

RESEARCH ARTICLE

Mine reclamation enhances habitats for wild ungulates in west-central Alberta

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Surface mining is the most prevalent form of coal extraction in North America. Reclamation aims to transform former surface mines into self-sustaining ecosystems that support uses similar to predevelopment conditions. Success of reclamation often is determined by assessing the re-establishment of landscape structure and vegetation communities. However, there is increasing interest in evaluating reclamation success in the context of higher trophic levels. We evaluated response to mining and reclamation by sympatric bighorn sheep (*Ovis canadensis*), elk (*Cervus elaphus*), and mule deer (*Odocoileus hemionus*) on reclaimed coal mines in west-central Alberta. We used direct ground counts on a fixed survey route to obtain data on abundance and distribution of ungulates during 2004 to 2017. We created a grid of 200 × 200 m grid cells and assigned each group of ungulates to a grid cell. We assigned landscape and topographic features to these grid cells to represent changes due to mining and reclamation. We estimated resource selection functions for bighorn sheep, elk, and mule deer showing how their use of reclaimed features and landscapes increased access to quality forage and decreased predation risk. Ungulates also responded to mining and reclamation in ways that we did not anticipate, e.g. sheep and elk often selected areas near haul roads. Understanding spatial relationships between reclamation prescriptions and higher trophic levels is important when designing “bottom up” reclamation to restore ecological functions including recruitment of wildlife.

Key words: bighorn sheep, elk, mule deer, open-pit mining, resource selection function

Implications for Practice

- Ecological reclamation is often evaluated in context of vegetation communities and abiotic parameters. However, considering spatial relationships between targeted reclamation and higher trophic levels improves our ability to use “bottom up” approaches for reclamation that can enhance recruitment of wildlife.
- Resource selection functions are an underutilized tool in restoration ecology that can be used to assess how wildlife will use reclaimed landscapes.
- In addition to vegetation communities and abiotic parameters, reclamation for wildlife should serve as a target for evaluating the success of ecological reclamation.

Introduction

Coal reserves are mined on every continent except Antarctica and, over the past 30 years, surface mining for coal has increased at a global scale (WCA 2020). In North America, surface mining has become the most prevalent form of coal extraction (EIA 2018) and in most areas has almost entirely replaced sub-surface methods of coal mining (Alberta Culture and Tourism 2019). Surface mining removes overlying rock and soil to access underlying mineral deposits, including strip, open-pit, and mountaintop removal mining. In general, surface mining can drastically alter natural habitats by stripping land of natural topography (Wickham et al. 2013), introducing soil compaction (Larkin et al. 2008), and altering vegetation communities

(Holl & Cairns 1994; Wickham et al. 2006). These modifications can result in changes to species distribution (Weir et al. 2009) and decreases in species diversity (Larkin et al. 2008; Arden et al. 2016).

Most jurisdictions require reclamation to transform industrially developed land into self-sustaining ecological systems that support uses similar to predevelopment condition. In some cases, reclamation falls short of returning landscapes to predevelopment conditions and might result in ecosystems in arrested stages of ecological succession (Suding et al. 2004). Reclamation also can create habitats for wildlife, restoring fauna to reclaimed landscapes. For example, retaining abandoned structures can provide hibernacula (Whitaker & Rissler 1992; Sherwin et al. 2000) and breeding sites (Johnson et al. 1978; Heath et al. 1986) for bats and birds. Seeding graminoids can restore grassland ecosystems and increase grazing opportunities for wild sheep (Elliott &

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McKendrick 1984; MacCallum & Geist 1992; Poole et al. 2016). Ultimately, reclamation can result in increased biological diversity (Benayas et al. 2009), ecosystem services (Benayas et al. 2009), and spatial heterogeneity (Müller et al. 2017), all of which can contribute to the sustainability of restored systems.

Traditionally, reclamation success is evaluated by assessing the re-establishment of abiotic parameters (Bernhardt & Palmer 2011; Wickham et al. 2013), landscape heterogeneity (Palmer et al. 2010), and vegetation communities (Holl & Cairns 1994; Wickham et al. 2006; Swab et al. 2017). This vegetation-centric (or bottom-up) approach can be characterized by the Field of Dreams hypothesis: “if you build it, they will come” (Palmer et al. 1997), which assumes that biotic diversity is correlated with habitat heterogeneity (Palmer et al. 2010). However, implicit in the Field of Dreams hypothesis is that there are direct relationships between the wildlife being recruited and re-established landscapes, which motivated our research to quantify landscape influences on reclaimed sites and compare patterns of habitat selection among different species. Further, several ecologists have identified the need for reclamation success to be evaluated in the context of higher trophic levels (Fraser et al. 2015; Foster et al. 2016; Jones & Davidson 2016).

We focused our study on three reclaimed open-pit coal mines in west-central Alberta, Canada, where reclamation was designed to create wildlife habitats for bighorn sheep (*Ovis canadensis*), elk (*Cervus elaphus*), and mule deer (*Odocoileus hemionus*). Restoration of native habitats, replacement of lost habitats, and creation of new habitats (MacCallum 2003) resulted in a landscape mosaic of reclaimed, disturbed, and undisturbed patches. The primary objectives of our study were to quantify relationships between wildlife and reclaimed landscape features, and to evaluate the efficacy of mine reclamation for ecological functions including wildlife habitats. Using direct observations of three ungulate species, bighorn sheep, elk, and mule deer, we developed resource selection functions (RSFs) to test the hypothesis that ungulates selectively used landscape features created through targeted reclamation prescriptions. For example, high walls are vertical rock walls (23–205 m high on slopes of 21–45°) left over from open-pit mining that are intentionally retained to function as escape terrain for bighorn sheep (MacCallum & Geist 1992) and are an example of a reclamation feature that bighorn sheep were expected to select. If ungulates select reclaimed landscape features, such as high walls and reclaimed grasslands, then the bottom-up reclamation prescriptions applied in our study area were efficacious at providing habitat for wildlife. However, if ungulates avoided features of mining, such as disturbed areas and haul roads, then there would be motivation to reclaim lingering disturbed areas to increase the success of bottom-up reclamation.

The second objective of our study was to model how wildlife selected habitats on re-established landscapes. We tested hypotheses about how reclamation needs varied by species and built models to create predictive maps depicting relative habitat selection for each species. How spatial patterns of habitat selection varied among ungulates can be used to adjust reclamation prescriptions to target multiple species. Ultimately, benchmarks for evaluating reclamation success have yet to be developed by

the Province of Alberta (Province of Alberta 2018), but our study demonstrates an approach for assessing reclamation success by including wildlife values.

