Habitat associations of American badgers in southeastern British Columbia

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Abstract: American badgers (*Taxidea taxus*) are endangered in British Columbia due to habitat loss and human-caused mortality. To better understand human impacts and to promote conservation planning, we described badger habitat relationships. At two spatial scales, we analyzed selection by 12 radio-implanted resident badgers for soil composition, forest overstory, land cover, vegetation productivity, terrain, and human influence. At a broad (23.8 km^2) landscape scale, soil parent-material associations were positive with glaciolacustrine and glaciofluvial and negative with colluvial. Soil-order associations were positive with brunisols and regosols and negative with podzols and luvisols. Association with fine sandy-loam texture was positive. Associations were negative with forested habitats and positive with open range, agricultural habitats, and linear disturbances. Associations were negative with elevation, slope, terrain ruggedness, and both vegetation productivity and moisture. At a fine (14.5 ha) scale, associations were positive with glaciofluvial, fine sandy-loam textured, and well-drained soils. Associations were negative with colluvial soils, forest cover, vegetation moisture, elevation, and ruggedness. Associations with open range and southern aspects were positive. The linear combination of a subset of variables could explain and predict habitat selection. At this range extent, natural conditions may restrict badger occurrence, increasing badger sensitivity to human factors that influence habitat quality and mortality.

Résumé : Les blaireaux d'Amérique (*Taxidea taxus*) sont menacés en Colombie-Britannique par la perte de leur habitat et la mortalité infligée par l'activité humaine. Pour mieux comprendre l'impact de l'activité humaine et pour encourager les programmes de conservation, nous avons étudié la relation entre le blaireau et son habitat. Nous avons analysé les choix de 12 blaireaux résidants porteurs d'un émetteur radio, quant à la composition du sol, à la strate supérieure de la forêt, à la végétation au sol, à la productivité végétale, au terrain et à l'influence humaine, à deux échelles spatiales. À l'échelle du paysage (23,8 km^2), les associations avec la roche-mère du sol sont positives dans le cas des sites lacustres et glacio-fluviaux et négatives dans le cas des milieux colluviaux. Les associations avec l'ordre des sols sont positives dans le cas des brunisols et des régosols et négatives dans le cas des podzols et des luvisols. L'association avec les sols argileux-sableux à texture fine est positive. Les associations avec les habitats forestiers sont négatives, mais positives dans le cas des terrains ouverts, des terres agricoles et des perturbations linéaires. Les associations avec l'altitude, la nature accidentée du terrain, de même qu'avec la productivité et l'humidité de la végétation sont négatives. À une plus petite échelle (14,5 ha), les associations avec les sols glacio-fluviaux, argileux-sableux à texture fine et bien drainés sont positives. Elles sont négatives dans le cas des sols colluviaux, de la strate supérieure de la végétation, de l'humidité de la végétation, de l'altitude et de la nature accidentée du terrain. Les associations avec les zones ouvertes et avec l'exposition vers le sud sont positives. La combinaison linéaire d'un sous-ensemble de variables peut éventuellement expliquer les choix d'habitatss et même les prédire. A cette échelle, il se peut que les conditions naturelles restreignent la présence des blaireaux, augmentant leur sensibilité aux facteurs humains qui influencent la qualité de l'habitat et la mortalité.

[Traduit par la Rédaction]

Introduction

The American badger (*Taxidea taxus*) is a solitary fossorial carnivore that occurs at a northern range limit in southern British Columbia (Rahme et al. 1995). Populations here are considered to be in decline due to loss of habitat and prey, unsustainable mortality due to vehicle collisions, and killing of badgers and their prey as nuisance animals. The subspecies occurring in British Columbia (*Taxidea taxus jeffersonii*) is thus considered to be endangered provincially (Cannings et al. 1999) and federally (COSEWIC 2000). Although badgers are adapted to hunting fossorial prey, their primary diet throughout their range (Salt 1976; Lampe 1982), they are also opportunistic feeders and supplement their diet with a wide variety of mammals, birds, eggs, reptiles, amphibians, invertebrates, and plants (Messick 1987). Badgers in North America have been known to occur from below sea level to elevations >3660 m. Their range is mostly associated with treeless areas, but includes savannah and forest in some regions (Lindzey 1982). Studies have been conducted in open, often agricultural landscapes (Todd 1980; Warner and Ver Steeg 1995), and shrub–steppe habitats (Messick and Hornocker

