

# Wildlife habitat selection on landscapes with industrial disturbance

BOGDAN CRISTESCU<sup>1,2,\*</sup>, GORDON B. STENHOUSE<sup>1</sup>, MARC SYMBALUK<sup>3</sup>,  
SCOTT E. NIELSEN<sup>4</sup> AND MARK S. BOYCE<sup>2</sup>

<sup>1</sup>Grizzly Bear Program, Foothills Research Institute, Hinton, Alberta, Canada, <sup>2</sup>Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada, <sup>3</sup>Environment Department, Teck Coal Ltd, Canada and <sup>4</sup>Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada

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## SUMMARY

Technological advancements in remote sensing and telemetry provide opportunities for assessing the effects of expanding extractive industries on animal populations. Here, we illustrate the applicability of resource selection functions (RSFs) for modelling wildlife habitat selection on industrially-disturbed landscapes. We used grizzly bears (*Ursus arctos*) from a threatened population in Canada and surface mining as a case study. RSF predictions based on GPS radiocollared bears ( $n_{\text{during mining}} = 7$ ;  $n_{\text{post mining}} = 9$ ) showed that males and solitary females selected areas primarily outside mineral surface leases (MSLs) during active mining, and conversely inside MSLs after mine closure. However, females with cubs selected areas within compared to outside MSLs irrespective of mining activity. Individual variability was pronounced, although some environmental- and human-related variables were consistent across reproductive classes. For males and solitary females, regional-scale RSFs yielded comparable results to site-specific models, whereas for females with cubs, modelling the two scales produced divergent results. While mine reclamation may afford opportunities for bear persistence, managing public access will likely decrease the risk of human-caused bear mortality. RSFs are powerful tools that merit widespread use in quantitative and visual investigations of wildlife habitat selection on industrially-modified landscapes, using Geographic Information System layers that precisely characterize site-specific conditions.

**Keywords:** environmental impact assessment, grizzly bear, individual variation, mining, resource selection function, RSF, scale, *Ursus arctos*

## INTRODUCTION

Knowledge of habitat selection by wildlife populations is central to environmental mitigation of industrial

developments affecting ecological systems. Development of radiotelemetry technologies allows collection of substantial amounts of animal-use data (Cagnacci *et al.* 2010), while high-resolution aerial and satellite imagery enable improved representations of landscape complexity. Coupling Geographic Information Systems (GIS) with statistical modelling provides a powerful framework to inform management and conservation (Strickland & McDonald 2006).

Resource selection functions (RSFs) have been widely used in studies of wildlife habitat selection (Boyce & McDonald 1999; Manly *et al.* 2002), but their predictive accuracy is dependent on the quality of animal-use data and input habitat layers (Morehouse & Boyce 2013). In addition, scale can influence RSF outputs (Boyce 2006), and modelling habitat selection is not straight-forward, particularly for wide-ranging, rare species with high inter-individual variability (Cristescu & Boyce 2013; Nielsen *et al.* 2013). With many conservation decisions requiring spatially-explicit baseline information for comparison of trends and impacts, RSFs could potentially provide a framework for predicting relative probability of animal response to land-use change along with identifying the direction of the response. However, such methods are difficult for dynamic landscapes that are characteristic of industrial sites (Johnson & Boyce 2004; Johnson *et al.* 2005), and are possibly site-specific. Further testing is required to assess the utility of using these statistical tools for predicting changes in habitat selection under conditions of changing landscapes at appropriate scale.

Surface (open-pit) mining provides an extreme example of landscape change as a result of human activity. While habitat is an important consideration in mine reclamation planning, more knowledge is required on the effects of mining on wildlife populations during and post mining, particularly for wide-ranging mammals of conservation concern. Most current knowledge on response of large/medium-bodied mammals to mining comes from studies on ungulates, which show varying response to mines ranging from avoidance to selection (Merrill *et al.* 1994; Bristow *et al.* 1996; Weir *et al.* 2007; Bleich *et al.* 2009; Blum *et al.* 2015). The effects of mining on omnivores and carnivores remain largely unknown despite expansion of this industry in the distribution ranges of many of these species. For example, in Alberta, Canada, mining occurs within the grizzly bear's (*Ursus arctos*) range, with the species threatened primarily due to human-caused

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\*Correspondence: Bogdan Cristescu, e-mail: [cristesc@ualberta.ca](mailto:cristesc@ualberta.ca)  
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mortality (AGBRT 2008). Grizzly bear population persistence is dependent on availability of suitable habitats that provide sufficient foods and are safe from humans (Nielsen *et al.* 2006). Industrial activities can change the spatial distribution of foods potentially placing bears at risk, for example, if natural foods become available close to humans (Roever *et al.* 2008) or if bears seek human-sourced foods on industrial sites (McLellan 1990). Reproductive classes and individual bears can vary in their behaviour in relation to extractive industries such as logging (Roever *et al.* 2008) and oil and gas (Labree *et al.* 2014).

