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Identification of Priority Areas for Grizzly Bear Conservation and Recovery in Alberta, Canada

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ABSTRACT: In Alberta, Canada, high rates of human-caused mortality threaten the long-term persistence of grizzly bears. To reduce this threat, the provincial grizzly bear recovery team suggested that core conservation areas of at least 2,400 km^2 be delineated for each of seven population units where open access road density is limited to 0.6 km/km^2 and buffered by secondary conservation areas where road density is limited to 1.2 km/km^2. We used a habitat model based on 81 radio-collared grizzly bears and a road network to identify core conservation areas for six population units using two comparative techniques: (1) simulated annealing; and (2) contours of safe harbor habitat – an index of secure habitat. Model effectiveness was evaluated by comparing grizzly bear detections (occupancy) in conservation areas to existing protected areas at 2,295 hair-snag sites. Habitat was similar among techniques, while simulated annealing resulted in lower road densities and higher occupancy rates. Overlap among techniques was 46% of combined area. Using results from both analyses, Alberta Sustainable Resource Development modified core areas to follow watershed boundaries, nearly doubling their extent to 33,364 km^2. Secondary conservation areas buffering and/or connecting core areas added an additional 23,224 km^2. Grizzly bear occupancy in final core areas did not differ significantly from protected areas, while occupancy was 4 to 6 times lower in secondary conservation areas. We suggest that the comparative modeling approach used strengthened decision support and value of models and that effectiveness monitoring and adaptive management be used to adjust future management strategies and locations of core area boundaries.

Keywords: Alberta, conservation areas, grizzly bears, habitat, road density, Ursus arctos

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INTRODUCTION

Grizzly bears (*Ursus arctos* L.) are a conservation icon in North America, frequently used as a focal and/or flagship species for conservation (Noss et al. 1996, Simberloff 1999, Carroll et al. 2001). Like many of the large mammalian carnivores, grizzly bears have low fecundity and large area requirements (low density) making them vulnerable to population decline and their recovery slow (Russell et al. 1998, Purvis et al. 2000). Remaining populations are most often associated with areas of low human density reflecting the importance of recent land use change and negative consequences of human-caused mortality (McLellan 1998, Woodroffe 2000, Mattson and Merrill 2002). In the contiguous USA, grizzly bear populations occupy about 1% of historic range with little hope of large-scale recovery (Servheen 1990, see however, Pyare et al. 2004 for an example of local recovery). Long-term viability for many remaining grizzly bear populations remains tenuous and largely predicated by connectivity to Canadian populations (Proctor et al. 2004, 2005). Although Canadian populations are more secure, they have also declined with prairie populations being extirpated and remaining populations listed as a *species of special concern* by the Committee on the Status of Endangered Wildlife In Canada (COSEWIC; Ross 2002).

Alberta represents the contemporary eastern limit of grizzly bear range in southern Canada, occupying the western fringe of the province. Populations are small relative to most other studied populations with only 229 individuals estimated for a 27,733 km^2 area of provincial and federal public lands bordering Jasper and Banff National Parks (Boulanger et al. 2005a, 2005b, 2007, 2008). This is approximately one quarter the density observed in nearby greater Glacier National Park area of Montana (240 grizzlies across 7,933 km^2) using similar survey techniques (Kendall et al. 2008). Since environmental conditions are generally comparable between the Glacier and Alberta areas, most consider the Alberta population to have declined substantially from historic levels with declines likely reflecting recent increases in human access and activity from energy (coal, natural gas, and oil) and forest extraction industries and local human population growth. As access and human activity increase, bear-human conflicts correspondingly increase resulting in lower survival rates (Mattson et al. 1996). Even in Alberta's protected areas where access and human activity are high, the vast majority of adult grizzly bear mortalities are human-caused (Benn and Herrero 2002, Nielsen et al. 2004a), illustrating the need to manage human access and activity rather than land use activity.

Given small and declining populations, as well as rapid growth in human access and activity, the province of Alberta established a Grizzly Bear Recovery Team in 2003. Recently, the team recommended that core conservation areas of at least 2,400 km^2 (approximating the extent of four female home ranges along the eastern slopes of Alberta) be delineated for each of seven grizzly bear population units in Alberta (Alberta Grizzly Bear Recovery Plan 2008), recognizing that there could be more than one core area in each population unit and that linkages and buffers among core areas should be considered for population dispersal and security. It was suggested by the recovery team that within each core conservation area open route (roads and trails on which motorized traffic is possible) density should be limited to 0.6 km/km^2 and linkages or buffers referred to as secondary conservation areas should have open route density limited to 1.2 km/km^2.

In this paper we identify grizzly bear conservation areas for six of the seven population units in Alberta where research using radio-telemetry has been on-going since 1999. Our objective was to follow the guidelines of the Alberta Grizzly Bear Recovery Plan (2008) by identifying core conservation areas totaling at least 2,400 km^2 for each population unit and evaluating their current effectiveness based on occupancy patterns of grizzly bears. Our strategy was to compare two techniques using the same habitat and road density information: (1) simulated annealing using the conservation planning software MARXAN (Ball and Possingham 2000); and (2) GIS contours of safe harbor habitat (Nielsen et al. 2006) that measures habitat quality and security. To evaluate model effectiveness among techniques and final government-selected conservation areas (core and secondary), we compared grizzly bear detections (occupancy) in conservation areas to existing protected areas using hair-snag genetic surveys at 2,295 sites across four of the six studied population units. Hair-snag genetic surveys provide an independent test of the effectiveness of conservation plans (Dixon et al. 2006).