Methods

Study Area

The study area, totaling 483 km², is located in west-central Alberta, Canada (approximately 53°04'N 117°26'W), and includes three mines (Fig. 1). Luscar and Gregg River are reclaimed coal mines located approximately 50 km south of Hinton, Alberta. Mining began at Luscar and Gregg River in 1969 and 1982, respectively, and reclamation began in 1971 and 1982, respectively. The Luscar mine, owned by Teck Coal Limited (Teck), totals 53 km² and was 60% partially reclaimed as of 2017. Gregg River, owned by Westmoreland Coal Company (Westmoreland), totals 37 km² and by 2017 was 99% reclaimed. Within the study area, reclaimed land has reached its predetermined end use of wildlife habitat. The Cheviot mine is active and extracted coal is transported via haul road to a processing facility on Luscar. Cheviot is 72 km² but the eastern half of the lease is undisturbed and by 2017 had yet to be mined. Thus, we included only the western half of the Cheviot MSL (totaling 44 km²) in the study area.

Grasslands on the reclaimed mines are dominated by non-native forage species including Kentucky bluegrass (*Poa pratensis*), Canadian bluegrass (*Poa compressa*), red fescue (*Festuca rubra*), orchard grass (*Dactylis glomerata*), alfalfa, cicer milkvetch (*Astragalus cicer*), and clover (*Trifolium* spp.) (Strong 2002). Woody species such as Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), balsam poplar (*Populus balsamifera*), willow (*Salix* spp.), and alder (*Alnus* spp.) were planted during reclamation to create shrubland and, eventually, mature forests. Natural forests are conifer at higher elevations and are mainly lodgepole pine, white spruce (*Picea glauca*), and Engelmann spruce. At lower elevations, balsam poplar and trembling aspen (*Populus tremuloides*) are present in mixed conifer-deciduous forests. Approximately 53% of the study area is forested and 15% is grasslands. Approximately 62% of grasslands were established through reclamation.

Habitats between Luscar and Gregg River are contiguous and there are no man-made boundaries to limit animal movement. To the east of the mines, human activities include motorized and nonmotorized recreational activity, forest harvesting, and drilling by oil and gas industries. Highway 40 receives heavy vehicular traffic and is the main road that services the mines and the hamlet of Cadomin. Protected land (Whitehorse Wildland Provincial Park and Jasper National Park) dominates the west side of the mines. Nonmotorized public trails exist on the reclaimed mines and allow passage to the wildlife management units to the west, mainly for hunting.

Ungulate Surveys

Bighorn Wildlife Technologies Ltd. (BWT; Hinton, Alberta) conducted direct ground counts of ungulates between 2004

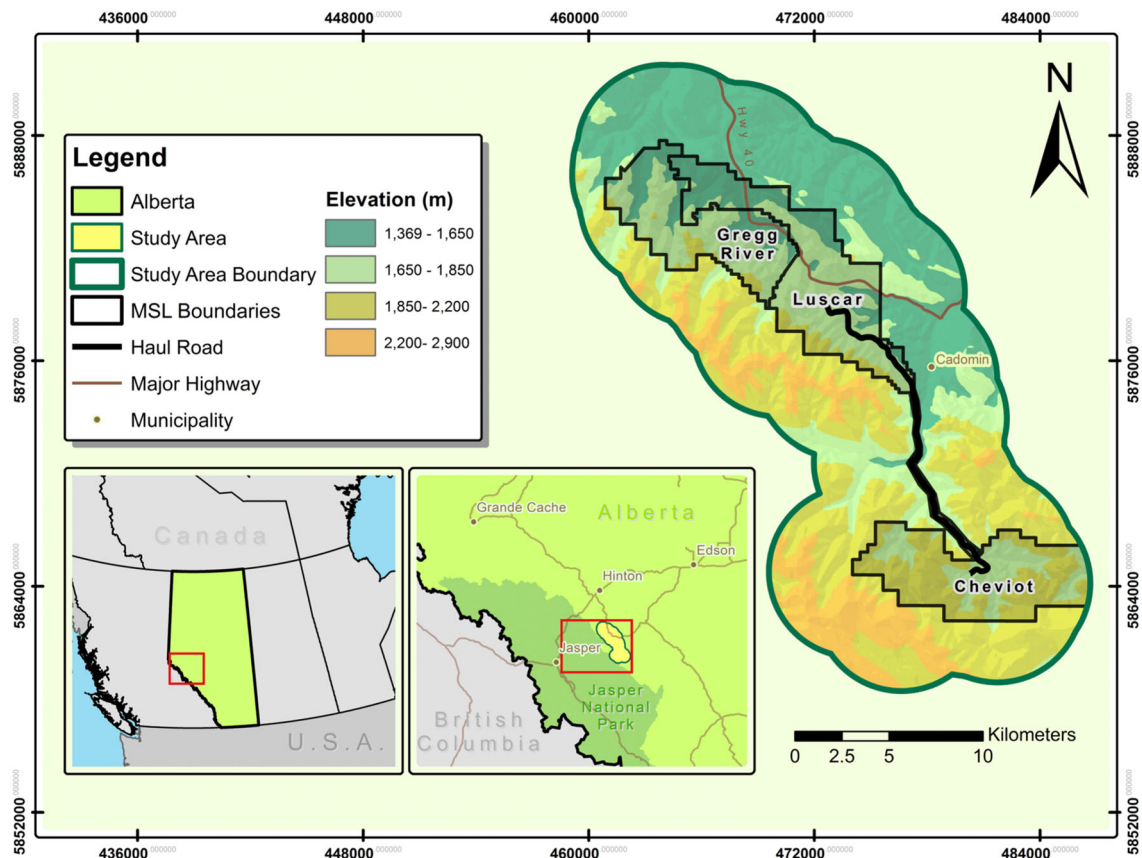


Figure 1. Three open-pit coal mines, Gregg River, Luscar, and Cheviot, in west-central Alberta, Canada. The mines are located east of Jasper National Park, southwest of Hinton, and west of Cadomin, Alberta.

and 2017, using a fixed survey route (Fig. 2), 4–6 times per year ($\bar{x} = 4.1$) during diurnal periods of the day. BWT made observations by vehicle or by foot using a spotting scope or binoculars to locate groups of ungulates and record species. BWT defined groups based on spatial aggregation, life histories, and behavioral traits of each species, e.g. sheep spatially aggregate into ram and nursery groups (Geist & Petocz 1977), so that they could estimate the geographical location of each group centroid. If groups moved during observation, they recorded the initial centroid location. If the entire survey route could not be completed, results were not included for analyses. We defined the extent of our study area by applying a buffer twice the distance of our furthest ungulate centroid to the survey route (i.e. 4,538-m buffer) as recommended by Buckland et al. (2001).