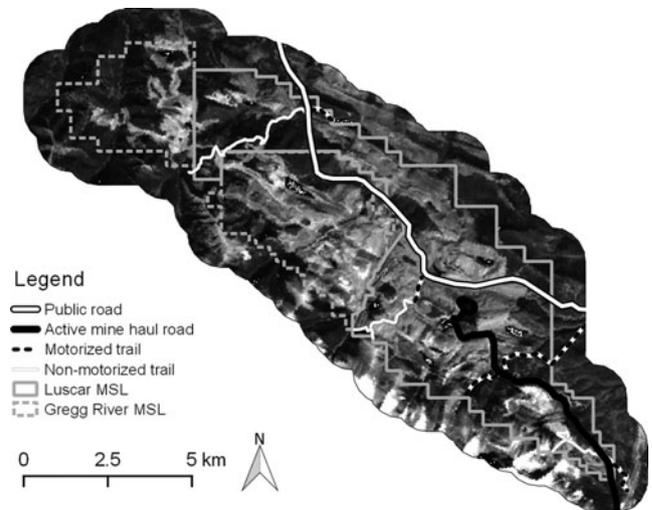
Management of grizzly bears and other omnivores or carnivores relies on habitat modelling often at large scales such as province, state, region or management area (Nielsen *et al.* 2006; Mace *et al.* 2008). Such scales can be appropriate for broad assessments but might not adequately incorporate finer-scale, site-specific conditions, particularly for highly dynamic landscapes such as those associated with mines. Anticipating grizzly bear response to active mining and mine closure can facilitate land-use planning that will allow persistence and possibly enhancement of bear populations on industrially-modified landscapes (Johnson & Boyce 2004; Johnson *et al.* 2005).

We used empirical data and a GIS framework to illustrate the application of habitat selection modelling for understanding wildlife response to industrial disturbance. We assessed grizzly bear habitat selection, differentiating individuals within reproductive classes (males, females, females with cubs) and comparing selection between active mining and post mining. We expected low selection of actively mined areas due to operational disturbances, and higher selection following mine closure because of reclamation to wildlife habitat. We also investigated potential differences in habitat selection inside and outside mines, using models derived at local and regional scales. If patterns of habitat selection were similar between scales, this would suggest that broad-scale models can be sufficient for site-specific management. We expected bears to avoid active areas or their proximity because of disturbance and to also avoid inactive areas due to lack of bear foods. Reclaimed (grassland) areas were expected to be used in proportion to availability as a trade-off between attractiveness of herbaceous foods planted as part of reclamation and potential risks associated with little hiding cover. We anticipated that bears would select undisturbed areas as these represented natural habitats.

## METHODS

### Study area

The study area was located in west-central Alberta at the boundary between the eastern slopes of the Rocky Mountains and Foothills. The predominant natural vegetation cover is conifer forest, with mixed conifer-deciduous forest at lower elevations. Shrub cover is found above tree line (~1800 m) and along river corridors with barren lands occurring naturally at elevations exceeding shrub range. The area includes Luscar



**Figure 1** Study area for grizzly bear habitat selection on and near open-pit mines in west-central Alberta, Canada. The area includes two MSLs and adjacent 1 km buffer. Dark gray shading indicates forest whereas light gray shading indicates barren land, grass or shrub. Satellite photo is a Landsat orthoimage, year circa 2006.

and Gregg River open-pit metallurgical coal mineral surface leases (MSLs) and a 1 km buffer around these leases (Fig. 1). The spatial extent reflects the size of the mining zone of influence considered locally in land-use planning as well as the 4-h step length (distance between two consecutive GPS relocations) of collared bears in the study (mean  $\pm$  SE: 1008  $\pm$  63 m; see ‘Grizzly bear data’ section). Public access is strictly regulated on MSLs and occurs along designated motorized and non-motorized trails. For either trail type, human-use data were not collected for this study.

Data were partitioned chronologically into two sampling periods to reflect changing landscape conditions and bear responses during (1999–2003) and post (2006; 2008–2010) mining. During-mining industrial operations involved removal of natural vegetation and soil, blasting to create coal extraction pits, mechanized shovelling to extract coal and overburden, as well as haul-truck traffic. Post-mining land reclamation efforts and related activities included sloping, soil placement and seeding. Reclamation activities occurred over shorter time spans and with smaller machinery than active mining and did not involve blasting. As mining did not occur simultaneously over the extent of MSLs and some areas remained undisturbed, the mined landscape consisted of active (mining ongoing), inactive (previously active; mining stopped), reclaimed or unaltered patches. We recognize that pooling data across years within each sampling period might not capture variability in mining activity within a given year. Partitioning was based on best available habitat and bear data (see below).

### Grizzly bear data

Grizzly bear GPS radiocollar data were collected by the Foothills Research Institute Grizzly Bear Program (Hinton, Alberta, Canada) and the University of Alberta

**Table 1** Predictor variables included in RSF analyses for grizzly bear habitat selection on and near Luscar and Gregg River open-pit coal mines in west-central Alberta, Canada.

<i>Model variable</i>	<i>Variable code</i>	<i>Variable type</i>	<i>Unit/scale</i>
Habitat features			
Land cover			
Forest	Frst	Categorical	n.a.
Grass	Grs	Categorical	n.a.
Shrub	Shrb	Categorical	n.a.
Barren land	Blnd	Categorical	n.a.
Terrain ruggedness index	TRI	Continuous	Unitless
Compound topographic index	CTI	Continuous	Unitless
Distance to river	Driv	Continuous	Metre
Distance to edge	Dedge	Continuous	Metre
Mine features			
Tree island	Tisl	Categorical	n.a.
Distance to high wall	Dhwall	Continuous	Metre
Distance to haul road	Dhrd	Continuous	Metre
Distance to active land	Dact	Continuous	Metre
Distance to inactive land	Dina	Continuous	Metre
Distance to reclaimed land	Drecl	Continuous	Metre
Human access			
Distance to public road	Dprd	Continuous	Metre
Distance to motorized trail	Dmtrl	Continuous	Metre
Distance to non-motorized trail	Dnmtrl	Continuous	Metre