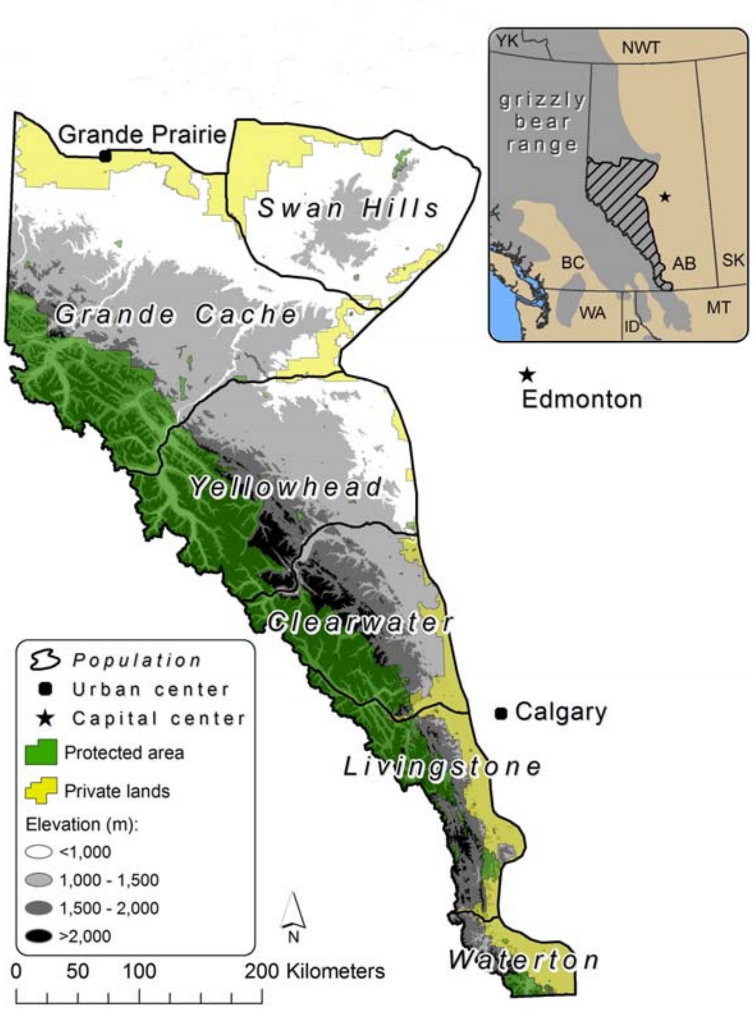
METHODS

Study area

We examined potential conservation areas for unprotected grizzly bear habitat in the east slopes of the Canadian Rocky Mountains in Alberta, Canada (Figure 1). This 132,076-km^2 region represents six of seven grizzly bear population units in Alberta, spans the southwestern border of the Province from Montana in the south to the 120th meridian in the north, and is dominated by mountainous and foothill (rolling forested and agricultural environments) ecosystems (Marshall and Schut 1999; Natural Regions Committee 2006). Elevations range from 218 to 3,747 m with a continental climate of cold winters and short, warm summers in the foothills and cold winters and very short, cool summers in the mountains (Natural Regions Committee 2006). Topographic relief and elevation strongly influence land cover and land use. Alpine meadows and extensive areas of rock and glacier dominate the highest elevations along the British Columbia border, while coniferous, deciduous, and mixed forests dominate the foothills region. Lodgepole pine (*Pinus contorta*), spruce (*Picea englemanii*, *P*. *glauca*, *P*. *mariana*), and fir (*Abies lasiocarpa* and *A*. *balsamea*) are common conifers in the region, while quaking aspen (*Populus tremuloides*) is the most common deciduous species.

Protected areas cover 23% of the region (30,319 km^2), but nearly all (~98%) occur in the mountains along the border of British Columbia. This includes three internationally recognized national parks (UNESCO World Heritage sites) of Jasper, Banff, and Waterton Lakes (18,526 km^2). Given the bias in protection of mountainous habitats, conservation gaps for grizzly bears occur in the foothills where protected areas exist in scattered fragments totaling no more than 2% of existing reserves, less than 1% of available habitat, and no larger than 100 km^2 (12-32% of a grizzly bear home range area; Nielsen et al. 2002, Nielsen 2005). Forestry and energy exploration and development (oil, gas, and coal) have led to a recent and rapid change in land use patterns, landscape characteristics, and human accessibility of the region (Aumann et al. 2007, Yamasaki et al. 2008).

FIGURE 1 Grizzly bear population units of Alberta, Canada.



Grizzly bear habitat model

Grizzly bear habitat was defined for each of the population units using resource selection functions (RSFs); a widely used wildlife habitat modeling technique that compares resource characteristics at animal use locations to random available locations (Manly et al. 2002). When using geo-spatial information (i.e., land cover from a remote sensing classification or terrain-related derivatives from a digital elevation model) to define resources, spatially-explicit predictions of habitat (based on selection) result. Habitat maps can subsequently be used to guide the regional conservation planning process by identifying critical sites for management/conservation or determine the potential impact of future land use activities on habitat security (Carroll et al. 2001, Nielsen et al. 2006, 2008).

We defined resource use for grizzly bears using 121,683 global positioning systems (GPS) telemetry locations acquired between 1999 and 2006 from 81 radio-collared bears (53 females; 28 males). Where possible, models were based solely on adult female grizzly bears (Yellowhead and Clearwater units), since this sex-age class has the highest demographic elasticity (Chapron et al. 2003, Harris et al. 2005) and is generally the focus of conservation efforts. Because habitat use for grizzly bears varies by time of year (Nielsen et al. 2004b, Munro et al. 2006), RSFs were estimated for each of three seasons representing the hypophagia (low food intake) period in the spring after den emergence (1 May to 15 June), the early hyperphagia (high food intake) period in early to mid-summer (16 June to 31 July), and the late hyperphagia period in the late summer and early fall prior to den entry (1 Aug to 15 Oct). For each season and animal, a 10% random sample of use locations was withheld for model validation. Available resources were defined for each animal's multi-annual minimum convex polygon (MCP) home range using random sampling at an intensity of 1 location per km^2. Since resource use and availability were defined for each animal, our analysis followed a design III habitat selection protocol (Thomas and Taylor 1990, Manly et al. 2002).

Sixteen GIS-based predictors were used to describe the RSF with global models estimated for all individuals. Predictors included seven categories of land cover (McDermid 2005), three variables describing forest stand canopy (McDermid 2005), one soil wetness variable (Gessler et al. 1995, Evans 2001) derived from a digital elevation model (DEM), and six distance variables relating to streamside areas and type of forest edge (Table 1, page 42). To mitigate problems related to variable correlation we excluded from the analysis all variables with a Pearson correlation coefficient exceeding an absolute value of 0.7. All distance variables (measured in meters) were transformed to exponential decays of the form $e^{-\alpha d}$ where d was the distance in meters to a landscape feature, and α set at 0.002. This ensured that the effects of local landscape features eroded precipitously beyond a few hundred meters and were essentially irrelevant at large distance (e.g., >1500 m). Exponential decays ranged from 1 at the feature to 0 at very large distances. In order to maintain consistency in interpretation of coefficients (i.e., positive coefficients represent further distances and negative coefficients near distances) the exponential decay variable was subtracted from a value of 1 resulting in distance metric that ranged from 0 at the feature to 1 at very large distances.

We estimated population-level RSF models for each of the six grizzly bear population units following a two-stage modeling process (Aebischer et al. 1993, Manly et al. 2002). In the first stage habitat selection was estimated for each animal (and season) using logistic regression, while in the second stage population estimates are made for each population unit by using a meta-analysis of individual RSF models from that population unit. Due to the small area of the Waterton unit and a small number of collared grizzly bears, this population unit was combined with the Livingstone unit resulting in five separate population-level models. Inverse variance weights were used in the meta-analysis to account for differences in sample sizes among individual bears (RSF models) thereby weighting population-level coefficients more for those animals with large sample sizes (Sutton et al. 2000). This ensured that the unit of replication was appropriately recognized as the individual animal, while further allowing coefficients (slopes) to vary by individual. In effect, this approach duplicated the random effect RSF model proposed by Gillies et al. (2006). We chose to use the two-stage model over that of random effects model from Gillies et al. (2006) since numerous resources were being considered simultaneously making estimation of random slopes for all parameters impractical. All statistical analyses were done in STATA 9 (College Station, Texas).

