Research Report

BC Journal of Ecosystems and Management

Relationships between grizzly bear source-sink habitats and prioritized biodiversity sites in Central British Columbia

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Abstract

The Central Interior and Sub-Boreal Interior ecoprovinces of British Columbia represent an important transitional population of grizzly bears (*Ursus arctos* L.) occupying the area between two major mountain systems (Coastal Ranges and Central Rockies), as well as defining the boundary of extirpated range in the Fraser Plateau South. To assist ecoregional planning in the area, grizzly bear habitat models were produced for density, mortality risk, and source-sink habitat. Bear density was based on population estimates for each management unit and downscaling approaches using local habitat suitability rankings; mortality risk was modelled using 339 mortality locations from 2004 to 2007 and a suite of environmental and anthropogenic factors as predictors. Both models were combined to form a two-dimensional framework of habitat states representing source-like and sink-like habitats that help prioritize areas for protection and restoration (road decommissioning), respectively, as well as provide a basis for comparing with other biodiversity features. Irreplaceability values based on rare biota and unique habitats measured as the sum of runs in Marxan were significantly higher in grizzly bear source habitats than sink habitats suggesting that protection of grizzly bear source habitats would confer an umbrella or surrogate effect to other biodiversity.

KEYWORDS: *biodiversity; British Columbia; ecoregional planning; grizzly bears; habitat modelling; source-sink habitats;* Ursus arctos.

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Nielsen, S. 2011. Relationships between grizzly bear source-sink habitats and prioritized biodiversity sites in Central British Columbia. *BC Journal of Ecosystems and Management* 12(1):136–147. ***http://jem.forrex.org/index.php/jem/article/view/73/59***

Introduction

Large carnivores are widely regarded as important regulators of biodiversity and indicators of ecosystem health (Tardiff and Stanford 1998; Berger 1999; Berger et al. 2001; Ripple et al. 2001) and thus often selected as candidate species for inclusion in ecoregional planning efforts (Noss et al. 1996; Carroll et al. 2001; Nielsen et al. 2009). Grizzly bears (*Ursus arctos* L.), in particular, are often used as a focal species for conservation planning in the mountains of western North America not only because of their direct affect on biodiversity, but also because of their large area requirements, their slow life-history traits, which make them sensitive to overkill (Russell et al. 1998; Purvis et al. 2000), and their charismatic nature, which helps garner public attention for conservation. Maintenance of areas large enough to satisfy the needs and long-term persistence of grizzly bears is thought to also promote umbrella effects to other species not directly affected by grizzlies simply because of the scale of landscapes needed to maintain viable bear populations (Noss et al. 1996). Such landscapes also need to have low human footprints, since grizzlies are vulnerable to population declines most often associated with human activity (Russell et al. 1998; Purvis et al. 2000). For instance, Benn and Herrero (2002) illustrated that even within protected areas populations of grizzlies may not be secure where human activity is prevalent. Areas that are able to maintain healthy grizzly bear populations are therefore likely to signal healthy ecosystems, a key focus of most conservation planning efforts.

An important challenge to including carnivores within ecoregional planning, however, is the need for maps representing the habitat requirements and vulnerabilities of the species. This is particularly important for grizzly bears since selection of habitats by grizzlies in some populations may be maladaptive, whereby animals use habitats that appear suitable or perhaps benefit growth and reproduction but survival is low leading to population declines (Nielsen et al. 2006, 2008). Considering that the slow life-history traits of grizzly bears result in high elasticity to survival (especially adult females), habitat conditions that identify source-sink conditions or mortality risk are crucial for representing the vulnerabilities of the species and the sites best suited for further conservation actions.

Areas that are able to maintain healthy grizzly bear populations are likely to signal healthy ecosystems, a key focus of most conservation planning efforts.

My objectives here are therefore to:

1. develop a common framework for estimating grizzly bear source-sink habitat conditions in British Columbia for conservation planning using readily available data; and
2. evaluate whether source habitats are positively related to irreplaceability patterns in the Central Interior (Loos 2011) with irreplaceability representing those sites most needed for satisfying the conservation objectives identified for the Central Interior.

The first objective focusses on building a grizzly bear source-sink habitat model identifying for the Central Interior and Sub-Boreal Interior ecoprovinces, whereas the second objective tests the potential for umbrella or biodiversity surrogacy effects of simply protecting grizzly bear source habitats rather than a full ecoregional analysis based on a large set of fine (species) and coarse (habitats) filter conservation features.

Methods

Study area

British Columbia's Central Interior ecoregion, represented by the Sub-Boreal Interior and Central Interior ecoprovinces, covers approximately 24.6 million ha of central British Columbia. Areas of flat-to-rolling terrain include the Chilcotin, Cariboo, Nechako, and McGregor plateaus, while the mountainous regions bounding the study area are represented by the Chilcotin, Bulkley, and Hart ranges, as well as the Omineca and Skeena mountains. Vegetation is dominated by sub-boreal spruce, interior Douglas-fir, and lodgepole pine ecosystems. Common land uses include forestry, cattle ranching, mining, agriculture, and tourism. Mountain pine beetle, which attacks lodgepole pine, has been at historically high infestation levels. With a wide diversity of topography and climates, the region supports a broad array of bird, fish, mammal, and insect species. Currently, however, only about 10% of this region is protected.

