Highway Effects on Gray Wolves within the Golden Canyon, British Columbia

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Abstract

We developed gray wolf (*Canis lupus)* movement and highway crossing mitigation models for the Golden Canyon, situated in the continental ranges of the Rocky Mountains, west of Yoho National Park and east of Golden, British Columbia. The study area includes approximately 23 km of the Canadian Pacific Railway and the Trans Canada Highway, for which highway expansion plans currently exist. The probabilistic movement model is spatially explicit and runs in a Geographic Information System (GIS). The movement model is an empirically-derived simulation that quantitatively assesses the probability of a wolf pack using and moving through the Golden Canyon during winter. The simulation is based on known relationships between wolf movement and physiographic and anthropogenic factors. We examined the distribution of wolf locations in relation to the biophysical parameters using polytomous logistic regression. We also developed a deterministic movement stimulus model to predict potential wolf movement corridors in the Golden Canyon. Simulated wolves selected travel routes between a designated point A and B that provide an optimal combination of security, habitat quality and energetic efficiency. Primary, secondary and tertiary pathways were generated. The least resistant pathways were used to identify areas of potential highway crossings. Physiographic restrictions limit the availability of wolf habitat in the Golden Canyon. Consequently, the canyon is not likely to support core habitat for a wolf pack. The canyon may, however, function as a regional corridor between the Columbia Valley and the Beaverfoot Valley and Yoho National Park. The simulated pathways through the canyon demonstrate that the TCH and the Railway converge on the best available habitat for wolves in the study area.

Introduction

Roads are a primary source of habitat fragmentation, which confines species into networks of small patches. This condition intensifies the threat to the survival of species that originally occupied more extensive and continuous habitats. The threat of habitat fragmentation is acute for species, such as the gray wolf, which exists in low densities and occupies large home ranges. These effects combine to have local and population-level influences by altering the composition of biological communities upon which wolves are dependent, reducing prey populations, restricting movements, and limiting access to prey. Obstructing movements also increases the vulnerability of wolves to other disturbances as they attempt to learn new travel routes. In the Rocky Mountains, natural landforms and the condensed arrangement of habitats make wolves highly susceptible to the adverse effects of roads. Because roads often occur in areas preferred by wolves, they elevate the risk of death and injury for wolves. Associated effects include decreased opportunities for wolves to move freely about, displacement or alienation from preferred ranges, and interruption of normal periods of activity. In less physiographically complex environments, multiple travel routes link patches of wolf habitat. Within these environments, destruction or degradation of 1 or 2 routes is not usually critical, because safe alternative routes are available. In contrast, wolves in the Rocky Mountains cannot avoid valley bottoms or use other travel routes without affecting their fitness. Therefore, tolerance of disturbance is probably lower than in other human-dominated environments where wolves can avoid disturbed sites without seriously jeopardizing survival.

Traffic and recreational development will continue to increase within the central Rockies, stimulating a demand for additional roads, highways, and railways. Plans exist for expanding the Trans Canada Highway through the Golden Canyon, British Columbia. Considering the potential effects of the expansion on wolf movements and survival, we require a better understanding of how linear infrastructures affect movements of wolves. Herein, we assess the influence of the Trans Canada Highway on habitat use, travel patterns, and dispersal capabilities of gray wolves in the Golden Canyon, British Columbia. We use a Geographic Information System (GIS) to model the connectivity, spatial distribution, availability, and quality of key habitats, report on the results of a pathway analysis for wolves moving through the Golden Canyon, and provide recommendations for mitigating highway effects.

Study Area

We developed wolf movement and highway crossing mitigation models for the Golden Canyon, which is situated west of Yoho National Park at

51^{o}, 24= N and -116 ^{o}, 65= W and east of Golden, British Columbia, Canada at 51^{o}, 30= N and -116^{o},94= W (Figure 1). The study area is approximately 156 km^{2}, and includes the Golden Canyon and approximately 23 km of the Trans Canada Highway. The Golden Canyon forms part of the Kicking Horse River drainage and is part of the continental ranges of the central Rocky Mountains.

Topographic features of the study area include rugged mountainous terrain, narrow, steep-walled tributary valleys, and a broad, canyon-like main valley. The main tributary is oriented in an east-west trend. Elevations range from 800 m to 2700 m. Most vegetation occurs along the valley bottoms and lower mountain slopes and shoulders.

The climate is continental, characterized by cold, moist, and snowy conditions. The winters are typically cold and long, and summers short and cool. Mean annual temperature ranges from -2 ^{O}C to +2^{O}C (Meidinger and Pojar 1991). Elevation and topography throughout the study area influence the regional climate and vegetation communities and thus contribute to a highly variable climate. The complex climate regimen is evidenced by the distribution of plants and animals in the study area (Janz and Storr 1977).