As the domains of our population-level RSF models were limited to occupied habitats (extent of grizzly bear home ranges), a sub-model representing the regional distribution (occupancy) of female grizzly bears were estimated and used to down-weight habitat values in unoccupied range (i.e., extrapolated regions of the model where grizzly bear distribution is limited). Regional female grizzly bear occupancy was estimated from all known female grizzly bear MCP home ranges south of the city of Grande Prairie, Alberta. A systematic grid of points located every 10-km was generated for the region in a GIS and classified as occupied (occurring within a known home range) or unoccupied (occurring outside a known home range) and the proportion of agriculture and natural sub-region (Natural Regions Committee 2006) within 10 km noted. From these samples, logistic regression was used to estimate the probability of occupancy. Final habitat predictions for each of the six population units were estimated in a GIS as the product of regional female grizzly bear occupancy and population-level RSFs. Map predictions were then categorized into 10 ordinal bins representing the relative probability of habitat selection (Boyce et al. 2002) using the reclassify function (quantiles) in the Spatial Analyst extension of ArcGIS. Map accuracy was assessed for within-sample (model training data) and out-of-sample (randomly withheld observations) animal use locations using the Spearman rank statistic with comparisons made between the rank class of the RSF bin and the frequency (adjusted for unit area) of animal use locations per habitat bin (Boyce et al. 2002).

TABLE 1 Predictor variables used to describe grizzly bear habitat in Alberta, Canada.

Variable	Data range
Landcover	
Upland treed[†]	0 or 1
Wet-treed	0 or 1
Regenerating forest	0 or 1
Shrub	0 or 1
Wet herb	0 or 1
Upland herb	0 or 1
Non-vegetated	0 or 1
Forest canopy	
Crown closure in treed (wet or upland) sites	1 to 100
Crown closure in regenerating forest	1 to 100
% Conifer canopy in upland treed sites	0 to 100
Soil wetness from a DEM (150 m average)	
Compound topographic index (CTI)	3.4 to 24.0
Distance to (exponential transformation)	
Opening in upland-treed	0 to 1
Opening in wet-treed	0 to 1
Forest edge in upland-herb	0 to 1
Forest edge in regenerating forest	0 to 1
Forest edge in non-vegetated	0 to 1
Stream	0 to 1

[†] Reference category used as an indicator for categorical contrasts.

Identifying conservation areas

We considered two approaches for identifying core conservation areas. First, we used the conservation planning program MARXAN (Ball and Possingham 2000) with the simulated annealing algorithm to identify a portfolio that satisfied the recovery plan goal of protecting the top 2,400 km^2 of unprotected grizzly bear habitat residing in areas of low road density. In our second analysis, we generated an index of secure habitat defined from Nielsen et al. (2006) as the safe harbor index where habitats are highly selected (based on a RSF) and risk of human-caused mortality (in this case measured by motorized road density) is low. Below we describe each approach in more detail.

Simulated annealing

We used systematic conservation planning software MARXAN (Bell and Possingham 2000) with the simulated annealing algorithm to select potential core conservation areas for six grizzly bear population units. Hexagon-shaped planning units, 1-km^2 in size, were generated in a GIS for each population unit and the status identified as protected (existing reserve), excluded (private lands), or available (Crown [public] lands). A habitat value was assigned to each planning unit based on the mean value of multi-seasonal (sum of three seasons) RSF scores. Because the Alberta Grizzly Bear Recovery Plan (2008) suggested two open route density management thresholds of 0.6 and 1.2 km/km^2 for core and secondary recovery areas respectively, we used these thresholds to define a cost (penalty factor) associated with including each planning unit in the final solution. A cost of 1 (equivalent to the area measures in km^2 for any one planning unit) was assigned to planning units having fewer than 0.6 km/km^2 of open roads (data were not available for open route density, so open road density was used instead), a cost of 2 for planning units having 0.6 to 1.2 km/km^2 of open roads (double the prior cost), and finally a cost of 4 for planning units exceeding 1.2 km/km^2 of open roads (again double the prior cost). Because it was desirable to avoid patchy, fragmented conservation areas, we added a boundary length modifier (BLM) to the MARXAN analysis. A BLM of 0.003 was chosen based on initial simulations at 0.001, 0.003, 0.0065, 0.01, 0.1, and 1 and a comparison of average habitat (RSF) scores and compactness of reserve solutions. BLMs lower than 0.003 resulted in fragmented solutions, while BLMs greater than 0.003 resulted in significant reductions in habitat (RSF) scores.

For each population unit, we set a conservation target by multiplying the mean planning unit habitat (RSF) score by 2,400. The simulated annealing algorithm was selected in MARXAN using default values for initial temperature and temperature decreases and run 300 times each at 1,000,000 iterations for each available population unit. Protected and excluded (private lands) units were not used in the analysis. We used the summed solution method (number of times each planning unit was selected out of 300) to quantify irreplaceability of planning units (Ball and Possingham 2000, Noss et al. 2002). Planning units were ranked for each population unit according to irreplaceability and the top 2,400 planning units selected as core conservation areas.

Contours of safe harbor habitat

Using the same habitat (RSF) models and road features used in the simulated annealing analysis, moving windows using the FOCAL STATISTICS function in the Spatial Analyst extension of ArcGIS were used to estimate local and regional patterns in habitat and road density. Open access road density was estimated in 10-km radius, while average multi-seasonal habitat (sum of seasonal RSFs) was analyzed in a 3x3 pixel moving window. Habitat and road density grids were combined to estimate a safe harbor index representing habitats that were high in value and low in risk of mortality (*sensu* Nielsen et al. 2006) with road density assumed to represent a proxy for mortality risk. The safe harbor index was calculated in a GIS using the Spatial Analyst RASTER CALCULATOR function in ArcGIS as the product of the RSF and a transformed index of road density (maximum road density minus observed road density). We identified areas of highest safe harbor habitat (i.e., candidates for core grizzly bear conservation areas) by using the CONTOUR function in the Spatial Analyst extension of ArcGIS. Beginning with contours enclosing the areas of highest safe harbor habitat, we selected successive contours of lower safe harbor habitat until an area of at least 2,400 km^2 was identified.

Core area boundary modifications and locations of secondary conservation areas

Alberta Sustainable Resource Development (hereafter ASRD) personnel examined the results of simulated annealing and contours of safe harbor habitat and made modifications to core area boundaries based on local knowledge of habitat, conservation needs, watershed boundaries, and the desire to minimize habitat fragmentation. In contrast to core conservation areas where explicit analyses were used to recommend potential conservation sites, secondary conservation areas were identified by ASRD staff in a post-hoc manner based on the distribution of selected core conservation areas, the desire to buffer core areas with areas having no more than 1.2 km/km^2 of open routes (recommendation of provincial recovery plan), and to maintain connectivity among population units. Contours of safe harbor habitat and to a lesser extent simulated annealing results were used to guide selection of watersheds for secondary conservation areas.

Effectiveness of core and secondary conservation areas

We evaluated the occupancy of grizzly bears in core and secondary conservation areas compared to protected area (where sampled) as a measure of model effectiveness. Grizzly bear occupancy was based on detections at 2,295 hair-snag genetic survey sites across 27,733 km^2 of range in the Clearwater (Boulanger et al. 2005b), Livingstone (Boulanger et al. 2007), Waterton (Boulanger et al. 2008), and Yellowhead (Boulanger et al. 2005a) population units. Logistic regression was used to estimate the odds of detecting grizzly bears in conservation areas compared to existing protected areas by using protected areas as the reference indicator (benchmark) for all contrasts. Analyses were conducted separately for each of the four population units and stages of analysis. In the first stage, core areas defined by simulated annealing and contours of safe harbor habitat were compared, while final core and secondary conservation areas were compared after final boundaries were established by ASRD. Habitat conditions (standard deviations from the population unit mean) and total road density (km/km^2) were also estimated to evaluate differences among techniques and final boundaries, as well as ensuring that road density management thresholds were met in each population unit.