(Edmonton, Alberta, Canada). Capture methods for radiocollar deployment included darting from a helicopter, culvert trapping and leg-hold snaring and were approved by the University of Saskatchewan and University of Alberta. GPS radiocollars used were Televilt GPS-Simplex (Televilt, Sweden), Telus UHF (Followit, Sweden) and ATS (Advanced Telemetry Systems, USA). After setting the constraint of a minimum of 50 telemetry relocations per individual bear within the study area in each sampling period (Leban *et al.* 2001), seven adult bears ( $n_{\text{males}} = 2$ ;  $n_{\text{females}} = 3$ ;  $n_{\text{females with cubs}} = 2$ ) were included in analyses during active mining, and nine adult bears after mine closure ( $n_{\text{males}} = 2$ ;  $n_{\text{females}} = 4$ ;  $n_{\text{females with cubs}} = 3$ ). Bear G040 was designated as having cubs in certain years, and solitary in other years, with a similar switch in reproductive class for bear G023. Considering that the density of this threatened grizzly bear population is 4.79 individuals/1000 km<sup>2</sup> (Boulanger *et al.* 2005), we were able to monitor with radiocollars a large proportion of the bears. All radiocollar data were rarefied to 4-h collar fix rate to minimize potential bias related to bear habitat selection at multiple scales (Ciarniello *et al.* 2007). The final dataset contained 1291 relocations during mining and 2514 locations after mine closure (Table S1).

### Study design and variables

The study followed a use-available design (Johnson *et al.* 2006), wherein habitat features at bear GPS fixes ('use' locations) were compared with those at random locations ('available' locations). Available locations were generated at a density of 30 spatially-referenced points/km<sup>2</sup> (Northrup *et al.* 2012) at two spatial scales: individual bear annual home range, and study-area extent. Sampling intensity was higher for home-

range areas that were used repeatedly across years. Home ranges were delineated using the least squares cross-validation procedure for fixed-kernel home ranges, based on 95% of GPS locations from each bear, and clipped to study-area extent.

Grizzly bear habitat-related variables (Table 1) were available in GIS format from the Foothills Research Institute Grizzly Bear Program, Teck and Alberta Environment and Sustainable Resource Development. We updated layers to reflect annual changes in landscape features associated with mining development, based on interpretation of orthorectified aerial photography (2001; 2004; 2007; 2010) and a SPOT image (2004). Land-cover categorization (30 m × 30 m) was reclassified to forest, shrub, grassland and barren land. We calculated distance to the nearest water course and habitat edge, defined as the boundary between forest and another land-cover type. Mining-specific covariates included a dummy variable (1/0) for tree island (original tree patch left undisturbed during mining, area range = 118–307 600 m<sup>2</sup>); distance to nearest mining pit high wall (designed to represent bighorn sheep escape terrain [MacCallum & Geist 1992]); distance to the nearest active mine haul road; and distances to different mine disturbance types including active, inactive and reclaimed land. We also calculated distance to the nearest public road, motorized trail and non-motorized trail.

GIS procedures were carried out in ArcGIS v.9.2 (ESRI, Redlands, USA), using the Spatial Analyst Extension, Home Range Extension for ArcGIS (Rodgers & Carr 2007), and Hawth's Analysis Tools for ArcGIS (Beyer 2004).

### Statistical modelling

We contrasted habitat features at grizzly bear GPS radiocollar and random (available) locations using logistic regression,

with the binary response variable (1/0) coding bear use and available locations. The model structure was,

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n) \quad (1)$$

where  $w(x)$  is the relative probability of selection by a bear based on predictor variables  $x_i$  and estimated coefficients  $\beta_i$ , with  $i = 1, n$ . Following the information-theoretic approach to model selection (*sensu* Burnham & Anderson 2002), we created 26 *a priori* candidate models to predict grizzly bear habitat selection on and in the immediate vicinity of MSLs. The models reflected hypotheses for grizzly bear habitat selection, including broad habitat characteristics, ungulate and herbaceous foods, mining-specific features and human access (Table S2). We constructed a correlation matrix for all independent variables and to minimize collinearity we excluded highly correlated variables ( $|r| > 0.7$ ) from the same model structure. For all continuous variables we tested the influence of non-linearities on model maximum log-likelihood estimation by including squared terms for covariates representing distance metrics. We used robust standard errors in STATA v.11.2 (StataCorp, College Station, USA) to account for heteroskedastic distribution of regression error terms. To assess model adequacy, we computed percentage deviance explained (hereafter, DE) for each model.

We estimated separate models for each bear during and post mining as delineated by closure of mining operations. We did not average models because covariate combinations generally varied between top models among bears in the same reproductive class and sampling period, as well as between supported models ( $\Delta AICc < 2$ ) for each bear (Cade 2015). The coefficients for the top models for each bear were used to generate predictive RSF surfaces at the home-range and study-area availability scales, separately for during and post mining. Prior to mapping, predicted relative probabilities were transformed in GIS using:

$$Tw(x) = \frac{w(x)}{1 + w(x)} \quad (2)$$

where  $w(x)$  is the prediction from eqn (1).

### Predictive accuracy

To assess predictive accuracy of top models for each bear we used  $k$ -fold cross-validation (Boyce *et al.* 2002). In this approach  $k$  was equal to  $n - 1$ , with  $n$  representing the number of individual bears of a given reproductive class and sampling period (Wiens *et al.* 2008). Logistic regression coefficients were estimated iteratively for  $k$  subsets of data withheld for model training, across all predictor variables present in the top model for the corresponding reference bear. The  $\beta_i$  estimates obtained from model training were used in eqn 1 in conjunction with predictor variables  $x_i$  corresponding to the reference bear (model testing). This framework allowed us to assess how population-level data could be used to predict relative probability of selection by any one bear.

### Site-specific and regional RSF predictions

Predictions were compared within vs. outside MSLs, as constrained by the 1 km buffer. We did not test for differences in predictions between these areas because we considered all RSF values (i.e., we did not sample). We thereby simply compared the estimates from the complete pixel census by plotting the mean RSF values for each reproductive class, sampling period and availability scale.

