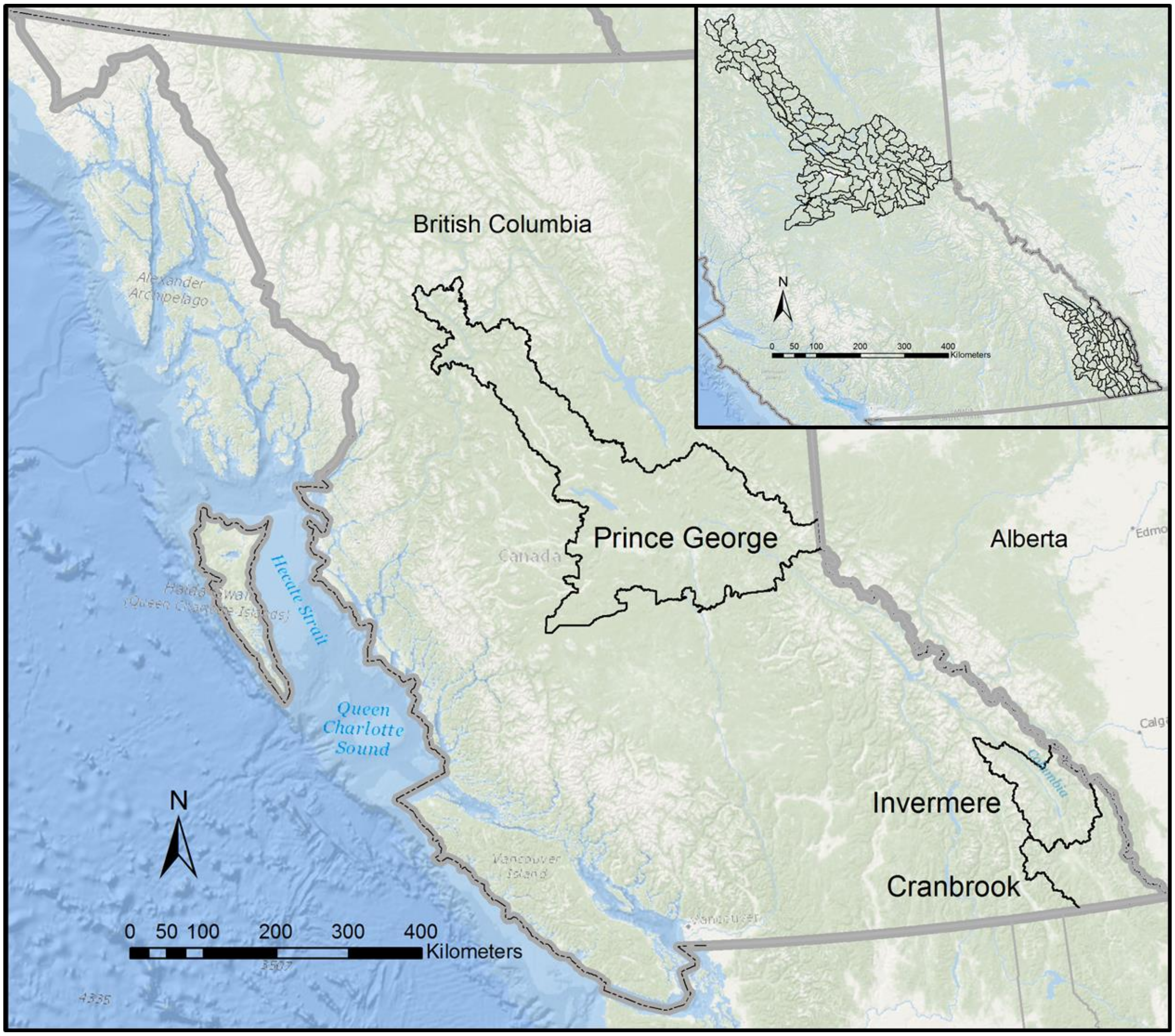

Figure 1. Timber supply areas (outlined in black on the large map) and landscape units (outlined in black on inset map) where the statistical relationship between forestry road density and cutblock density was modeled at the landscape unit scale.

75% of roads in B.C. are resource roads (i.e., roads developed for resource extraction) and 75% of resource roads were developed for forest harvest. Therefore, I multiplied the road length in each landscape unit and AWA by 0.56 (i.e., 0.75 x 0.75) to estimate the length of forestry roads in each area. I divided forestry road length by the total area of the landscape unit or AWA to calculate forestry road density (km/km^2).

2.1. Current Cutblock Density

Spatial data on cutblocks from 1955 to 2015 was obtained from the 2015 consolidated cutblocks dataset[9]. The total area of cutblocks was calculated within each landscape unit and AWA and divided by the total area to obtain an estimate of cutblock density (km^2/km^2). Any AWA with a cutblock density of 0 km^2/km^2 was removed from the analysis, as it was assumed roads in these areas were not created for forestry. All spatial data analysis was completed using ArcGIS 10.2.

2.2. Landscape Unit Urban Population

Preliminary data analysis indicated that the number of people living within a landscape unit was related to the density of roads in the unit, i.e., units with more people had more roads. Therefore, for the landscape unit scale analysis I calculated the total urban population within each landscape unit by identifying population centres in landscape units[10] and summing the total population of those centres using population estimates from 2015.[11]

2.3. Timber Supply Area

I identified which TSA each landscape unit or AWA occurred in to account for the effect of more localized conditions (e.g., forest inventory, climate, terrain, regulations) on forestry road development. Preliminary data analysis at the landscape unit scale indicated that there was variability in the relationship between cutblock density and road density across TSAs (Muhly, unpublished data). I therefore included TSA as a fixed effect or random effect factor in regression models (see below).

2.4. Fire Density

Spatial data on the location of the outer perimeter of fires less than 40 years old[12] was used to define areas disturbed by fire in caribou range. The total area of less than 40 year old burns was calculated within each AWA and divided by the unit area to calculate less than 40 year old burn density (km^2/km^2).

2.5. Current Caribou Habitat Disturbance Density

I measured the amount of disturbed caribou habitat in each AWA. Disturbed habitat was defined as roads (all types, as defined above) and cutblocks less than 40 years old buffered by 500 m and areas of less than 40 year old burns (Environment Canada 2012; Environment Canada 2014). Total disturbed area in each AWA was divided by the total area of the AWA to calculate disturbed habitat density (km^2/km^2). All spatial data processing was completed using ArcGIS 10.2.

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[9] https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-
[10] https://catalogue.data.gov.bc.ca/dataset/bc-major-cities-points-1-2-000-000-digital-baseline-mapping
[11] http://www.bcstats.gov.bc.ca/StatisticsBySubject/Demography/PopulationEstimates.aspx
[12] https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical

2.6. Linear Regression Models of Forestry Road Density

I calculated two models of the statistical relationship between cutblock density and road density, one at the landscape unit scale and another at the AWA scale. At the landscape unit scale, I modeled forestry road density as a function of cutblock density using the linear regression model function in Program R version 3.2.4 (R Core Team 2016). I fit a set of candidate regression models that included single and quadratic independent covariates for cutblock density, a covariate for urban population in the landscape unit and a factor covariate for TSA (i.e., whether the landscape unit occurred within the Cranbrook, Invermere or Prince George TSA). The candidate set of models that were tested are provided in Appendix B. Models were compared and ranked using Akaike Information Criteria (AIC; Anderson et al. 2000; Burnham and Anderson 2002). AIC evaluates models based on their fit (log-likelihood) and complexity (number of model covariates). Models that best fit the data with the fewest covariates have lower AIC values and are ranked higher. Models with a difference in AIC score (ΔAIC) of less than two from the highest ranked model are considered equivalent and are averaged (Burnham and Anderson 2002). Akaike weights (AIC_w), which are the approximate probabilities that a model in the set of candidate models is the best model, were also calculated to compare the models (Anderson et al. 2000; Burnham and Anderson 2002). The top ranked model(s) indicated which covariates were important for predicting forestry road density and the top ranked model equation can be used to predict future forestry road density at the landscape unit scale.