RESULTS

Grizzly bear habitat

Habitat selection varied substantially among seasons and population units making generalizations about all populations difficult. Overall, open herbaceous and open forest habitats were selected most often, while use of closed forests tended to occur along forest edges or streamside habitats (Table 2). Mesic to wet terrain locations (soil wetness index) were nearly always selected, except for the Yellowhead population where wetlands are more common. For many population units, deciduous stands were selected over conifer stands, although this was again attenuated in the Yellowhead population. Seasonal variation in habitat selection was pronounced for many predictors and population units, but especially within stand-level responses such as crown closure and soil wetness (Table 2).

Table 2 Habitat selection responses (negative [–], positive [+], and neutral [0]) by population unit and season (season 1 [S1], season 2 [S2], and season 3 [S3]).

	Living./Waterton			***Clearwater***			***Yellowhead***			***Grande Cache***			***Swan Hills***		
Variable	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Landcover															
Wet tree	*NA*	*NA*	*NA*	–	–	–	0	0	0	–	–	–	0	–	0
Regen/Cut	0	–	–	–	–	–	–	–	0	–	–	–	–	–	–
Shrub	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–
Wet herb	*NA*	*NA*	*NA*	–	–	–	+	0	–	–	–	–	–	–	–
Upland herb	0	–	–	0	–	–	+	+	+	+	+	–	–	–	–
Non-vegetated	–	–	+	0	–	–	+	0	0	–	+	–	–	–	–
Crown closure															
Forest	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Regen/Cut	0	+	0	–	+	0	0	–	–	0	–	–	–	–	–
% Conifer	–	–	–	0	–	–	0	0	0	–	–	–	0	–	0
Soil wetness															
CTI	+	+	0	+	+	+	0	–	–	0	+	+	0	+	+
Distance to															
Opening in Upland tree	0	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Opening in Wet tree	*NA*	*NA*	*NA*	–	–	–	+	0	0	–	–	–	–	0	0
Forest in Upland herb	–	–	–	–	–	+	0	–	–	–	0	–	0	–	–
Forest in Regen-cut	–	–	+	–	–	–	–	–	–	0	+	–	–	0	–
Forest in Non-vegetated	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+
Stream	+	–	–	0	–	0	–	–	–	–	–	–	–	–	–

Regional occupancy of female grizzly bears was predicted by natural sub-region identity and proportion of agriculture within 10-km. Agriculture was inversely related to grizzly bear occurrence, while natural sub-region occupancy ranked from highest to lowest in alpine, sub-alpine, montane, upper foothills, lower foothills (reference category), foothills parkland, foothills fescue, and central mixedwood respectively (Table 3). No female home ranges were observed in dry mixedwood, mixed grassland, central parkland, and Peace River parkland natural sub-regions. Occupancy for these areas was assumed to be 0.

Mapped probabilities of regional occupancy (Figure 2a) were consistent with the distribution of known female home ranges and demonstrated good, within-sample, predictive accuracy (ROC AUC = 0.922) and model significance (LR χ^2 = 988.5, df = 8, p <0.001). Local grizzly bear habitat predictions based on the product of regional occupancy and RSF scores (Figure 2b) also demonstrated good predictive accuracy for most seasons and population units (Table 4, page 47). The exception was the spring hypophagia period (season 1) for the Livingston/Waterton and Clearwater units which had non-significant, but positive relationships between area-adjusted frequency of use and predicted ordinal habitat selection category.

Table 3 Model coefficients describing regional probability of female grizzly bear occupancy.

Variable	*b*	SE	*p*
Agriculture	-7.982	1.718	<0.001
Natural sub-region:			
Alpine	5.208	0.722	<0.001
Sub-alpine	4.399	0.402	<0.001
Montane	1.685	0.266	<0.001
Upper Foothills	1.536	0.191	<0.001
Lower Foothills	0 (*reference category*)		
Central Mixedwood	-1.679	0.386	<0.001
Foothills Fescue	-0.226	0.673	0.737
Foothills Parkland	-0.099	0.672	0.882
Constant	-0.865	0.121	<0.001

Figure 2 Regional grizzly bear distribution and local habitat.

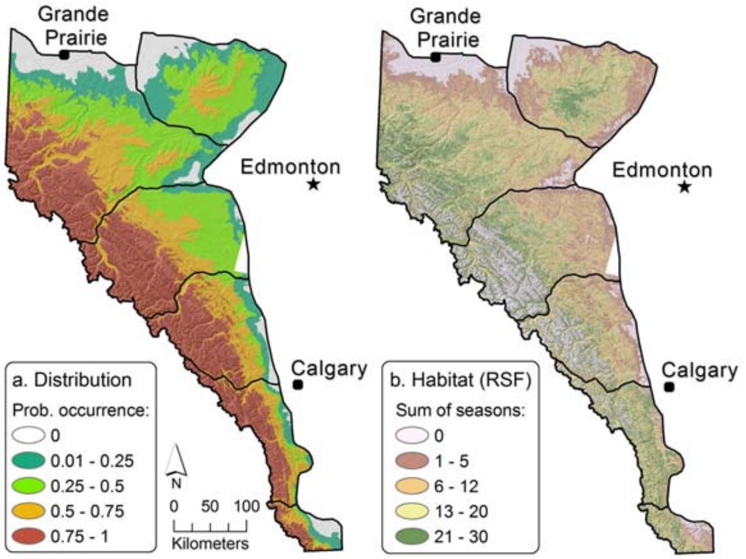


Table 4 Predictive accuracy of seasonal population unit habitat maps based on spearman rank correlations (rs) of habitat bin and area-adjusted frequency of use per habitat bin. Results reported by training (within sample) and testing (withheld out-of-sample) datasets.