Grizzly bear habitat model

Compared to other regions of British Columbia, information on grizzly bear habitat conditions for the Central Interior is quite limited (see, however, McNay and Sutherland 2009). The only extensive studies of grizzly bear habitat in the Central Interior using empirical information is from Ciarniello et al. (2007a, 2007b) for the Hart Ranges of the Central Canadian Rockies and adjacent plateau region near Prince George. This work was based on resource (habitat) selection functions (RSFs) predicting habitat conditions using telemetry data and common geospatial predictors (Boyce and McDonald 1999; Manly et al. 2002). Resource selection function models, however, often extrapolate poorly into novel environments where human activities, environmental differences, and animal densities vary (Johnson and Seip 2008). Given the wide variation in environmental conditions across the Central Interior region, an alternative approach to extrapolation of RSFs from one region to the broader area was needed. As an alternative, I have used the Broad Ecosystem Inventory (BEI) habitat suitability (highest value) rankings from Hamilton (2007) to define regional patterns in grizzly bear habitat conditions. Although the BEI product may not distinguish in as much detail as RSFs the importance of local stand-level factors, it provides a consistent habitat product across the Central Interior at scales relevant for ecoregional planning. To add population relevance to individual habitat suitability sites, I estimated local grizzly bear densities using management unit population estimates provided by Hamilton (2007) that were based on population estimates from Hamilton and Austin (2004) and revisions by Hamilton et al. (2004). Management unit population boundaries follow that of Hamilton et al. (2004). Population estimates were scaled to local habitats using the BEI ordinal rankings (Table 1) and the methods of estimating habitat-based densities of animals from Boyce and McDonald (1999).

The methods of Boyce and McDonald (1999) contain a number of intermediate steps. First, I estimated a utilization index for each habitat suitability polygon in each management unit density class (management units with the same estimated bear density) using the formula:

$$U(x_i) = \frac{w(x_i)\,A(x_i)}{\sum_j w(x_j)\,A(x_j)} \qquad [1]$$

where: $U(x_i)$ is the utilization index for habitat suitability class i; $A(x_i)$ is the area (km^2) of that habitat class and $w(x_j)$ the overall habitat suitability rank for that class. The utilization index of equation 1 was then used to estimate a population size for each habitat suitability class in each management unit by appropriating the total population estimated for that management unit (N) into each of the habitat suitability classes. More formally, the population size for each habitat suitability class i was estimated as:

$$N_i = N \times U(x_i) \qquad [2]$$

Densities per habitat suitability class per management unit class were then derived using the population estimate for each class and its area, or more specifically:

$$D(x_i) = N_i \,/\, A(x_i) \qquad [3]$$

where: $D(x_i)$ is the density of bears estimated for habitat suitability class i; N_i is the estimated population size for that habitat suitability class; and $A(x_i)$ the area of that habitat suitability class. The region where grizzly bears are known to be extirpated in the southeast was given a density of 0 bears.

TABLE 1. Broad ecosystem inventory (BEI) grizzly bear habitat suitability values and rescaled ordinal rank used for estimating habitat-based densities of grizzly bears

Habitat suitability		
Value/Code	**Description**	**Ordinal rank**
0	Not rated	0
1	Best	5
2	Good	4
3	Moderate	3
4	Low	2
5	Very low	1
6	Nil	0
8	Lake (water)	0

Human-caused mortality risk model

To estimate an index of human-caused mortality risk for grizzly bears, I used the approach of Nielsen et al. (2004) where a sample of known mortality locations was compared to a random sample of study area locations using logistic regression. A provincial grizzly bear mortality database, containing 339 human-caused grizzly bear mortality locations (2004–2007) with known accuracy in the study area, was provided by Tony Hamilton (B.C. Ministry of Environment) and used to characterize patterns of survival. Available (random) characterization of the landscape was based on 2571 systematically sampled locations on a 10-

km alternating spacing using the Generate Regular Points tool in Hawth's Analysis Tools (Beyer 2004) for ArcGIS™ geographic information system software (ESRI®, Redlands, Calif.). Because initial analyses revealed geographic non-stationarity in mortality patterns, three geographic regions were identified for the study area where the number of mortality locations was approximately equal and the environmental conditions more consistent. These areas included the Central Interior and Fraser Basin, the Central Canadian Rocky Mountains, and the Omineca and Skeena Mountains with each having 112, 113, and 114 mortality records, respectively. Within each region, 100 mortality records were randomly assigned to a model training group and the remaining mortality locations ($n = 39$) used for model evaluation (i.e., model testing). Random (available) locations were similarly identified for each region and to balance the ratio of events (mortalities) to control (random) samples, importance weights were assigned to each random observation so that random observations in each study region summed to a value of 100 (i.e., importance weights = $100/n$; where n is the number of random available locations for that study region).