At the AWA scale, I modeled forestry road density as a function of cutblock density using a mixed effects linear regression model function using the R Package lme4 (Bates et al. 2015) in Program R version 3.2.4 (R Core Team 2016). I fit a regression model that included a fixed effect coefficient for cutblock density and a random intercept for TSA and random slope for cutblock density by TSA. I only fit a linear relationship between road density and cutblock density because preliminary analyses of quadratic relationships produced nonsensical road density predictions at high cutblock densities (Muhly, unpublished data).

2.7. Linear Regression Model of Caribou Habitat Disturbance Density

I fit mixed effects linear regression models between caribou habitat disturbance density (dependent variable) and cutblock, road and fire density (independent variables) at the AWA scale. I fit models with different combinations of fixed effect linear and quadratic terms for road and cutblock density and with and without fire density. I also fit the same models with a random effect intercept at the TSA scale and the same random effect slopes for road and cutblock density at the TSA scale. Mixed effects models were calculated using the R Package lme4 (Bates et al. 2015) in Program R version 3.2.4 (R Core Team 2016). I visually evaluated the fits of the different models by comparing actual to predicted amount of caribou habitat disturbance and by assessing how the model predicted caribou habitat disturbance across a range of road and cutblock density values.

3. Results

3.1. Road Density Landscape Unit Scale Analysis

The top-ranked linear regression model of forestry road density at the landscape unit scale included covariates for cutblock density (including a quadratic term for cutblock density), urban population and timber supply area (Table 1). The second-ranked model had a difference of greater than two ($\Delta AIC = 2.8$) from the top-ranked model, and a weight of 0.2 compared to 0.8 for the top-ranked model, therefore, models were not averaged.

Coefficients of the top-ranked model (Table 2) were all statistically significant (p-values less than 0.05). Forestry road density was positively related to cutblock density, but approached an asymptote at higher cutblock densities (Fig. 2). Only a few landscape units (n = 9) had an urban population greater than 0, yet forestry road density increased logarithmically with urban population. Increasing the urban population of a landscape unit from 0 to 1,000 people increased the predicted forestry road density by 0.02 km/km^2, and increasing the urban population of a landscape unit from 0 to 10,000 people increased the predicted forestry road density by 0.21 km/km^2.

There were notable differences in the relationship between cutblock density and forestry road density at the landscape unit scale across the three TSAs. Predicted forestry road density was lowest in the Prince George TSA and highest in the Cranbrook TSA (Table 2; Fig. 2). Forestry road density within landscape units in the Cranbrook TSA was 0.46 km/km^2 greater than landscape units in the Prince George TSA and 0.14 km/km^2 greater than landscape units in the Invermere TSA. Forestry road density within landscape units in the Invermere TSA was 0.33 km/km^2 greater than landscape units in the Prince George TSA.

3.2. Road Density Assessment Watershed Area Scale Analysis

The fixed effects coefficients of the mixed effects model of forestry road density at the AWA scale indicated that on average across British Columbia, each 0.10 km^2/km^2 increase in cutblock density resulted in a 0.12 km/km^2 increase in road density (Table 3). However, the intercept and slope of the model varied across TSAs (Table 3), indicating the relationship between roads and cutblocks varies across the province. For example, in the Cranbrook TSA, more roads were created per area of cutblock than in the Prince George TSA, but less than in the Pacific TSA (Fig. 3). This result is consistent with the landscape unit analysis, and suggests that more or less roads may be needed to extract timber in some areas compared to others. Minimum road densities also varied by TSA (i.e., the random effects intercepts varied; Table 3), indicating that the amount of roads needed to initiate forestry in a TSA varied, or the amount of non-forestry related roads varied across TSAs. For example, road densities in AWAs within the Cranbrook, Fort St. John, and Prince George TSAs were typically lower than in the Okanagan and Strathcona TSAs (Fig. 3).In addition, the relationship between cutblock density and road density appeared to vary differently within a TSA. For example, road density varied more in the Okanagan and Strathcona TSAs compared to the Prince George TSA. Thus, the model fit varies across TSAs, and predictions from this model may be more or less accurate in some TSAs compared to others. Forestry road density model fits for all TSAs in British Columbia are provided in Appendix C.

Table 1. Akaike Information Criteria (AIC) ranking of candidate linear regression models to predict forestry road density in landscape units in the Cranbrook, Invermere and Prince George timber supply areas. The top-ranked model has the lowest AIC value and models with an AIC difference (ΔAIC) less than two are equivalent. Akaike weight (AIC_w) indicates the approximate probability that a model in the set of candidate models is the best model**.**

Model Terms	AIC	ΔAIC	AIC_w	Adjusted R-squared
Cutblock density + Cutblock density^2 + Population + TSA	25.10	0.0	0.8	0.722
Cutblock density + Population + TSA	27.87	2.8	0.2	0.716
Cutblock density + Cutblock density^2 + TSA	57.19	32.1	0.0	0.661
Cutblock density + TSA	61.51	36.4	0.0	0.651
Cutblock density + Cutblock density^2 + Population	100.26	75.2	0.0	0.469
Cutblock density + Population	110.48	85.4	0.0	0.507
Cutblock density + Cutblock density^2	117.96	92.9	0.0	0.529
Cutblock density	129.46	104.4	0.0	0.559

Table 2. Coefficient values of the top-ranked linear regression model of forestry road density at the landscape unit scale in the Cranbrook, Invermere and Prince George timber supply areas.

	Coefficient	SE	t-value	p-value
Intercept	0.42	0.06	7.232	<0.001
Cutblock density	3.36	0.43	7.826	<0.001
Cutblock density^2	-1.91	0.88	-2.158	0.032
Population	0.000021	0.000003	6.038	<0.001
TSA (Invermere)	-0.14	0.06	-2.358	0.020
TSA (Prince George)	-0.46	0.05	-9.154	<0.001