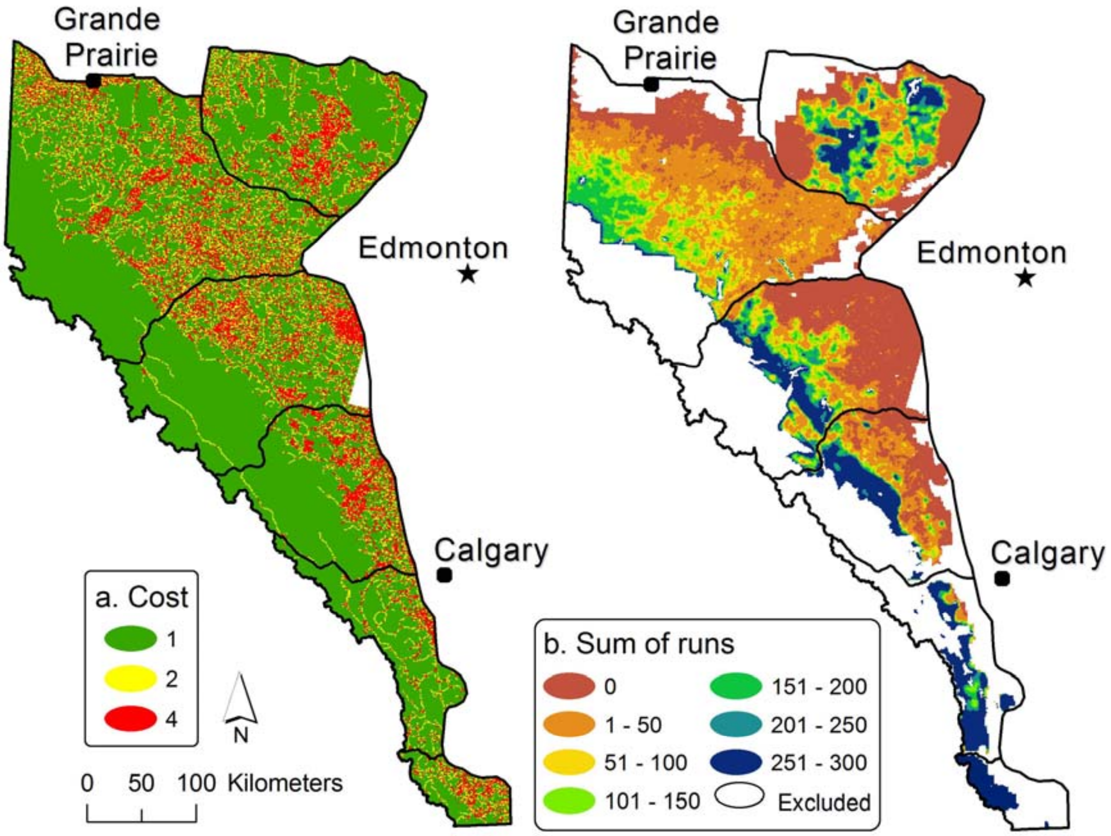
Season and population	***Training data***		***Testing data***	
	r_s	p	r_s	p
Season 1:				
Livingstone/Waterton	0.200	0.555	0.582	0.060
Clearwater	0.620	0.042	0.508	0.111
Yellowhead	0.627	0.039	0.591	0.056
Grande Cache	0.718	0.013	0.782	0.005
Swan Hills	0.982	<0.001	0.991	<0.001
Season 2:				
Livingstone/Waterton	0.864	0.001	0.746	0.009
Clearwater	0.873	0.001	0.822	<0.001
Yellowhead	0.746	0.009	0.782	0.005
Grande Cache	0.836	0.001	0.836	0.001
Swan Hills	0.982	<0.001	0.991	<0.001
Season 3:				
Livingstone/Waterton	0.627	0.039	0.655	0.029
Clearwater	0.900	<0.001	0.918	<0.001
Yellowhead	0.746	0.009	0.736	0.010
Grande Cache	0.855	0.001	0.846	0.001
Swan Hills	0.973	<0.001	0.955	<0.001

Identifying core conservation areas

Simulated annealing

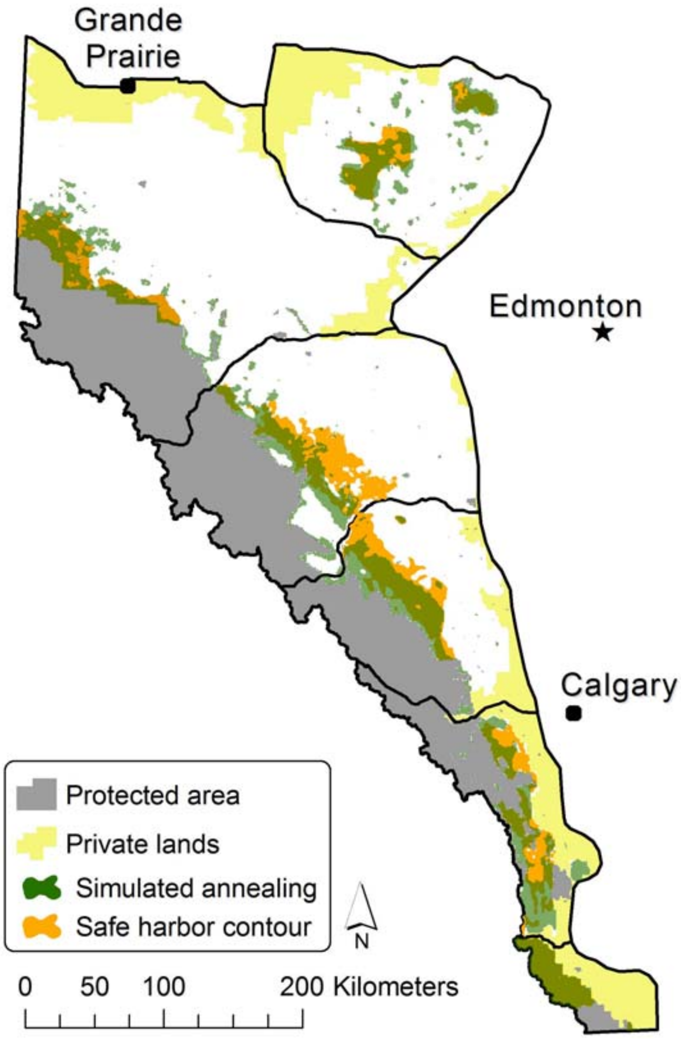
Available sites (unprotected public lands) for core conservation area designation in the Waterton population totaled 1,314 km^2 (32.9% of population unit area). Because this fell below the target of 2,400 km^2, all public areas were classified as a core conservation area and no further analysis was conducted. For the remaining population units, areas with the highest irreplaceability (highest number of sum of runs in MARXAN analyses) were most often associated with rugged terrain where road density (i.e., the cost function) was low and habitat values high, frequently bordering existing protected areas. This was especially evident for the Clearwater, Grande Cache, and Yellowhead population units where core conservation areas were all adjacent to existing mountain parks (Figure 3). Patterns for the Livingstone and Swan Hills units were more complicated. In the Livingstone unit, nearly all planning units were selected as having high irreplaceability, since only 3,427 km^2 (31.6% of the total population unit) was available for core area designation. Planning units closest to the Calgary urban area had the lowest irreplaceability resulting in the selection of distant planning units (Figure 3). For the Swan Hills population, two separate areas near the center of the population unit emerged as having high irreplaceability. The smaller area in the northeast was separated from the larger area in the south by a region of high road density (Figure 3). Small, fragmented patches of irreplaceable habitat surrounded these two core areas.

Figure 3 Planning unit cost and irreplaceability (sum of runs).



The 2,400 most irreplaceable planning units were selected for each population unit (excluding Waterton) and classified as core conservation areas. Swan Hills and Grande Cache core areas had high patchiness, while the Clearwater core areas had the greatest compactness (Figure 4). Core areas for the Livingstone population unit increased connectivity among existing protected areas, but still illustrated fragmented patterns in the south and southeast due to large areas of private land ownership. Although the Waterton population had the highest percent of private lands (56.3%), the distribution of private to public lands was less patchy than the Livingstone population. In both the Livingstone and Waterton populations, there was little to no residual area for consideration of secondary conservation areas.