Precipitation increases with increasing elevation. Mean annual precipitation for the area ranges from 491 mm at 1000 m above sea level in Golden (British Columbia Ministry of the Environment) to 687.7 mm at 4100 m above sea level at the Yoho National Park Warden Compound (Yoho National Park Warden Service). The snowfall regimen within the study area exerts a significant ecological influence on the study area. Many alpine areas remain snow-covered for 10 months a year; montane areas have snow cover for 6 or 7 months a year. Snowfall can vary dramatically from year to year. Mean annual winter snowfall varies from 184 cm in Golden (British Columbia Ministry of the Environment) to 230.5 cm at the Yoho National Park Warden Compound (Yoho National Park Warden Service). Maximum snow depths occur in November-December and maximum snow crusting occurs in March-April.

The Golden Canyon lies in the Engelmann spruce-subalpine fir ecological zone (Meidinger and Pojar 1991). Engelmann spruce (*Picea engelmannii)* and subalpine fir *(Abies lasiocarpa)* dominate the climax forest canopy. Engelmann spruce typically dominates the lower elevation canopies and subalpine fir typically dominates the moist and upper elevation canopies. Lodgepole pine(*Pinus contorta)*, limber pine *(Pinus flexilius)*, alpine larch (*Larix lyallii)*, Douglas fir (*Pseudotsuga menziesii)*, western red cedar *(Thuga plicata*), and western hemlock *(Tsuga heterophylla)* also occur within the Egelmann spruce-subalpine fir ecological zone. Avalanche slide paths are common in the study area (Meidinger and Pojar 1991), where vegetation consists of a mosaic of shrub and herbaceous species, including slide alder (*Alnus crispa spp.)* and cow parsnip *(Herqcleum lanatum).*

Figure 1. Golden Canyon wildlife movement study area Golden Canyon, British Columbia

A portion of the Trans Canada Highway occurs throughout the Golden Canyon. The highway consists of single lanes interspersed with passing lanes. Monthly traffic volumes range from 15, 298 to 139, 862. Annual traffic volume was 1, 438, 874 in 1997 (Parks Canada unpublished data).

Methods

The Friction Model

We constructed a probabilistic model of wolf habitat use and movements using biological information collected from studies of wolf ecology in the Rocky Mountains (Cowan 1947, Carbyn 1974, Huggard 1991, 1993a, 1993b, 1993c, Paquet 1993, Weaver 1994, Callaghan in progress). The model relates the movements and habitat use of wolves to availability of prey, physiography, and human activity. The model is spatially explicit and runs in a Geographical Information System. We euphemistically call the model the Afriction model@ because it quantifies the resistance of the landscape surface to movement of wolves. We emphasize that many extraneous factors contribute to a variance in behaviour of individual wolves. Because ecologists have developed no reasonable expression of those differences, we apply this model at the pack level.

The Central Rockies Wolf Project and Geomar developed the original friction model for the Bow Valley Study (Paquet *et al.* 1996). The model assessed the effects of human activity on wolf movements and persistence in the Bow Valley of Banff National Park. The model was developed using snow tracking and radiotelemetry data collected in Banff National Park between 1989 and 1993.

The friction model presented herein is an empirically-derived simulation, which quantitatively assesses the probability of a wolf pack using and moving through the Golden Canyon, British Columbia during winter. The model simulates how wolves may use the valley by assessing the probability and suitability for movements by wolves within a specific landscape window. The simulation is based on known relationships between wolf movements and factors such as elevation, slope, aspect, terrain ruggedness, vegetation cover, and prey habitat quality. Each simulation predicts the "pathway of least resistance" and estimates the "cost" of moving along the preferred route. Cost is an amalgamation of energetic expenditures, attraction to preferred habitats (e.g., slope, aspect, prey availability), and level of security (e.g., exposure to human activities and facilities).

We used biophysical coefficients to create a landscape surface that reflects the effectiveness of habitat to support wolves without the presence of humans. The probability that a wolf will use a certain habitat or travel a particular path is expressed as a function of behavioural characteristics, physical environment, and distribution of resources (water, cover, prey). Included are the effects of physiography on the distribution, size, geometry, and juxtaposition of habitat patches and behavioural responses of wolves to the natural physical environment. The model output displays graphically the probability of any given pixel being of high survival value to the wolves.

Habitat Model

To develop a wolf habitat suitability model for the study area, we used the methodology of Paquet *et al.* (in press), which we summarize in the following paragraphs. We developed a wolf habitat suitability model for the central Rocky Mountains based on 1, 350 radiotelemetry locations collected between 1989 and 1997, after removing data points associated with den sites. We tested the model using an independent set of 1, 000 radiotelemetry locations collected over the same period. We divided data into 2 seasons: the summer season occurred between April 1 and September 30 and the winter season occurred between October 1 and March 31. These seasons correspond with the summer and winter activity patterns of wolves.