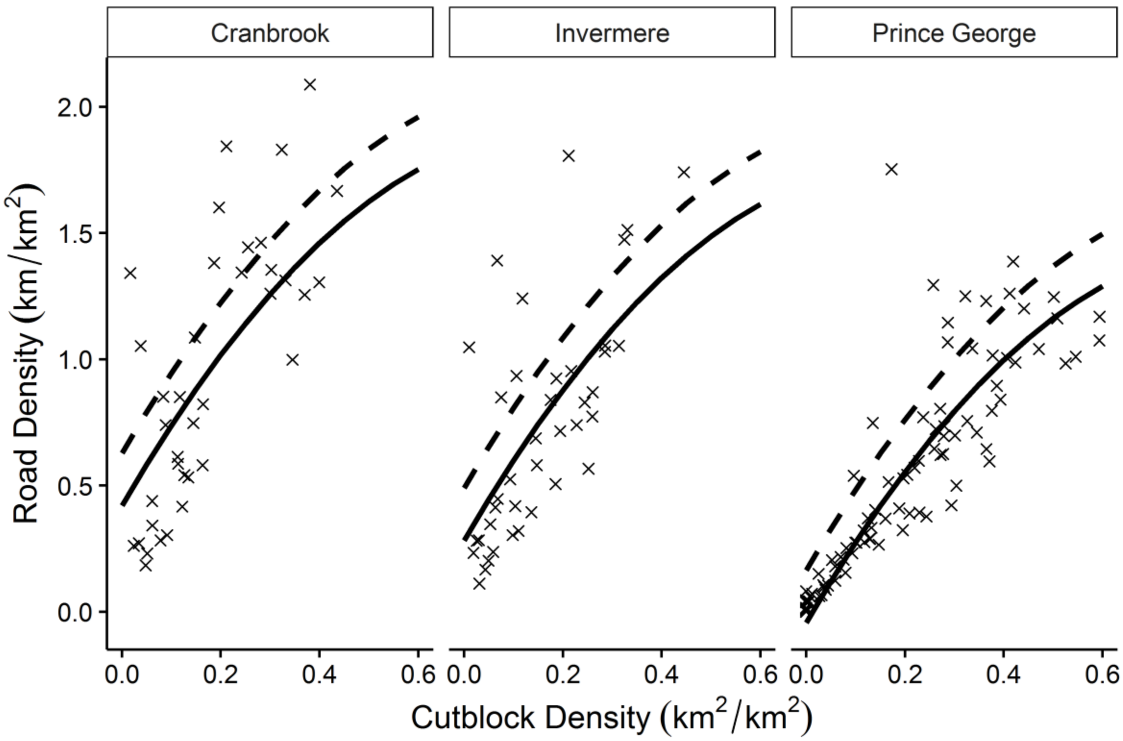


Figure 2. Predicted forestry road density as a function of cutblock density at the landscape unit scale in three timber supply areas (Cranbrook, Invermere and Prince George) in British Columbia. Solid line indicates the relationship in landscape units with no urban areas and dashed line indicates the relationship in landscape units with urban areas of 10,000 people.

Table 3. Coefficient values and standard errors (SE) of the mixed effects model of forestry road density at the assessment watershed area (AWA) scale across British Columbia.

Fixed Effects			
	Coefficient	SE	t-value
Intercept	0.16	0.02	8.7
Cutblock density	1.16	0.1	12

Random Effects

Timber Supply Area	Intercept	Cutblock Density Slope
100 Mile House	0.085	-0.783
Arrow	0.029	0.541
Arrowsmith	0.283	-0.277
Boundary	0.271	-0.122
Bulkley	0.025	-0.439
Cascadia	0.026	0.028
Cassiar	-0.098	0.114
Cranbrook	-0.036	0.305
Dawson Creek	-0.037	-0.41
Fort Nelson	-0.108	-0.487
Fort St. John	-0.082	-0.36
Fraser	0.248	-0.512
Golden	-0.067	0.035
Invermere	-0.046	0.405
Kalum	-0.053	-0.185
Kamloops	0.058	-0.007
Kingcome	-0.026	2.098
Kispiox	-0.056	-0.484
Kootenay Lake	-0.042	0.624
Lakes	-0.02	-0.32
Lillooet	-0.054	0.255
MacKenzie	-0.071	-0.107
Merritt	0.003	0.016
Mid Coast	-0.145	0.308
Morice	-0.025	-0.433
Nass	-0.1	-0.268
North Coast	-0.147	-0.344
Okanagan	0.22	-0.327
Pacific	0.018	1.63
Prince George	-0.009	-0.608
Queen Charlotte	-0.042	-0.085
Quesnel	0.087	-0.506
Revelstoke	-0.085	0.475

Robson Valley	-0.099	0.249
Soo	-0.051	0.117
Strathcona	0.237	-0.106
Sunshine Coast	-0.063	0.303
Williams Lake	-0.031	-0.334

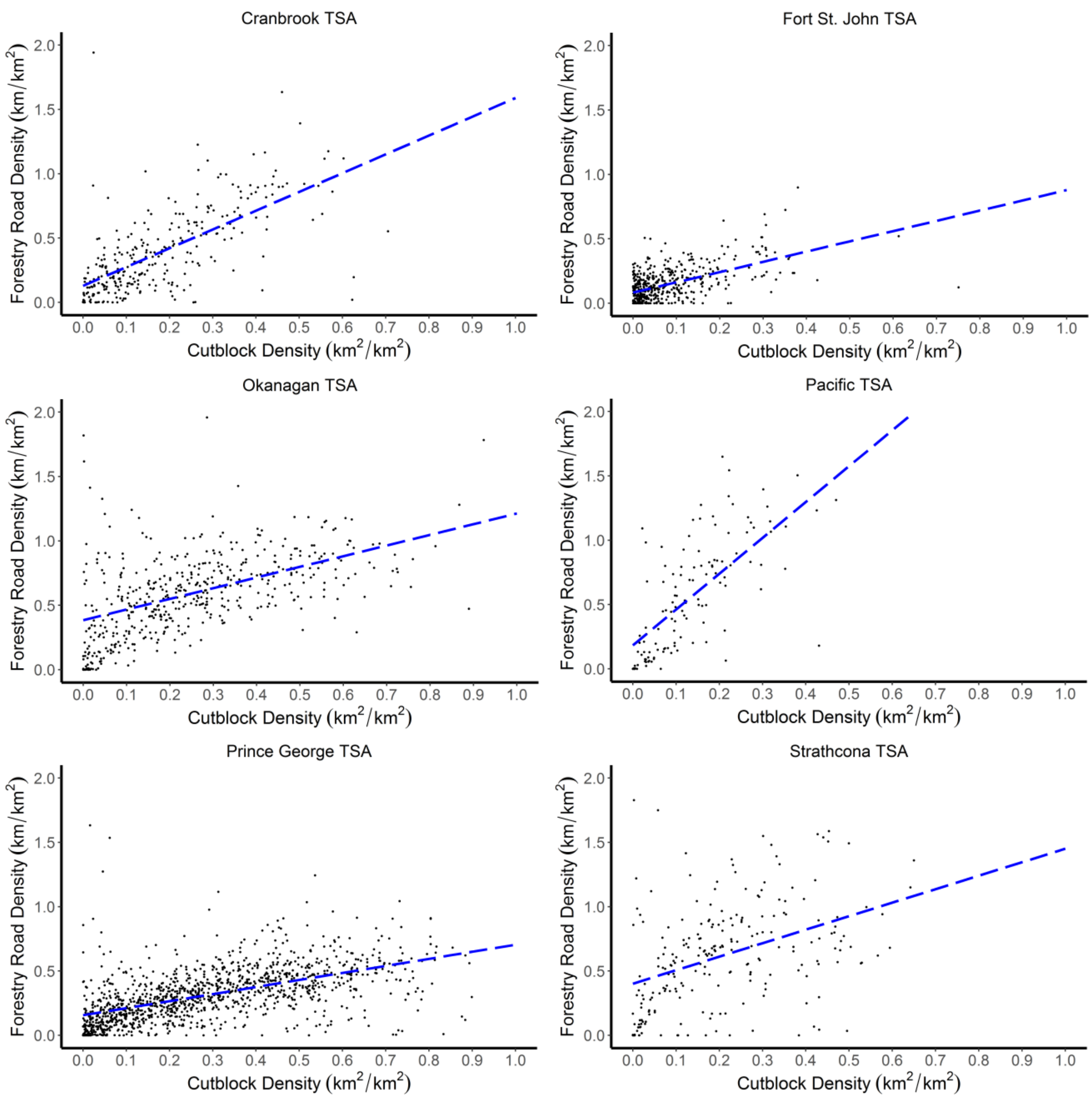


Figure 3. Predicted forestry road density as a function of cutblock density at the assessment watershed area scale from a sample of timber supply areas across British Columbia. For other timber supply areas, see Appendix D.