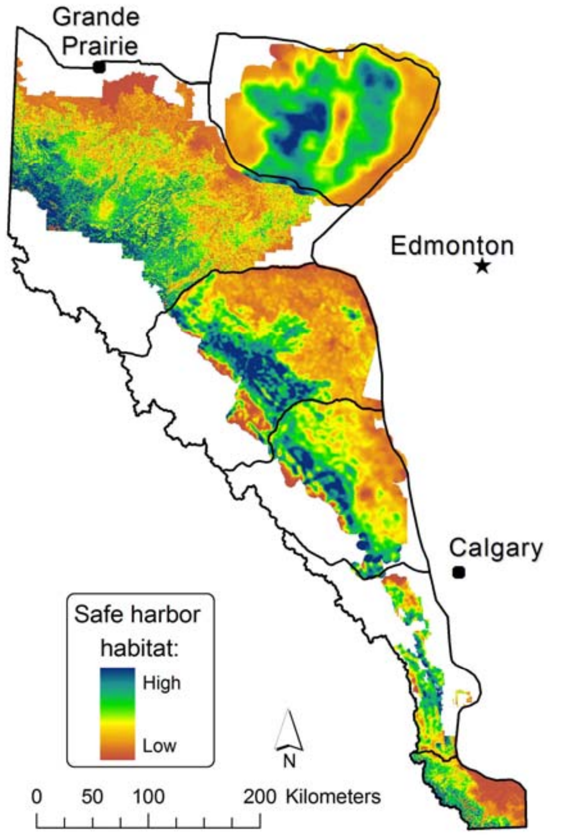
Figure 4 Distribution of model core areas.



Contours of safe harbor habitat

All public lands were classified as a core conservation area in the Waterton population unit, since the available area for classification fell below the target area of 2,400 km^2. Contours associated with the highest safe harbor values and approximating 2,400 km^2 in size were selected as core conservation areas for each of the remaining five population units (Figure 5b) and were qualitatively similar to areas having high irreplaceability from simulated annealing (Figure 5a). Because contours were not controlled for areal extent, core areas delineated from contours were more variable in size than core areas identified through simulated annealing. Safe harbor core areas, however, were less fragmented than simulated annealing core areas. Safe harbor core areas ranged in size from 1,849 km^2 in the Swan Hills population unit to 2,909 km^2 in the Yellowhead population unit (Table 5, page 51).

Figure 5 Safe harbor habitat.



Similar to simulated annealing patterns, core areas delineated through contours of safe harbor habitat were concentrated along the eastern boundaries of existing protected areas in the Clearwater, Grande Cache, and Yellowhead population units where upper foothills gave way to mountainous terrain (Figure 5). Safe harbor core areas, however, were less fragmented in these populations units, as well as the Swan Hills population unit where two single patches similar in location to those identified with simulated annealing were selected. Overall, there was moderate agreement in the location of core areas using simulated annealing and safe harbor contours, with area of overlap ranging from 1,255 km^2 in the Livingstone population to 1,654 km^2 in the Clearwater population (percent overlap from 30% in the Yellowhead to 50% in the Swan Hills). Combined area of core areas ranged from 2,837 km^2 in the Swan Hills population unit to 4,080 km^2 in the Yellowhead population unit (Table 5, page 51). For the Grande Cache, Swan Hills, and Yellowhead population units, percent overlap of large contiguous core areas was much higher than all core area sites, since simulated annealing solutions for the Swan Hills were more fragmented than in other population units (Figure 5).

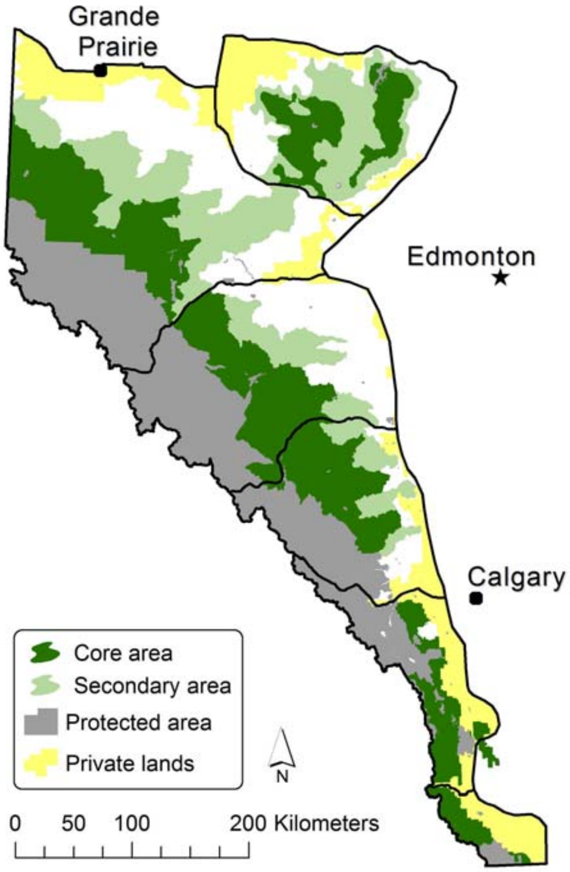
Table 5 Area (km^2) by population unit of simulated annealing core areas, safe harbor contour core areas, combined areas, and area of overlap among techniques.

Population unit	Unit area	Simulated annealing	Safe harbor contour	Combined area	Area of overlap
Clearwater	17,628	2,403	2,631	3,380	1,654
Grande Cache	48,617	2,432	2,250	3,241	1,442
Livingstone	10,841	2,408	2,105	3,258	1,255
Swan Hills	22,467	2,413	1,849	2,837	1,424
Waterton	3,993	1,314	1,314	1,314	1,314
Yellowhead	28,529	2,414	2,909	4,080	1,243
Total	132,075	13,384	13,058	18,110	8,332

Core area boundary modifications and location of secondary conservation areas

ASRD recognized the value of both approaches for delineating grizzly bear core areas resulting in an 18,110-km^2 core conservation area (Table 5). As a consequence, core conservation areas exceeded the suggested minimum 2,400 km^2 size for all population units except the Waterton unit where Crown land available for conservation was less than recovery plan recommendations; therefore, all available lands were designated as a core conservation area. For the remaining population units, additional modifications to core area boundaries were made to reduce fragmentation, include areas deemed important by ASRD personnel that were not selected during simulated annealing or safe harbor contour analyses, and to follow watershed boundaries. Because the Grande Cache population unit was substantially larger (48,716 km^2) than the other population units evaluated (20,088 km^2 larger than the next largest population unit), the core area for the Grande Cache population unit was expanded following recommendations from the recovery team. Considering all six population units, final core conservation areas totaled 33,364 km^2 or approximately 25% of total population unit area (Figure 6, page 52), ranging from a low of 20.5% of the Grande Cache population unit to a maximum of 32.9% of the Waterton population unit (Table 6, page 52). With the exception of one population unit the minimum size of core conservation area suggested by the recovery plan was met. The management goal of core conservation areas will be to keep open route density below 0.6 km/km^2.

Figure 6 Grizzy bear conservation (core and secondary) areas.