We further contrasted our results with those from regional-scale grizzly bear habitat selection models for pooled adult females with/without cubs, which included our study area extent (Nielsen 2005). Our site-specific models rendered annual relative probabilities of habitat selection. The regional models were, however, seasonal (3×) and we included all seasons for comparisons. Because regional models were based on data collected during active mining at the home-range scale of availability, comparisons with fine-scale models were restricted to this sampling period and scale of availability. All regional surfaces were clipped to study area extent and we applied a similar procedure to the one for our site-specific models to assess differences in mean RSF scores within vs. outside MSLs.

## RESULTS

There was substantial variability among individual bears, with AICc support received for diverse hypotheses related to broad habitat characteristics, ungulate and herbaceous distribution, mining-specific features and human access (Appendix S1). We report main patterns focusing on instances where selection was consistent in terms of sign of parameter estimate and confidence intervals not overlapping zero for at least 50% of monitored individuals within a reproductive class.

### Habitat features

Barren land was avoided by males and solitary females as well as by females with cubs during but not post mining (Tables 2 and 3, and Appendix S2). Shrub was avoided by males and solitary females post mining but selected by these reproductive classes (at study-area availability scale for males) during mining. Grassland was selected by males and females with cubs during mining. Males selected areas of intermediary ruggedness. Males and solitary females selected edge proximity or areas far from edges after mining, whereas females with cubs selected such areas during mining. Males selected intermediary distance to riparian areas during mining.

### Mine features

Females with cubs selected tree islands on mined land after mining (Tables 2 and 3, and Appendix S2). Males and solitary females (the latter at home-range availability scale) selected areas either close or far from high walls after mining, with

**Table 2** Individual grizzly bear habitat selection on mined lands and adjacent area, west-central Alberta, Canada, with availability drawn at home-range level. Coefficients for which the confidence intervals did not overlap zero have an asterisk (\*). No reporting of coefficients refers to the specific variable(s) not being included in the top model. Forest land-cover type was withheld as reference category. During mining: 1999–2003; after (post) mining: 2006 and 2008–2010. ‘+’ corresponds to positive selection coefficient whereas ‘-’ denotes negative selection. Note that for distance variables ‘-’ implies selection of areas close to the respective feature.

Model variable	Male		Female		Female cubs	
	During (n = 2)	After (n = 2)	During (n = 3)	After (n = 4)	During (n = 2)	After (n = 3)
Habitat features						
Land cover						
Grs	+*	+ -	+* -	+ + -* +*	- +*	+*
Shrb	+	- -*	+* +*	-* + -* +	- +	-
Blnd	-*	- -*	- -*	-* -* -* -*	-* -	+
TRI		+ +*	- +	+ + +*	+ -	-*
TRI <sup>2</sup>		- -*	- -	- - -	- +	+
CTI	-			+		
CTI <sup>2</sup>	+			+		
Driv	+*			+		
Driv <sup>2</sup>	-*			-*		
Dedge		-* -*	- -*	-* -* -*	-* -*	-*
Dedge <sup>2</sup>		+ +*	- +*	+* +* +*	+ +	+*
Mine features						
Tisl						+* +*
Dhwall		+ -*	- - +*	-* -* +	+ -*	- -
Dhwall <sup>2</sup>		-* +*	- +* -*	+ +* -	- +	+ -
Dhrd	+*					+*
Dhrd <sup>2</sup>	-*					-*
Dact						
Dact <sup>2</sup>						
Dina						+*
Dina <sup>2</sup>						-*
Drecl						-*
Drecl <sup>2</sup>						+*
Human access						
Dprd	+ -*	+* +*	-* +	-* + - +*	+ -*	-
Dprd <sup>2</sup>	- +*	-* -*	+* -*	+* - - -*	-* +*	-
Dmtrl	-* +	- +	- +	+* -* -* +	+*	+*
Dmtrl <sup>2</sup>	+* -	+* -	+ -	-* +* + -	-*	-
Dnmtrl	- -	+* +	- +*	+* +* +* +*	+*	-
Dnmtrl <sup>2</sup>	+ -	- -	- -*	-* - -* -*	-*	+*
Intercept	-* -*	-* -*	+ -* -*	- - - - -*	-* -	-* -* +

proximity to walls selected by females with cubs during mining at home-range availability scale. During mining, males selected areas at intermediary distances from mine haul roads (home-range availability). After mining, solitary females and females with cubs also selected intermediate distances from haul roads (study-area availability).

### Human access

Males selected areas close or far from public roads during mining (home-range availability) but intermediary distances to public roads after mining (Tables 2 and 3, and Appendix S2). Solitary females selected areas far or at intermediary distances from public roads after mining (study-area availability). Areas close or far from public roads

were selected by females with cubs during mining (home-range availability). Males during mining and solitary females after mining (the latter at home-range availability scale) selected areas near or far from motorized trails. However this pattern switched for solitary females after mining when study-area availability was considered, with selection for intermediate distance to motorized trails apparent. After mining, males avoided non-motorized trails, whereas solitary females selected areas at intermediary distance from such trails. Such intermediary distances were also selected by females with cubs during mining.