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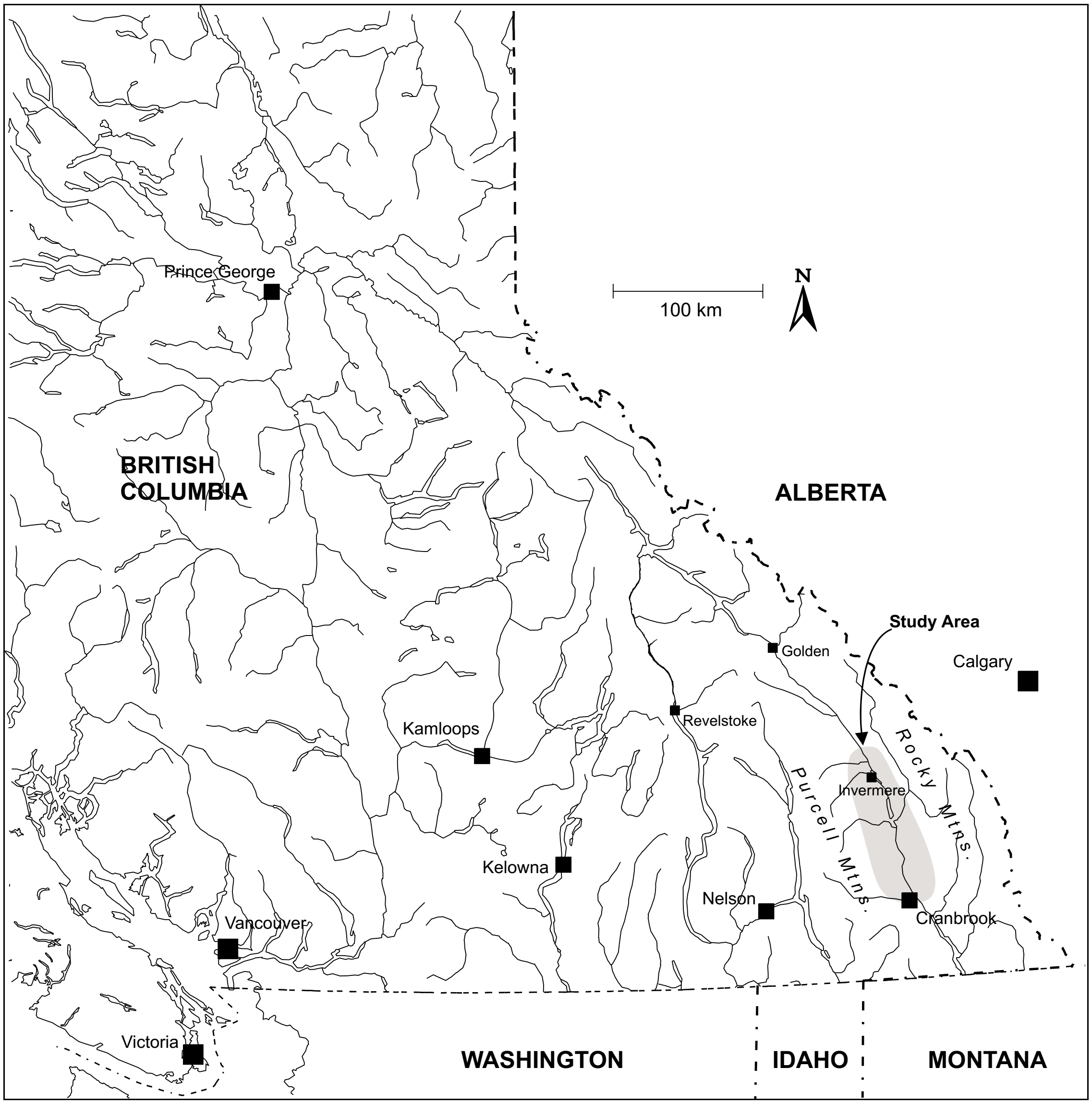
Fig. 1. East Kootenay American badger (*Taxidea taxus*) study area in southeastern British Columbia.



1981). Beyond this, there is little known of badger habitat associations, which is necessary to implement appropriate conservation measures.

We describe an analysis of biotic, abiotic, and human factors associated with badger habitat selection at two spatial scales in southeastern British Columbia. We also develop and evaluate a multivariate habitat-selection model as a means of accounting for badger habitat relationships in conservation planning. Badgers appear to use space extensively in southeastern British Columbia, perhaps due in part to dispersed resources, with a mean 95% fixed kernel home range of 70 ± 72 (1 SD) km^2 for males and 30 ± 29 km^2 for females (Newhouse and Kinley 2001). Hence, we expect that individuals will exhibit habitat associations at a correspondingly broad spatial scale. At this level, preferred landscapes may primarily relate to physiographic and climatic conditions that limit the distribution and continuity of general conditions which support badgers. Resources of food and security may relate to forest overstory and soil conditions that promote fossorial prey and the ability of badgers to effectively burrow. Although badgers may respond to the distribution of such conditions within the broader landscape, selection may also be apparent at finer scales depending on local environmental heterogeneity. Across spatial scales, the overall pattern of habitat selection by badgers near northern range limits may correspond to specific land uses and management objectives that need to be considered in conservation planning for this species.

Materials and methods

Study area

The study area encompassed approximately 3000 km^2 within the upper Columbia and upper Kootenay valleys of southeastern British Columbia, from 49°30′N to 50°50′N (Fig. 1). It occurred largely within the East Kootenay Trench ecosection (Demarchi 1996) and primarily comprised the Ponderosa Pine (PP), Interior Douglas-fir (IDF), and Montane Spruce (MS) biogeoclimatic zones (Meidinger and Pojar 1991). Study animals also periodically ranged within the Interior Cedar – Hemlock (ICH), Engelmann Spruce – Subalpine Fir (ESSF), and Alpine Tundra (AT) zones of the adjacent Rocky and Purcell mountain ranges. Within the PP and IDF zones, open stands dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*), respectively, were the predominant climax forest types, with upland sites in those zones varying from grassland or shrub–steppe to dense forest, depending on site characteristics, history, and aspect. Settlement within the East Kootenay Trench was concentrated in the PP and IDF zones, and significant portions of it had been converted to agricultural fields, settlements, and transportation corridors. Forest management for timber and Christmas trees had occurred over most of these two zones, but land cover was also largely influenced by fire suppression, resulting in forest in-growth and encroachment into open habitats and grasslands (Gayton et al. 1995). The PP zone was associated with the warmest, driest portions of the Trench floor and was surrounded by the IDF zone at slightly higher elevations. Above the IDF zone, the MS zone was associated with a climax overstory of hybrid white spruce (*Picea glauca* × *engelmannii*). The ICH zone occurred at corresponding elevations in some valleys, tributary to the Trench, and was associated with a climax overstory of western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*). The ESSF zone occurred immediately upslope of the MS and ICH zones and was associated with a climax overstory of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). Owing to a history of natural and human disturbance, much of the MS, ICH, and ESSF zones were in a mid-successional state, dominated by lodgepole pine (*Pinus contorta*) and to a lesser degree by western larch (*Larix occidentalis*). At the highest elevations, whitebark pine (*Pinus albicaulis*) and alpine larch (*Larix lyalli*) acceded to AT. Typical annual precipitation ranged from 370 mm in portions of the IDF zone (Achuff et al. 1984) to roughly 900 mm in the ESSF zone (Braumandl and Curran 1992).

Potential fossorial prey included Columbian ground squirrels (*Spermophilus columbianus*), in open habitats throughout the study area, and northern pocket gophers (*Thomomys talpoides*), which were restricted to the PP zone in the southernmost portion of the study area.