We developed density maps for summer and winter wolf habitat use in the central Rockies. We assumed that density of radiotelemetry locations is positively correlated with wolf habitat quality. To test the telemetry data for optimal size of the experimental units (window), we built 15 summer and winter density location (DL) maps, using a variety of window sizes. We conducted an interpercentile analysis (SPSS) to determine the window size that provides the best spread of values. The best spread of area-weighted density values provides the greatest discriminating power among low, moderate, and high concentrations of wolf telemetry locations. To avoid potential bias in the analysis due to selection of the point of origin of the density maps, we repeated the interpercentile analysis after shifting the point of origin of the density maps by half a window size to the south, east, and southeast. We determined that the point of origin did not bias the testing for optimal window size. A window size of 0.5 km X 0.5 km for the winter model and 0.6 km X 0.6 km for the summer optimized the spread of the density of radiotelemetry fixes. We then classified the DL maps into the following discrete density classes: no locations; low DL; Moderate DL; high DL.

For each of the DL classes, the following biophysical parameters were extracted: terrain ruggedness, elevation, aspect, hiding cover, and prey habitat quality. We used a Digital Elevation Model (DEM) to derive information on elevation and aspect. We developed a Terrain Ruggedness (TR) index of the central Rockies using a moving window technique. TR is an index capturing complexity of terrain, and was derived using the following equation:

$$TR = (De\ Ac)/(De+Ac),$$

where De = density of contour lines within a given window and Ac = an index of aspect variability within a given window. We generated a prey habitat suitability layer and a hiding cover layer using an Ecological Land Classification System (Holroyd and Van Tighem 1983) and wolf prey preference data from kill sites and scat analyses (Paquet and Callaghan unpublished data).

We examined the distribution of wolf locations in relation to the biophysical parameters using polytomous logistic regression (North and Reynolds 1996, SAS, SPSS). We also used univariate statistics to determine pairwise comparisons of all biophysical parameters to determine the relative contribution of each parameter on the model. Parameters were ranked according to their contribution. The biophysical associations were tested for predictive reliability using independent data. Our analysis produced a strong, statistical model for summer and winter seasons. From this model, we generated a probability surface layer, which shows continuous probability values expressing the likelihood of each 30 m x 30 m pixel within the study area of being suitable wolf habitat.

The Golden Canyon Habitat Suitability Model was developed using the above methods for winter only (Figure 2). To apply the wolf habitat suitability model to the Golden Canyon study area, we developed a 1:20,000 Digital Elevation Model of the area based on the elevation points and break lines provided in the British Columbia TRIM digital land information data sets. From the DEM, we derived elevation and aspect information.

We used the British Columbia Ministry of Forests forest cover data to derive information on hiding cover and prey habitat quality.

Given very limited information on the distribution of ungulates in the study area, we developed the map of elk (*Cervus elaphus)* distribution by using a set of decision rules solicited from wildlife experts (D. Pole and P. Paquet, pers. comm.), rather than from empirical data collected in the study area. Elk were chosen as the focal prey species because they are the primary food source for wolves in the central Rockies (Paquet 1993) and because wolf and elk habitat use overlaps by >90% (Paquet unpublished data). Table 1 summarizes the decision rules applied to the construction of the four-class elk habitat-suitability map. AOpen areas@ were defined as 100 meter wide Aedge@ zones around and into openings in the forest.

Table 1. Decision rules used to generate a four-class elk habitat suitability map. Expert advice on elk habitat use provided by D. Pole and P. Paquet.

ATTRIBUTE	**SUITABILITY**			
	None	**Low**	**Moderate**	**High**
Elevation (N-facing slopes)	**>1400 m**	**<1400 m**	**<1400 m**	**<1400 m**
Elevation (S-facing slopes)	**>1200 m**	**<1200 m**	**<1200 m**	**<1200 m**
Slope angle (%)	**>30%**	**<30%**	**<30%**	**<30%**
Vegetation	**Any type**	**Conifer**	**Open areas**	**Deciduous**

Movement Model

In modeling wolf movement, we made 2 fundamental assumptions inferred from previous research in the Bow Valley watershed (Paquet 1993, Paquet *et al.* 1996, Paquet *et al.* in press): habitat quality influences wolf movement (i.e. the spatial juxtaposition of habitat patches of various qualities strongly influences movement);wolves are aware of the presence of all human land use developments.

We developed a deterministic movement stimulus to model potential wolf movement corridors in the Golden Canyon area. The deterministic mode of movement implies that wolf packs move through the landscape determined to go from point A to point B. Simulated wolves are placed into the rasterised landscape and moved to a target area.[1] A pathway analysis is used to simulate movements and calculate the cost of travel. Cost is the summation of resistance levied by individual pixels. Higher costs reflect increased environmental resistance to movement. Simulated wolves select travel routes that provide an optimal combination of security, habitat quality, and energetic efficiency. Conversely, wolves avoid human facilities and activities, terrain that is difficult to negotiate, and habitat of low quality. For example, wolves avoid deep snow, are attracted to concentrations of prey, and avoid the Trans Canada Highway.

For the Apristine@ model run (Figure 3), we developed the wolf Afriction@ surface (a surface expressing, in relative terms, ease of movement through the landscape) as the reciprocal of the winter habitat probability values (e.g., we would assign areas of low habitat quality a relatively high friction value). We modified this surface to reflect the influence of the Kicking Horse River and the Trans Canada Highway on wolf movement. We used crossing coefficients developed for the Bow River and the portion of TCH that runs through Banff National Park as modifiers (Paquet *et al.* 1996).