3.3. Caribou Habitat Disturbance and Road and Cutblock Density

I identified the model with linear fixed and random effect terms for road density and cutblock density as the best model for calculating caribou habitat disturbance density (Table 4). Caribou habitat disturbance was positively related to both cutblock and road density, and these relationships varied across timber supply areas. The relationship between actual and predicted caribou habitat disturbance was generally good, with a clear positive relationship (Fig. 4). Models with quadratic terms appeared to over-fit the data, with lower disturbance values predicted at very high road or cutblock densities. Models with terms for fire density did not converge, and inspection of the data indicated there was not a strong relationship between fire density and disturbance density.

4. Discussion

There was a clear positive statistical relationship between cutblock density and forestry road density in AWAs across British Columbia and in landscape units in the Cranbrook, Invermere and Prince George TSAs. The results indicate that future simulated cutblock density can be used to model future forestry road density at both scales. Modeling future forestry road development is important for assessing the impacts of future forestry development on wildlife. Roads influence the density and distribution of many wildlife species, including priority management species in British Columbia such as grizzly bear.

In addition, I found a positive statistical relationship between road density, cutblock density and caribou habitat disturbance, as defined by Environment Canada (Environment Canada 2012; Environment Canada 2014), at the AWA scale. This statistical model can be used in combination with the road density model to assess potential effects of future forestry on caribou. Caribou are of particular conservation concern in British Columbia and Canada because of their declining numbers.

4.1. Model Limitations

There are limitations to these models that should be considered when applying them. First, the forestry road model did not consider the type of forestry road in the analysis, such as how much traffic was on the road, the types of roads users or the status of roads (e.g., paved, gravel, deactivated, open or closed). Some road types may have lesser or greater effects on specific wildlife species, which may need to be considered in some analyses of the effects of roads on wildlife. Second, both the forestry road and caribou habitat disturbance models used current spatial variability in cutblock density and road density to model future road density or caribou habitat disturbance density. It is plausible that temporal development of roads and forestry may follow a different pattern than what is currently present spatially. However, temporal data on cutblock and road development is unavailable and the spatial pattern of development likely represents a reasonable facsimile of how forestry develops over time.

Table 4. Coefficient values and standard errors (SE) of the mixed effects model of caribou habitat disturbance at the assessment watershed area (AWA) scale in caribou range across British Columbia.

Fixed Effects			
	Coefficient	SE	t-value
Intercept	0.13	0.01	8.86
Cutblock density	1.25	0.09	14.10
Road density	0.43	0.03	16.05
Random Effects			
Timber Supply Area	Intercept	Road Density Slope	Cutblock Density Slope
100 Mile House	0.234	-0.072	-0.757
Arrow	0.063	-0.109	-0.265
Boundary	0.162	-0.171	-0.558
Bulkley	0.007	-0.008	-0.133
Cascadia	-0.007	0.000	-0.158
Cassiar	-0.100	0.363	-0.121
Cranbrook	0.084	-0.198	-0.243
Dawson Creek	0.019	0.008	0.105
Fort Nelson	-0.046	0.178	0.909
Fort St. John	-0.041	0.209	0.306
Golden	-0.078	-0.012	0.046
Invermere	-0.042	-0.049	-0.209
Kalum	-0.051	0.092	0.655
Kamloops	0.022	-0.068	-0.491
Kingcome	-0.094	0.076	0.289
Kispiox	-0.072	0.157	0.296
Kootenay Lake	0.016	-0.169	0.366
Lakes	0.092	-0.046	-0.370
Lillooet	-0.051	0.025	0.647
MacKenzie	-0.064	0.089	-0.328
Mid Coast	-0.049	0.086	0.648
Morice	0.008	0.048	-0.325
Nass	-0.096	0.182	0.370
Okanagan	0.178	-0.139	-0.634
Pacific	-0.056	0.049	0.168
Prince George	0.020	-0.043	-0.241
Queen Charlotte	-0.052	-0.071	-0.063
Quesnel	0.123	-0.128	-0.488
Revelstoke	-0.044	-0.105	0.070
Robson Valley	-0.075	-0.098	0.397
Sunshine Coast	-0.070	0.056	0.214
Williams Lake	0.059	-0.132	-0.100

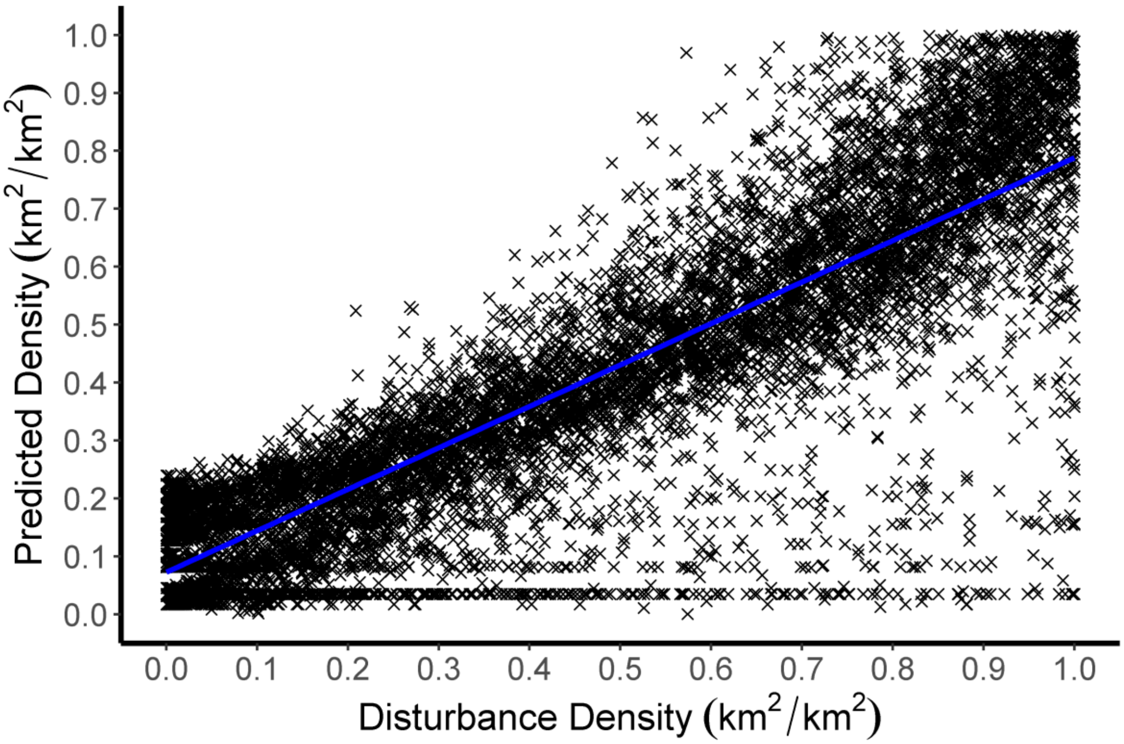


Figure 4. Predicted caribou habitat disturbance density from a mixed effects model as a function of the measured disturbance density in assessment watershed areas (AWAs) in caribou range across British Columbia.