Capture and radiotelemetry

Between 1996 and 2000, we trapped and radio-implanted 20 badgers. Trap stations were placed at active burrows, located with the assistance of direct badger sightings or by inspecting known Columbian ground squirrel colonies. At burrow entrances, #1½ Soft Catch® (Woodstream Corp., Litiz, Pa.) padded leghold traps were set, baited with ground squirrels, rabbits, beef liver, or scent lure, and were checked at least daily. Trapped badgers were noosed and hand-injected with either 10 mg/kg of tiletamine hydrochloride/zolazepam hydrochloride mixed at 100 mg/mL or a combination of 0.3 mg/kg of midazolam mixed at 1.0 mg/mL and 9 mg/kg of ketamine hydrochloride mixed at 100 mg/mL. Surgical implantation of intraperitoneal transmitters (Advanced Telemetry Systems, Isanti, Minn.) was conducted in a veterinary clinic or in the field (Hoff 1998). Once alert, badgers were released at trap sites or nearby burrows. No obvious signs of significant trap-related injuries were evident during handling nor were there any indications of abnormal gait or behaviour during releases. Authorization to trap, handle, implant radio transmitters in, obtain samples from, and monitor badgers was provided annually by the British Columbia Ministry of Environment, Lands and Parks, Cranbrook office, through its sundry permit process.

Using a Cessna 172 fixed-wing aircraft and standard techniques (Samuel and Fuller 1996), study animals were located weekly during April through September and twice-monthly during October through March when badgers were typically less active, resulting in 967 radiolocations. Each location was referenced to a Universal Transverse Mercator (UTM) grid coordinate to the nearest 10 m, using 1 : 20 000 forest cover maps and 1 : 20 000 aerial photographs. Ground-based accuracy tests ($n = 20$), using a hand-held GPS unit, suggested that 95% of radiolocations were within 215 m (mean = 62 ± 63). Because badgers are known to periodically enter torpor, we considered sequential locations to be independent samples only when animals were known to have moved from a burrow between locations. For most winter locations, this was confirmed by identifying burrows using ground telemetry and placing a twig across the burrow entrance to determine whether badgers left burrows between locations. Where ground visits were not done and aircraft telemetry could not confirm that the animal was active between locations, we assumed it was inactive and did not use those locations in the analysis.

Geographic information system (GIS) habitat data

A GIS habitat database was assembled for the study area, extending to all lands within a minimum 15-km radius of badger radiolocations. Data were compiled from 1 : 20 000 forest inventory planning files (FIP; Resources Inventory Branch 1995), 1 : 20 000 terrain resources information management files (TRIM; Surveys and Resource Mapping Branch 1992), 1 : 50 000 soil associations (Terrestrial Studies Branch 1976), 1 : 250 000 baseline thematic mapping of land cover (BTM; Surveys and Resource Mapping Branch 1995), and Landsat thematic mapper (TM) scenes taken during August 1995 and 1996. From digital data, we derived variables reflecting soil composition, forest overstory, land cover, vegetation productivity, terrain, and human influence (Table 1).

As a fossorial carnivore, we expected that badger ecology would be influenced by soil composition. Our analysis, therefore, considered five soil parent materials, five soil orders, and five soil textures that commonly occur within the study area, as well as soil drainage and gravel composition (Table 1). The structure and composition of the forest overstory may also influence badger ecology and the abundance and availability of certain prey species. We expected that any relationship with stand age would be nonlinear. Therefore, we derived three stand age classes, reflecting gross structural differences among dominant species within the study area, and which conform to the age-class convention of the provincial forest inventory system. Canopy closure depicted the ocular cover of the stand overstory. Site index reflected forest productivity based on stand age and height as calculated by species-specific equations (Thrower et al. 1991). Overstory species composition indicated ecosystem associations and climatic variability. Individual or grouped species were in-

Table 1. Variables derived for analyses of American badger (*Taxidea taxus*) habitat selection in southeastern British Columbia, 1996–2000.

Group	Variables
Soil	
Parent material	Morainal, glaciolacustrine, glaciofluvial, fluvial, colluvial
Order	Podzolic, brunisolic, chernozemic, regosolic, luvisolic
Texture	Sandy loam, silt loam, silty clay loam, organic, sandy, fine-sandy
Characteristic	Gravel index: low to high (10→30); drainage index: poor to rapid (10→60)
Overstory	
Stand age	<20, 21–120, >120 years
Miscellaneous	Canopy closure (%), forest stand site productivity index, overstory forest cover (%)
Composition	Mesic conifer, Douglas-fir, deciduous, lodgepole and white pine, ponderosa pine, larch (%)
Hydrography	Proximity to water (m)
Linear disturbance	Proximity to highways, proximity to linear disturbance (m)
"Nonproductive" forest	Marsh, alpine tundra, cultivated, open range, urban
Baseline thematic	Avalanche tracks, alpine tundra, old (>100 years) forest, young (<100 years) forest, logged forests, rangelands, agricultural lands
Vegetation indices	Green vegetation index, wet vegetation index
Terrain variables	Elevation (m), slope (%), north→south aspect (0→100), east→west aspect (0→100), terrain ruggedness index, terrain curvature index

Note: Variables depict the average proportion or value of attributes within a defined landscape.

cluded in the analysis if their spatial composition was >5% of the study area. In addition, we derived a variable indicating whether a given site was associated with forest overstory cover of any type. We anticipated a potentially negative relationship with areas having permanently wet soil because of poor burrow stability and the presence of water in burrows. Therefore, from the TRIM hydrology data, stream networks and lake perimeters were identified as a surrogate for potential riparian habitats as were marsh and swamp lands identified from the FIP data. Because human disturbances may influence ground squirrel abundance, and another study has found a correlation between badger activity and linear disturbances (Warner and Ver Steeg 1995), we considered two variables to be associated with road disturbances: one included the density of all linear disturbances (roads and power lines) and another included only those lands within the road allowance of a paved highway. Because other research has suggested that badgers are typically associated with open habitats, we derived four variables from FIP data depicting different types of nonforested lands: alpine tundra, cultivated lands, open range, and urban development. We included terrain variables because they are assumed to influence vegetative, habitat structure, and soil conditions. These included elevation, slope, and aspect as described by two ratio-scale (0→100) variables depicting north→south and east →west aspects. A terrain ruggedness index was derived by adapting a technique (Beasom et al. 1983) for GIS using 150-m elevation contours, yielding a continuous (0→100) variable that is relative to the scale of contour data and pixel size.