Environmental and anthropogenic information representing land cover, terrain, streams, and human access were queried at each mortality and random location using a range of scales (extents around each observation) to represent different processes affecting human-caused bear mortality (Nielsen et al. 2004). The following six moving circular window radii were used: (1) 1 km, (2) 3 km, (3) 5 km, (4) 14.3 km, (5) 22.6 km, and (6) 41.9 km. Land cover was summarized as percent composition for each moving window scale and land cover category. Because grizzly bears are often associated with forest edges (Nielsen et al. 2009) and are known to have higher mortality risk in habitat edges (Nielsen et al. 2004), I further estimated mean distance to forest edge for each of the six scales. Distance to human access (any type, paved, and unpaved) and stream features (1:50 000) were similarly estimated for each radius. Finally, a ruggedness index (Riley et al. 1999) using an Arc Macro Language script from Evans (2004) and a digital elevation model (DEM) was summarized (mean value) for the area, again using all six moving window scales.

Moving window scales were chosen to bracket local (1 km) to regional (41.9 km) effects that were thought to be relevant to grizzly bear habitat and population characteristics and to recognize that the mortality locations, although cleaned for accuracy, still contained spatial uncertainty. The selection of scales was based on studies of grizzly bear dispersal by Proctor et al. (2004) for the 14.3-km and 41.9-km scales (female and male dispersal distances, respectively) and the habitat work of Nams et al. (2006) for the 3-km and 22.6-km scales (small/meso and large-scale relationships, respectively). As well as using environmental and human predictors, grizzly bear density by wildlife management unit (0–42.5 bears per 1000 km^2) was used as a predictor of mortality risk to acknowledge that, after holding other factors constant (e.g., the same road access), the rate (ratio) of recorded mortality should be highest in areas with high bear density.

Logistic regression models were fit for each geographic stratum using a step-wise model-building approach following the recommendations by Hosmer and Lemeshow (2000). Univariate models (including quadratic effects where hypothesized) for each predictor were first tested and ranked in importance. Final multivariate models were based on the sequential addition of non-correlated ($r < |0.7|$) and significant (at ~ $p < 0.1$) variables. Model significance, fit, and predictive accuracy were evaluated using likelihood ratio χ^2, McFadden's R^2, and area-under-the-curve (AUC) receiver operating characteristic (ROC), respectively. Care, however, should be given in the interpretation of these metrics given the asymmetry of errors in the response variable due to the presence, pseudo-absence study design (Boyce et al. 2002; Johnson et al. 2006). In the presence of contamination (pseudo-absence contaminating a presence-event), such metrics would be conservative. We also evaluated map predictions using a Spearman rank assessment to measure the relationship between the habitat rank and area-adjusted frequency of observations within each habitat class and for an independent source (historic locations) of mortality events (Boyce et al. 2002).

Maps predicting habitat-based grizzly bear density and mortality risk were estimated across the study area using model relationships for mortality risk and equations 1–3 for habitat-based densities. Mortality risk estimates were first re-classified into 10 ordinal categories of risk using the quantile option in the reclass function of spatial analyst and subsequently reclassified into simplified risk categories based on the distribution of training and testing observations (i.e., model evaluation). Grizzly bear habitat density classes were also simplified to fewer categories for ease of interpretation and to reduce the complexity of final habitat state classes.

Habitat states (source- and sink-like habitats)

Using the habitat and mortality risk models, habitat states were estimated for the region following the two-dimensional habitat state concepts of Naves et al. (2003) and the methods for estimating the two-dimensional habitat states at local scales from Nielsen et al. (2006, 2008). The first dimension is measured as habitat selection or habitat quality with the assumption that these metrics relate to factors affecting reproductive success. The second dimension reflects factors affecting survival, which for grizzly bears is most often associated with human-caused mortalities (McLellan 1989; Benn and Herrero 2002). When the habitat and survival factors (dimensions) are combined, an index of habitat states or source-like and sink-like habitats is produced. In cases where habitats are measured through habitat selection studies, sink-like habitats can also be defined as attractive sinks (ecological traps), thus recognizing the presence of maladaptive habitat selection (use of risky habitats) in grizzly bears (Nielsen et al. 2006).

Instead of using habitat selection models, here I use measures of population density and relate this to different levels of mortality risk. However, since risk to population decline (habitat sinks) depends on population size, sink-like habitat definitions were based on different thresholds of risk where a higher mortality risk was necessary for sink-like conditions to occur in areas of high grizzly bear density. Finally, these habitat states were further reclassified into a simple binary landscape of source- and sink-like conditions for ease of reporting and inclusion in ecoregional planning situations.