Ranking of both home-range and study-area availability models showed that top models for post mining generally received more substantial support ( $w_{AICc} > 0.9$ ) compared to during mining models. Post-mining models also explained

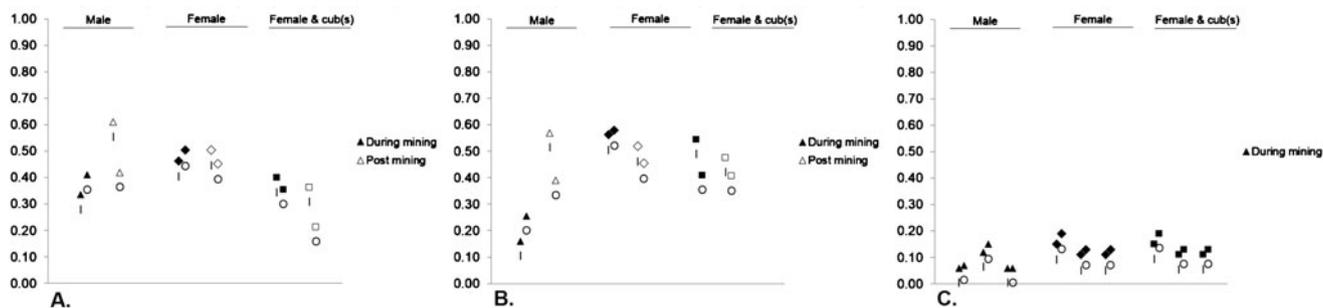
**Table 3** Individual grizzly bear habitat selection on mined lands and adjacent area, west-central Alberta, Canada, with availability drawn at the study-area level. Coefficients for which the confidence intervals did not overlap zero have an asterisk (\*). No reporting of coefficients refers to the specific variable(s) not being included in the top model. Forest land-cover type was withheld as reference category. During mining: 1999–2003; after (post) mining: 2006 and 2008–2010. ‘+’ corresponds to positive selection coefficient whereas ‘-’ denotes negative selection. Note that for distance variables ‘-’ implies selection of areas close to the respective feature.

<i>Model variable</i>	<i>Male</i>		<i>Female</i>		<i>Female cubs</i>	
	<i>During</i> ( <i>n</i> = 2)	<i>After</i> ( <i>n</i> = 2)	<i>During</i> ( <i>n</i> = 3)	<i>After</i> ( <i>n</i> = 4)	<i>During</i> ( <i>n</i> = 2)	<i>After</i> ( <i>n</i> = 3)
<b>Habitat features</b>						
Land cover						
Grs	- +*	+ -	+* -* -		-	+*
Shrb	- +*	- -*	+* +* +		-	+
Blnd	-* -*	-* -*	- -* -*		-*	+
TRI	-	+ +*	+ +		+	-*
TRI <sup>2</sup>	-	- -*	- -		-	+
CTI	-		-			
CTI <sup>2</sup>	+		+			
Driv	+*		+*			
Driv <sup>2</sup>	-*		-*			
Dedge	-	-* -*	-* -		-*	-*
Dedge <sup>2</sup>	-	+* +*	+ +		+	+*
<b>Mine features</b>						
Tisl						+* +*
Dhwall	+	+ -*	- +*		+	- -*
Dhwall <sup>2</sup>	+	-* +*	+* -*		-	- +*
Dhrd				+* - + +*	-	+* +*
Dhrd <sup>2</sup>				-* - -* -*	-*	-* -*
Dact						
Dact <sup>2</sup>						
Dina						
Dina <sup>2</sup>						
Drecl						
Drecl <sup>2</sup>						
<b>Human access</b>						
Dprd	+* -*	+* +*	-* + +*	-* +* + +*	+* -*	-
Dprd <sup>2</sup>	- +*	-* -*	+ -* -*	+ - - -*	-* +*	-
Dmtrl	-* +	- +	+ +*	+* - -* +*	+	+*
Dmtrl <sup>2</sup>	+* -	+* -*	- -	-* +* - -*	-	+
Dnmtrl	+ -	+* +	+ +*	+* +* +* +*	+*	-
Dnmtrl <sup>2</sup>	- -	- -	-* -*	-* -* -* -*	-*	+*
Intercept	-* -*	-* -*	-* -* -*	-* -* -* -*	-* -*	-* -* -*

more deviance than models from active (during) mining (Table S3). Models had variable predictive accuracy, with substantial differences occurring in relation to bear reproductive class and sampling period (Appendix S3 and Fig. S1). Differences in predictive accuracy within reproductive class in relation to scale of availability were most pronounced for males and solitary females. For these two reproductive classes, home-range availability models had more distinctive predictive differences between sampling periods compared to study-area availability models. Overall, habitat models for solitary females (during mining) and males and females with cubs (post mining) had the highest predictive power for selection (eqn 1) across all reproductive classes and sampling periods.

Mean RSF scores on vs. outside MSLs differed within reproductive class irrespective of scale of availability (Fig. 2). Males and solitary females had higher mean RSF values within a 1 km buffer outside MSLs compared to inside MSLs during mining with the opposite pattern observed post mining. Females with cubs, however, had consistently higher RSF scores within MSLs regardless of sampling period (Fig. 2).

Mean RSF scores for the regional models (during mining) also differed, being higher within a 1 km buffer outside MSLs compared to inside MSLs (Fig. 2). One exception occurred for males in the third (fall) season, when RSF scores were similar on MSLs and the 1 km buffer. The spatial location of high RSF score pixels showed major differences between regional and



**Figure 2** Mean relative probability of grizzly bear habitat selection inside (I) and outside (O) coal MSLs in west-central Alberta, Canada. Reproductive classes include males ( $\Delta$ ), solitary females ( $\diamond$ ) and females with cubs ( $\square$ ). Filled symbols correspond to during mining whereas symbols with no fill represent post mining. Predictions are based on study area – specific availability drawn at the home-range (*a*) and study-area level (*b*); and on regional scale availability drawn at the home-range level for three separate seasons (*c*; Nielsen 2005). For regional availability, RSF calculations pooled females and females with cubs, and regional RSF surfaces were only available during mining.

fine-scale models. In particular, the northern block on Gregg River MSL, northern sector of Luscar MSL and extreme south-eastern sector of the latter MSL were highly selected by males and some solitary females (Fig. 1 and Appendix S4) based on the fine-scale home-range during-mining models, as compared to the regional models. Differences between spatial predictions were even more obvious for females with cubs, which based on the top fine-scale home-range during-mining models selected the southern block on Gregg River MSL, central, central-northern and eastern sectors of Luscar MSL (Fig. 1 and Appendix S4), in contrast with regional model predictions.