We derived several variables from the BTM data of present land cover, allowing us to consider several variables that could not be derived from the FIP data. We considered BTM data to be appropriate for this analysis because the minimum mapping unit was 15 ha, approximating the 95% error associated with our telemetry data. We extracted alpine (areas virtually devoid of trees at high elevations) and avalanche tracks. We delineated old forests (>100 years), young forests (<100 years), and those where timber harvesting had occurred within the past 20 years or more if tree cover was <40% and <6 m high. Rangelands were unimproved pasture and grasslands, based on cover rather than use, and agricultural land encompassed any land-based agricultural activity. From the Landsat TM data, we derived the green vegetation index and the wet vegetation index of the tasseled cap transformation (Crist and Cicone 1984), reflecting vegetation productivity and moisture, respectively.

We derived each variable as a separate raster layer within the GIS, with a resolution of 50 m. At each spatial scale (see Analysis design), continuous variables reflected mean composition within a defined landscape and dichotomous variables reflected proportional composition. All GIS applications employed the raster-based software Idrisi 32 (Clark Labs for Cartographic Technology and Geographic Analysis 1999).

Analysis design

We designed our analysis in accordance with Thomas and Taylor's (1990) Study Design 3, with inferences relevant at the individual level. This accounted for unequal capture effort throughout the study area, a relatively small animal sample (7 males (M), 5 females (F)), and a variable radiolocation sample among animals (mean = 65 ± 45, range = 22–161). We did not include data for animals with <20 radiolocations.

For each study animal, we analyzed habitat selection at two nested spatial scales, following methods described by Apps et al. (2001). At each level, we sampled landscape composition at badger radiolocations and at paired locations of fixed distance but random azimuth from badger locations. At level 1, the broader analysis scale, badger and paired random locations were separated by 11.4 km, representing the radius of the largest area we consider potentially available to badgers in moving between sequential radiolocations. We considered our data to be independent at this distance because, within the approximate 1-week sampling interval, 5% of movements between sequential radiolocations were ≥11.4 km for 8 (5 M, 3 F) of the 12 resident study animals we included in the analysis. We defined the used landscape at level 1 as that within a 2.75-km radius of badger locations, representing the net movement between 50% of sequential locations for 8 (5 M, 3 F) of 12 resident study animals. Habitat data were aggregated to this landscape scale using a GIS moving window routine (Bian 1997). This 2.75-km distance also represented the radius of available area at level 2, the finer analysis scale. This was considerably greater than the 218-m radius of the minimum mappable unit of the smallest scale polygon data (BTM) used in this analysis. Thus, given our data, we considered this finest analysis level to be broad enough to detect habitat selection. We defined the radius of the used landscape at level 2 as the 95th percentile of spatial error (±215 m) assumed for badger locations. Neither lands for which data were unavailable nor water bodies were considered to be part of the surrounding landscape when running the moving window routine, and random locations were excluded from these areas. At each analysis level, we extracted habitat attributes associated with badger and random landscapes to a database.

For each of the 52 variables, we assessed univariate differences between used and random landscapes for each badger, at each scale, using Student's *t* tests ($\alpha = 0.05/52$ variables = 0.001). We defined a measure of consistency in habitat selection among badgers as the absolute difference between the number of badgers exhibiting at least marginal ($P < 0.1$) preference versus avoidance. Selection was considered to be consistent among our sample of 12 animals if this value was ≥6, and only corresponding variables were entered into multivariate analysis. Although arbitrary, this ensured that variables were only included if consistent selection was exhibited by at least 1/2 of the animals, or at least 2/3 if a maximum of 1/3 showed contrary selection.

We employed multiple logistic regression (MLR) to derive probabilistic resource-selection functions (Manly et al. 1993) for the pooled sample of badgers and across the two spatial scales. Model output was the probability (*p*) that the variable attributes of any given site represent badger habitat. Landscapes used by badgers and random landscapes represented the dichotomous dependent variable. However, the design differed from the scale-dependent univariate analyses in that paired random locations occurred at distances ranging from 2.75 to 11.4 km, spanning the two spatial scales. We screened variables for multicollinearity by pooling data among badgers and examining linear regression tolerance statistics (Menard 1995). Where problematic collinearity occurred (tolerance <0.2, Menard 1995), we used Pearson's correlation coefficients to identify offending variables. Of highly correlated pairs, variables that were less significant in univariate analyses among most animals were excluded from multivariate modeling. To account for unequal samples among individuals, we adjusted the weighting of individual locations in the analysis so that each study animal contributed equally to model development. Estimated coefficients reflected the relative contribution of each variable in discriminating landscapes used by badgers from those randomly available to them. We evaluated the improvement of the fitted model over the null model according to the reduction in (–2) loglikelihood ratios (Menard 1995), and we evaluated model performance from classification success across a range of habitat probability cut points. All applications employed the software SPSS 10.0 (SPSS Inc. 1999).

Following the resource selection probability function of Manly et al. (1993: eq. 8.5), we applied the best-fit MLR habitat model to our GIS database using algebraic overlays. This produced a badger habitat probability surface for the study area, facilitating visual inspection of model fit across the study area.