Patterns of source-sink grizzly bear habitat and biodiversity-based irreplaceability

Irreplaceability values were compared by grizzly bear source-sink habitat states to test whether protection of source grizzly bear habitats would also protect areas of high irreplaceability and thus offer an umbrella or surrogate effect for other biota and conservation features in the Central Interior. To test this, irreplaceability of source habitats was compared to sink habitats for each grizzly bear density class (where present) using a Wilcoxon rank-sum test (Mann-Whitney two-sample statistic) in STATA 9.2. Here I define irreplaceability from Loos (2011) as the average sum of runs from the terrestrial Marxan analysis of the Central Interior using targets (goals) of 5%, 10%, 20%, 30%, 40%, and 50%. Broadly defined, irreplaceability represents the likelihood a planning unit (site) is needed in order to meet the conservation planning targets based on representation of the biodiversity features (Pressey et al. 1994; Ferrier et al. 2000; Carwardine et al. 2007). Since targets for common species and conservation features can be satisfied nearly anywhere, those sites having rare biota and unique habitats are often ranked as having high irreplaceability (i.e., they cannot be easily replaced by other sites if lost).

Results

Habitat-based grizzly bear densities

Excluding the extirpated region in the southeast Central Interior, habitat-based density estimates by management unit varied from a low of 3 grizzlies per 1000 km^2 to a high of 73 grizzlies per 1000 km^2 in the Skeena Mountains and southern portions of the Central Canadian Rocky Mountains (Table 2; Figure 1a). Habitat-based grizzly bear densities were reclassified into five categories for subsequent analyses: (1) very low density (1–9 bears per 1000 km^2); (2) low density (10–19 bears per 1000 km^2); (3) moderate density (20–39 bears per 1000 km^2); (4) high density (40–59 bears per 1000 km^2); and (5) very high density (60–73 bears per 1000 km^2). Very low and low densities were most common to the Fraser Basin, Fraser Plateau, and Chilcotin Ranges, whereas moderate densities were most common to the Eastern Hazelton Mountains, the southern regions of the Omineca and Skeena mountains, and the northern areas of the Central Canadian Rocky Mountains (Figure 1a). Areas of high and very high density were found in the northern areas of the Skeena Mountains and the southern areas of the Central Canadian Rocky Mountains.

Human-caused mortality risk

Grizzly bear mortality risk was positively related to grizzly bear density in the Fraser Basin region as well as the Canadian Rocky Mountains but not the Omineca and Skeena mountains (Table 3). Mortality risk was negatively related to alpine habitats within a 3-km radius for the Canadian Rockies and Omineca and Skeena mountains but not in the Fraser Basin where alpine habitats were rare. Avalanche habitat within a 22.6-km radius was positively related to mortalities only within the Omineca and Skeena mountains, whereas non-vegetated habitats were negatively related to mortality risk in the Canadian Rockies at a 5-km radius (Table 3).

TABLE 2. Habitat-based grizzly bear density (per 1000 km^2) estimates for six habitat suitability classes and nine Wildlife Management Units (WMU) having similar overall population density

WMU density	Habitat suitability rank (BEI)					
	0	1	2	3	4	5
0	0	0	0	0	0	0
7.5	0	3.5	7.0	10.4	13.9	17.4
12.5	0	5.6	11.2	16.7	22.3	27.9
17.5	0	6.8	13.6	20.3	27.1	33.9
22.5	0	8.6	17.1	25.7	34.3	42.9
27.5	0	11.0	22.0	33.0	43.9	54.9
32.5[a]	0	11.0	22.0	33.0	43.9	54.9
37.5	0	13.2	26.3	39.5	52.7	65.9
42.5	0	14.6	29.2	43.8	58.5	73.1

[a] The area for this density class was too small to estimate habitat-based densities and was therefore assumed to be the same as that for WMUs having approximately 27.5 bears per 1000 km^2.