Initially, we selected 2 movement entry points, at the east end of the study area, on either side of Trans Canada Highway and calculated a series of equivalent Acost@ surfaces. Cost surfaces express cumulative cost of movement relative to the point of entry, calculated in 8 directions with the search radius equal to the extent of the study area. Diagonal directions increased a cell=s friction value by 41%. For each of the cost surfaces, we assigned 2 exit points at the west end of the study area (on both sides of the TCH) and calculated the routes of least resistance (pathways) connecting the point of entry with exit points (Figure 3).

Preliminary evaluation of the computer simulated routes indicated minor differences between the routes generated from either of the entry points. Therefore, we focussed our attention on a single entry point that corresponded to the more likely entry position into the study area (i.e., the point within favourable winter habitat, at the valley bottom). We conducted multiple runs of the model, each time disabling the pathway generated in the previous simulation. This allowed us to generate the primary, secondary, and third order pathways that, while reflecting decreasing probability of route selection, allowed us to delineate a wolf Amovement corridor@ through the Golden Canyon area. Finally, we plotted the simulated least resistance pathways on the map to identify potential Aconflict@ areas where a crossing of the highway is more likely to occur (Figure 4 - 6).

In modeling wolf lateral movement (across the valley), we assumed that the crossings are likely to occur in locations where high quality wolf or elk habitat spans either side of the highway (Figure 7 - 9). We tested the TCH crossing points against crossing location data collected for ungulates in the

[1]In the simulation, we Aforce@ wolves to complete a travel assignment. In reality, human activity often deters wolves from moving through an area. However, we have not identified how much disturbance wolves will tolerate. Forcing wolves through an area allows us to attach a cost to routes we know wolves will not use, thus proving insights into tolerance.

Golden Canyon between December 1997 and March 1998.

Results

The Wolf Habitat Suitability Model shows that high quality wolf habitat is limited in the Golden Canyon (Figure 2). The canyon=s steep terrain and narrow walls influence the availability of habitat for wolves and elk. Ninety-two per cent of wolf telemetry locations (n = 3, 350) in the Bow Valley were on slopes below 20^{o} and 95% of locations occurred below 1,850 m (Paquet and Callaghan unpublished data). Steep rock, ice-covered slopes, and deep snow, which are associated with higher elevations, are avoided by wolves and their prey. The highest quality habitat within the study area occurs along the river flats next to Yoho National Park, and along the benches near the town of Golden.

Preliminary evaluation of the simulated routes through the study area, where wolves had an option of starting at the east end of the study area on either side of the TCH, indicated small differences between the routes generated from either of the entry points (Figure 3). The simulated pathway follows the best available habitat through the canyon. The pathways originated on either side of the TCH, where the valley bottom is broad, then pinched into 1 pathway where the valley bottom is narrow, and split into 2 pathways where the valley broadens on the west end of the study area. This suggests that the narrow valley bottom limits travel options for wolves travelling between Yoho National Park and the Columbia Valley.

The primary least resistance pathway shows 2 TCH crossings (Figure 4 B 6). Two of the crossings occur near bridges over the Kicking Horse River; the other crossing occurs at the west end of the study area, close to high quality elk habitat. The secondary and tertiary least resistance pathways show 3 and 4 TCH crossings (Figure 4 B 6). All pathways are near the TCH and Railway because these structures are situated close to the valley bottom. Moreover, the highway and railway likely follow topographically efficient routes and gradients.

In modeling wolf lateral movement (across the valley), we assumed that crossings are likely to occur in locations where high quality wolf or elk habitat spans the highway. Computer simulations of lateral movement showed a series of wide zones of increased crossing probabilities (Figures 7 - 9). Eight crossing zones for wolves and elk were established throughout the study area. We tested the crossing points against crossing location data collected for ungulates in the Golden Canyon between December 1997 and March 1998. Fifty-six per cent of ungulate crossings observed (n = 25) occurred within the zones predicted by the model.

Figure 2. Wolf habitat map - Golden Canyon study area Golden Canyon, British Columbia 1998.

Figure 3. Computer simulation of wolf/elk movement corridor Golden Canyon, British Columbia 1998.

Figure 4. Computer simulation of wolf/elk movement pattern Golden Canyon, British Columbia 1998.

Figure 5. Computer simulation of wolf/elk movement pattern Golden Canyon, British Columbia 1998.

Figure 6. Computer simulation of wolf/elk movement pattern Golden Canyon, British Columbia 1998.

Figure 7. Potential for lateral movement in the Golden Canyon Area Golden Canyon, British Columbia 1998.

Figure 8. Potential for lateral movement in the Golden Canyon Area Golden Canyon, British Columbia 1998.

Figure 9. Potential for lateral movement in the Golden Canyon Area Golden Canyon, British Columbia 1998.