Results

At the broad scale (level 1), badger habitat selection was consistent among study animals for 31 variables (Table 2). Soil parent-material associations were positive with glaciolacustrine and glaciofluvial and negative with colluvial. Soil-type associations were positive with brunisols and regosols and negative with podzols and luvisols. A positive association with fine sandy-loam texture was also apparent. Badgers were negatively associated with forest cover, which was specifically reflected in the results for old (>120 year) age classes, lodgepole/white pine, larch, mesic conifers, site productivity, canopy closure, cover from the FIP data, and old forest and young forest from the BTM data. Among nonforest cover types, associations were positive with open range and agricultural or cultivated habitats and were negative with alpine and avalanche chutes, based both on the FIP and BTM data. Badgers were positively associated with highways and linear disturbances. Associations were negative with the Landsat-derived green and wet vegetation indices. Elevation, slope, and terrain ruggedness were negatively associated with preferred badger habitats.

At the fine scale (level 2), badger habitat selection was consistent among study animals for 17 variables (Table 3). As with level 1, soil parent-material associations were positive with glaciofluvial and negative with colluvial, whereas the association with fine sandy-loam texture was positive. Associations were negative with gravelly soils but positive with well-drained soils. Badgers were again negatively associated with forest cover, specifically mid (21–120 years) and old (> 120 years) age classes, young forest as defined by the BTM data, Douglas-fir, canopy closure, forest cover, and site productivity but were positively associated with open range. Badgers were also negatively associated with the Landsat-derived wet vegetation index. Associations with elevation and terrain ruggedness were again negative, and a positive association with southern aspects was apparent.

The best-fit MLR model was highly significant over null models ($\chi^2 = 1616.1$, df = 20, $p < 0.001$), achieving an overall correct classification of 80.4% (habitat probability cut point $p = 0.5$). The predictive subset of variables that best describe badger habitat selection (Table 4) represented both broad and fine scales. In discriminating between badger and random locations, the model achieved the highest overall predictive success at habitat probability cut points of p = 0.5–0.6 (Fig. 2). Spatial application of the MLR badger habitat-selection model to our GIS database also suggested that the model was highly efficient in predicting badger habitat use across the study area (Fig. 3).

Table 2. Univariate badger habitat selection in southeastern British Columbia, 1996–2000, at a broad spatial scale (level 1).

	Badger ID											
Variable	F/01 (*n* = 161)	F/03 (*n* = 142)	F/05 (*n* = 27)	F/07 (*n* = 81)	F/14 (*n* = 40)	M/02 (*n* = 56)	M/04 (*n* = 81)	M/06 (*n* = 38)	M/09 (*n* = 67)	M/11 (*n* = 23)	M/12 (*n* = 42)	M/15 (*n* = 22)
Soil parent material												
Glaciolacustrine	+++	+++	o	–	+++	+++	++	++	– –	+++	+++	+++
Glaciofluvial	+++	+++	o	+++	+	+++	+++	+++	o	–	o	+
Colluvial	– – –	– – –	– – –	– – –	– – –	– – –	– – –	–	– – –	– – –	o	–
Soil order												
Podzolic	– – –	– – –	– –	– – –	–	– – –	– – –	– –	– –	– –	– – –	–
Brunizolic	+++	o	++	+++	– – –	+++	+++	++	+++	+	+	o
Regosolic	+++	+++	o	+++	– –	+++	o	+	++	++	o	o
Luvisolic	o	o	–	– – –	–	–	–	– – –	– – –	o	+++	o
Soil texture												
Fine sandy-loam	+++	+++	o	+++	+++	+++	+++	+++	o	– –	– –	++
Overstory stand age												
>120 years	– – –	– – –	– – –	– –	– – –	– – –	o	o	o	– – –	– – –	o
Overstory composition												
Lodgepole/white pine	– – –	– – –	– – –	– – –	– – –	– – –	– – –	–	– – –	–	+++	–
Larch	– – –	–	–	– – –	– – –	– – –	o	–	– – –	o	–	+
Mesic conifer	– – –	– – –	– – –	– – –	o	– – –	– – –	o	–	–	o	–
Nonproductive forest												
Alpine	– – –	– – –	–	– – –	o	– – –	– – –	o	o	– –	– – –	o
Open range	+++	+++	+++	+++	+++	+++	+	++	++	+++	o	o
Cultivated	+++	+++	+	+++	+++	+++	++	+	+++	+++	–	o
Overstory miscellaneous												
Canopy closure	– – –	– – –	– – –	– – –	– – –	– – –	– –	– – –	– – –	– – –	– – –	– – –
Overstory cover	– – –	– – –	– – –	– – –	– – –	– – –	++	–	o	o	+++	– –
Site productivity index	– – –	– – –	– – –	– – –	– – –	– – –	++	o	– – –	–	+++	–
Linear disturbance												
Highways	+++	+++	+++	+++	– – –	+++	++	o	o	+++	+++	–
Linear disturbance	+++	+++	+	+++	– – –	+++	+++	+++	+++	++	+++	+++
Baseline thematic												
Alpine	– – –	– – –	–	– – –	o	– – –	– – –	o	–	–	– – –	o
Avalanche tracks	– – –	– – –	o	– – –	–	– – –	– – –	o	– –	– – –	– – –	o
Old forest	– – –	– – –	– – –	– – –	– – –	– – –	–	o	– –	– – –	– – –	–
Young forest	++	– – –	– – –	– –	– – –	–	o	– –	o	o	– – –	– – –
Rangelands	o	+++	+++	+++	+++	+++	o	+	o	+	o	o
Agricultural lands	+++	+++	o	+++	+++	+++	+	++	+++	+++	– –	o
Vegetation indices												
Green vegetation index	– – –	– – –	– – –	– – –	– – –	– – –	o	– –	– –	+	++	o
Wet vegetation index	– – –	– – –	– – –	– – –	– – –	– – –	o	– –	– – –	– – –	– – –	o
Terrain variables												
Elevation	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– –	– – –	– – –	– –	–
Slope	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– –	–
Terrain ruggedness	– – –	– – –	– –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– –	o

Note: The significance of *t* tests is indicated by +/– ($p < 0.1$), ++/– – ($p < 0.01$), and +++/– – – ($p < 0.001$), where the sign indicates the direction of the association. Only those variables for which habitat selection was consistent (absolute difference between number of animals exhibiting preference and avoidance ≥6) are shown.