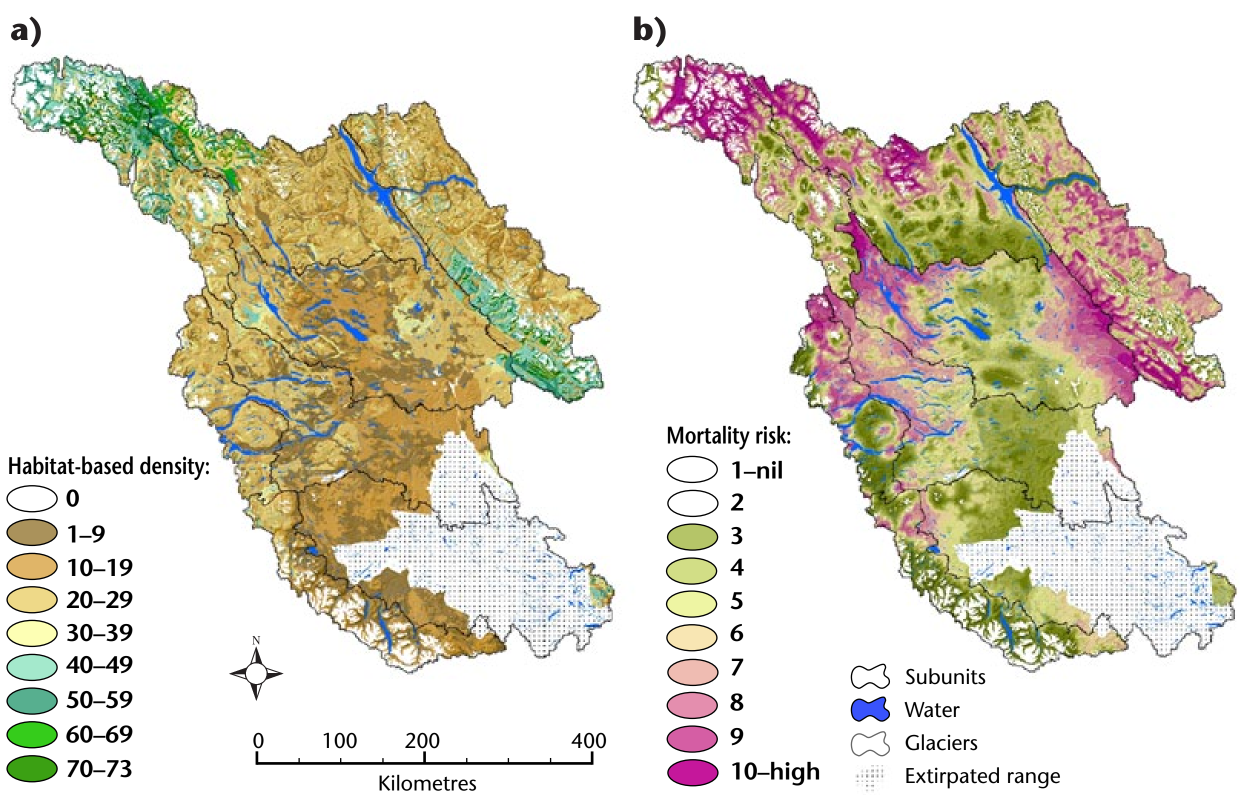

FIGURE 1. (a) Habitat-based densities of grizzly bears and (b) predicted mortality risk (ordinal class from 1 [nil] to 10 [high]). Sub-boundaries for each map reflect ecoprovinces boundaries.

TABLE 3. Logistic regression coefficients (β), standard errors (S.E.), and significance values (p) describing the relative probability of a human-caused grizzly bear mortality for three regions of the Central Interior and Sub-Boreal Interior ecoprovinces of British Columbia

	Scale (km)	Central Interior and Fraser Basin			Central Canadian Rocky Mountains			Omineca and Skeena Mountains		
Predictor variable[a]		β	S.E.	p	β	S.E.	p	β	S.E.	p
Bear density										
log(grizzly density)	na	0.696	0.267	0.009	1.073	0.528	0.042			
Land cover										
alpine	3				–0.039	0.013	0.002	–0.054	0.013	< 0.001
avalanche	22.6							0.116	0.038	0.002
non-vegetated	5				–0.115	0.064	0.073			
open forest	42	0.048	0.013	< 0.001						
forested	14	0.488	0.289	0.092						
forested^2	14	–0.003	0.002	0.079						
logged	3				0.078	0.045	0.085			
logged^2	3				–0.002	0.001	0.119			
Edge (fragmentation)										
forest edge	41.9							6.307	0.026	0.003
forest edge^2	41.9							–0.396	0.173	0.022
Distance to human access										
road (any type)	1							–0.087	0.026	0.001
unpaved road	1	–0.277	0.087	0.001						
Model intercept	***na***	***–22.5***	***12.2***	***0.065***	***–3.217***	***1.730***	***0.063***	***–0.818***	***0.346***	***0.018***
Model significance and fit										
LR χ^2		72.5	$p < 0.001$		30.9	$p < 0.001$		71.7	$p < 0.001$	
McFadden's R^2		0.262			0.112			0.259		
ROC–AUC		0.819			0.712			0.818		

[a] Predictor variables include bear density (Hamilton and Austin 2004; Hamilton et al. 2004), land cover/land use, distance to forest edge, and distance to human access features, each summarized at five scales ranging from 1 km (local patches) to 41.9 km (male dispersal distance; Proctor et al. 2004) radius moving windows.

Areas with intermediate amounts of logging within a 3-km radius were also associated with higher mortality risk in the Canadian Rockies, whereas in the Fraser Basin, areas with higher amounts of open forests (42-km radius scale) and intermediate amounts of forested habitat (14-km radius) were associated with higher grizzly bear mortality risk. For edge-related variables, only distances to forested edges at large scales (42-km radius) in the Omineca and Skeena mountains were significant (Table 3). Distance to road variables within a 1-km radius were significant for the Fraser Basin (unpaved roads) and Omineca and Skeena mountains (all road types) but not the Canadian Rocky Mountains.