4.2. Landscape Unit Scale Model of Forestry Roads

The modeled relationship between forestry road density and cutblock density at the landscape unit scale was not linear, but approached an asymptote at higher cutblock densities. This suggests that forestry road development in a landscape unit reaches a saturation point. This is not surprising, as previous forestry road development likely also provides access to some forested areas that can be cut in the future. In this analysis, the quadratic relationship was primarily driven by data from the Prince George TSA, which had landscape units with approximately 50% higher cutblock densities than landscape units the Cranbrook and Invermere TSAs. Indeed, preliminary analysis of the data exclusively from the Cranbrook and Invermere TSAs indicated the relationship between cutblock density and forestry road density was more likely to be linear than quadratic, whereas preliminary analysis of the data exclusively from the Prince George TSA indicated the relationship was quadratic (Appendix D). The relationship between forestry road density and cutblock density was unique for each TSA. Therefore, forestry road density models should be completed for each TSA. This is ideally done by including TSA as a random effect in the models, as was done for the AWA scale analysis described here.

Urban areas in landscape units, particularly urban areas greater than 10,000 people, were an important covariate for predicting forestry road density. It may be that more roads are created to access cutblocks in areas with a larger urban population, perhaps because forestry roads near urban areas are more likely to serve multiple purposes (e.g., for recreation, rural residential and forestry reasons). Alternatively, the proportion of roads that are forestry roads may be lower closer to urban areas because of the development of other types of roads around urban areas. Therefore, the urban population covariate may be accounting for some non-forestry roads in and around urban areas.

4.3. Assessment Watershed Area Scale Models of Road Density and Caribou Habitat Disturbance

I found a positive statistical relationship between road density and cutblock density at the AWA scale that may be used to simulate future road density from future simulated forestry cutblock development. Random effects from the model will be useful for modeling this relationship in different TSAs, where the amount of roads created per cutblock or the amount of non-forestry roads in a watershed may differ. Similarly, I found a positive statistical relationship between road density, cutblock density and caribou habitat disturbance at the AWA scale that also included random effects at the TSA scale. These models may be useful for assessing the effects of future forestry on wildlife species. One notable example (in addition to caribou) where these models may be useful is for assessing forestry effects on grizzly bear, which are negatively influenced by road development. Roads typically have a significant negative effect on grizzly bear survival. Throughout western North America (McLellan and Shackleton 1988; McLellan 1998; McLellan 1990; Mace et al. 1996; Nielsen et al. 2004; Proctor et al. 2004; Boulanger and Stenhouse 2014), research shows that roads facilitate interactions between humans and grizzly bear that can result in grizzly bear mortalities. Grizzly bear mortality rates may reach unsustainable levels (i.e., causing population declines) once road density increases beyond 0.75 km/km^2 (Boulanger and Stenhouse 2014), and a road density less than 0.6 km/km^2 is a target for grizzly bear conservation units in Alberta (Alberta Grizzly Bear Recovery Plan 2008) and is a recognized threshold of concern in British Columbia.[13]

5. Summary

Here I describe an approach to simulate future forestry road density and caribou habitat disturbance from simulated future cutblock density outputted from timber supply models. This approach may be useful for assessing the effects of future forestry development on wildlife in general and caribou in particular, as part of the AAC determination process. Roads influence the density and distribution of many wildlife species. Therefore, if a goal of timber supply planning is to assess the effects of timber harvest on wildlife, then future road development needs to be incorporated into the timber supply analysis process.

I provide models of forestry road density at two different spatial grains, landscape units and AWAs. Model fit subjectively appeared to be better at the landscape unit scale than AWA scale for at least some TSAs, as there appeared to be less variability in road density as a function of cutblock density at the landscape unit scale. This may be because many factors influence road development at the AWA scale, for example, terrain and the presence of non-forestry development activities, but ultimately at larger scales these factors may become less important than simply the amount of forestry development. Nevertheless, finer-scale simulations of road density may be necessary for some analyses, for example, to assess potential effects of forestry on wildlife species that use a relatively small area. Analysts using these models should consider the appropriate analytical scale. Analysts should also carefully consider model fit for the TSA where they wish to complete their analysis, as the model subjectively appeared to better fit the data in some TSAs better than in others. Nevertheless, overall the model results indicate that cutblock density reasonably correlates with forestry road density at the landscape unit and AWA scales. Thus, the model may be a useful tool to simulate future forestry road density from simulated future forestry development in British Columbia.

Here I modeled caribou habitat disturbance at the AWA scale and found a reasonably strong positive relationship between habitat disturbance and road and cutblock density. I previously modeled this relationship at the landscape unit scale (Muhly 2016), however, there I found that the scale of analysis may have been too coarse to simulate and asses the amount of future disturbance in some caribou ranges. Specifically, some caribou ranges only contained portions of landscape units, and thus current and simulated future forestry within those landscape units but outside of caribou arranges would influence the amount of disturbance predicted in those ranges. This would sometimes result in over-predicting disturbance in smaller caribou ranges. The AWA scale may be less sensitive to these effects and is therefore the recommended scale for these models. Interestingly, fire density was not a factor in predicting caribou habitat disturbance density. This may be because disturbance density in most areas is primarily driven by landscape development by humans (i.e., cutblocks and roads), and thus the effect of fire is negligible.

[13] http://www.env.gov.bc.ca/soe/indicators/plants-and-animals/grizzly-bears.html

Here I provide some statistical models to support the strategic assessment of the effects of future forestry on wildlife. Specifically, the models address the issue of how to simulate future roads from simulated future cutblocks that are outputted from timber supply models. Roads are an important aspect of forestry development that influences a variety of wildlife species. The models provided here may allow for a more complete assessment of future forestry effects on wildlife species of conservation and management concern in British Columbia.

6. Literature Cited

Alberta Grizzly Bear Recovery Plan: 2008-2013. 2008. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species Recovery Plan No. 15. Edmonton, AB. 68 pp. Available from: http://aep.alberta.ca/fish-wildlife/species-at-risk/species-at-risk-publications-web-resources/mammals/documents/SAR-GrizzlyBearRecoveryPlan2008-2013-Dec2008.pdf

Anderson, D. R., Burnham, K. P., & Thompson, W. L. (2000). Null hypothesis testing: problems, prevalence, and an alternative. The Journal of Wildlife Management 64, 912-923.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48.

Boulanger, J., & Stenhouse, G. B. (2014). The impact of roads on the demography of grizzly bears in Alberta. PloS one, 9(12), e115535.

Burnham, K. P.; Anderson, D. R. (2002), Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach (2nd ed.), Springer-Verlag

Environment Canada. 2012. Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. xi + 138pp.

Environment Canada. 2014. Recovery Strategy for the Woodland Caribou, Southern Mountain population (*Rangifer tarandus caribou*) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. viii + 68 pp.

Forest Practices Board. (2015). Access Management and Resource Roads: 2015 Update. Available from: https://www.bcfpb.ca/sites/default/files/reports/SR49-Access-Management.pdf.

Forman, R. T. (2000). Estimate of the area affected ecologically by the road system in the United States. Conservation Biology, 14(1), 31-35.

Forman, R. T., & Alexander, L. E. (1998). Roads and their major ecological effects. Annual review of ecology and systematics, 207-C2.