We created a grid of 12,373 nonoverlapping 200×200 -m grid cells covering the study area. We selected this grid size in an effort to encompass any positional sampling error in ungulate centroids. We estimated positional sampling error using the Viewshed tool in ArcGIS (ESRI 2017). The Viewshed tool uses a 25-m resolution digital elevation model (DEM; AltaLIS 2019) and an observer survey route as input to determine areas that are visible and nonvisible from the survey route, based on topography. We determined ungulate centroids that were located in non-visible areas ($n = 22$) and calculated the Euclidean distance to

nearest visible area. The maximum distance was 50 m, which we assumed was a conservative estimate of positional sampling error. Further, we chose to use grid cells to account for the subjective nature of a human observer defining an ungulate group. We assigned each ungulate centroid to a grid cell based on geographical location.

Correcting for Detectability

We examined ungulate detectability in two vegetation classes using program DISTANCE version 7.1, Release 1 (Thomas et al. 2010). We stratified our study area due to detection differences in open versus forested vegetation classes. We pooled annual data between 2004 and 2017 for each of the target species, for two vegetation classes, creating a total of six detectability analyses. We assigned vegetation class based on land cover classification data (see below for development of these data). We considered grasslands, shrubs, nonvegetated (barren/rocky), and water to be open vegetation classes, because these classes do not have canopy cover. For each vegetation class and species, we calculated the perpendicular distance from each ungulate centroid to the nearest point on the survey route.

For each vegetation class and species, we fit a preliminary model, a half-normal key function with a cosine-series expansion,

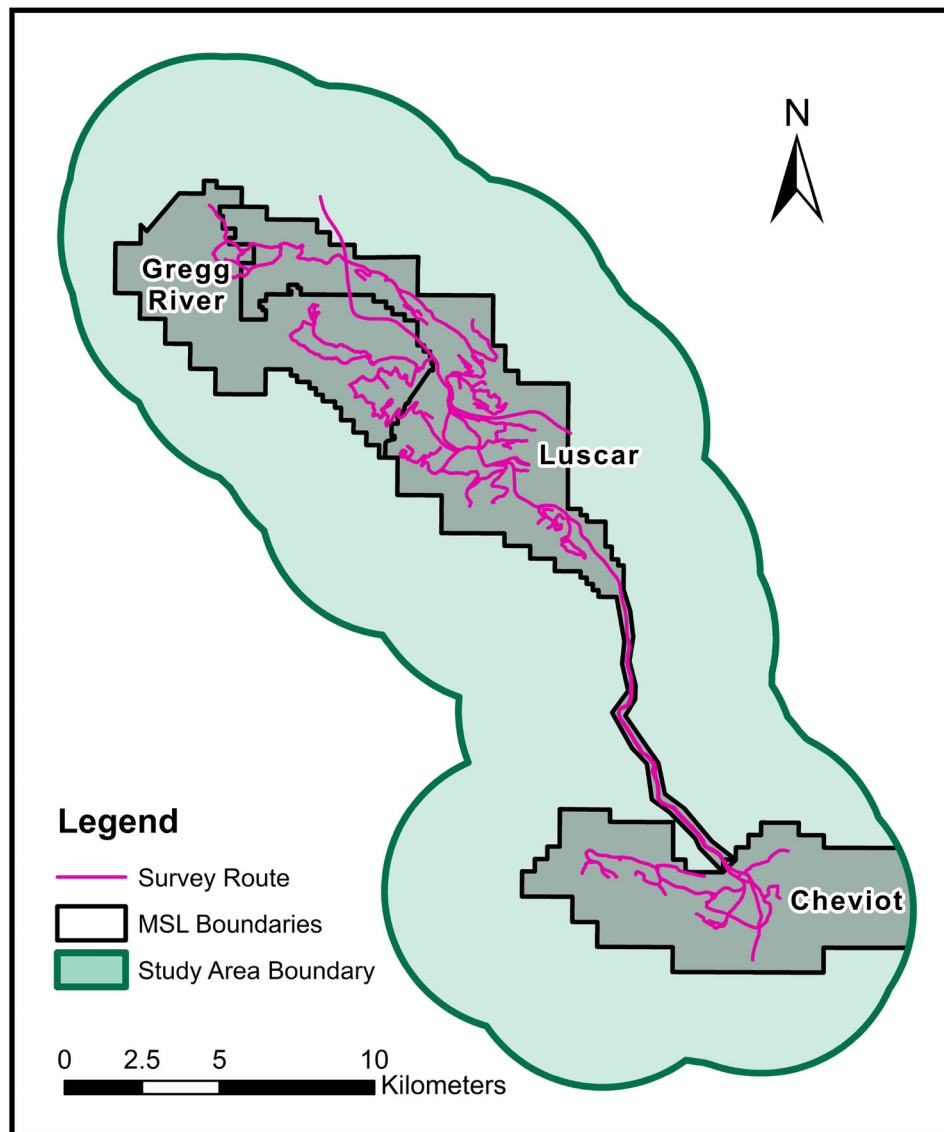


Figure 2. Survey route used to directly observe bighorn sheep, elk, and mule deer at Cheviot, Gregg River, and Luscar in west-central Alberta, Canada.

to nontruncated data as recommended by Buckland et al. (2001). We examined histograms to determine the right-truncation distance w where $g(w) = 0.15$ (Table S1) for each vegetation class and species. Here, the truncation distance represents the distance at which detections drop and observations become unreliable (Buckland et al. 2001). We truncated our modeling dataset to remove observations farther than the minimum truncation distance for each species to ensure that we modeled habitat selection with grid cells that were observed reliably.

To remove observations beyond truncation distances, we first assigned a distance from each grid cell to the survey route. To do this, we subdivided each 200×200 -m grid cell into one hundred 20×20 -m pixels. We calculated the perpendicular distance from each pixel centroid to the nearest point on the survey route. Within each 200×200 -m grid cell, we calculated the mean distance to survey route for $n = 100$ pixels and assigned

the mean distance to each grid cell. We chose this method to ensure that the tortuosity and configuration of the survey route were accounted for when calculating mean distances to assign per grid cell. Then we removed grid cells with mean distances $>w$, based on w for each species, from further habitat modeling.