Discussion

Physiographic restrictions limit the availability of wolf habitat in the Golden Canyon. Consequently, the canyon area is not likely to support core habitat for a wolf pack. Telemetry and snow tracking data collected from the Yoho wolf pack, for example, suggest the pack travels through the canyon only occasionally. The canyon, however, likely functions as a regional corridor between the Columbia Valley and the Beaverfoot Valley and Yoho National Park. Wolves dispersing between the northwestern portion of Banff National Park or the southwestern portion of Jasper National Park and the Columbia Valley would also travel through the Golden Canyon.

The simulated pathways through the canyon show that the TCH and the Railway converge on the best available habitat for wolves in the study area. The crossing coefficients used to weight the probability of wolves crossing the railway did not incorporate the probability of wolves travelling on the railway. Consequently, the simulation of the primary least resistance pathway may not accurately predict the movement of wolves through the canyon. Train traffic may displace wolves to a sub-optimal movement corridor in more difficult terrain, with an associated cost of travelling with increased energy expenditure. Alternatively, if wolves choose to travel along the railway, the consequence may be reduced survivability.

The simulated pathways predict where wolf crossings are likely to occur through the canyon. The number of highway crossings is small due to the barrier effect of the TCH. Because the optimal pathway for wolves occurs along the valley bottom, 2 significant crossings of the TCH occur where the highway crosses the Kicking Horse River.

The simulations of wolf lateral movements connect patches of high quality wolf or elk habitat occurring on either side of the TCH. Stressing that the crossing zones are based on analysis of the habitat quality in the canyon, and not high resolution information on local movement impediments (e.g., small rock outcrops or scree slopes) is imperative. Thus the identified crossing zones should be used as focal points for further analysis of potential crossing sites, based on the interpretation of large-scale ortho-corrected aerial photographs and ground-truthed data. This would enhance the establishment of site-specific mitigative recommendations.

Because wolves are sensitive to human disturbance, exist in low densities, occupy large home ranges, and specialize in valley bottom habitats that often overlap with linear developments, they are adequate indicators of road effects. Wolf habitat is also highly correlated with elk habitat (Paquet *et al.* 1996). Thus, mitigative strategies for wolves will likely have positive effects for elk. Land development, however, should be compatible with a broad range of wildlife. A selective focus on wolves might inadvertently alter the composition of established biological communities, reduce abundance of some species, and reduce species diversity. Wolf movements and habitat use are not strongly correlated with those of bighorn sheep (*Ovis canadensis)*, for example. Sheep habitat needs and highway crossings are therefore not captured by this model. Sheep are likely affected by the TCH in the Golden Canyon, and we recommend an independent assessment of these effects.