Secondary conservation areas were delineated by ASRD personnel based on the distribution of final core areas, safe harbor contours (as a guide), and watershed boundaries with the intent of buffering core areas and maintaining connectivity among population units. Because core conservation areas in Swan Hills population unit were isolated from the Grande Cache population unit, secondary conservation areas were used to connect populations through a northeast-southwest corridor (Figure 6). No secondary conservation areas were delineated in the Waterton population unit, since no additional land was available. In remaining population units, secondary conservation areas ranged in size from 2,506 km^2 in the Clearwater population unit (14.2% of area) to 10,564 km^2 in the Grande Cache population (21.7% of area), although the Swan Hills had the highest proportion of secondary conservation area at 29.6% or 6,646 km^2 (Table 6). In total, 23,224 km^2 (17.6% of total population unit area) was delineated as a secondary conservation area. The management goal of secondary conservation areas will be to keep open route density below 1.2 km/km^2.

Table 6 Area (km^2) of existing protected areas and final core and secondary conservation areas by population unit.

	Protected areas		***Core areas***		***Secondary areas***	
Population unit	Area-km^2	% of Total	Area-km^2	% of Total	Area-km^2	% of Total
Clearwater	5,677	32.2	5,701	32.3	2,506	14.2
Grande Cache	9,990	20.5	9,978	20.5	10,564	21.7
Livingstone	4,201	38.8	3,412	31.5	0	0
Swan Hills	153	0.7	5,202	23.2	6,646	29.6
Waterton	512	12.8	1,314	32.9	0	0
Yellowhead	8,694	30.5	7,757	27.2	3,508	12.3
Total	29,228	22.1	33,364	25.3	23,224	17.6

Effectiveness of core and secondary conservation areas

Simulated annealing versus contours of safe harbor habitat

Grizzly bear occupancy (detections at hair-snag sites) differed significantly between core conservation areas and existing protected areas for the Clearwater, Yellowhead, and Livingstone population units (Table 7, page 54). Occupancy was higher in simulated annealing core areas than sampled protected areas for the Clearwater and Yellowhead population units and lower in core areas from contours of safe harbor habitat for the Livingstone and Yellowhead population units (Table 7, page 54). No significant difference was evident between core conservation areas and sampled protected areas for the Waterton population unit or the safe harbor contour-based core areas in the Clearwater population unit.

Habitat characteristics in core conservation areas were similar among techniques, but variable among population units. Habitat in the Livingstone core areas was most similar to that of the overall population unit at 0.2 standard deviations above the population unit mean, while the Swan Hills core areas was most dissimilar to that of the population unit at 1.1 standard deviations over that of the population unit mean (Table 7, page 54). Despite variations in habitat conditions among population units, habitat conditions in all core conservation areas exceeded population unit averages. In contrast to habitats that were similar among techniques, road densities in core areas varied between simulated annealing and safe harbor contour approaches. Road densities were lower in core areas delineated by simulated annealing for the Clearwater, Swan Hills, and Yellowhead population units (Table 7, page 54). In the Swan Hills, road density marginally exceeded the management threshold for the safe harbor core areas at 0.63-km/km^2 (simulated annealing solution at 0.49 km/km^2) and was near the management threshold at 0.53-km/km^2 in the safe harbor core areas for the Yellowhead population unit (simulated annealing solution at 0.16 km/km^2). Road densities were half the management goal suggested by the recovery team for the Grande Cache and Livingstone population units regardless of technique, while the Clearwater population unit had the lowest road densities in the simulated annealing core areas at 0.04 km/km^2 (Table 7, page 54).

Effectiveness of final core and secondary conservation areas

There was no significant difference between grizzly bear occupancy in final core conservation areas compared to sampled protected areas for all four population units examined, illustrating their importance as core grizzly bear habitat (Table 7, page 54). In contrast to core conservation areas, grizzly bear occupancy in secondary conservation areas was significantly lower than in protected areas illustrating variability in occupancy within population units and a general gradient in occupancy from the occupied mountainous and upper foothill regions to lower or unoccupied habitat in the lower foothills and plains (Table 7, page 54, Figure 6, page 52).

Habitat conditions in final core conservation areas were all poorer than those in initial models, but still exceeded average habitat conditions within population units, ranging from 0.2 deviations above the mean in the Clearwater and Livingstone population units to 0.8 deviations above the mean in the Swan Hills population unit (Table 7, page 54). Habitat conditions in secondary conservation areas were lower than in core conservation areas, generally being similar to the population mean except for the Swan Hills population unit where it was 0.5 deviations above the population mean (Table 7, page 54). Road densities in core areas ranged from 0.28 km/km^2 in the Livingstone population unit to 0.63 km/km^2 (marginally exceeding the management goal) in the Swan Hills population unit. Road densities in final core areas were higher than initial core area models for the Clearwater and Grande Cache population units and similar to safe harbor core areas for the Livingstone, Swan Hills, and

Table 7 Conservation area effectiveness based on occupancy, habitat (standard deviations from the population mean), and road density (km/km^2) characteristics. Odds ratio (standard errors in parentheses) of detecting grizzly bears at hair-snag sites by population unit and modeling technique (a.). Significance ($p<0.05$) indicated by the superscript symbol of † and based on an indicator contrast with existing protected areas.

	Modeled core areas		***Final conservation areas***	
Population unit	**Simulated annealing**	**Safe harbor contours**	**Core area**	**Secondary area**
a. Occupancy (odds ratio compared with protected areas)				
Clearwater	$2.38^{\dagger}$ (0.68)	0.74 (0.22)	0.85 (0.24)	$0.26^{\dagger}$ (0.11)
Livingstone	0.94 (0.23)	$0.58^{\dagger}$ (0.16)	0.66 (0.14)	*N.A.*
Waterton*	0.71 (0.30)	0.71 (0.30)	0.71 (0.30)	*N.A.*
Yellowhead	$3.17^{\dagger}$ (1.30)	$0.49^{\dagger}$ (0.18)	0.81 (0.52)	$0.16^{\dagger}$ (0.13)
b. Habitat (StDev from population mean)				
Clearwater	0.4	0.5	0.2	0
Grande Cache	0.7	0.7	0.5	0.1
Livingstone	0.2	0.2	0.2	*N.A.*
Swan Hills	1.1	1.1	0.8	0.5
Waterton*	0.5	0.5	0.5	*N.A.*
Yellowhead	0.9	0.8	0.5	0.1
c. Road density (km/km^2)				
Clearwater	0.04	0.2	0.48	1.09
Grande Cache	0.25	0.24	0.48	1
Livingstone	0.32	0.26	0.28	*N.A.*
Swan Hills	0.49	0.63	0.63	1.23
Waterton*	0.37	0.37	0.37	*N.A.*
Yellowhead	0.16	0.53	0.47	1.07

*Waterton population unit results are the same across all core area comparisons, since all available Crown land was categorized as a core conservation area.

Yellowhead population units (Table 7, page 54). Road densities in secondary conservation areas all exceeded 1 km/km^2, with only the Swan Hills secondary conservation area marginally exceeding the management goal at a road density of 1.23 km/km^2 (Table 7, page 54).