Landscape Features

We created a database of biologically relevant landscape features (Table 1) to be used as covariates. We obtained spatial data from numerous sources including Foothills Research Institute (Hinton, Alberta, Canada), Teck, BWT, and GeoBase Series (Natural Resources Canada). We obtained spatial data for years 2004–2010 from Cristescu et al. (2016), as these layers were created for previous research on the study area and already represented annual landscape changes. We updated all spatial data

Table 1. Summary of landscape features as covariates for modeling ungulate habitat use on reclaimed mines in west-central Alberta. When using “distance to” we mean “distance to nearest” feature. Covariate code, type of variable, and units are displayed. Distance to forest, riparian area, and reclaimed grassland were included in elk and mule deer models only. Distance to high wall was included in bighorn sheep models only.

Covariate	Covariate code	Type of variable	Unit
Nonmining specific features			
Distance to forest	forest	Continuous	Meters
Distance to main road	road	Continuous	Meters
Distance to other grassland	grass	Continuous	Meters
Distance to riparian area	riparian	Continuous	Meters
Terrain ruggedness index	TRI	Continuous	Unitless
Relative topographic position index	RTP	Continuous	Unitless
Mining specific features			
Distance to high wall	highwall	Continuous	Meters
Distance to haul road	haul road	Continuous	Meters
Proportion edge habitat	edge	Continuous	Unitless
Distance to disturbed areas	disturbed	Continuous	Meters
Distance to reclaimed grassland	r.grass	Continuous	Meters

between 2011 and 2017 to reflect annual landscape changes by interpreting annual orthorectified aerial photography, following Cristescu et al. (2016) to ensure consistency. Progress in mining and reclamation is represented through annually updated spatial layers.

We obtained annual land cover classification data (grain: 30×30 m), which categorized our study area into five categories (McDermid 2005). We defined edge as the linear boundary between forest land cover and another nonforest land cover classification, to represent forest edge habitats. We did not differentiate between edges created by mining activities and edges caused by either alternative processes (e.g. highways, naturally occurring rugged terrain). We applied a 20-m buffer on both the inside and outside of all edges to represent where common predators of ungulates, such as cougars (*Puma concolor*), hunt (Holmes & Laundre 2006).

We split all grassland land cover into either reclaimed or other grasslands. We defined reclaimed grasslands as areas deliberately seeded post-coal mining with agronomic species. We titled all grassland that was not introduced through mining reclamation as “other grassland”; other grasslands arose due to a combination of anthropogenic activities (other than mining) and natural processes. We separated reclaimed and other grasslands to discern the contribution of post-mining reclamation from the contribution of alternative anthropogenic activities on ungulate habitat selection in our study area. We represented areas adjacent to rivers and streams (permanent and ephemeral) as riparian areas. We defined haul roads as wide gravel roads (3–4 lanes) on

the mines that received regular daily traffic from heavy equipment. We defined main roads as roads with ≥ 2 lanes, servicing areas off the mines. We defined disturbed areas as actively or inactively mined areas, excluding the haul road. Actively disturbed areas receive regular and predictable human activity, 24 hours per day. Active areas may become inactive, and human activity in the inactive area ceases. However, the landscape remains disturbed in inactive areas. We represented bench walls, foot walls, and free-dumped talus as high walls. For each landscape feature, we created a raster layer to represent the Euclidean distance from the center of each grid cell to the nearest point of each respective feature. For edge, we calculated the proportion of edge habitat within each grid cell.

We used DEMs to calculate a terrain ruggedness index (TRI; Riley et al. 1999) and a relative topographic position index (RTP; Jenness 2006). TRI is an index used to measure the elevation difference between neighboring cells in a DEM. RTP compares the elevation of each cell in a DEM to the mean elevation of neighboring cells. Positive RTPs indicate the cell is higher than its surroundings and negative RTPs indicate the cell is lower than its surroundings. We assigned TRI and RTP based on the mean value across each grid cell.

For each species, we employed a used versus available design (Manly et al. 2002; Johnson et al. 2006) to create an exponential resource selection function (RSF), fitted with logistic regression:

$$RSF(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \dots + \beta_n x_n)$$

where β_i represents the selection coefficient for covariate x_i , for n total covariates. Our study area was constrained based on the distance between observed ungulates and the survey route, so the study area did not fully encompass ungulate home ranges nor was it constrained enough to model fine scale habitat selection. Thus, we effectively evaluated habitat selection between the third and fourth order scales (Johnson 1980). Because ungulates were surveyed a mean of 4.1 times per year, surveys represented instantaneous habitat selection and we could not be certain how each species was selecting habitats during the remainder of each year. Thus, we interpreted grid cells with greater than 0 ungulate centroids as each species’ “used” habitats among a set of “available” habitats. We defined available habitats as a random sample of grid cells within the specific truncation distance for each species (Table S1). We selected available habitats at a ratio of 1 used to 5 available grid cells, based on the mean number of grid cells used annually. We investigated alternate ratios of used to available grid cells but found that beta coefficient estimates for covariates resulted in similar conclusions, regardless of the ratio employed. We replicated the same suite of available grid cells each year for the 14-year study period to represent the same domain of availability each year. We pooled observations annually to conserve sample sizes (Table S2), which limited our ability to decipher seasonal differences in habitat selection.

We designed each species’ candidate set of models a priori (Table 2). We used base models to account for covariates that we anticipated would be most important to each species

Table 2. A priori candidate model sets for the analysis of bighorn sheep, elk, and mule deer habitat selection on reclaimed mines. Separate model sets were created for bighorn sheep and elk & mule deer to reflect different biologically relevant covariates that were considered for each species. A random intercept for year is notated by “(1year)”.