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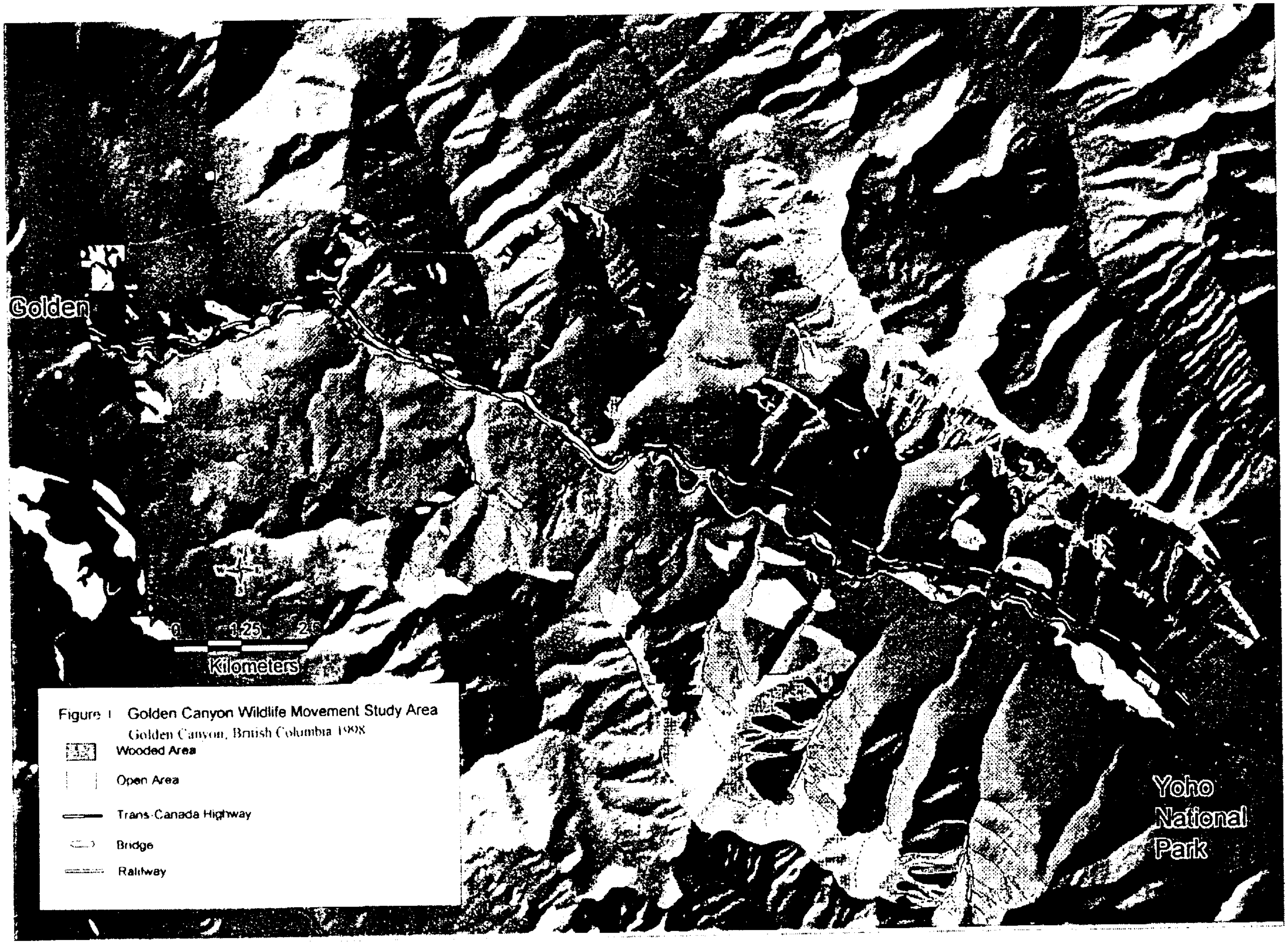
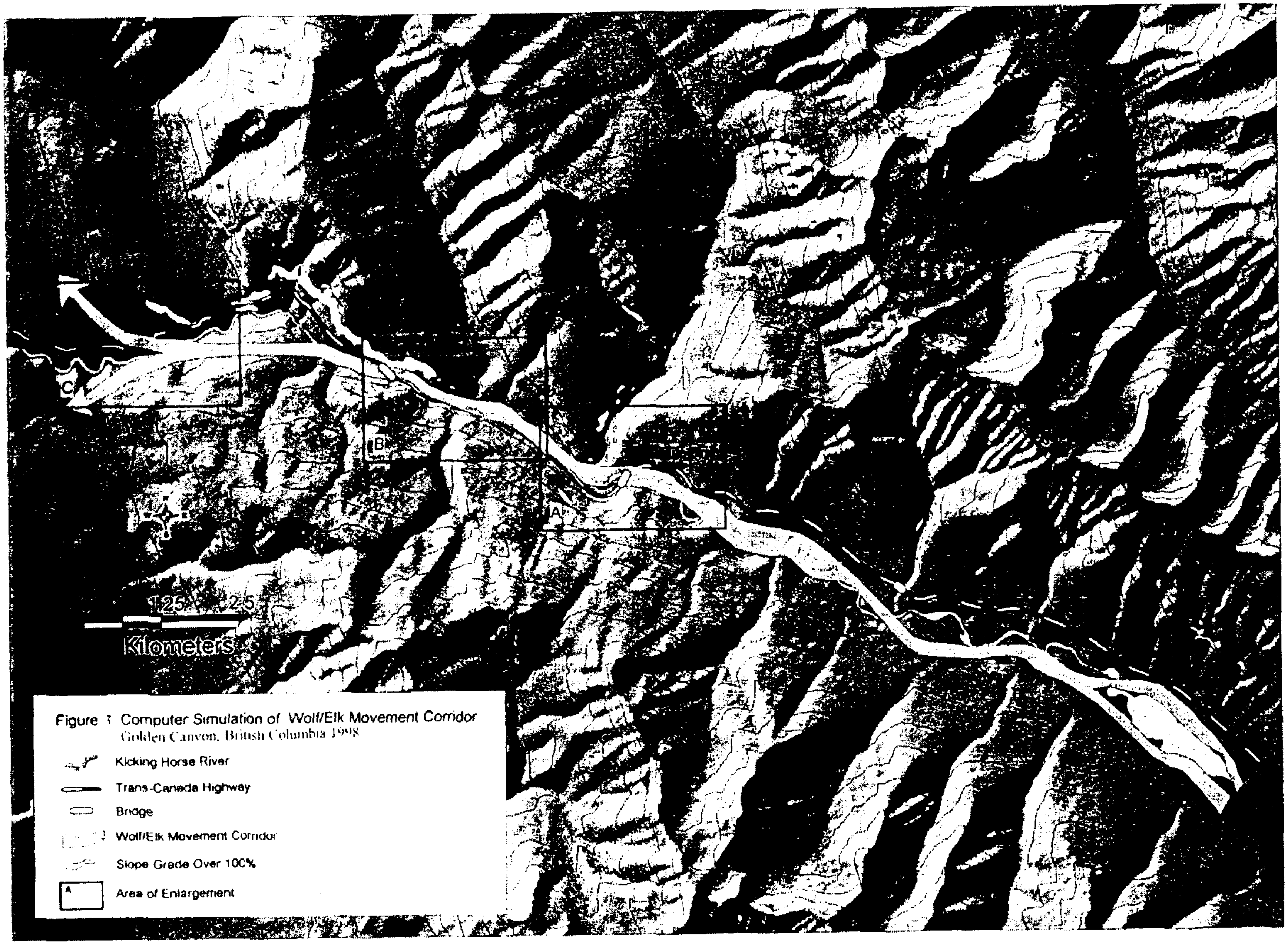