Mace, R. D., Waller, J. S., Manley, T. L., Lyon, L. J., & Zuuring, H. (1996). Relationships among grizzly bears, roads and habitat in the Swan Mountains Montana. Journal of Applied ecology, 1395-1404.

McLellan, B. N. (1989). Dynamics of a grizzly bear population during a period of industrial resource extraction. I. Density and age-sex composition. Canadian Journal of Zoology, 67(8), 1856-1860.

McLellan, B. N. (1990). Relationships between human industrial activity and grizzly bears. Bears: Their Biology and Management, 57-64.

McLellan, B. N., & Shackleton, D. M. (1988). Grizzly bears and resource-extraction industries: effects of roads on behaviour, habitat use and demography. Journal of Applied Ecology, 451-460.

Nielsen, S. E., Boyce, M. S., & Stenhouse, G. B. (2004). Grizzly bears and forestry: I. Selection of clearcuts by grizzly bears in west-central Alberta, Canada. Forest Ecology and Management, 199(1), 51-65.

Proctor, M. F., Servheen, C., Miller, S. D., Kasworm, W. F., & Wakkinen, W. L. (2004). A comparative analysis of management options for grizzly bear conservation in the US-Canada trans-border area. Ursus, 15(2), 145-160.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Appendix A. ArcScan settings for converting rasterized road data to vector format.

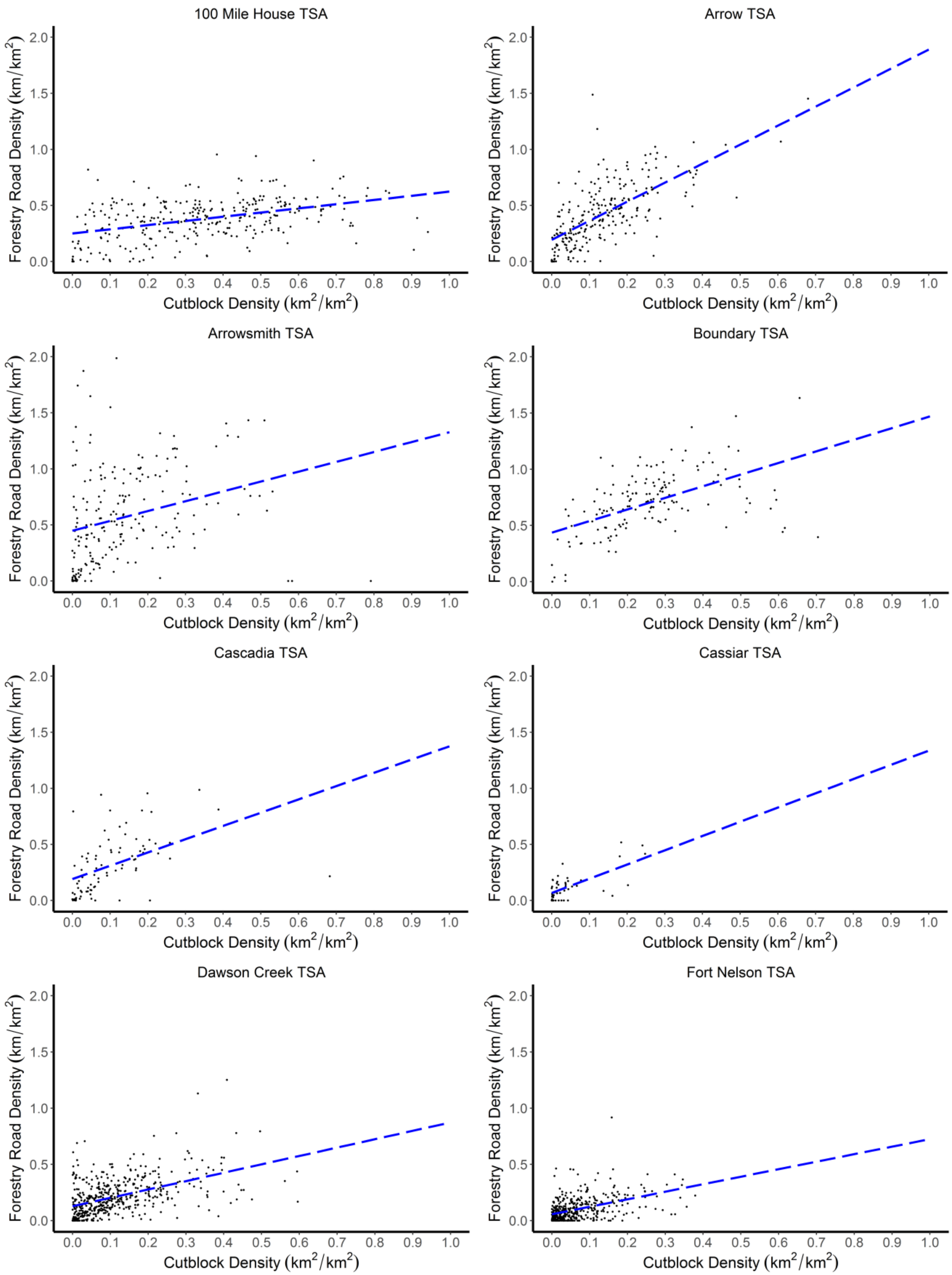
Vectorization settings:

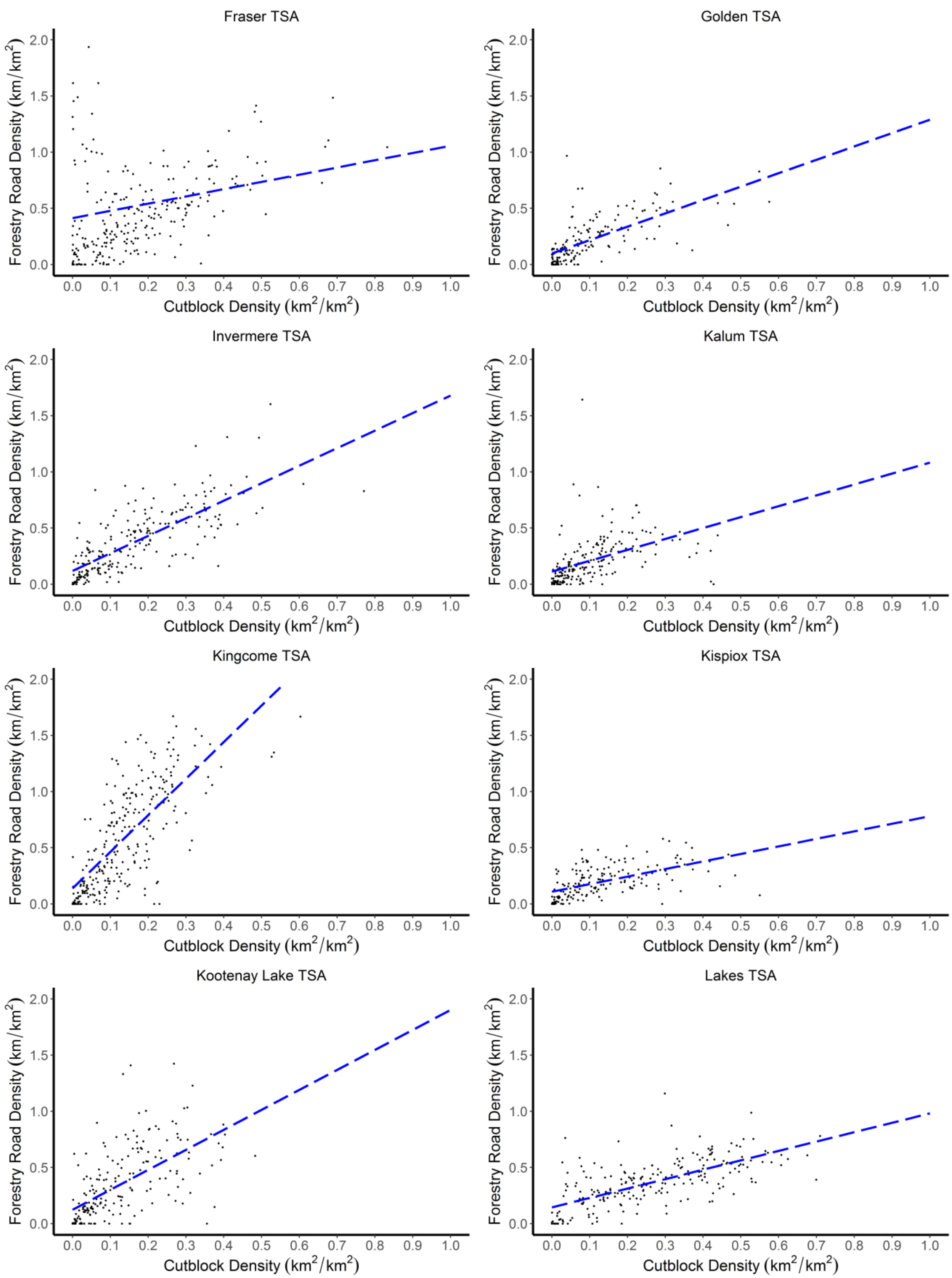
- Geometrical intersection
- Max line width = 20
- Noise level = 20
- Compression tolerance = 0.025
- Smoothing weight = 3
- Hole size = 3