Model	Explanatory Variables	What Does Model Evaluate?
Bighorn sheep		
Null	(1year)	Landscape features predict habitat selection
Base	highwall + edge + RTP + (1year)	Avoid predation by cougars and wolves, and maintain unobstructed views
1	Base + disturbed	Avoid only disturbed areas
2	Base + haul.road	Avoid only haul roads
3	Base + disturbed + haul.road	Avoid only mining disturbances
4	Base + disturbed + haul.road + road	Avoid all disturbances
5	Model 3 + grass	Avoid other grasslands
6	Model 4 + grass	Avoid other grasslands
7	Model 3 + grass + TRI	Select rugged terrain
8	Model 4 + grass + TRI	Select rugged terrain
Elk & Mule deer		
Null	(1year)	Landscape features predict habitat selection
Base	r.grass + forest + RTP + TRI + riparian + (1year)	Select habitat as a trade-off between acquiring forage and minimizing predation risk
1	Base + disturbed	Avoid only disturbed areas
2	Base + haul.road	Avoid only haul roads
3	Base + disturbed + haul.road	Avoid only mining disturbances
4	Base + disturbed + haul.road + road	Avoid all disturbances
5	Model 3 + grass	Avoid other grasslands
6	Model 4 + grass	Avoid other grasslands
7	Model 3 + grass + edge	Avoid increased edge habitat on mines
8	Model 4 + grass + edge	Avoid increased edge habitat on mines

(i.e. based on support from the literature and field observations). Base models helped to reduce the overall number of models in candidate sets while still evaluating hypotheses related to remaining covariates (i.e. distance to disturbed areas, haul roads, main roads, other grasslands, and TRI). We standardized ($\bar{x} = 0$, $SD = 1$) all continuous covariates, then tested for multicollinearity using Pearson's correlation coefficient. We included only biologically relevant covariates that were not highly correlated ($|r| < 0.70$) in each model. Because distance to high wall and distance to reclaimed grassland were highly correlated, we did not include both covariates. We included distance to high wall in bighorn sheep models because bighorn dependence on escape terrain is well documented (Smith et al. 1991; Andrew et al. 1999; Singer et al. 2000; Bleich et al. 2009). Moreover, we included distance to reclaimed grassland in elk and mule deer models because high walls have little biological significance to either species. We did not consider distance to forest or riparian areas in bighorn sheep models.

We included a random intercept for year in all models to account for annual variation in habitat selection. By combining all years into one dataset and applying a random intercept for year, we treated subsequent years as replicates. We submit that in doing so, we were unable to make predictions about habitat selection for individual years during our study period. The goal of our analysis, however, was to provide robust estimates of habitat selection, independent of any particular year, which was achievable given our methodology.

We calculated Akaike's information criterion corrected for small sample size (AICc) and Akaike weights (Burnham & Anderson 2002) for each model in a candidate set. We considered models with $\Delta AICc$ less than 2.0 as competitive (Burnham & Anderson 2002), and used AICc and parsimony to select the top model (i.e. the top model is the competitive model with the fewest parameters). We validated top habitat-selection models with 5-fold cross validation (Boyce et al. 2002). We divided data into 5 folds and tested the relationship between area-adjusted frequency of predicted "used" observations and 10 RSF bin ranks, for each of the 5 folds. We used the mean Spearman's rank correlation coefficient (\bar{r}_s) averaged across all folds to determine the predictive capability for each top RSF model.

We compared scaled beta coefficients for landscape covariates to quantify whether a species had a strong, moderate, or weak strength of response to reclamation, which facilitated comparison of differential habitat selection among study species. For ease of discussion, we classified strong selection as $\beta \geq 1$, moderate selection as $0.2 \leq \beta < 1$, and weak selection as $0 < \beta < 0.2$ and classified strong avoidance as $\beta \leq -1$, moderate avoidance as $-0.2 \geq \beta > -1$, and weak avoidance as $0 > \beta > -0.2$. We classified covariates with betas where 95% confidence intervals overlapped 0 as having no effect. Finally, to visualize differential ungulate habitat selection spatially, we created predictive maps using top RSF models for each species. Predictive maps were created for the entire study area (i.e. beyond truncation distances) in ArcGIS using unscaled beta coefficients from top habitat-selection models. Predictive maps were symbolized using equal interval bins for ease of interpretation.

Results

We observed bighorn sheep, elk, and mule deer using 2,871, 819, and 782 grid cells, respectively, between 2004 and 2017. The top model for bighorn sheep included the base model in addition to disturbed areas, haul roads, main roads, and other grasslands (Model 6, Table S3). For elk, the top model included the base model, in addition to various mining-specific features and other grasslands (Model 5, Table S3). Similarly, the top model for mule deer included the base model in addition to various mining-specific features (Model 6, Table S3). All species' models exhibited high predictive capability (Table 3).

As expected, bighorn sheep exhibited strong selection for high walls ($\beta_{\text{highwall}} = -8.04$, $SE = 0.36$; Table S4). Bighorn sheep also exhibited moderate selection for high RTP, moderate avoidance of other grasslands, edge habitat, and haul roads, as well as weak selection for disturbed areas and main roads ($\beta_{\text{RTP}} = 0.28$, $SE = 0.02$; $\beta_{\text{grass}} = 0.38$, $SE = 0.03$; $\beta_{\text{edge}} = -0.31$, $SE = 0.03$; $\beta_{\text{haul. road}} = -0.21$, $SE = 0.04$; $\beta_{\text{disturbed}} = -0.05$, $SE = 0.04$; $\beta_{\text{road}} = -0.10$, $SE = 0.03$; Table S4). Similar to bighorn sheep, elk exhibited moderate selection for high RTP and weak avoidance of other grasslands ($\beta_{\text{RTP}} = 0.23$, $SE = 0.04$; $\beta_{\text{grass}} = 0.09$, $SE = 0.05$; Table S4).

In contrast to bighorn sheep, elk exhibited stronger selection for haul roads and avoidance of disturbed areas ($\beta_{\text{haul. road}} = -0.30$, $SE = 0.07$; $\beta_{\text{disturbed}} = 0.32$, $SE = 0.06$; Table S4). Elk, however, strongly selected reclaimed grasslands, as we predicted ($\beta_{\text{r. grass}} = -0.89$, $SE = 0.17$; Table S4). Elk also moderately avoided riparian areas and rugged terrain, and weakly avoided forests ($\beta_{\text{riparian}} = 0.31$, $SE = 0.04$; $\beta_{\text{TRI}} = -0.36$, $SE = 0.04$; $\beta_{\text{forest}} = 0.07$, $SE = 0.04$; Table S4).

Comparable to elk, mule deer strongly selected reclaimed grasslands, moderately avoided riparian areas and rugged terrain, and weakly avoided forests ($\beta_{\text{r. grass}} = -1.27$, $SE = 0.19$; $\beta_{\text{riparian}} = 0.10$, $SE = 0.05$; $\beta_{\text{TRI}} = -0.23$, $SE = 0.05$; $\beta_{\text{forest}} = 0.11$, $SE = 0.05$; Table S4). Mule deer more strongly selected disturbed areas than bighorn sheep and more strongly avoided other grasslands than elk ($\beta_{\text{disturbed}} = -0.26$, $SE = 0.06$; $\beta_{\text{grass}} = 0.41$, $SE = 0.05$; Table S4). Moreover, mule deer moderately avoided haul roads, which was opposite to both bighorn sheep and elk ($\beta_{\text{haul. road}} = 0.45$, $SE = 0.07$; Table S4). Lastly, mule deer exhibited weaker selection for high RTP than both other species ($\beta_{\text{RTP}} = 0.19$, $SE = 0.04$; Table S4).