DISCUSSION

In Alberta, Canada, high rates of human-caused mortality threaten the long-term persistence of a small peripheral (eastern range boundary) population of grizzly bears (Benn and Herrero 2002). Human access in Alberta grizzly bear range has increased substantially over the past few decades due to the expansion of road networks associated with the energy (coal, natural gas, and oil) and forest industries and is projected to increase further over the next few decades (Nielsen et al. 2008). As a result of these threats and low population size (Boulanger et al. 2005a, 2005b, 2007, 2008), conservation areas of at least 2,400 km^2 and with less than 0.6 km/km^2 of open access roads have been suggested for each of seven grizzly bear population units (Alberta Grizzly Bear Recovery Team 2008). Rather than identifying conservation areas based solely on open access road density, we compared for six population units two approaches that considered habitat value and road density simultaneously: (1) simulated annealing; and (2) a contour GIS analysis of secure habitats referred to as safe harbor habitat (Nielsen et al. 2006). Habitat was measured using resource selection functions based on 121,683 GPS radio-telemetry locations gathered from 81 grizzly bears between 1999 and 2006. As the majority of animals used for assessing habitat were females (53 females; 28 males), definitions of core areas for both techniques were biased towards female animals, the gender of focus for most grizzly bear conservation efforts (Wiegand et al. 1998). Both approaches attempted to locate areas of high habitat value and low road density.

Core areas for simulated annealing and contours of safe harbor habitat were broadly similar in location with an overlap of 46% of combined area and generally located adjacent to existing protected areas. Simulated annealing resulted in more fragmented solutions for three of the population units, but had lower road densities and better effectiveness in capturing occupied habitat defined by detections of grizzly bears at hair-snag genetic survey sites. Alberta Sustainable Resource Development (ASRD) examined both solutions and modified conservation areas to align with watershed boundaries for ease of management implementation and to conform to other management programs. Additional expansions of conservation areas were made by ASRD staff resulting in final conservation areas that totaled 33,364 km^2 (approximately 25% of population units) or more than a two-fold increase over the minimum area recommended by the Alberta Grizzly Bear Recovery Team (2008). Additional watersheds totaling 23,224 km^2 (17.6% of population units) of more marginal habitat were selected by ASRD staff and represent secondary conservation areas that buffer core conservation areas, while also providing connectivity between the Grande Cache population and the isolated Swan Hills population. For each core and secondary conservation area, the recovery team recommended that open access road density be capped at 0.6 km/km^2 and 1.2 km/km^2 respectively (Alberta Grizzly Bear Recovery Team 2008). Access management, including gating, earth-berming, road decommissioning, and multi-stakeholder land use planning, will likely be needed to maintain open access road density below these threshold levels.

Although controlling open route densities is an important conservation tool that can directly limit road-kills and reduce vulnerability to poaching by reducing frequency of encounters between humans and bears (Mattson et al. 1996), grizzly bear conservation in Alberta will ultimately depend on changing human attitudes towards bears (Pimm 1996), as well as reducing the incidence of ‘human conditioned’ and ‘problem’ bears. Grizzly bear populations are already reduced or displaced from many areas of the foothills where open route densities are below management thresholds, suggesting that limiting future road development alone in these areas may do little to recover populations. Acceptance and support of grizzly bear protection by local residents, as well as access management, will collectively be critical to population recovery. In fact, in situations where residents are antagonized by imposed access management, mortality rates of grizzly bears may actually increase thereby hastening population decline (Mattson et al. 1996, Pimm 1996). In southern Alberta where private lands are immediately adjacent to public lands within grizzly bear range, a consistent protocol for dealing with problem bears is especially needed. Unnecessary animal relocations or animal removals compromise conservation actions and goals of population recovery. Dealing effectively with depredations of livestock and limiting bear attractants is an important conservation element required in many areas of Alberta.

Monitoring conservation area effectiveness and population recovery

Implementation of grizzly bear conservation areas and population recovery actions should be done in light of an effectiveness monitoring program where human access and human activity are monitored along with grizzly bear population recovery. Where gates or other temporary devices are used to limit access, monitoring devices such as trail/road counters and trail cameras should be used to evaluate their effectiveness. One approach is to locate road counters before and after gates to estimate compliance with closures.

For grizzly bears, hair-snag genetic surveying (Woods et al. 1999) at permanent sample sites may be the most effective way of monitoring long-term occupancy or changes in occupancy rates among core and secondary conservation areas. A systematic grid or habitat-based stratified sampling design for each watershed should be considered with repeated measures taken at permanent sites on a semi-annual basis. Hair-snag genetic surveys may also prove useful for estimation of vital rates (Schwartz et al. 2007), as well as regional estimates of population connectivity (Dixon et al. 2006, Proctor et al. 2004, 2005). For example, hair-snag genetic surveys could be used to evaluate the effectiveness of the secondary conservation area (corridor) connecting the Swan Hills and Grande Cache populations. Finally, health markers, such as sex steroids and glucocorticoids, could be measured from hair samples collected at hair-snag monitoring sites to monitor reproduction and long-term stress, crucial factors for bear recovery (Koren et al. 2002, Accorsi et al. 2008).

Although routine capture and handling of grizzly bears is not warranted for monitoring conservation area effectiveness, animal relocations or removals may be considered necessary management actions in some situations. When these situations arise, conservation effectiveness could be enhanced by ensuring a standardized set of health information (e.g., sex, body mass, and morphometric measurements) and samples (e.g., hair, skin biopsy, and blood) collected from each animal.

Use of comparative modeling and monitoring for decision support

We used a comparative modeling approach for conservation planning of grizzly bear habitat in Alberta, Canada. Comparative or multiple modeling approaches provide a useful form of sensitivity analysis that helps strengthen the decision support value of conservation actions or plans. Areas of model consensus help delineate irreplaceable sites and increase accuracy of subsequent conservation decisions (Margules and Pressey 2000, Marmion et al. 2008). Where prioritization of conservation actions are necessary, consensus areas can be used to delineate critical sites. In our example, Alberta Sustainable Resource Development used a precautionary approach by using consensus areas, as well as areas of model disagreement, but where finer-level detail is needed areas of consensus can be used to further prioritize conservation areas. As well as using comparative analyses for initial decision support, monitoring of human activity and bear populations will facilitate adjustment of management strategies where needed. This could include modification of conservation area boundaries using adaptive management.

CONCLUSION

One critical element, among several, for grizzly bear conservation and population recovery in Alberta is limiting motorized access in grizzly bear range. We identified core conservation areas for six of seven population units in Alberta and describe government acceptance and expansion of conservation area boundaries, including secondary conservation areas that buffer and connect core areas. Although open route densities would be limited in these areas, additional management actions relating to human dimensions (development of a stewardship ethic) will be critical to the success of grizzly bear population recovery (Pimm 1996). In fact, many grizzly bear populations in Alberta already occur in areas where open route density is lower than maximum targets (such as the core conservation areas identified here), but demonstrate population declines. Certainly capping future road development at selected management thresholds is an important initial conservation action, but it alone will not recover declining populations of grizzly bears. Managing depredations and attractants and more broadly changing human attitudes to reduce human-caused grizzly bear mortality will be critical to the success of population recovery. Where human attitudes have been favorable and attractants have been managed effectively, grizzly bear populations have expanded (Pyare et al. 2004). Following implementation of conservation areas, management of depredation, attractants, and human attitudes should therefore be considered a priority. In addition, monitoring should be used to assess the effectiveness of conservation areas for maintaining populations or reducing population decline and used subsequently to adjust management strategies.

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