Table 3. Univariate badger habitat selection in southeastern British Columbia, 1996–2000, at a fine spatial scale (level 2).

Variable	Badger ID F/01 (n = 161)	F/03 (n = 142)	F/05 (n = 27)	F/07 (n = 81)	F/14 (n = 40)	M/02 (n = 56)	M/04 (n = 81)	M/06 (n = 38)	M/09 (n = 67)	M/11 (n = 23)	M/12 (n = 42)	M/15 (n = 22)
Soil parent material												
Glaciofluvial	+++	+++	o	+++	o	+++	++	o	+	o	o	o
Colluvial	– – –	– – –	o	o	o	–	– – –	o	o	o	– –	– –
Soil texture												
Fine sandy-loam	+++	+++	o	+	o	+++	+	+	++	o	o	o
Soil characteristic												
Gravel index	– – –	– – –	o	– – –	o	–	o	– –	o	o	o	– –
Drainage index	+++	+++	o	o	o	++	+	o	++	++	o	o
Overstory stand age												
21–120 years	– – –	+++	– –	– – –	–	o	o	o	–	o	–	–
>120 years	– – –	– – –	–	o	–	–	– – –	–	o	–	o	–
Overstory composition												
Douglas-fir	– – –	o	– –	o	–	o	–	–	o	o	o	– –
Nonproductive forest												
Open range	+++	o	+++	+	+++	++	o	+	o	++	o	o
Overstory miscellaneous												
Canopy closure	– – –	– – –	– – –	– – –	– – –	– –	– – –	– – –	– – –	– –	o	– – –
Overstory cover	– – –	o	– – –	– – –	–	– –	–	–	o	o	++	– – –
Site productivity index	– – –	–	– – –	– – –	–	– – –	o	o	o	–	+	– –
Baseline thematic												
Young forest	– – –	– – –	– –	– – –	– – –	–	– – –	o	o	–	–	– –
Vegetation indices												
Wet vegetation index	– – –	– – –	– – –	–	– – –	– – –	– – –	– – –	– – –	– –	o	o
Terrain variables												
Elevation	– – –	– – –	o	o	o	– – –	– – –	o	o	o	– – –	–
Slope	+++	+++	+	o	o	+	++	o	o	o	o	++
Terrain ruggedness	– – –	– – –	o	–	–	–	– – –	o	o	o	–	o

Note: The significance of t tests is indicated by +/– ($p < 0.1$), ++/– – ($p < 0.01$), and +++/– – – ($p < 0.001$), where the sign indicates the direction of the association. Only those variables for which habitat selection was consistent (absolute difference between number of animals exhibiting preference and avoidance ≥6) are shown.

Table 4. Multiple logistic regression model parameters of badger habitat selection ($p < 0.001$) in southeastern British Columbia, 1996–2000.

Variable	Level	*b*	SE	*R*
Soil parent material				
Glaciofluvial	1	0.037	0.004	0.115
Glaciolacustrine	1	0.017	0.005	0.039
Soil order				
Brunisolic	1	–0.026	0.005	–0.069
Luvisolic	1	–0.062	0.007	–0.117
Regosolic	2	–0.025	0.003	–0.103
Chernozemic	2	–0.018	0.004	–0.056
Soil texture				
Fine sandy-loam	1	–0.046	0.005	–0.115
Soil characteristic				
Drainage index	2	–0.029	0.010	–0.033
Overstory stand age				
>120 years	1	0.045	0.009	0.067
21–120 years	2	0.013	0.003	0.066
Overstory composition				
Douglas-fir	1	0.020	0.005	0.049
Larch	1	0.036	0.012	0.035
Mesic conifer	1	0.041	0.015	0.033
Overstory miscellaneous				
Canopy closure	2	–0.079	0.007	–0.147
Linear disturbance				
Linear disturbance	1	0.097	0.019	0.066
Highway	1	0.099	0.044	0.024
Nonproductive forest				
Open range	1	0.080	0.013	0.085
Marsh	2	–0.035	0.009	–0.049
Baseline thematic				
Alpine	1	–0.319	0.042	–0.101
Rangelands	1	–0.045	0.007	–0.093
Old (>100 years) forest	1	–0.048	0.010	–0.066
Agricultural lands	1	0.026	0.007	0.049
Vegetation indices				
Wet vegetation index	2	–0.045	0.007	–0.091
Green vegetation index	1	0.173	0.023	0.102
Terrain variables				
Elevation	2	–0.010	0.001	–0.169
Slope	1	–0.071	0.014	–0.068
Constant		–1.209	1.071	0.000

Discussion

Badger habitat selection

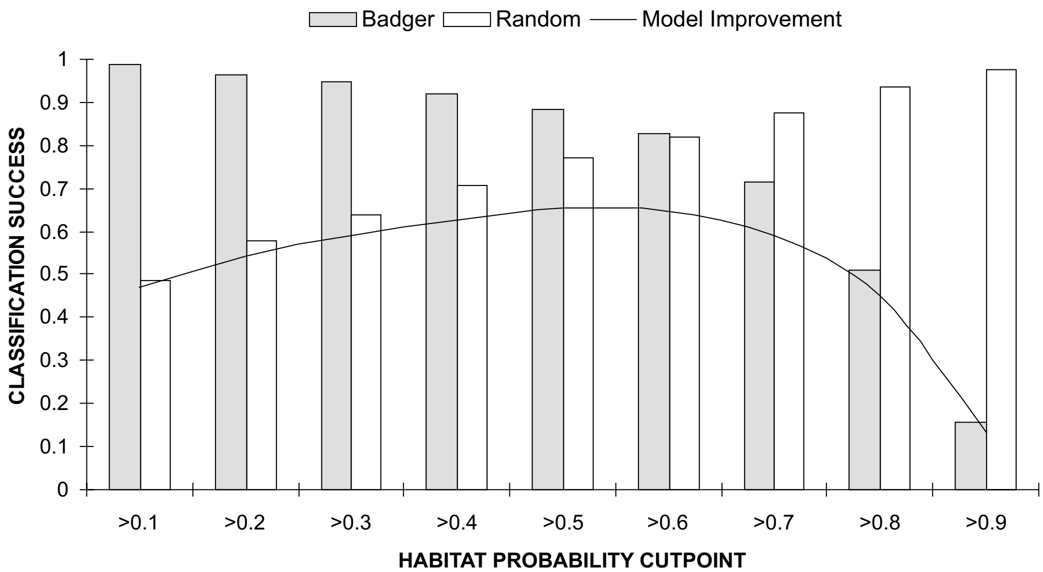
Badger selection for broad landscapes may be largely influenced by climatic conditions. Long (1972) speculates that American badgers are limited in a northwards distribution by the subarctic climate. The glaciations of the Pleistocene are believed to have displaced badgers southwards. Subsequent northwards expansion likely occurred during interglacial periods, evidenced by one record in central Alaska dated to the Pleistocene (Long 1972). The distributional limits may be a function of climatic effects directly on badgers. For example, badgers can enter torpor (Harlow 1981), but this may not provide sufficient energy conservation, relative to hibernation, to allow them to survive long northern or alpine winters. Badgers may also be indirectly limited by forest overstory or soil conditions that may limit prey species in temperate forest and alpine ecosystems of northern latitudes and at upper elevations.