## DISCUSSION

We illustrated how habitat features on a dynamic landscape can be linked to animal telemetry data across different time periods, enabling spatial visualization of wildlife habitat selection. The RSF approach enables retrospective assessments of animal response to landscape change and the mapping outputs are informative for land-use planning and environmental impact mitigation.

Mining activity at the two mines under study created variance in behavioural response of bears. Higher selection of mining areas by males and solitary females after mine closure suggests that active mining deters these reproductive classes, but individuals are able to colonize reclaimed mines in our study system. Selection of MSLs during and post mining by females with cubs could be a reflection of potentially avoiding males at the active mining stage, and trading security for forage once mines were reclaimed. Although human-caused habitat disturbance and fragmentation have been suggested to affect the ability of females with cubs to elude infanticidal males (Fernández-Gil *et al.* 2010), no infanticide data were available for our study system. Alternatively, selection patterns documented for females with cubs could be a result of increased tolerance of human activities associated with mining, to acquire foods in mining areas.

Barren land avoidance by all reproductive classes is likely connected to scarcity of grizzly bear foods on this land-cover category. Differences in selection within the shrub land class before and after mining are possibly related to selection of secure cover provided by shrubs during mining and less need for such cover following mine closure. Selection of grassland by males and females with cubs probably occurred because reclaimed herbaceous material provides forage (Cristescu *et al.* 2015). Selection of areas of intermediary ruggedness by males also may be indicative of foraging, with *Hedysarum* spp. roots frequently associated with ruggedness (Hamer & Herrero 1987). Edge selection across reproductive classes as well as tree island selection by females with cubs could be associated with forest proximity enabling escape to vegetation cover when encountering threats (Nielsen *et al.* 2004a), or opportunities for bear consumption of ungulates (Cristescu *et al.* 2014). The predicted selection of proximity to high mine walls is likely related to the distribution of individuals within MSLs and may not necessarily reflect hunting of ungulates. Bighorn sheep use high walls on mines to evade predators (MacCallum & Geist 1992) and this species forms only a small proportion of bear diet (Cristescu *et al.* 2015).

Avoidance of public roads by males is in accordance with studies documenting grizzly bear response to roads (McLellan & Shackleton 1988). While females have been shown to select areas near public roads (Graham *et al.* 2010; Roever *et al.* 2010), we showed that solitary females avoided roads whereas females with cubs selected proximity of these roads. Selection of roaded areas by females with cubs might be an outcome of sexual segregation manifested due to male avoidance (Wielgus & Bunnell 1994). Selection of areas located at intermediary distance from active haul roads by all reproductive classes is a novel finding. The avoidance of non-motorized trails by all reproductive classes suggests a loss in grizzly bear habitat effectiveness associated with human recreation, which may become problematic if recreationists use MSLs extensively following mine closure. Although data on recreational activity levels along these trails were unavailable, carnivore avoidance of human-use trails has been documented (Muhly *et al.*

2011) and might relate to unpredictability of non-motorized traffic. Response of bears to motorized traffic was less conclusive, with such traffic possibly more predictable to wildlife because of long-range detection of engine noise.

Irrespective of scale of availability and bear reproductive class, post-mining habitat selection models had greater DE and received more support than during mining models. This finding suggests that modelling habitat selection for reclaimed mines is easier than modelling habitat selection on highly dynamic industrial landscapes such as those supporting active mining operations. Predictive accuracy varied between individuals within reproductive class possibly in connection to different life history strategies, which have been demonstrated for grizzly bears (Northrup *et al.* 2012), as well as more broadly for other species (Bolnick *et al.* 2003).

We showed that broad-scale habitat modelling does not necessarily reflect site-specific conditions influencing grizzly bear habitat selection. Spatially, site-specific RSFs showed high selection for certain areas within MSLs during mining, with the largest difference compared to regional predictions recorded for females with cubs (Appendix S4). We suspect that differences between regional and fine-scale predictions are mainly caused by improved GIS layers and adequate model covariates representative of site-specific conditions. For example, much of the area within MSLs was classified as barren land in the regional-level land-cover layer, whereas our fine-scale land-cover layer included grassland, which is present on MSLs and grazed by bears following reclamation (Cristescu *et al.* 2015). Furthermore, our model-ranking procedure suggested that fine-scale factors such as human access can be key predictors of bear habitat selection. Detailed knowledge of the area reflected in realistic GIS layers, as well as understanding of the target species' ecology, are essential, especially when scientific outputs are to be used in environmental conservation and management decisions. We suggest that habitat modelling on highly dynamic industrial landscapes such as those with surface mining operations be carried out using best available fine-scale layers (see also Morehouse & Boyce 2013).

While our results are likely species and site specific, the approach outlined herein can be used as an example for future studies that aim to assess wildlife responses to mining and other industrial activities, enabling land-use planning strategies for wildlife conservation in industrially-modified landscapes. An important improvement for future studies would be to collect data prior to industrial disturbance, in addition to during and after operational activity, allowing understanding of wildlife response at multiple temporal phases. Sampling a large proportion of the target wildlife population is important and will affect results and interpretation. Our study has relatively small sample sizes especially within reproductive class. However given the low density of grizzly bears in the region (Boulanger *et al.* 2005) we are confident that we monitored a substantial proportion of individuals.