All models were significant overall based on likelihood ratio χ^2 tests (Table 3). Deviance explained (McFadden's R^2) ranged from 11.2% for the Canadian Rocky Mountains to 26.2% for the Fraser Basin. Model predictive accuracy using receiver operating characteristic area-under-the-curve estimates suggested very good predictive accuracy for the Fraser Basin (ROC AUC = 0.819) and the Omineca and Skeena mountains (ROC AUC = 0.818), and good predictive accuracy for the Canadian Rocky Mountains (ROC AUC = 0.712). Spearman rank statistics for mortality risk classes and training data were significant for all three areas (Fraser Basin: $r_s = 0.964$, $p < 0.001$; Omineca and Skeena mountains: $r_s = 0.818$, $p = 0.038$; Canadian Rockies: $r_s = 0.976$, $p < 0.001$). Spearman rank correlations for historic mortality locations (1976–2003) were similar to training data, despite lack of confidence in the spatial accuracy of these locations. There were too few withheld mortality locations to statistically assess out-of-sample predictive accuracy; although 77.8% of withheld mortalities did fall within mortality risk categories of 6 or greater with only 38.7% of the study area representing these levels of risk (an odds ratio of 2.01). I reclassified (simplified) the mortality risk model into five ordinal classes of risk ranging from none (1–5), low (6), moderate (7), high (8), and very high (9–10). Predictive accuracy of the reclassified product was excellent (Fraser Basin: $r_s = 1.0$, $p < 0.001$; Omineca and Skeena mountains: $r_s = 0.90$, $p = 0.037$; Canadian Rockies: $r_s = 1.0$, $p < 0.001$). Mortality risk hotspots included the southern Canadian Rockies, the northern Omineca and Skeena mountains, and scattered areas in the eastern Hazelton Mountains (Figure 1b).

Habitat states (source- and sink-like habitats)

Since risk to population decline (habitat sinks) depends on population size, source-like and sink-like habitats were defined based on different levels of population density and mortality risk (Table 4), thus assuming that a much higher mortality risk would be required for sink-like conditions in areas with high grizzly bear density. Habitat states representing five source-like and five sink-like habitats along with a non-habitat/extirpated category were mapped for the region with two main sink populations evident: (1) the southern Canadian Rockies; and (2) the Skeena Mountains in far northwest part of the Central Interior study region (Figure 2).

Comparison of source-sink grizzly bear habitat and biodiversity-based irreplaceability

Irreplaceability of biodiversity features was significantly ($p < 0.05$) higher (from median values) in grizzly bear source habitat than sink habitat for all grizzly bear density classes (and overall) suggesting that protection of grizzly bear source habitat would confer some umbrella effect to other biodiversity features. Irreplaceability also increased with grizzly bear density in all density classes except for the lowest grizzly bear density class, which likely relates to the selection of lower elevation planning units that were needed to achieve biodiversity targets in the terrestrial Marxan analysis (Figure 3).

TABLE 4. Thresholds used to classify source- and sink-like habitat states based on local estimates of grizzly bear density and ordinal-ranked mortality risk

Habitat-based bear density class	Source-like habitat	Sink-like habitat
Very low (1–9 bears per 1000 km^2)	risk < 6	risk > 5
Low (10–19 bears per 1000 km^2)	risk < 7	risk > 6
Moderate (20–39 bears per 1000 km^2)	risk < 8	risk > 7
High (40–59 bears per 1000 km^2)	risk < 9	risk > 8
Very high (60–73 bears per 1000 km^2)	risk < 9	risk > 8