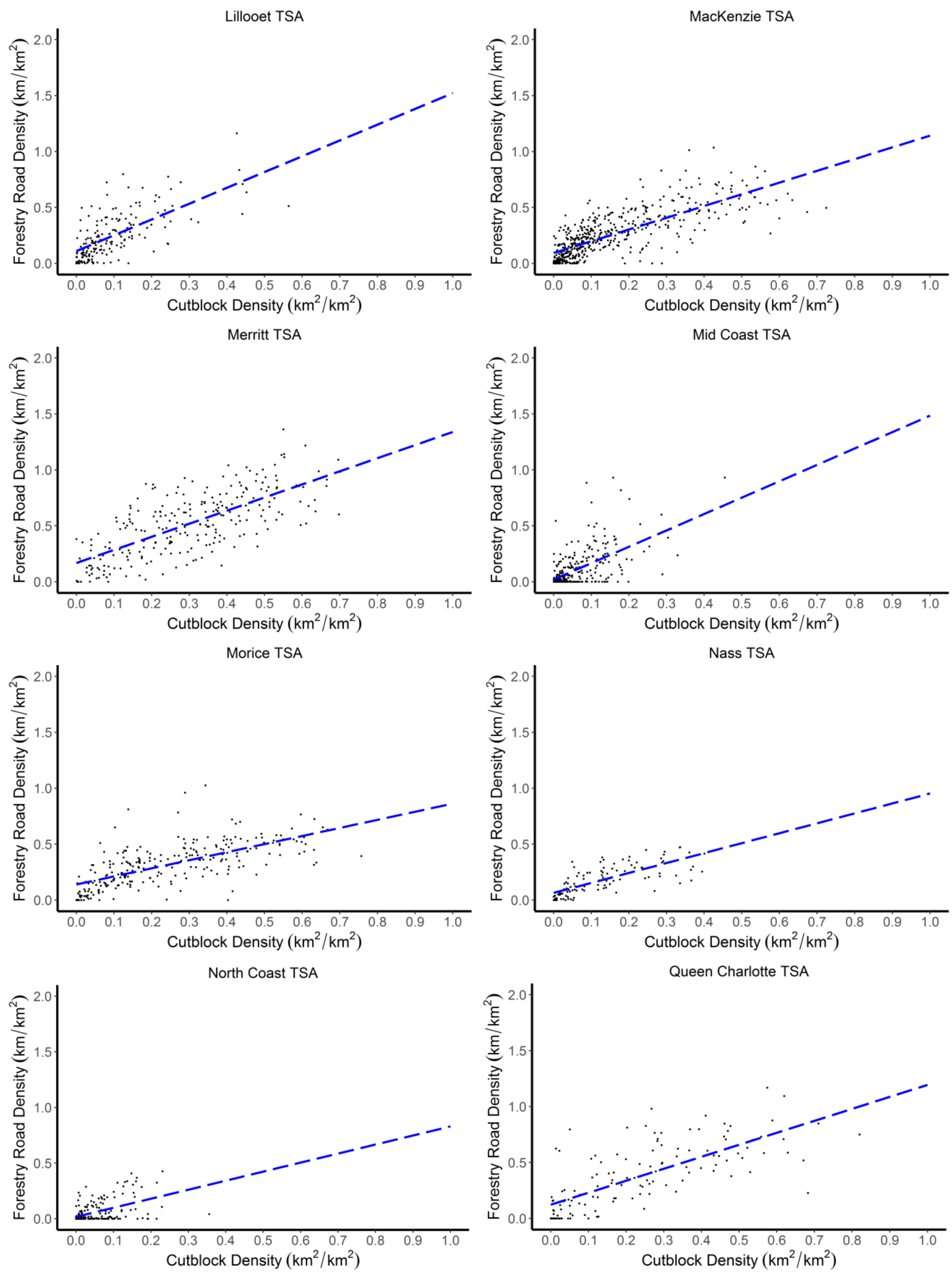
Appendix B. Candidate regression models that were fit at the landscape unit scale.

Model Terms
Cutblock density + Cutblock density^2 + Population + TSA
Cutblock density + Population + TSA
Cutblock density + Cutblock density^2 + TSA
Cutblock density + TSA
Cutblock density + Cutblock density^2 + Population
Cutblock density + Population
Cutblock density + Cutblock density^2
Cutblock density