Areas of high relative habitat selection by bighorn sheep were tightly clustered around reclaimed grasslands within 300 m of high walls (Figs. 3 & 4). In contrast, areas of high relative habitat selection by elk were centered around reclaimed grasslands but also spread widely throughout the study area (Figs. 3 & 5). Areas of high relative selection by mule deer were slightly more dispersed than sheep and also appear to be more tightly clustered around reclaimed grasslands than elk (Figs. 3 & 6).

Discussion

We showed that direct relationships between ungulate populations and re-established landscapes existed on three reclaimed coal mines in west-central Alberta. We also demonstrated that

Table 3. Summary of 5-fold cross validation results for top habitat selection models for bighorn sheep, elk, and mule deer. A mean Spearman's rank correlation coefficient (\bar{r}_s) and p -value are provided. Signs indicate the sign of the beta coefficient estimates. \bar{r}_s and p -values presented are means across 5 folds.

Species	Top Model	\bar{r}_s	p Value
Bighorn sheep	– highwall – edge + RTP – disturbed – haul.road – road + grass + (1year)	0.94	<0.001
Elk	– r.grass + forest + RTP – TRI + riparian + disturbed – haul.road + grass + (1year)	0.89	<0.01
Mule deer	– r.grass + forest + RTP – TRI + riparian – disturbed + haul. road + grass + (1year)	0.94	<0.001

reclamation success can be evaluated by considering higher trophic levels and illustrated that the reclamation prescription applied in our study area was highly effective at providing habitat features for ungulates. Both elk and mule deer selected reclaimed grasslands, presumably to forage on high-quality forage (Torstenson et al. 2006; Webb et al. 2013; DeVore et al. 2016), including a variety of agronomic grasses and legumes such as alfalfa (*Medicago sativa*), civer milkvetch (*Astragalus cicer*), and clover (*Trifolium* spp.), that were seeded during reclamation (MacCallum & Geist 1992). Bighorn sheep, however, strongly selected the high walls left by design after coal extraction, which emphasized how critical escape terrain is to bighorn sheep (Smith et al. 1991; Andrew et al. 1999; Singer et al. 2000; Bleich et al. 2009).

Ungulates responded to disturbed features in ways that we did not anticipate, suggesting that ungulates can tolerate and even integrate disturbed features on reclaimed mines into their respective niches. Bighorn sheep selected disturbed areas, haul roads, and main roads. Elk, however, selected haul roads but avoided disturbed areas. Bighorn sheep are sensitive to unpredictable events (MacArthur et al. 1982), when sheep cannot predict how humans will behave (i.e. erratic human recreation; Wiedmann & Bleich 2014), but can habituate to predictable human disturbance (Hicks & Elder 1979; MacArthur et al. 1982) when human behavior is relatively predictable. Most mining activities in our study area are predictable. In disturbed areas, humans operate heavy equipment to remove coal without directly interacting with wildlife. Furthermore, predators often avoid humans (Hebblewhite et al. 2005; Ordiz et al. 2011; Morrison et al. 2014; Jennings et al. 2016), lowering predation risk and creating refuges for prey in the areas that predators avoid (Hebblewhite & Merrill 2007; Schmidt & Kuijper 2015). Bighorn sheep might have sought human refuge in disturbed areas and near haul roads to take advantage of reduced predation risk. Elk also seek human refuge as an anti-predator strategy (Hebblewhite & Merrill 2007; Shannon et al. 2014), but disturbed areas and haul roads might not equally provide human refuge for elk. Further, we often observed bighorn sheep licking segments of haul roads and main roads, as well as vehicles parked in disturbed areas, which supports that sheep selected these areas for their source of minerals.

Mule deer selected disturbed areas and avoided haul roads, and avoidance of haul roads was unique to mule deer. Mule deer might be displaced to lower-quality habitats to avoid competition with elk (Johnson et al. 2000; Ager et al. 2003; Stewart et al. 2010; Lendrum et al. 2012), which could support why mule deer avoided the same haul roads that elk selected. Alternatively, mule deer might not rely on human refuge as an anti-predator strategy and instead rely on topography and rugged terrain to detect and avoid predators, respectively (Lingle 2002; Lingle et al. 2008).

Ungulates selected habitat features to decrease predation risk. All study species selected high RTPs, which provide unobstructed visibility, early detection of predators, and an advantageous position for escaping relative to local topography (Kuck et al. 1985; Cassirer et al. 1992; Kunkel & Pletscher 2001; Mao et al. 2005). Elk avoided rugged terrain and forests and, as an alternative to