In our study area, habitats preferred by badgers were generally associated with nonforest or open-canopied forest. This was reflected in both broad- and fine-scale results and is consistent with dominant habitats associated with other badger study areas (Todd 1980, Messick and Hornocker 1981; Warner and Ver Steeg 1995). These results may at least partially relate to abundance of the most common fossorial prey, Columbian ground squirrels. In Idaho, concentrations of Belding's ground squirrels (*Spermophilus beldingi*) have been positively related to the distribution and abundance of badgers (Todd 1980). In our study area, we expect that Columbian ground squirrels are associated with habitats of low canopy closure. For example, Weddell (1989) found that Columbian ground squirrel burrow densities in Washington and Idaho were greater in native meadow steppe, disturbed steppe, and hawthorn (*Crataegus* spp.) thickets than in conifer stands.

The broad-scale associations with soil order that we report may reflect badger preferences for landscapes dominated by generally appropriate climatic and vegetative conditions. Textural characteristics, potentially influencing fossorial prey availability and the ability of badgers to burrow, may directly influence habitat preference at finer scales. For example, podzols generally develop under moist coniferous forests and were avoided, while brunisols, which are typical of drier, more open forests at lower elevations, were preferred at the broad scale. Elliot (1983) found that most Columbian ground squirrel burrows in his Idaho study area were in dry cover types with 3–15% soil moisture. Fine sandy-loams with little gravel and good drainage, attributes preferred at the finer scale in our study, may provide optimal conditions for burrows. Burrows within finer soil textures, resulting from a greater silt and clay component, may be prone to saturation and collapse when wet, while very coarse textures may also be prone to collapse even when dry. A high gravel component, which by definition may include particles up to 8 cm in diameter, can also be expected to impair the ability of badgers to dig. Although no other studies have assessed selection of soil types by badgers, Hoff (1998) did characterize his Colorado study area as consisting of primarily sandy and loamy soils. Parent material does not always correspond directly to soil characteristics, but colluvium tends to be rocky material deposited by gravity at the base of slopes. Thus, its avoidance by badgers at both scales may relate to its low potential for burrowing.

Our results for regosolic soils illustrate the potential influence of spatial scale on badger habitat selection. These soils lack well-defined horizons, are usually young, and are typically associated with alpine areas or river systems. In our study area, they were most concentrated at the bottom of the Trench, associated with the Kootenay and Columbia river floodplains. Because these soils are generally rock, mud, or seasonally flooded, we do not expect them to be important to badgers. Although badger associations with regosols were positive at the broad scale, we expect that this reflects spurious relationships with other preferred landscape attributes. Consistent with our expectation, badgers did avoid regosolic soils at the fine scale.

Fig. 2. Predictive efficiency of badger habitat model across cut-point probability levels in southeastern British Columbia. Model improvement (correctly classified badger minus incorrectly classified random) indicates the optimum cut point in discriminating badger habitat from nonhabitat.



Model fit

Our best-fit MLR model suggests that a linear combination of variables can efficiently discriminate badger use from random locations across scales, and the resulting model may be a useful predictor of relative badger habitat quality. The scales at which variables were represented indicate that the model explained broad- and fine-scale variation in the data. As a final assessment of predictive veracity, validation of this model against an independent dataset of different animals during different years within the intended area of extrapolation is required. Until then, our confidence in the model's utility as a decision-support tool is a reflection of the spatial, temporal, and animal representation of our dataset. We expect that our animal sample represented 1/3–2/3 of the population within the study area, based on extensive searches, location of sightings, and knowledge of spatial organization.