Figure 1 Golden Canyon Wildlife Movement Study Area
Golden Canyon, British Columbia 1998


Yoho National Park
Golden
Figure 2. Wolf Habitat Map - Golden Canyon Study Area
Golden Canyon, British Columbia
Non - habitat (< 25% habitat probability)
Low Wolf/Elk Habitat (25 to 50% habitat probability)
Moderate Wolf/Elk Habitat (50 to 75% habitat probability)
High Wolf/Elk Habitat (>75% habitat probability)
Kicking Horse River
Trans-Canada Highway
Bridge


A
B
C
1.25
2.5
Kilometers
Figure 3 Computer Simulation of Wolf/Elk Movement Corridor
Golden Canyon, British Columbia 1998
Kicking Horse River
Trans-Canada Highway
Bridge
Wolf/Elk Movement Corridor
Slope Grade Over 100%
Area of Enlargement

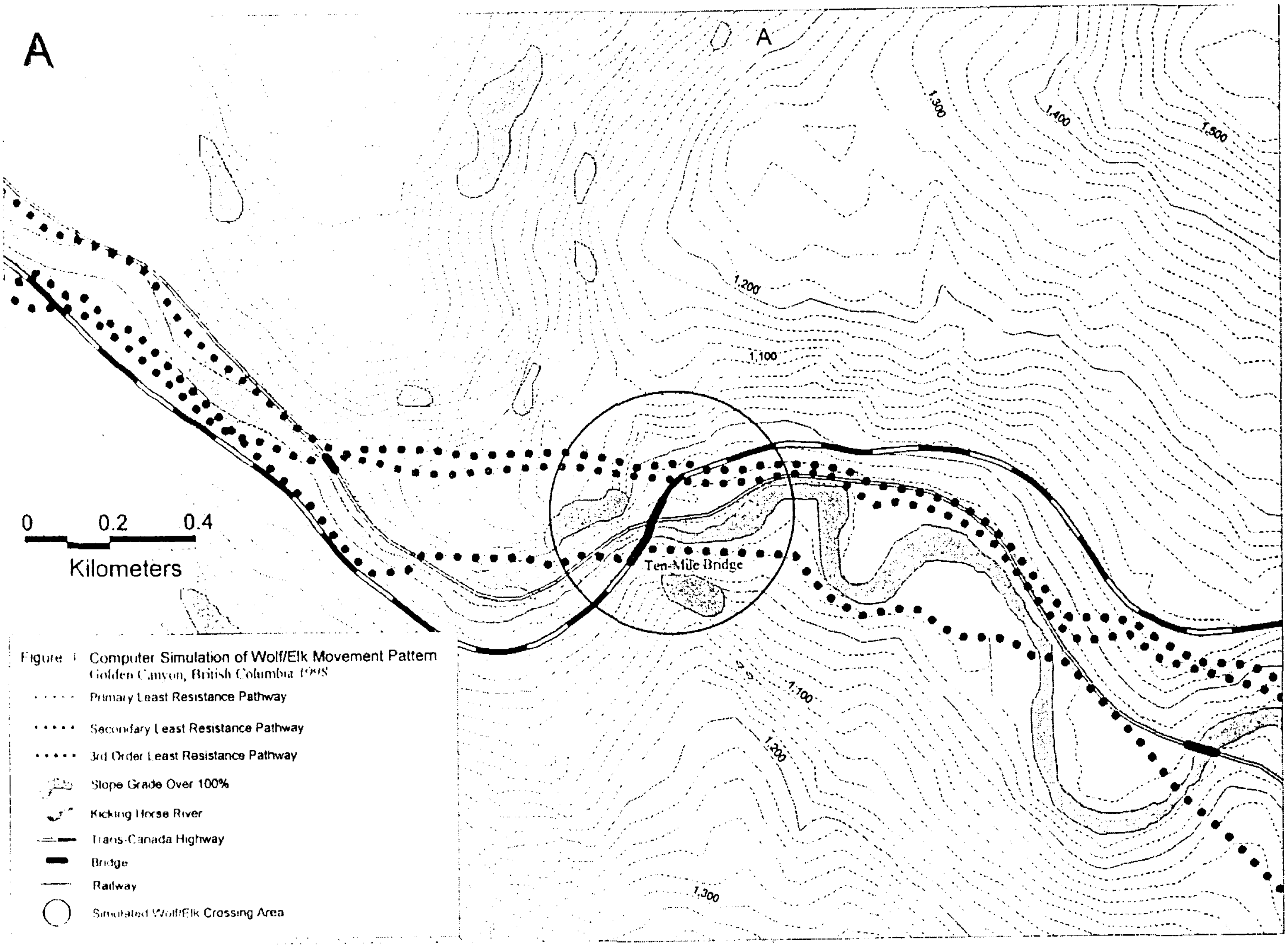


Figure 1 Computer Simulation of Wolf/Elk Movement Pattern
Golden Canyon, British Columbia 1998

Figure 5. Computer simulation of wolf/elk movement pattern Golden Canyon, British Columbia 1998

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Figure 6. Computer simulation of wolf/elk movement pattern Golden Canyon, Brisitsh Columbia 1998.