Following reclamation, grizzly bears of all reproductive classes selected mine sites under study. The documented selection of tree islands by females with cubs emphasizes the importance of preserving natural habitat patches on mined areas to minimize long-term displacement and promote colonization of mines. Because reclaimed MSLs under study contain ungulate and herbaceous foods that attracted bears of all reproductive classes, such industrially-disturbed sites could potentially serve as local refugia for bears. However, not all open-pit mines may contain the abundance of foods that our study sites have.

As open-pit coal mines are reclaimed in this area, and these lands are opened for public use it would be important to undertake grizzly bear mortality risk assessments for identifying key areas for protection and management. Such an assessment has been performed regionally (Nielsen *et al.* 2004b), but mining site-specific conditions likely do not reflect region-wide mortality risk because access restrictions and hunting prohibition on MSLs likely decrease bear mortality. Adaptive management will be necessary for conserving grizzly bears and other wildlife on and around mine sites in response to stakeholder pressures regarding future land use.

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## Supplementary material

To view supplementary material for this article, please visit <http://dx.doi.org/10.1017/S0376892916000217>

## References

- AGBRT (2008) Alberta Grizzly Bear Recovery Plan 2008–2013. Government of Alberta, Alberta Grizzly Bear Recovery Team, Alberta Species at Risk Recovery Plan No. 15.
- Beyer, H.L. (2004) Hawth's Analysis Tools for ArcGIS [www document]. URL [www.spatial ecology.com/htools](http://www.spatial ecology.com/htools)
- Bleich, V.C., Davis, J.H., Marshal, J.P., Torres, S.G. & Gonzales, B.J. (2009) Mining activity and habitat use by mountain sheep (*Ovis canadensis*). *European Journal of Wildlife Research* **55**: 183–191.
- Blum, M.E., Stewart, K.M. & Schroeder, C. (2015) Effects of large-scale gold mining on migratory behavior of a large herbivore. *Ecosphere* **6**: 74.
- Bolnick, D.I., Svanback, R., Fordyce, J.A., Yang, L.H., Davis, J.M., Hulsey, C.D. & Forister, M.L. (2003) The ecology of individuals: incidence and implications of individual specialization. *American Naturalist* **161**: 1–28.
- Boulanger, J., Stenhouse, G.B., Proctor, M., Himmer, S., Paetkau, D. & Cranston, J. (2005) 2004 population inventory and density estimates for the Alberta 3B and 4B grizzly bear management area. Report prepared for Alberta Sustainable Resource Development, Fish and Wildlife Division. Nelson, Canada: Integrated Ecological Research.
- Boyce, M.S. & McDonald, L.L. (1999) Relating populations to habitats using resource selection functions. *Trends in Ecology & Evolution* **14**: 268–272.
- Boyce, M.S. (2006) Scale for resource selection functions. *Diversity and Distributions* **12**: 269–276.
- Boyce, M.S., Vernier, P.R., Nielsen, S.E. & Schmiegelow, F.K.A. (2002) Evaluating resource selection functions. *Ecological Modelling* **157**: 281–300.
- Bristow, K.D., Wennerlund, J.A., Schweinsburg, R.E., Olding, R.J. & Lee, R.E. (1996) Habitat use and movements of desert bighorn sheep near the Silver Bell Mine, Arizona. Arizona Game and Fish Department Technical Report 25. pp.57 [www document]. URL [www.gf.state.az.us/w\\_c/documents/TR-25-HABITATUSEANDMOVEMENTSOFDESERTBIGHORNSHEEPNEARTHESILVERBELLMINEARIZONA.pdf](http://www.gf.state.az.us/w_c/documents/TR-25-HABITATUSEANDMOVEMENTSOFDESERTBIGHORNSHEEPNEARTHESILVERBELLMINEARIZONA.pdf)
- Burnham, K.P. & Anderson, D.R. (2002) Model selection and multimodel inference: a practical information-theoretic approach. New York, USA: Springer.
- Cade, B. (2015) Model averaging and muddled multimodel inferences. *Ecology* **96**: 2370–2382.
- Cagnacci, F., Boitani, L., Powell, R.A. & Boyce, M.S. (2010) Animal ecology meets GPS-based radiotelemetry: a perfect storm of opportunities and challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences* **365**: 2157–2162.
- Ciarniello, L.M., Boyce, M.S., Seip, D.R. & Heard, D.C. (2007) Grizzly bear habitat selection is scale dependent. *Ecological Applications* **17**: 1424–1440.
- Cristescu, B. & Boyce, M.S. (2013) Focusing ecological research for conservation. *Ambio* **42**: 805–815.
- Cristescu, B., Stenhouse, G.B. & Boyce, M.S. (2014) Grizzly bear ungulate consumption and the relevance of prey size to caching and meat sharing. *Animal Behaviour* **92**: 133–142.
- Cristescu, B., Stenhouse, G.B. & Boyce, M.S. (2015) Grizzly bear diet shifting on reclaimed mines. *Global Ecology and Conservation* **4**: 207–220.
- Fernández-Gil, A., Swenson, J.E., Granda, C., Naves, J., Perez, T., Dominguez, A., Ordiz, A. & Delibes, M. (2010) Sexually selected infanticide in an endangered brown bear population. *Animal Behaviour* **79**: 521–527.
- Graham, K., Boulanger, J., Duval, J. & Stenhouse, G. (2010) Spatial and temporal use of roads by grizzly bears in west-central Alberta. *Ursus* **21**: 43–56.
- Hamer, D. & Herrero, S. (1987) Grizzly bear food and habitat in the front ranges of Banff National Park, Alberta. *Bears: Their Biology and Management* **7**: 199–213.
- Johnson, C.J. & Boyce, M.S. (2004) A quantitative approach for regional environmental assessment: application of a habitat-based population viability analysis to wildlife of the Canadian central Arctic. Canadian Environmental Assessment Agency, Research and Development Monograph Series. Ottawa, Ontario: Canadian Environmental Assessment Agency.
- Johnson, C.J., Boyce, M.S., Case, R.L., Cluff, H.D., Gau, R.J., Gunn, A. & Mulders, R. (2005) Cumulative effects of human developments on Arctic wildlife. *Wildlife Monographs* **160**: 1–36.
- Johnson, C.J., Nielsen, S.E., Merrill, E.H., McDonald, T.L. & Boyce, M.S. (2006) Resource selection functions based on use-availability data: theoretical motivation and evaluation methods. *Journal of Wildlife Management* **70**: 347–357.
- Laberee, K., Nelson, T.A., Stewart, B.P., McKay, T. & Stenhouse, G.B. (2014) Oil and gas infrastructure and the spatial pattern of grizzly bear habitat selection in Alberta, Canada. *The Canadian Geographer* **58**: 79–94.
- Leban, F.A., Wisdom, M.J., Garton, E.O., Johnson, B.K. & Kie, J.G. (2001) Effect of sample size on the performance of resource selection analyses. In: *Radio-Tracking and Animal Populations*, eds. J.J. Millsaugh & J.M. Marzluff. New York, USA: Academic Press.
- MacCallum, B.N. & Geist, V. (1992) Mountain restoration: soil and surface wildlife habitat. *GeoJournal* **27.1**: 23–46.
- Mace, R.D., Waller, J.S., Manley, T.L., Ake, K. & Wittinger, W.T. (2008) Landscape evaluation of grizzly bear habitat in western Montana. *Conservation Biology* **13**: 367–377.
- Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T. & Erickson, W.P. (2002) Resource Selection by Animals. Statistical Design and Analysis for Field Studies. Dordrecht, the Netherlands: Kluwer Academic Publishers.
- 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* **25**: 451–460.
- McLellan, B.N. (1990) Relationships between human industrial activity and grizzly bears. *Bears: Their Biology and Management* **8**: 57–64.
- Merrill, E.H., Hemker, T.P., Woodruff, K.P. & Kuck, L. (1994) Impacts of mining facilities on fall migration of mule deer. *Wildlife Society Bulletin* **22**: 68–73.
- Morehouse, A.T. & Boyce, M.S. (2013) Deviance from truth: telemetry location errors erode both precision and accuracy of habitat-selection models. *Wildlife Society Bulletin* **37**: 596–602.
- Muhly, T.B., Semeniuk, C., Massolo, A., Hickman, L. & Musiani, M. (2011) Human activity helps prey win the predator–prey space race. *PLoS ONE* **6**: e17050.
- Nielsen, S.E. (2005) Habitat ecology, conservation and projected population viability of grizzly bears (*Ursus arctos* L.) in west-central Alberta, Canada. PhD Thesis. Edmonton, Canada: University of Alberta.