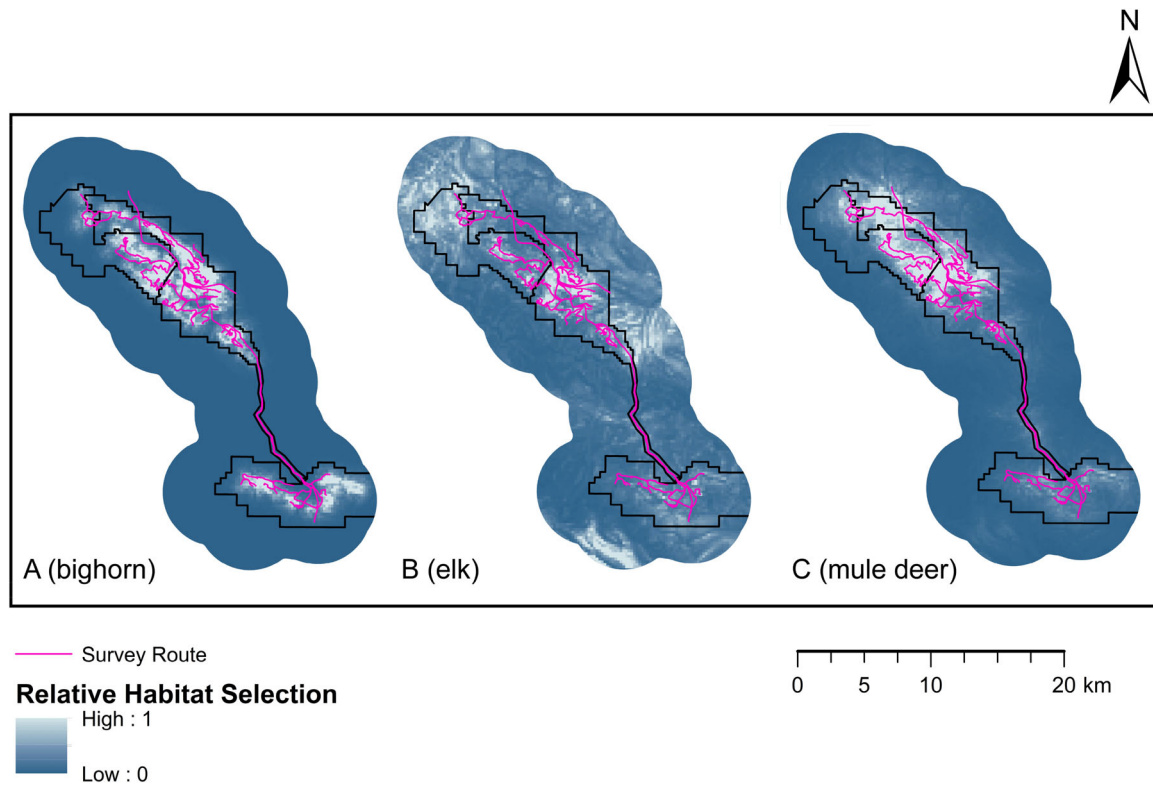


Figure 3. Predicted relative habitat selection for bighorn sheep (A), elk (B), and mule deer (C) during 2017 in the west-central Alberta study area, which encompasses three mines (outlined in black). Relative habitat selection was determined by fitting exponential RSFs, selecting a top model, and scaling predictions between 0 (low relative habitat selection; dark blue) and 1 (high relative habitat selection; light blue) for each species.

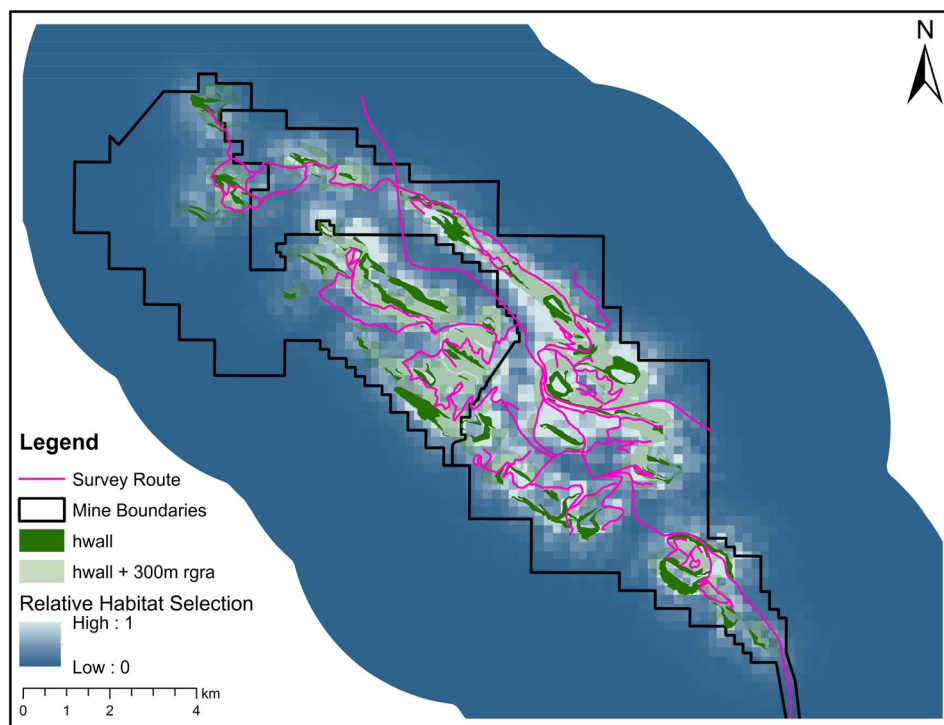


Figure 4. Predicted relative habitat selection for bighorn sheep on Gregg River and Luscar mines (outlined in black) in relation to high walls (dark green). Reclaimed grasslands (rgra) within 300 m of high walls are symbolized in translucent green (Smith et al. 1991). Relative habitat selection is scaled between 0 (low, dark blue) and 1 (high, light blue). Landscape data from 2017 were used to create this map.

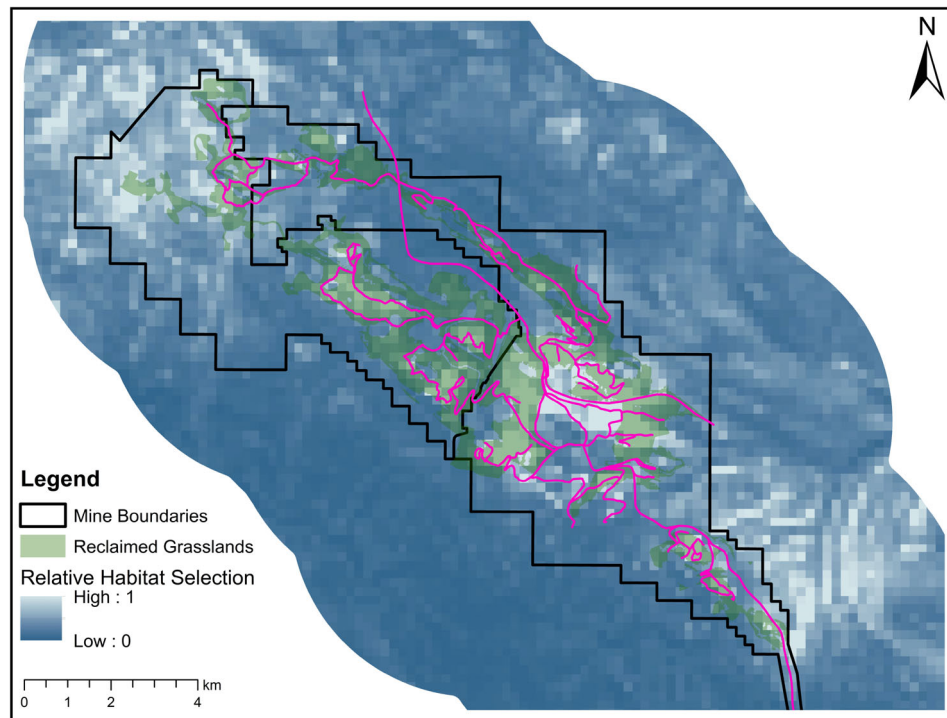


Figure 5. Predicted relative habitat selection for elk on Gregg River and Luscar mines (outlined in black) in relation to reclaimed grasslands (translucent green). Relative habitat selection is scaled between 0 (low, dark blue) and 1 (high, light blue). Landscape data from 2017 were used to create this map.