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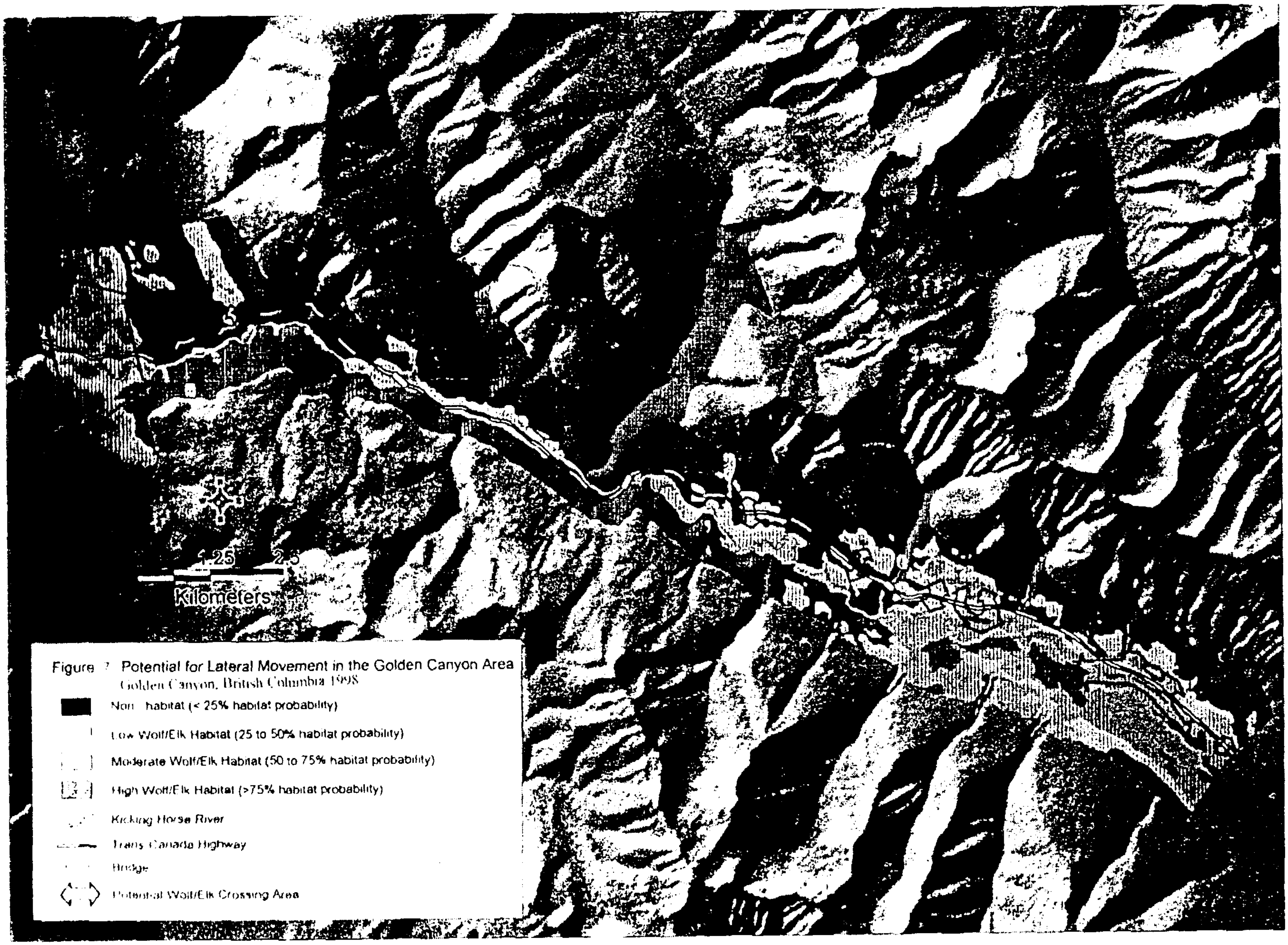

Figure 7 Potential for Lateral Movement in the Golden Canyon Area
Golden Canyon, British Columbia 1998

Figure 8. Potential for lateral movement in the Golden Canyon Area, Golden Canyon, British Columbia

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Figure 9. Potential for lateral movement in the Golden Canyon Area, Golden Canyon, British Columbia

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