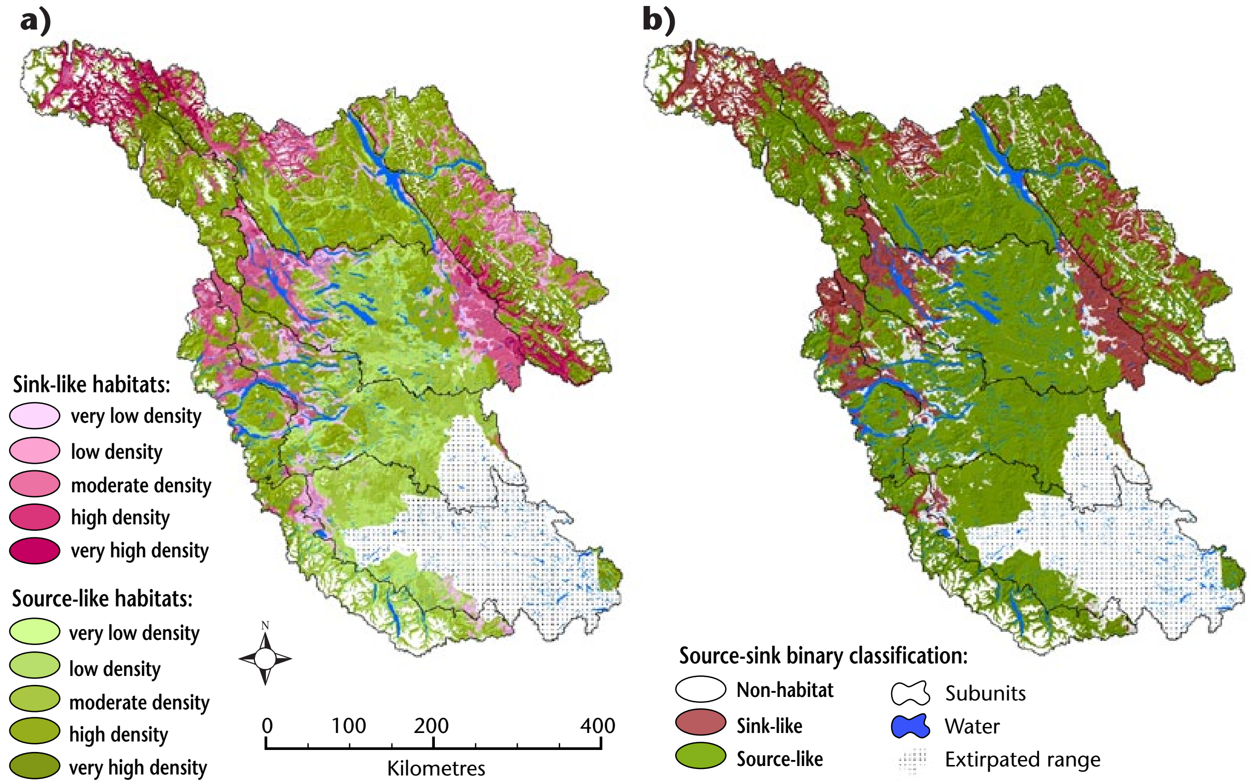

FIGURE 2. Predicted habitat states (source- and sink-like habitat) based on: (a) five bear density habitat classes and five mortality risk classes (white areas represented extirpated habitat or glaciers/water); or (b) a simplified source-sink binary classification.

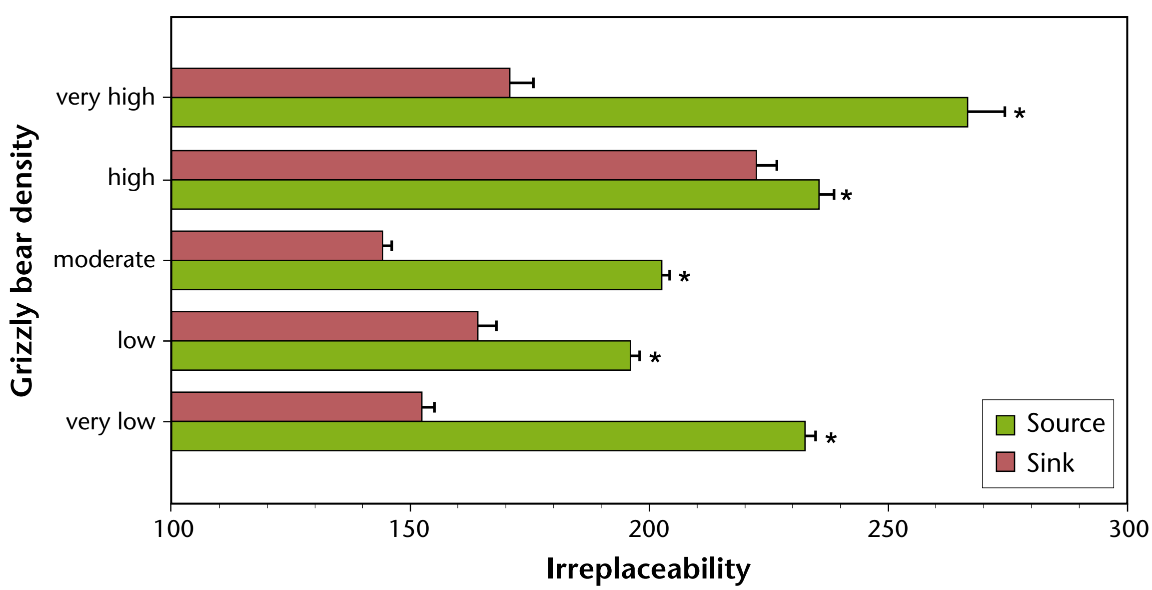

FIGURE 3. Mean and standard errors of irreplaceability values from the terrestrial Marxan runs (out of 500) for source and sink grizzly bear habitat by bear density class for the Central Interior of British Columbia. Significance ($p < 0.05$) between source and sink habitat irreplaceability based on a Wilcoxon rank-sum test (Mann-Whitney two-sample statistic) is indicated by an asterisk.