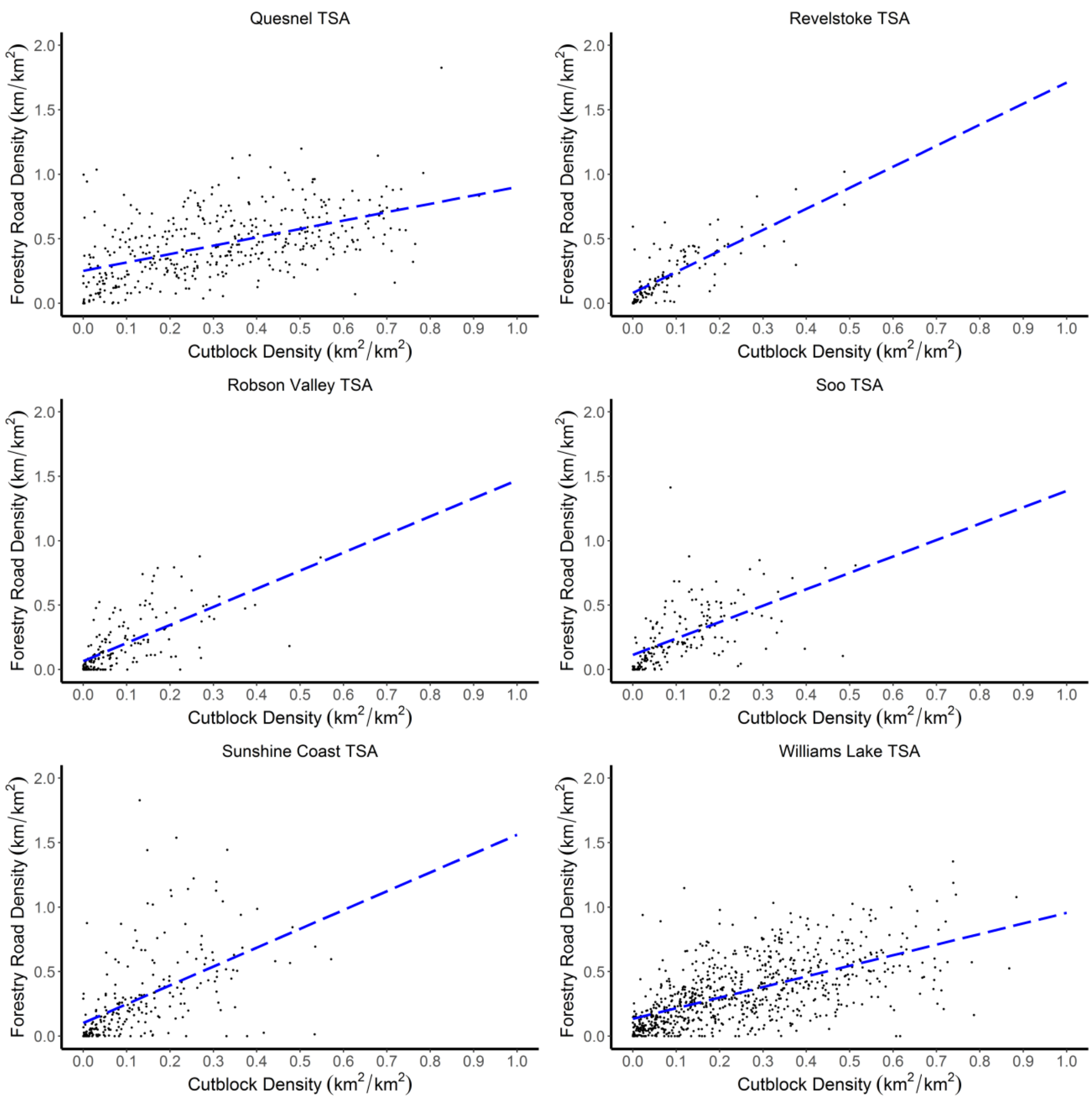
Appendix C. Predicted forestry road density as a function of cutblock density and timber supply area at the assessment watershed area scale across British Columbia.




Fraser TSA
Golden TSA
Invermere TSA
Kalum TSA
Kingcome TSA
Kispiox TSA
Kootenay Lake TSA
Lakes TSA
Forestry Road Density (km/km^2)
Cutblock Density (km^2/km^2)
0.0 0.5 1.0 1.5 2.0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0



Lillooet TSA
MacKenzie TSA
Merritt TSA
Mid Coast TSA
Morice TSA
Nass TSA
North Coast TSA
Queen Charlotte TSA
Forestry Road Density (km/km^2)
Cutblock Density (km^2/km^2)


Quesnel TSA
Revelstoke TSA
Robson Valley TSA
Soo TSA
Sunshine Coast TSA
Williams Lake TSA
Forestry Road Density (km/km²)
Cutblock Density (km²/km²)

Appendix D. Results of forestry road density predictions using linear regression models that were completed independently for the Cranbrook and Invermere and Prince George TSAs.

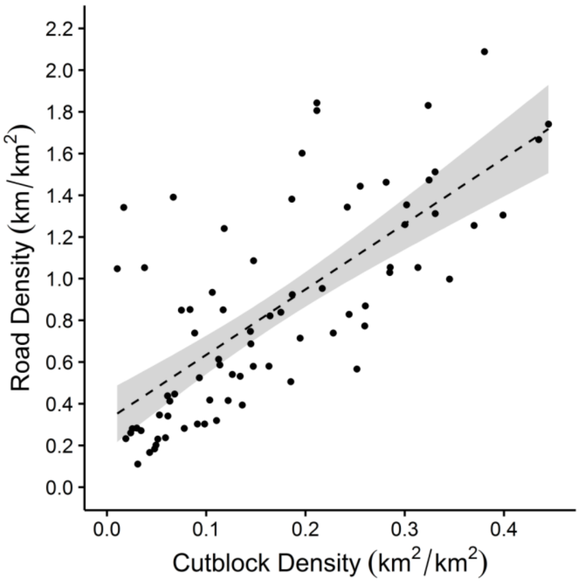


Figure C.1. Relationship between cutblock density and forestry road density in landscape units in the Invermere and Cranbrook TSAs. Regression fit line (dashed line) and 95% confidence interval (grey shaded are) are indicated.

Table C.1. Akaike Information Criteria (AIC) ranking of candidate linear regression models to predict forestry road density in landscape units in the Cranbrook and Invermere timber supply areas. The top-ranked model has the lowest AIC value and models with an AIC difference (ΔAIC) less than two are equivalent. Akaike weight (AIC_w) indicates the approximate probability that a model in the set of candidate models is the best model.

Model Terms	AIC	ΔAIC	AIC_w	Adjusted R-squared
Cutblock density	58.98	0	0.7	0.511
Cutblock density + Cutblock density^2	60.92	1.9	0.3	0.504

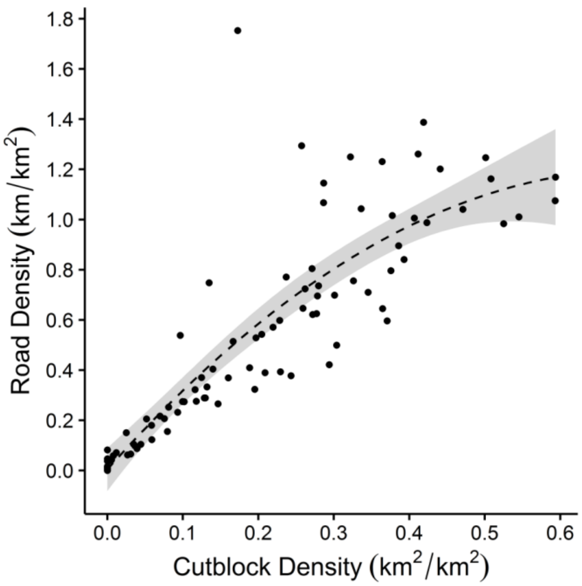


Figure C.2. Relationship between cutblock density and forestry road density in landscape units in the Prince George TSA. Regression fit line (dashed line) and 95% confidence interval (grey shaded are) are indicated.

Table C.2. Akaike Information Criteria (AIC) ranking of candidate linear regression models to predict forestry road density in landscape units in the Prince George timber supply area. The top-ranked model has the lowest AIC value and models with an AIC difference (ΔAIC) less than two are equivalent. Akaike weight (AIC_w) indicates the approximate probability that a model in the set of candidate models is the best model.

Model Terms	AIC	ΔAIC	AIC_w	Adjusted R-squared
Cutblock density + Cutblock density^2	-20.91	0	1.0	0.754
Cutblock density	-14.38	6.5	0.0	0.733