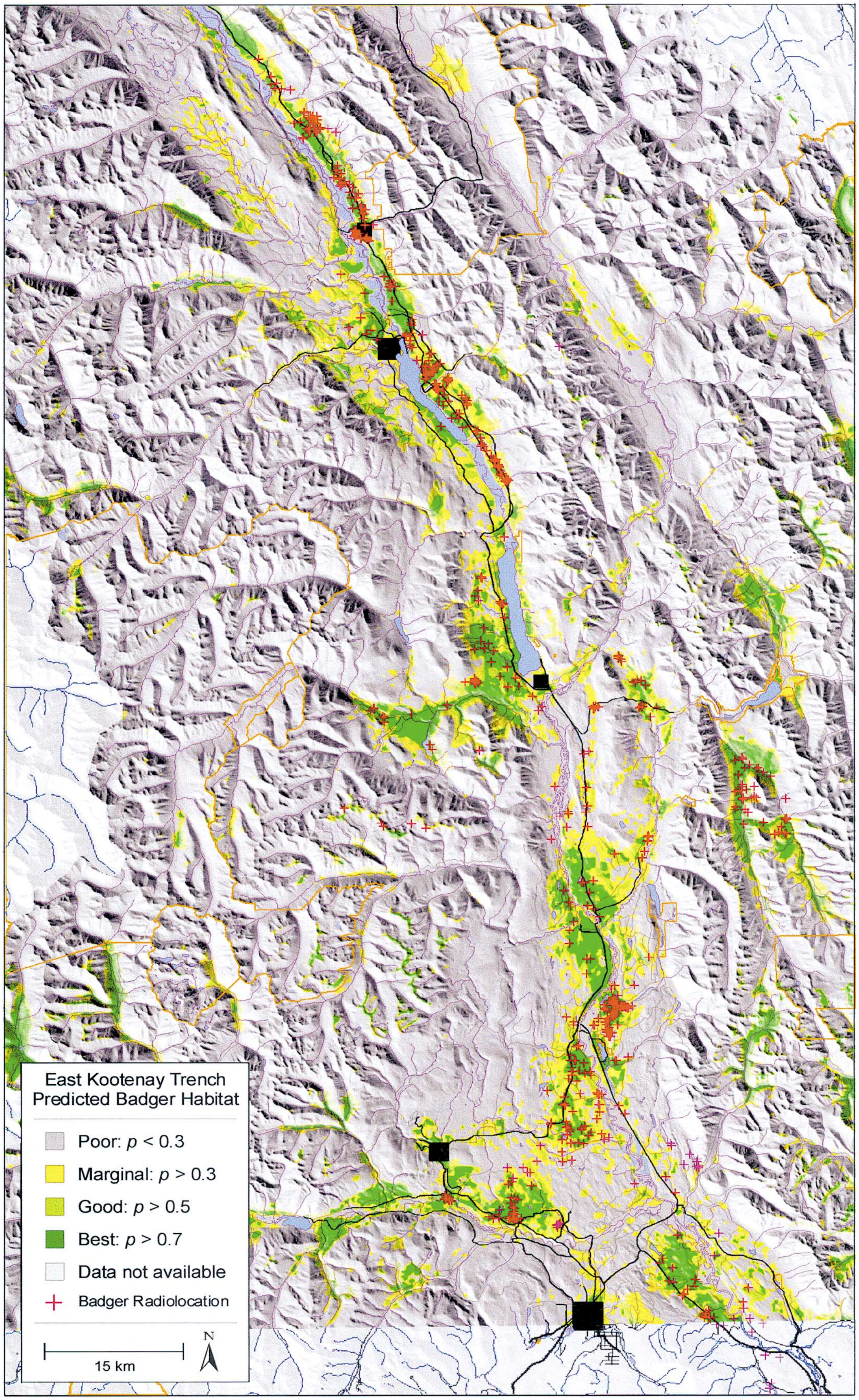
Management implications

Several factors may influence the occurrence and distribution of badger populations and the quality of badger habitat within southeastern British Columbia. These may largely relate to climatic conditions, availability of open habitats, and soil characteristics, and may influence badger vital rates directly or through the distribution and abundance of their prey. Although our analysis was limited to a defined range of spatial scale, our broad-scale results provide insight into the factors that may influence badger occurrence at the scale of geographic distribution in this region. Natural conditions may restrict badger occurrence at this northern range limit, and this may render the existing population vulnerable to human factors that influence habitat quality and mortality risk.

The spatial application of our model within the study area demonstrates several key considerations for badger-population conservation and locations for habitat protection or enhancement in southeastern British Columbia. Using a habitat probability cut point of $p > 0.5$, the model output suggests that while the PP and IDF zones represented 18% of the study area, they encompassed 55% of badger habitat, each representing a much greater proportion of probable habitat than any other zone. Similarly, private land, which largely occurred within these zones, represented 9% of the study area but encompassed 35% of the probable habitat. In contrast, the 15% protected area representation encompassed only 3% of the probable habitat. This suggests that (*i*) habitat-management priorities for badgers should be highest in the PP and IDF zones, (*ii*) private land stewardship should be an important component in habitat-conservation efforts, and (*iii*) existing protected areas may be of little value to badger conservation.

Our results suggest that within landscapes defined by preferred climate, terrain, and soil conditions, badgers were generally associated with dry habitats of little forest overstory. Human management has most certainly influenced vegetation composition within the East Kootenay Trench and throughout the northwestern extent of badger range. Despite uncertainty regarding the range of conditions expected under a natural disturbance regime, forest in-growth and encroachment due to fire suppression currently pervades (Gayton et al. 1995). Thus, we expect that badger habitat quality in southern British Columbia is lower than would be expected under natural disturbance and will benefit from current ecological restoration programs intended to return the East Kootenay Trench to historic vegetative conditions. The model we describe may aid in decision-support to this end, but it should not be applied in a prescriptive sense. The variables we have included may represent only surrogates of attributes to which badgers respond directly. Moreover, it is unlikely that we have included all variables that influence badger habitat selection within our defined range of spatial scale. In particular, the forest cover data used in this analysis provided little information on vegetative condition within nonforested habitats. In our study area, open habitats vary considerably in grazing history, grass and forb species composition, and shrub components, and these may influence badger habitat quality. We advocate pre- and post-restoration monitoring of badger and prey occurrence on treatment sites to maximize the effectiveness of subsequent enhancement prescriptions.

Fig. 3. Badger radiolocations and predicted habitat in the East Kootenay, British Columbia.



Several of the variables we have included in this analysis relate directly or indirectly to human influence. However, our model reflects habitat suitability and does not account for badger mortality risk resulting from direct killing and highway mortality or any other factors. Although badgers are legally protected on provincial land in British Columbia, human-caused mortality is a potential conservation issue. Within our study area, the potential significance of this impact on population viability is apparent when we consider the limited distribution of probable badger habitat, its coincidence with highways and private lands, and its minimal representation within protected areas. The wide-ranging nature of badgers in our study area and the proximity of preferred habitats to highways may result in individuals using highway allowances as travel routes. This may result in unsustainably high rates of highway mortality, an issue that may be offset by habitat enhancement in landscapes not associated with highway or urban development.

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