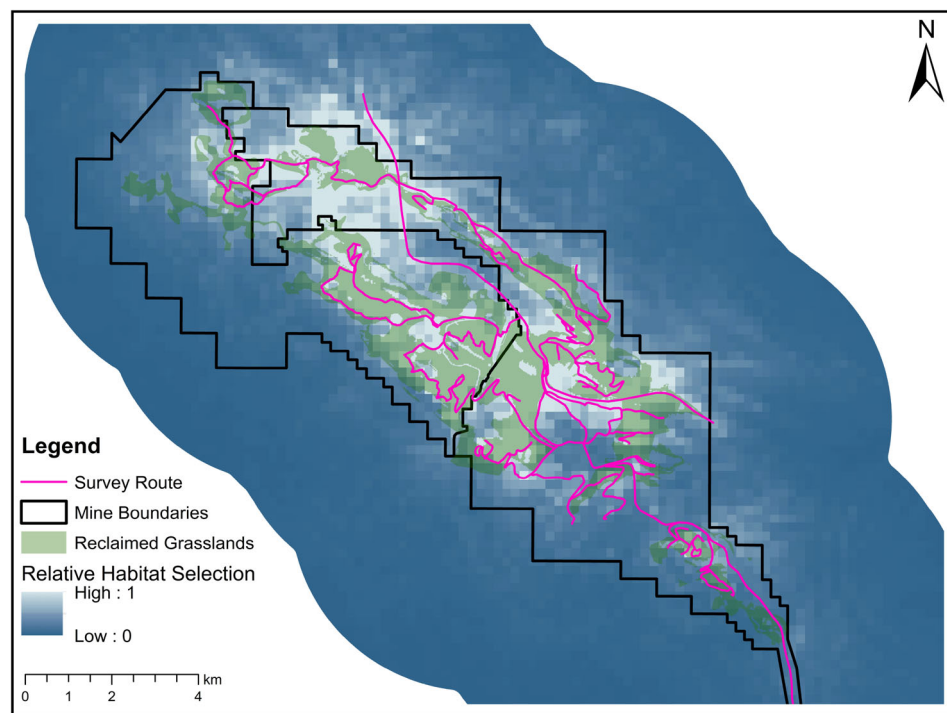


Figure 6. Predicted relative habitat selection for mule deer on Gregg River and Luscar mines (outlined in black) in relation to reclaimed grasslands (translucent green). Relative habitat selection is scaled between 0 (low, dark blue) and 1 (high, light blue). Landscape data from 2017 were used to create this map.

seeking forest cover (Creel et al. 2005), elk might have instead congregated into large groups to dilute individual risk of predation (Hamilton 1971; Dehn 1990; Jedrezejewski et al. 1992; Hebblewhite & Pletscher 2002). Both elk and mule deer avoided riparian areas, which are travel paths for cougars (Dickson & Beier 2002) and wolves (*Canis lupus*; Kunkel & Pletscher 2000, 2001; Bergman et al. 2006; Kauffman et al. 2007), both of which are present in the study area. However, only bighorn sheep avoided edge habitats. Cougars use forest edges (Holmes & Laundre 2006) to stalk and ambush prey (Beier et al. 1995) and can be highly effective predators on bighorn sheep (Ross et al. 1997; Rominger 2018), which might explain why bighorn sheep were the only ungulate to avoid forest edges. Alternatively, bighorn sheep might simply avoid forests. Further, the temporal scale at which ungulates escape predation likely differed from the annualized observations that were conducted, which might explain inconsistencies in ungulate predator-avoidance strategies and the patterns of habitat selection that we observed. Ungulates also might exhibit varying habitat selection during crepuscular and nocturnal periods that were not observable with diurnal surveys (Kohl et al. 2018), thus restricting our inference regarding selection to diurnal periods.

Predictive maps illustrated that reclaimed features were used variably across species and supported that reclamation efforts should target a breadth of habitat features to attract multiple ungulate species. Bighorn sheep exhibited strong fidelity to reclaimed features, while elk were spread widely, and mule deer fell somewhere in the middle between sheep and elk. Predictive maps also indicated that all study species were unlikely to select habitats outside the mine boundaries, which might have been due to the placement of the survey route within the mine boundaries. Further, removing potentially unreliable observations of ungulates outside truncation distances could have reduced the variability of habitats in which ungulates were observed, resulting in high relative habitat selection near the survey route.

In our study, we employed a statistical modeling method (i.e. resource selection functions) to evaluate relationships between recolonized wildlife and restored landscapes. Our approach not only focused on assessing higher trophic levels, but also focused on evaluating reclamation success in a province where no regulations or benchmarks for determining reclamation success yet exist. In some cases, reclamation fails to reestablish wildlife populations (Larkin et al. 2008; Bennett et al. 2013; Peipoch et al. 2015) and may occur for a number of reasons, including lack of landscape connectivity (Larkin et al. 2008; Peipoch et al. 2015), heterogeneity (Larkin et al. 2008; Peipoch et al. 2015), quality (Bennett et al. 2013), and complexity (Manning et al. 2013). Although ecologists must consider abiotic parameters, landscape heterogeneity, and vegetation communities when evaluating successful ecological reclamation, spatial relationships affording the reclamation of higher trophic levels also must be a consideration for restoring functioning ecosystems (Fraser et al. 2015; Jones & Davidson 2016).

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Summary of truncation distances and subsequent grid cells removed for each species and vegetation class (veg. class).

Table S2. Sample size of “used” grid cells for bighorn sheep, elk, and mule deer for logistic regression, when considering data split into four seasons, two seasons, and when seasons are pooled.

Table S3. Top-ranked logistic regression models to estimate habitat selection for bighorn sheep, elk, and mule deer on reclaimed mines in west-central Alberta, Canada.

Table S4. Scaled beta coefficients and 95% confidence intervals (CI) from top habitat selection models for bighorn sheep, elk, and mule deer, comparing used grid cells (bighorn $n = 2,871$, elk $n = 819$, mule deer $n = 782$) to available grid cells.

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