Discussion

To assist with ecoregional planning in the Central Interior and Sub-Boreal Interior ecoprovinces for Nature Conservancy Canada, spatially explicit grizzly bear habitat models were created to represent habitat suitability (from Hamilton 2007), local bear abundances (density), and indices of survivorship (mortality risk, *sensu* Nielsen et al. 2004) at a common scale (grain) of 1 ha. The mortality risk model, generated for the area based on empirical relationships between known mortality locations and land cover and anthropogenic predictors, suggested good fit and predictive accuracy to both current (2004–2007) and historic (1976–2003) distributions of bear mortalities. This suggested that spatial patterns of mortality risk within three main zones assessed for Interior British Columbia were temporally invariant even though mortality rates themselves may change (Nielsen et al. 2004). Grizzly bear mortalities in the Fraser Basin were most related to landscape patterns of forest cover and the presence of unpaved roads, whereas amount of logging, forest edge, and non-forested habitats (e.g., alpine and avalanche areas) were significant predictors of bear mortality locations in the more mountainous ecosystems. These dissimilarities likely reflect differences in bear habitat associations and patterns of human access and activity, but overall are quite similar to the spatial patterns of grizzly bear mortalities found in Alberta (Nielsen et al. 2004) and northeast British Columbia (Ciarniello 2006).

Using the risk model in combination with the habitat-based density model, a two-dimensional representation of habitat states (Naves et al. 2003; Nielsen et al. 2006) was estimated and classified into source- and sink-like conditions by grizzly bear density, thus recognizing population processes which are not currently considered in other habitat models for grizzly bears in British Columbia. One advantage of habitat state models over prior models is their use in prioritizing future conservation actions, such as protection or maintenance of source-like habitats by minimizing or restricting future road developments (Nielsen et al. 2009) or alternatively targeting areas most suitable for road decommissioning (sink-like habitats) as suggested by Noss et al. (2009).

When comparing irreplaceability of biodiversity features from Loos (2011) by source and sink habitats, source habitats consistently out-ranked sink habitats, which suggests protection of grizzly bear source areas would confer an umbrella effect to other biota and rare habitats. Variation in irreplaceability values among grizzly bear density classes, however, illustrated that the relationship between irreplaceability and bear density was non-linear with average irreplaceability highest in both the lowest and highest grizzly bear densities classes. The high irreplaceability value for low-elevation sites reflects the importance of rare conservation features (biota and habitats) and the general lack of protection (relative to the mountains) for the lower-elevation plains in the Fraser Basin. If the highest density source habitats for grizzly bears were used for targeting future conservation areas, important areas of high biodiversity value for low-elevation plains between the mountain ranges would therefore be overlooked. This is particularly evident for the extirpated grizzly bear habitats in the Fraser Basin, where comparisons with grizzly bear habitats were not assessed yet contained noticeable areas of highly irreplaceable habitat (Loos 2011). This research therefore suggests that if grizzly bears are used as a focal surrogate species for conservation planning, source-like habitats across the range of bear density classes should be considered, as well as the extent of the analysis, to acknowledge that at larger extents the extirpated habitats common to low elevations will be overlooked, and yet are critical to the conservation of threatened biodiversity.

These results suggest that protection of grizzly bear source habitats across different bear density classes does provide a reasonable umbrella effect or shortcut for protection of other important conservation features in grizzly bear range.

Conclusions

Several conservation-planning efforts have used one or a few focal carnivore species to guide prioritization of sites for future protected areas (Noss et al. 1996; Carroll et al. 2001; Nielsen et al. 2009) and have often been criticized for doing so (Andelman and Fagan 2000). These results suggest that protection of grizzly bear source habitats across different bear density classes does provide a reasonable umbrella effect or shortcut for protection of other important conservation features in grizzly bear range. Although we cannot be certain whether the inclusion of the grizzly bear model within the terrestrial Marxan analysis of the Central Interior (Loos 2011) would substantially alter the final results, the fact that many of the source habitats had higher irreplaceability than the sink habitats suggests the final results would not have been altered dramatically with inclusion of grizzly bear source habitats. It does, however, miss the need for consideration of restoration efforts in sink habitats whereby road decommissioning could be used to improve habitat security and thus increase source habitats. Future assessments should attempt to prioritize areas where restoration efforts would be most significant, not only for grizzly bears but also for other biota (Noss et al. 2009).

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ARTICLE RECEIVED: **September 20, 2010**
ARTICLE ACCEPTED: **January 7, 2011**

Production of this article was funded by Nature Conservancy of Canada and, in part, by the British Columbia Ministry of Forests, Lands and Natural Resource Operations.

Test Your Knowledge . . .

Relationships between grizzly bear source-sink habitats and prioritized biodiversity sites in Central British Columbia

How well can you recall some of the main messages in the preceding Research Report?
Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. What factor makes an umbrella species particularly useful for protecting other species?
   A) Charismatic nature
   B) Ecosystem engineer
   C) Large body size
   D) Large area (home range) requirement

2. Defining source-sink habitats requires knowledge of what two factors:
   A) Survival (mortality risk)
   B) Patch-size
   C) Reproduction (habitat quality/suitability)
   D) Connectivity

3. For grizzly bear conservation needs, protecting areas of high irreplaceability generally won't do what?
   A) Protect source grizzly bear habitat
   B) Prioritize areas for restoration (road decommissioning) of sink habitat
   C) Increase habitat connectivity
   D) Enhance population viability

ANSWERS

1. D 2. A and C 3. B