- Nielsen, S.E., Boyce, M.S. & Stenhouse, G.B. (2004a) Grizzly bears and forestry I: selection of clearcuts by grizzly bears in west-central Alberta, Canada. *Forest Ecology and Management* **199**: 51–65.
- Nielsen, S.E., Herrero, S., Boyce, M.S., Mace, R.D., Benn, B., Gibeau, M.L. & Jevons, S. (2004b) Modelling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies ecosystem of Canada. *Biological Conservation* **120**: 101–113.
- Nielsen, S.E., Shafer, A.B.A., Boyce, M.S. & Stenhouse, G.B. (2013) Does learning or instinct shape habitat selection? *PLoS ONE* **8**: e53721.
- Nielsen, S.E., Stenhouse, G.B. & Boyce, M.S. (2006) A habitat-based framework for grizzly bear conservation in Alberta. *Biological Conservation* **130**: 217–229.
- Northrup, J.M., Pitt, J., Muhly, T.B., Stenhouse, G.B., Musiani, M. & Boyce, M.S. (2012) Vehicle traffic shapes grizzly bear behaviour on a multiple-use landscape. *Journal of Applied Ecology* **49**: 1159–1167.
- Rodgers, A.R. & Carr, A.P. (2007) HRE: The Home Range Tools for ArcGIS™ (Beta Test Version 0.9). Centre for Northern Forest Ecosystem Research. Ontario Ministry of Natural Resources [www document]. URL <http://flash.lakeheadu.ca/~arodgers/hre/>
- Roever, C.L., Boyce, M.S. & Stenhouse, G.B. (2010) Grizzly bear movements relative to roads: application of step selection functions. *Ecography* **33**: 1113–1122.
- Roever, C.L., Boyce, M.S. & Stenhouse, G.B. (2008) Grizzly bears and forestry II: grizzly bear habitat selection and conflicts with road placement. *Forest Ecology and Management* **256**: 1262–1269.
- Strickland, M.D. & McDonald, L.L. (2006) Introduction to the special section on resource selection. *Journal of Wildlife Management* **70**: 321–323.
- Weir, J.N., Mahoney, S.P., McLaren, B. & Ferguson, S.H. (2007) Effects of mine development on woodland caribou *Rangifer tarandus* distribution. *Wildlife Biology* **13**: 66–74.
- Wielgus, R.B. & Bunnell, F.L. (1994) Sexual segregation and female grizzly bear avoidance of males. *Journal of Wildlife Management* **58**: 405–413.
- Wiens, T., Dale, B., Boyce, M.S. & Kershaw, P. (2008) Three way *k*-fold cross-validation of logistic regression models. *Ecological Modelling* **212**: 244–255.